Proceedings of the 1st symposium

Knowledge Exchange for Young Scientists (KEYS)

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Sub-Saharan African Standards for
Cement and Concrete Research
-
Raw Materials, Quality Control and Maintenance of
Cementitious Products

9th – 11th June 2015, Dar es Salaam Tanzania

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Foreword

Welcome to the first symposium on Knowledge Exchange for Young Scientists (KEYS) in Dar es Salaam, Tanzania, 9th – 11th June 2015. This symposium is part of a three phase series organised by BAM, and funded by VolkswagenStiftung. Each symposium will focus on relevant themes in the construction sector and will include adequate training as well as offer an opportunity to participate in informal discussions between key players and young scientists, which will facilitate the fundamentals of knowledge transfer.

Our world of cement and concrete faces tremendous challenges for the future. Without doubt cement-based materials will remain the most widely used construction materials in the world. Concrete can be made available everywhere in the world, and it is more sustainable than other materials. Nevertheless, in order to become even more sustainable, we need to find solutions to reduce CO_2 generation for the cement production, to quickly solve problems of housing and infrastructures, and to cope with ever increasing customer needs in terms of performances.

There is no global optimum solution for concrete. Best concrete practices always has to be found locally and regionally based on raw materials, supply chains, and construction needs, but it can be inspired by other regions. In order to tackle the future challenges and build more innovative with concrete, we need to enhance interdisciplinary engineering skills and create networks between future decision makers.

Therefore, the KEYS symposia series offers a platform whereby young African scientists can get together with peers from Germany as well as with experienced academic engineers, industry specialists and scientists from across the globe for better implementation of research analysis in their respective fields of study. This primarily provides the opportunity to obtain further knowledge in the demand for the home-base innovation and growth of the education sector. It will also provide an opportunity to network with their peers and gain relevant and objective knowledge.

The theme for this first symposium is sub-Saharan African standards for cement and concrete research – raw materials, quality control and maintenance of cementitious products. The symposium is divided into 8 sections and includes presentations from 9 international keynote speakers and 22 young scientists, who were selected out of a high number of applicants based on the excellence of their scientific writing.

We would like to thank all participants for their valuable contribution to the symposium. We are blessed to receive tremendous input from the distinguished keynote speakers and we thank them for their attendance. Last but not least, we would like to acknowledge the funding body, VolkwagenStiftung, for their support. We hope you enjoy the symposium and find your engagement valuable with the entire team in sustaining your professional development in the global world of cement and concrete.

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KEYNOTES

PRACTICAL OPTIONS FOR MORE SUSTAINABLE CEMENT BASED BUILDING MATERIALS

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Brief author biography

Karen Scrivener PhD graduated in Materials Science from University of Cambridge, UK and has a doctorate from Imperial College, London, UK. She is Professor and Head of the Laboratory of Construction Materials, at EPFL, Ecole Polytechnique Fédérale de Lausanne, Switzerland. The work of this laboratory is focussed on improving the sustainability of cementitious building materials. She is the founder and co-ordinator of Nanocem, a Network of industry and academia for fundamental research on cementitious materials and Editor-in-Chief of Cement and Concrete Research, Switzerland.

Introduction

Options for more sustainable cementitious materials are reviewed. The most viable option involves blending Portland cement clinker with increasing levels of supplementary cementitious materials (SCMs), but the availability of common SCMs is low compared to the demand for cement. Calcined clays are the only other materials that are potentially available in large enough amounts to continue the trend of reducing clinker content in blended cements. Recently we demonstrated that partially replacing clinker by calcined clays combined with limestone (LC^3 blends) can be used to achieve blended cements with good performance at much lower levels of clinker. Such blends can make a significant contribution to the reduction of CO_2 emission associated with cement production.

As global demand for concrete follows the growth of the middle class in the 21st century, the concrete industry faces one defining challenge: finding ways to increase the availability of concrete while at the same time reducing its environmental footprint. To have a significant global impact, solutions have to be abundant, affordable, and adapted to the users in the developing world, where most growth is expected.

Concrete is an eco-efficient material

Cement and concrete are essential to the infrastructure of the modern. No other material is able to fulfil the growing demand for building materials with such a low environmental footprint. Its widespread availability and low cost make cement by far and away the most used material on earth, with reinforced concrete accounting for more than half of all the manufactured materials and products we produce. It is only because of these enormous volumes that overall the production of cement and concrete is estimated to account for around 5-8% of man-made CO2 emissions.

Table 1 shows relative figures for the energy and CO2 emissions of some common building materials [1]. Here, typical values for concrete are shown, as this is the final product used in the field. As discussed elsewhere [2], there is a huge scope also for reducing the amount of cement in concrete and it should always be borne in mind that sustainability can and should be considered at all stages of the process. The figures in Table 1 are per kg and the strength of concrete is not the same as the specific strength of steel or wood. These issues have been considered by several authors [e.g. 3]. Nevertheless, the advantages of concrete remain clear in most construction related application; even more so when the availability of materials to substitute concrete is considered. As an example, although the amount of wood used worldwide is around one tenth that of concrete, our consumption of wood is already considered to be unsustainable; we are cutting down more trees than we are planting. It follows that, independent of any other considerations; wood cannot make a significant further contribution to meeting the increasing demand for building materials worldwide.

Demand for cement is increasing

Figure 1 shows the projected increase in demand for cement. Most of the increase in the coming decades will be in emerging and developing countries, which already make up over 80% of global production. Today, China's production alone exceeds that of the whole world 10 years ago. India is the country in which the increase is likely to be the largest – today the consumption per capita in India is only 1/6th that in China.

Options to reduce environmental impact

Cement production accounts for the overwhelming majority of the CO_2 emissions associated with concrete. Unlike other materials, less than half (~40%) the CO_2 emitted during cement production is related to fuel and electricity. The remaining 60% comes from the decomposition of the main raw material – limestone, or $CaCO_3$. Great improvements have been made in the last few decades in lowering energy-related CO2. Today, the production of Portland cement clinker is one of the most efficient industrial thermal processes in existence (approaching 70 % of theoretical efficiency) and it is unlikely that significant further gains can be made here as discussed in more detail by Gartner [4]. Furthermore cement plants can now use a wide range of substitute fuels, reducing the need for primary fossil fuels to below 20% in some modern plants. This versatility, the fact that the calorific value of such a wide range of waste products can be exploited in a safe manner, should be seen as another advantage of cement production.

Any attempt to reduce the remaining 60% of "chemical" emissions coming from the decarbonation of limestone will have the inevitable consequence of changing the cement's chemistry. Consequently, the reactions and performance of new materials will not necessarily be the same as the reference Portland cement. It took more than 100 years of empirical testing to develop the basis for use of Portland cement. The use of the most common blended materials – blends of Portland cement clinker with slag and fly ash – has taken more than 30 years to become established. We do not have the time to go through this long testing phase for every new material that comes along. That is why we must now move towards a more scientific basis, which can only come (on a reasonable timescale) through a systematic understanding of cementitious processes and materials at the nano-scale, extended across all the scales involved in cement and concrete production, to provide the multidisciplinary assessment and prediction tools needed to assess the functional and environmental performance of new materials.

The options for new cement chemistries are ultimately limited by the composition of the earth. Just eight elements constitute more than 98% of the earth's crust – oxygen, silicon, aluminium, iron, calcium, sodium, potassium, and magnesium. The relative abundances are shown logarithmically in Figure 2 [5]. As a first approximation, cost will be closely related to availability, leaving only 7 oxides as possible candidates for cement making. These are summarized in Table 2, which broadly considers first potential to from space filling hydrates and then their geological distribution.

The potential to form space-filling hydrates is the key to hydraulic cement. First, the anhydrous cement is mixed with water. The solid content of the resulting mixture cannot exceed around 50% (W/C ~ 0.3) if the mixture is to be flowable. Then the anhydrous material must dissolve and precipitate new solids incorporating water with a higher solid volume than the original anhydrous material. The phases present in Portland cement clinker are ideal in this respect as there is roughly a doubling in solid volume, which enables most of space initially occupied by water to be filled, yielding a strong solid with low porosity.

The alkali oxides retained from Figure 2, Na2O and K2O, cannot produce hydraulic compounds as these have a very high solubility and will not deposit hydrates. Nevertheless, small amounts of these compounds play an important role in Portland cement, where they nearly all end up in the pore solution, conferring the concrete with the high pH needed to protect reinforcement. Iron and magnesium oxide, on the other hand, lead to the opposite problem. These oxides do form insoluble hydrates, but because their mobility in the alkaline pore solution of cements is very low, these hydrates are almost exclusively deposited within the boundaries of the original grains and do not contribute to filling the space initially occupied by water or to binding the grains together. Even in very old cement pastes (even > 100 years [6]), we see bright areas corresponding to the original ferrite phase in the cement, as in Figure 3 (a). In slag cements, the magnesium component of the slag remains within the boundaries of the original slag grains and does not contribute to binding the materials together (Figure 3 (b)).

This brings us back to the three oxides that dominate Portland cement – lime, silica and alumina.

Strategies to lower the environmental impact of cement manufacturing are already applied by the industry and their future potential has been evaluated in detail in by the IEA (International Energy Agency) for the Cement Sustainability Initiative (CSI) study of the World Business Council for Sustainable Development (WBCSD), from which Figure 4 is adapted [7]. Today the three most important approaches are:

1. Improvement of energy efficiency (red part);
2. Use of biofuels and other alternative fuels (blue part), and
3. Replacement of clinker by substitute materials or supplementary cementitious materials (SCMs). Materials used include fly ash, various slags, and natural pozzolans (green part).

Beyond these approaches the CSI study imagines the remaining reduction in CO2 to come from Carbon Capture and Storage (CCS) (grey area), which is now widely thought to be, at best, very expensive (increasing cement prices 2-4 times). As seen in the Figure 4, the further gains from energy efficiency are limited as they are reaching a plateau of optimization. Gains from alternative fuels are projected to increase, but remain a fairly modest proportion of the total. The projected impact of the third option, substituting clinker by SCMs, is limited by the forecast supply of commonly used SCMs, notably slag and fly ash. For example, although slag can substitute up to 90% and typically 70% of clinker in blends, the worldwide amount of slag available is only around 5% of the amount of clinker produced. Fly ash, although available in larger amounts (around 30% of clinker worldwide, but absent in many countries), is of variable quality and much is unsuitable for cement production. So the strategy of clinker substitution could go much further if new sources of SCMs were available. However very few materials are available in the large quantities needed for cement production.

Radically different technologies

Before discussing in detail alternative supplementary cementitious materials it is important to say something about radically different technologies such as alternative clinkers or clinker free materials.

Alternative clinkers

Figure 5 shows the "chemical" CO_2 emissions of the hydraulic minerals in the CaO – SiO_2 – Al_2O_3 – (SO_3) system from two perspectives: first per g of anhydrous material, then per ml of hydrates that can be formed, this latter is related to their space filling capacity and so to strength development. The volume of hydrates for the aluminate compounds (monocalcium aluminate and ye'elimite) is shown with and without added sulphate. Here it can be seen that the figures for the two most important Portland cement clinker minerals – C_3S and C_2S – have fairly similar values. Notably we see that C_2S only presents a saving of around 10% in CO_2 compared to C_3S. This means that for belite rich cements to represent a "real" CO_2 saving, they have to have more than 90% of the performance of alite rich cements. Despite intensive research efforts, we are far from achieving this in terms of the performance needed in modern construction. This table clearly shows that the most interesting minerals from the point of view of their associated CO_2 values are monocalcium aluminate (CA), the main component of calcium aluminate cements (CACs), and ye'elemite or Klein's compound ($C_4A_3\$$), the main component of calcium sulfoaluminate cements (CSAs or SACs). It is therefore worth discussing the viability of clinkers based on these mineral in some more detail.

The main problem is that while alumina is very abundant in the earth's crust, it exists mainly in feldspars and clays, where it is present alongside silica with Si:Al ~ 2 similar to that found in most Portland clinkers. To obtain the desired alumina a rich compound, a more concentrated source of alumina is needed, typically bauxite. But bauxite is not nearly as widely distributed as clay minerals and is highly sought after for the production of aluminium, making it is a much more costly raw material. But this is not the end of the story, as will be explained from the perspective of calcium aluminate cements.

Calcium aluminate cements (CACs) have been in commercial production for nearly 100 years, yet the total amount produced annually is less than 1/1000 of the production of Portland cement clinker, and only a small proportion of this is used in construction. This is because the cost of CAC is more than five times the cost of Portland cement. The high cost of raw materials and production accounts for only part of this huge discrepancy. The other part lies in the number of people needed to support the use of this special material, in terms of factories producing smaller amounts, and sales and technical assistance for a specialised material that does not behave in the same way as the reference Portland cement. Consequently the use of CAC can only be justified where their special properties justify the higher cost.

Calcium sulfo aluminate cements have gained a lot of attention recently, as, in addition to the low chemical CO_2 of ye`elemite, the firing temperature is lower and they are more easily ground. CSAs are a very diverse family of cements. They may contain from 70% ye'elemite down to 30% or less. The main other phase that is present is usually belite. This leads to a two-stage development of properties, with the fast reaction of the ye'elemite giving early strength and the belite hydration giving later strength gain. Another complication is that the behaviour can be changed from rapid hardening to expansive by the amount of calcium sulphate added during grinding. Due to this diversity it is difficult to generalize, but it can certainly be said that today, these are specialist products along the lines of CACs rather than cements for general construction. They have been produced in China for several decades and have been used for some large-scale constructions, yet to this day, they represent less than 0.1% of the cement produced in China and are mostly used for internal partition walls.

Personally, I am doubtful that CSA cements can be competitive with blended cements discussed below on either an economic or environmental basis in general use. The need to support consumers in their use of cements that behave differently to the Portland reference, in addition to the higher raw materials cost, will mean that the commercially viable cost will be very much more than that of Portland cement. Nevertheless such developments may be interesting in more specialist applications, for example for precast concrete.

Clinker free binders

At present many researchers (and funding agencies) are attracted by the idea of "clinker free binders, such as alkali activated materials, also known as "geopolymers," claiming their advantages as low CO_2 cements. Despite the hype, it is highly unlikely that such materials will have a major impact on the sustainability of cementitious materials for many reasons:

- First, the environmental advantages of these materials are questionable. The environmental assessment made by Habert et al [8] indicates that while the production of geopolymer concrete can have a slightly lower impact on global warming than standard Ordinary Portland Cement (OPC) concrete, it has a higher environmental impact regarding other impact categories related to the production of concentrated sodium silicate solution and the dangers of handling highly alkaline solutions.
- Second, the performance of these materials is very sensitive to small variations in the starting materials, such as slag or fly ash. The setting time and rheology are difficult to control and may vary widely on a batch-to-batch basis. They are also very sensitive to contamination by conventional Portland cements. This makes use on-site by typical construction workers challenging.
- Third, the durability and long term performance of these materials is not well known.
- Finally, and perhaps most importantly, the materials used in these alkali activated materials are the same SCMs discussed above – slag, fly ash, etc., which are only

available in relatively low amounts compared to cement clinker. The materials that perform best in these systems are the same as those that perform best in cement blends.

So from a practical point of view, one is faced with a choice of how to use slag: either (a) as a component of a Portland based blend in a well-known and tested technology with proven durability that can be used in existing mix designs with conventional equipment, or (b) in a clinker free system with the attendant problems of sensitivity, strongly alkali materials, risks of contamination, and unknown long-term performance. Again the cost of providing technical support to users also means that a price significantly higher than that of Portland cement will have to be charged for such materials to be a commercially viable.

Alternative SCMs: LC^3 – limestone, calcined clay, clinker cements

Faced with the limited supply of traditional SCMs, the key question becomes: what alternative SCMs are available in the very large quantities needed? Materials such as plant ashes, notably rice husk ash, can be interesting, but the quantities available are relatively small and localized (both geographically and to certain periods of the year). There are extensive reserves of natural pozzolans worldwide (e.g. volcanic ashes), but generally these have a fairly low reactivity and are very variable from place to place. The one material which has a real potential to make a significant contribution to lowering the clinker (and so CO_2 emissions) of cement is clay, which becomes reactive when calcined at temperatures between 600 – 800 °C.

The use of calcined clays as pozzolans has been known for some time, it was widely used in India in the 1970s (before fly ash was widely available) and is currently being used in countries without supplies of the common SCMs, notably Brazil. However, substitution just as a pozzolan is only practical up to about 30%, at which level the cost of calcination usually does not make this an economically viable option. Recently, it has been shown that by making a coupled substitution of calcined clay with limestone, an additional 15% or so of clinker can be replaced by limestone with no decrease in mechanical performance so that the extra saving of clinker can offset the cost of calcination. This is because the aluminate component of the calcined clay can react with calcium carbonate (limestone) and calcium hydroxide to produce space filling corbo aluminate hydrates:

$$A_{\text{(from calcined clay)}} + Cc + 3CH \rightarrow C_3A.Cc.H_{11}$$

Clays are the weathering product of all rock types and as such are abundantly available close to the earth's surface in all geological settings. They are made up of silicon and aluminium oxides, which together constitute around three quarters of the earth's crust. The most suitable clay types, those containing kaolinite, are typical in tropical and subtropical environments, where most of the increase in demand for cement is forecast to occur. Kaolinite clay occurs in abundance in association with soils that have formed from the chemical weathering of rocks in hot, moist climates, Alfisols (pale green) and Ultisols (yellow) on the map (Figure 6.). This confirms the abundance of clay, especially in India and South East Asia.

The potential for ternary blends of limestone, calcined clay and clinker, which we call LC^3 (limestone calcined clay cement), to give good performance at 50% clinker content or less has been demonstrated in the collaborative research between the Laboratory of Construction Materials (LMC) at EPFL, Switzerland, and CIDEM in Cuba [10].

The kaolinite content needed for LC^3 blends is much lower than for the "pure" kaolinitic clays used in the ceramic or paper industries. This means that the use of such "low grade" clays would not compete with demand for resources by other industries. Our experience in India [11] has shown that abundant amounts of low-grade clays exist as over or under burden in existing quarries, currently regarded as waste. The use of such resources would not require opening new quarries nor deplete agricultural soils. With an optimum at around 700 to 800°C, the calcination temperature is much lower than the 1450°C needed for clinker manufacturing, hence consuming less fuel. Furthermore, this calcination process does not emit chemical CO_2 and can be carried out with existing equipment (rotary kilns or tower calcinations units).

Limestone is always available at cement plants. The LC^3 blends typically contain around 15% limestone, and limestone unsuitable for clinker production can be used. For example, high dolomite contents produce periclase during clinker production, which causes expansion. Such materials can be used safely in interground materials, leading to more efficient use of limestone quarries. Depending on the exact scenario, the amount of cement that can be produced from the same identified limestone reserve could be increase by up to a factor of two.

Further important advantages of LC^3 technology are:

- Cheaper or similar production costs
- LC^3 can be produced using the existing equipment in a cement plant
- Use of LC^3 also does not need any major changes in concrete technology.

This leads to an enormous potential for rapid uptake of the technology with significant potential for CO_2 reduction and efficient use of resources.

LC^3 has the potential to provide a large-scale solution to the two main challenges facing the production of building materials today. A rough estimation of the impact of LC^3 on the CO_2 reduction scenarios is evaluated in relation to the results of the WBCSD CSI study [7] (Figure 7). This assumes that the supply of SCMs can be increased by a fairly modest 600 million tonnes worldwide by 2050. This graph shows how LC^3 can significantly contribute to the growth of the cement sector without increasing emissions.

This is more feasible than compensating a business as usual strategy with carbon storage and capture. Importantly, the uptake of LC^3 would allow developing countries to satisfy rapidly growing demand while reducing the CO_2 intensity of their activities and is thus a politically very attractive global environment option.

Strength of LC3 blends prepared from low grade clays

Further investigating the potential of blends based on limestone, calcined clay, and clinker (LC^3), blends incorporating calcined clay from several countries (India, Brazil, Thailand, Cuba) were analyzed. An example of the strengths obtained is shown in Figure 8.

Plotting these results against the kaolinite content of the clays, it can be seen that kaolinite content is the main parameter determining strength development (Figure 9).

In these experiments the cements were prepared by intermixing based on the same ground clinker. It can be seen that the one day strengths are still rather low, but, for a kaolinite content of 50% or more, higher strengths than the reference are achieved by 7 days. In practice one day strength can be improved by intergrinding as is currently done for many fly ash blended cements.

Durability of LC^3 cements

When considering a new cement formulation, the question of durability is of prime importance. Will these materials perform as well as existing materials over the lifetime of a typical building or structure? A wide-ranging and detailed study of the durability of LC^3 is underway in Switzerland, India and Cuba. This study will look at the Underlying scientific mechanisms as well as full scale exposure. However, we have every reason to expect that these materials will have good durability:

- First, the phase compositions of the materials is very similar to existing Portland and blended cements. The principal hydrate is calcium silicate hydrate, C-S-H, whose long-term behaviour is well known and understood. The other aluminate containing phases, mono and hemi carbonate and ettringite are also formed in limestone cements, widely used in Europe for many years.
- Second, analysis of the pore structure shows that, as for other blended cements [e.g. 12], the pores are smaller, even though the overall porosity may be slightly higher (Figure 10) [13].
- Third, preliminary results on the resistance to penetration of chloride ions are extremely good. Figure 11 shows the chloride profiles after two years ponding in 0.5M NaCl solution [13].

Concluding remarks

Fulfilling the needs of the growing world population for food and habitation and at the same time avoiding drastic climate change due to the emission of greenhouse gasses is the most important challenge facing the world today. In the field of building materials, cement and concrete remain the best option as they can be produced in large quantities almost anywhere in the world and have an intrinsically low environmental footprint compared to alternatives. Nevertheless, they are the focus of intensive research efforts to reduce the 5-8% of CO_2 emissions attributable to their production. This paper tries to present a brief but comprehensive analysis of options for cements of the future, starting from the composition of the earth and considering the practicalities of producing such a low cost material that can be used by anyone, even with little or no training. This shows that blends in which around half of the conventional Portland cement clinker is replaced by a combination of limestone and calcined clay – *LC^3 blends* – present an extremely promising option to achieve lower CO_2 emissions, lower costs, and increase supply – particularly in tropical and subtropical countries where the increase in demand will be the highest in coming decades. We have already received strong expressions of interest in this technology from many cement producers worldwide.

More work is needed to provide a solid scientific and engineering foundation for these new materials. A large body of work is already underway, undertaken by a network of researchers in Switzerland, India, and Cuba. The core of this work has been made possible through significant funding provided by the Swiss Agency for Development and Collaboration. In the coming years, we hope to extend this network to more countries as a co-ordinated worldwide effort is needed to accelerate the introduction of such environmentally friendly options.

Figures and tables

Table 1: Embodied energy and associated CO_2 emissions for common construction material [1]

Material	Embodied Energy (MJ/kg)	CO_2 (Kg CO_2 /kg)
Normal concrete	0.95	0.130
Fired clay bricks	3.00	0.22
Road & pavement	2.41	0.14
Glass	15.00	0.85
Wood (plain timber)	8.5	0.46
Wood (multilayer board)	15	0.81
Steel (from ore)	35	2.8

Table 2: Summary of suitability of common oxides for cementitious materials

oxide	hydrates		geology	
CaO	Good mobility, hydrates can fill space	✓	Limestone, widely distributed	✓
SiO_2	Less soluble but still a major component of space filling hydrates	✓	Most common oxide, everywhere	✓
Al_2O_3	Variable solubility, hydrates fill space	✓	With silica in feldspars, clays, etc. also more concentrated and localised as bauxites	✓ / ?
Fe_2O_3	Low mobility / solubility in alkaline solutions, poor contribution to space filling	?	Very widely distributed	✓
MgO	Low mobility / solubility in alkaline solutions, poor contribution to space filling		Mainly as impurity in limestone, more concentrated sources localised.	

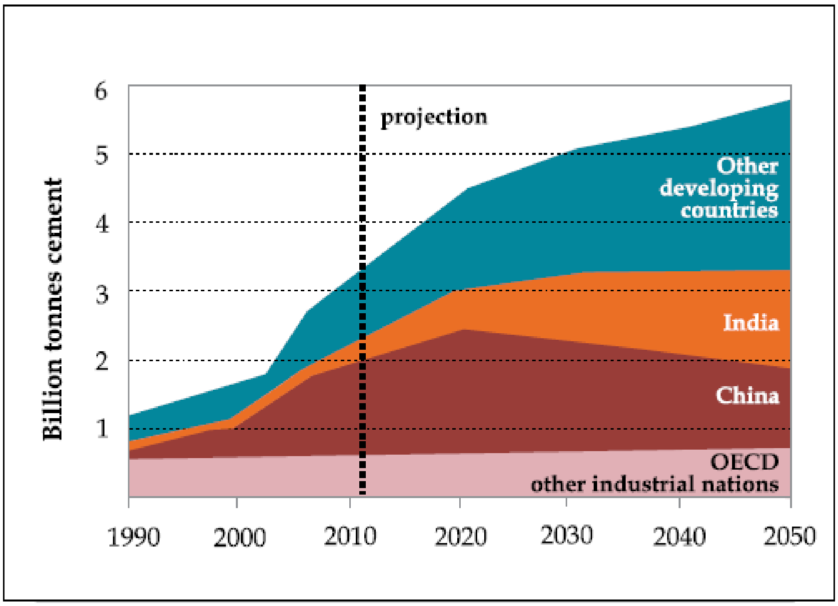

Figure 1: Forecast rise in cement production until 2050 (adapted from CEMBUREAU)

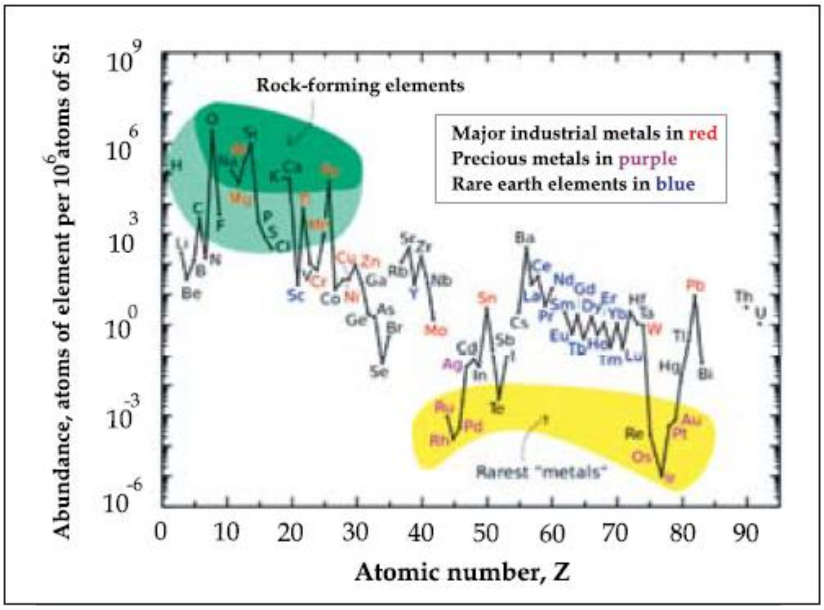

Figure 2: Relative abundance of elements, source US Geological Survey via Wikipedia [5]

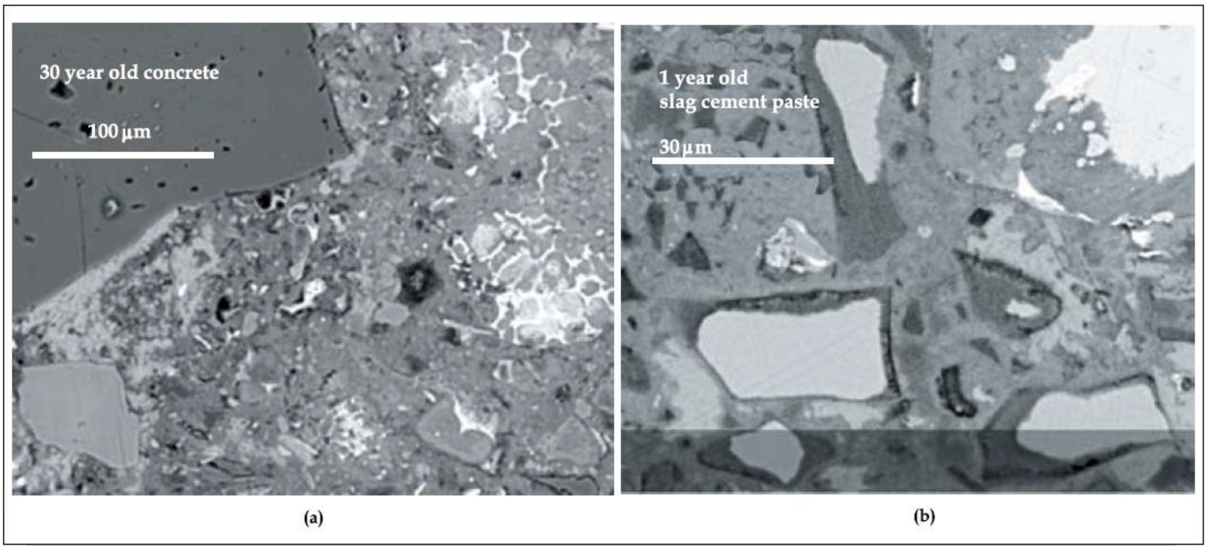

Figure 3: (a) Micrograph of old concrete shows low mobility of iron, which remains in the bright areas corresponding to the ferrite phase in the original cement grains.
(b) Micrograph of slag cement paste shows low mobility of magnesium, which remains within the boundaries of the original slag grains.

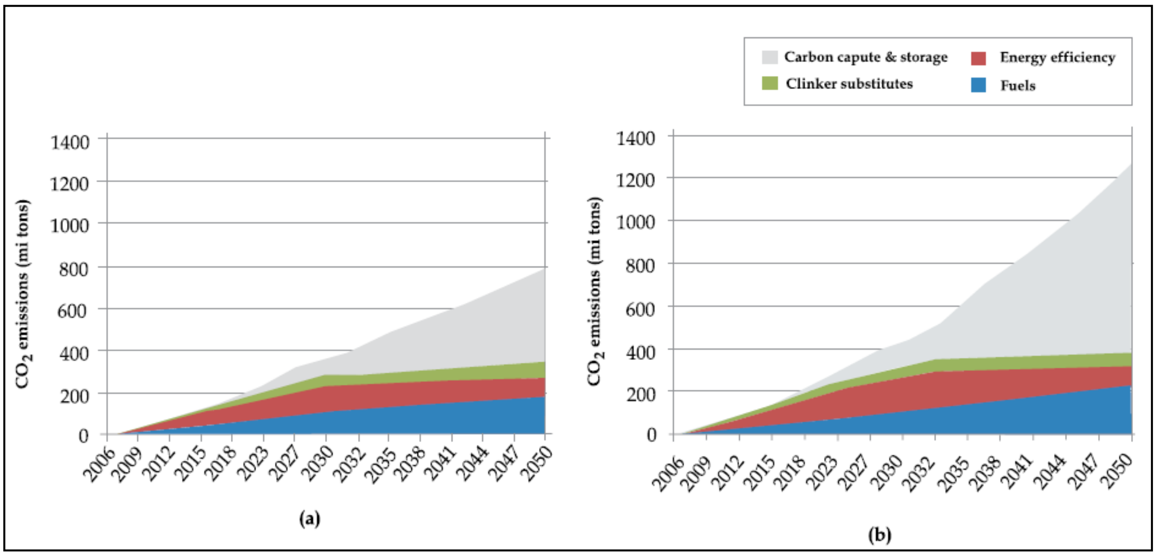

Figure 4: CO_2 reduction scenarios compared to 2005 baseline from CSI study Low (a) and high (b) scenarios for demand increase

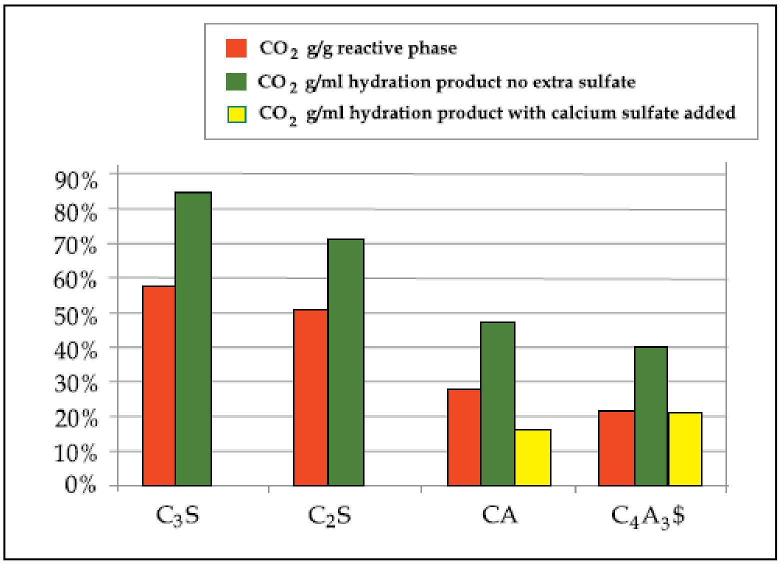

Figure 5: CO_2 emissions related to the major hydraulic minerals

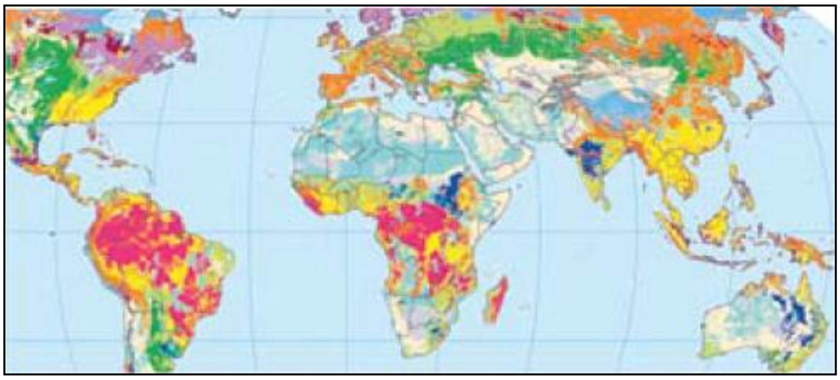

Figure 6: World soil map. Kaolinite rich clays are most likely to exist near the surface (tap 5m) in the yellow and pale green regions [9]

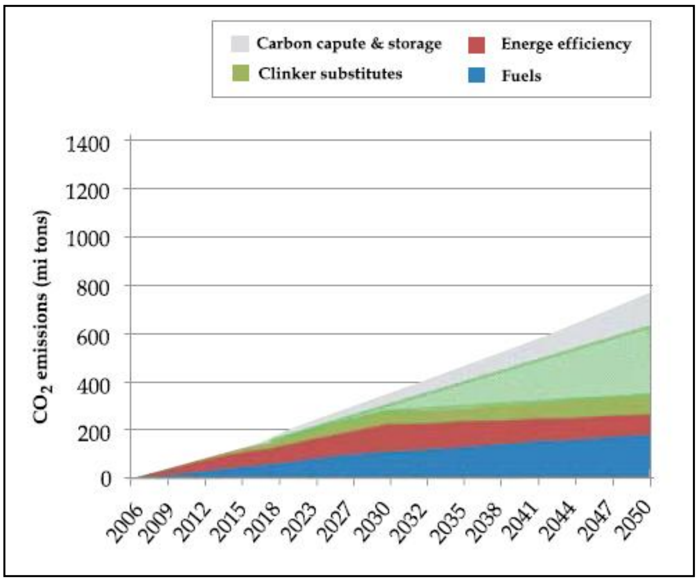

Figure 7: Potential additional reduction of CO_2 by clinker substitution through the use LCC (calcined clay, limestone) technology.

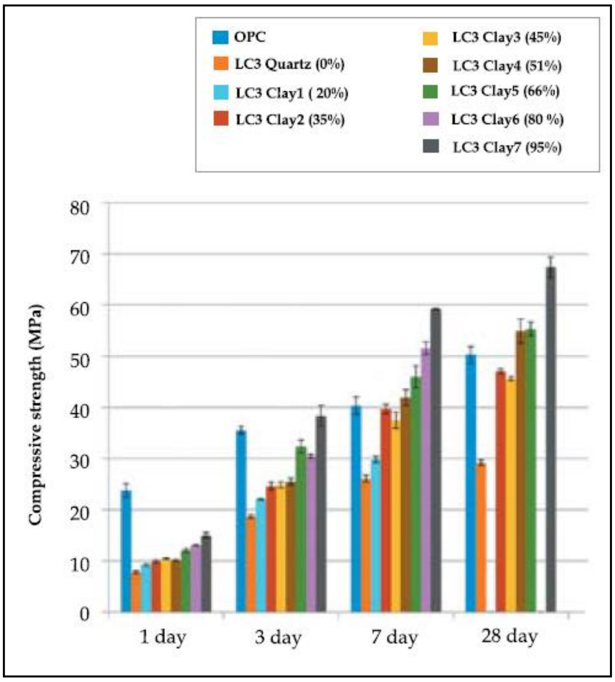

Figure 8: Strength development for a range of blends all containing 50 % clinker, 5 % gypsum, 15% limestone and 30 % calcined clay. The calcined clays originate from India, Brazil, Thailand and Cuba

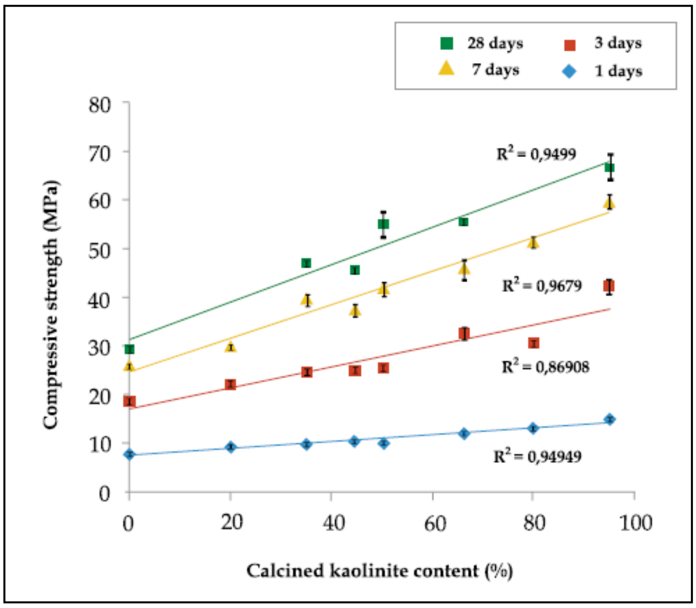

Figure 9: Relation between kaolinite content of the clay which is calcined and strength

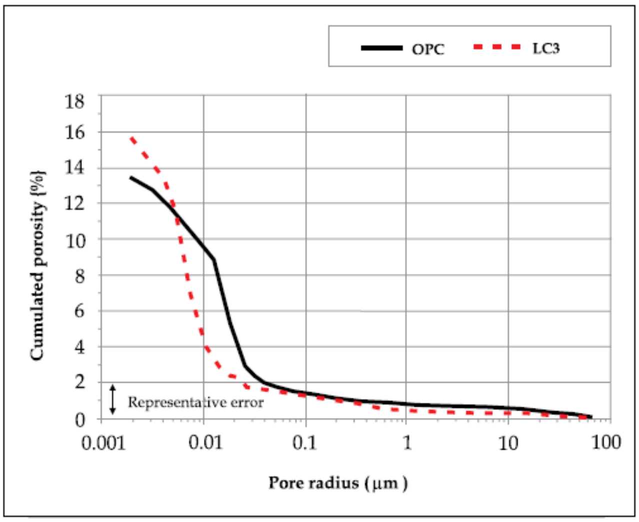

Figure 10: Mercury intrusion porosity results for LC3 blend and reference Portland cement

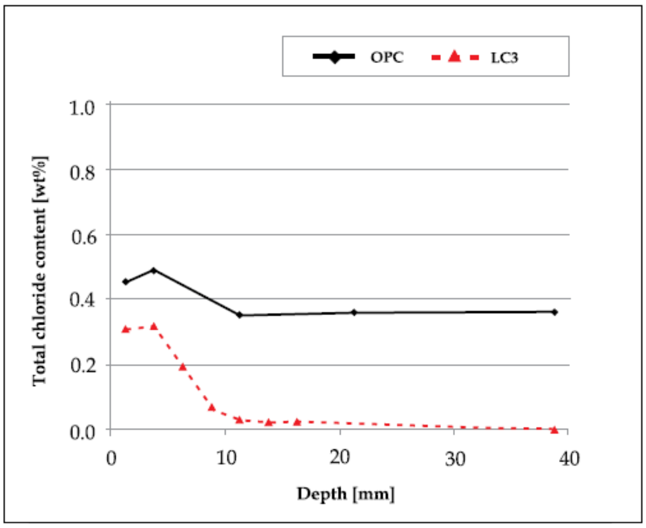

Figure 11: Chloride profiles after 2 years ponding in 0.5M NaCl solution

References

[1] Hammond G.P. and Jones C.I, ICE version 1.6ª, 2008 Proc Instn Civil Engineers. www.bath.ac.uk/mech-eng/sert/embodied/.

[2] Damineli, B.L., Kemeid, F.M., Aguiar, P.S., John, V.M., Measuring the eco-efficiency of cement use, Cement and Concrete Composites, September 2010,Vol. 32, No. 8, pp. 555–562.

[3] P. Purnell, Material Nature versus Structural Nurture: The Embodied Carbon of Fundamental Structural Elements, Environmental Science and Technology, 2012, Vol. 46, pp. 454–461, dx.doi.org/10.1021/es202190r.

[4] E.M. Gartner, Industrially interesting approaches to "low-CO2" cements, Cement and Concrete Research, 2004, Vol. 34, pp. 1489 – 1498.

[5] US geological survey: http://upload.wikipedia.org /wikipedia /commons /0 /09 /Elemental_abundances.svg.

[6] Scrivener, K.L., "A study of the microstructure of two old cement pastes", 389-393. (Proc. 8th Int. Cong. on the Chemistry of Cements, Vol. III, Rio de Janeiro, 1986).

[7] IEA, WBCSD. Cement technology roadmap 2009 carbon emissionsreductions up to 2050. [Internet].Paris:;Conches-Geneva, Switzerland: OECD/IEA;WBCSD;2009. Available from: hptt: / / wbcsdcement.org /pdf /technology /WBCSD IEA_Cement%20Roadmap.pdf.

[8] Habert, G., d'Espinose de Lacaillerie, J.B., Roussel, N. 2011. An enviromental evaluation of geopolymer based concrete production: reviewing current research trends. Journal of Cleaner Production, 19, 1229-1238.

[9] US Department of Agriculture, Natural Resources Conservation Service http: / /www.nrcs.usda.gov /wps /portal /nrcs /detail /soils/ use /maps /?cid=nrcs142p2_054013.

[10] Antoni, M. Rossen, J, Martirena, F and Scrivener, K.L. Cement substitution by a combination of metakaolin and limestone. Cement and Concrete Researche, 2012. 42(12): p. 1579-1589.

[11] Bishnoi, S., Maity, S., Mallik, A., Joseph, S., Krishnan, S., Joseph, A.M., Shah, V., Pilot scale manufacture of Limestone Calcined Clay Cement: The Indian experience. Indian Concrete Journal, This issue.

[12] Poon, C. S., Wong, Y. L.. The influence of different curing conditions on the pore structure and related properties of fly-ash cement pastes and mortars. Construction and Building Materials, Vol. 11, Nos 7-8. pp. 383-393, 1997.

[13] Antoni, M, Investigation of cement substitution by blends of calcined clays and limestone. EPFL PhD thesis N°6001,2013 (hptt: // infoscience.epfl.ch/ record/ 190756/ feles/ EPFL_TH6001.pdf).

EMBEDDED SUSTAINABILITY-DRIVEN APPROACH INTO CONSTRUCTION

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Brief author biography

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Introduction

Sustainable development is a process, which enables all people to realise their potential and improve their quality of life in ways that simultaneously protect and enhance the Earth's life support systems. Sustainable development involves maintaining our current rate of development whilst leaving suitable resources behind for later generations to continue to develop. Thus, environmental problems must be tackled by considering their relationship with both the state of the economy and the well-being of society. There is need to take a holistic approach to each facet of sustainability; the environment, the economy and society. Taken together, Fig. 1 includes everything that there is need to consider for a healthy, prosperous and stable life.

Since the Brundtland report in 1987, the weight of sustainable development keeps growing and everyone is pressed to do his best to contribute to its achievement. The preservation of the environment is one of the principal features of sustainable development with the urge to reduce greenhouse gas (GHG) emissions.

Concrete represents a large part of worldwide CO_2 emissions. But it is not a polluting product by itself. Even if during its manufacturing the carbon release is important (cement creation), it is its wide use that makes of concrete a polluting material. However, concrete's thermal mass proves to be a good feature of the material. Well design and using this advantage, a concrete structure can make the difference in terms of energetic efficiency during its service life [1]. So if concrete is not environment friendly in the manufacturing process, it does remain an excellent mean to achieve energetic efficiency and therefore to reduce global CO_2 emissions [2].

Moreover, Kyoto protocol has engaged most countries to reduce its emissions. To reach this objective, it is essential that the concrete industry achieves great improvements. To target those enhancements and know what could be their extents, it is important to be able to assess the carbon footprint of the concrete.

CO2 and greenhouse effect

Greenhouse effect is a natural phenomenon. It refers to the atmosphere capability to prevent part of sun radiance to go back into space. The mechanism insures that earth average temperature is kept between -18°C and 15°C.

Gases which allow this phenomenon are not naturally highly concentrated in the atmosphere but human activities have been increasing those concentrations. Therefore atmosphere characteristics and greenhouse effect has been altered. This alteration often considered as the main cause of global warming.

Over the last century, carbon dioxide concentration in the atmosphere has increased of 30% and it is estimated that in 2013, CO_2, with approximately 467 million tonnes (Mt), represented 83% of UK's greenhouse emissions (Figure 2) [3, 4].

In general, this report will not deal with other gas but when CO_{2e} will be considered, they are considered to be included. It is this massive participation that makes of CO_2 the priority of any policy aiming a reduction of greenhouse emissions. However, because their global warming potential is greater than the one of CO_2, these other gas must be kept in mind and further studies might be carried out.

The challenges of sustainable construction

Sustainable construction takes account of two major global challenges.

- The environmental challenge: when a building's total lifecycle is considered, the construction industry: is responsible for 40% of CO_2 emissions and waste in developed countries, accounts for 40 % of the energy demand in these countries.
- The economic and social challenge: the construction sector accounts for 10% of world GDP (gross domestic product) and employs over 100 million people, i.e. 28% of employment in the world.

Building sustainably

Sustainable construction aims to limit the environmental and human impact of construction while guaranteeing the highest quality in terms of aesthetics, durability and strength. Sustainable construction takes account of the complete lifecycle of a building, from the choice of initial materials to demolition and recycling. Sustainable construction means:

- Reducing the negative impact of building sites to benefit both workers and nearby residents (noise, dust, repetitive tasks, etc.),
- Integrating renewable energy sources at the design stage,
- Using recyclable materials during construction to preserve natural resources,

- improving the thermal inertia of buildings to reduce heating and air-conditioning costs as well as CO_2 emissions,
- Controlling the aging of constructions,
- Recycling materials and structures after demolition,
- Designing low-cost housing to improve living conditions for low income populations.

It is estimated that concrete products represent at least 5 percent of humanity's carbon footprint from CO_2 emissions. Figure 3 shows the world production of cement by region from 2001 to 2013 [4]. There is a significant international strategy to reduction carbon foot print by developing sustainable concrete having lower embodied energy and encourage to use waste materials and reducing land fill, and to improvement of processes for the reuse of materials. The supplementary cementing materials are useful by-products of other industrial processes, particularly fly ash (FA), ground granulated blast furnace slag (GGBS) and metakaolin, etc. which would potentially otherwise be sent to landfill. Their incorporation in concrete as replacement of cement can translate into direct reduction in energy consumption and CO_2 emissions. The indicative CO_{2e} for the main cementitious constituents of concrete are shown in Table 1 and have been calculated from calendar year 2010 data. Data are 'cradle to factory gate', so transport from the place of manufacture of the cementitious material to the concrete plant is not included (Table 1) [5]. GGBS can replace up to 70% of cement in a concrete mix and fly up to 50%. Together, fly ash and GGBS account for 15% of total UK consumption of cementing materials. The UK uses approximately 1.5 million tonnes of GGBS and FA as SCM every year with the following environment benefits: Reduction in annual CO_2 emissions of 1.5Mt; reduction in primary energy use by 2000 million kilo Watt/hours; saving of 1.5 Mt of quarry material; and saving 1.5 Mt of landfill [6].

Alternative cementing materials contains no cement and concretes made with materials generally have similar to or better engineering performance compared to those of conventional concrete. The alternative cementing materials group geopolymers, activated glassy cement, hydraulic fly ash cements, activated slag cements, calcium aluminate cements, calcium sulfoaluminate cements, magnesia-based cement, or CO_2 cured cement. Extensive research has been undertaken to industrialise alkali activated concrete, also known as geopolymer concrete (GPC) and alkali liquids are usually used to react with silica and alumina rich natural materials, like metakaolin or with by-products, such as fly ash, silica fume, rice husk ash or slag binders [7, 8]. GPC has recently emerged as a novel eco-friendly construction material with a promising potential to replace ordinary Portland cement concrete. Using this green material to replace the Portland cement concrete can reduce CO_2 emissions by up to 80% of various applications including as a replacement for Portland cement. The most common binders in geopolymer concrete are usually industrial by-products i.e. Pulverised Fuel Ash (PFA) and ground granulated blast furnace slag (GGBS).

Conclusions

With infrastructure and engineering products and processes becoming increasingly complex, engineers need to integrate consideration of whole-life environmental and social impacts – positive as well as negative – with the mainstream and commercial aspects of their work. Wise use of natural resources, minimum adverse impact and maximum positive impact on people and the environment are the targets. The sustainability is defined as the service life per unit of non-renewable resources used and the alternative cementing materials are among the alternatives solutions having highest sustainability. The carbon footprint of these materials is much lower, while the anticipated service life is the same as or a greater than those made with normal cement. Many guidelines regarding specifications do not give any information about alternative cementing materials, therefore there is need to work to broaden these materials in specifications. There is need to develop additional standards for acceptance these alternative cementing materials.

Figures and tables

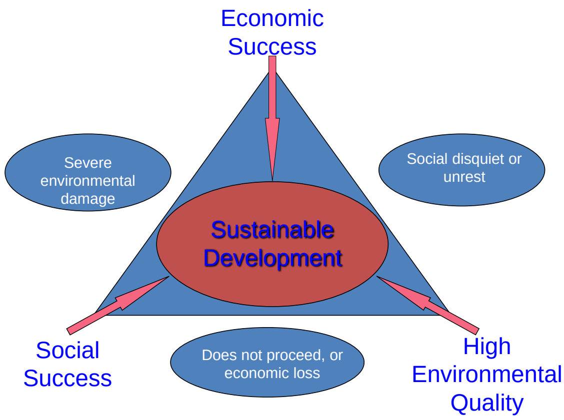

Figure 1: Triple bottom line of Sustainability.

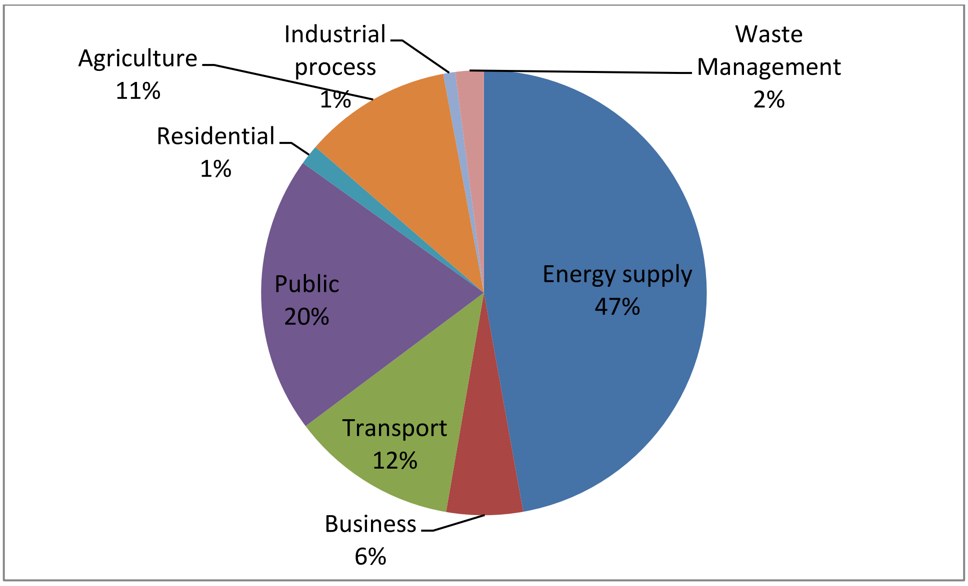

Figure 2: UK greenhouse gas emissions by source, 2014 [4].

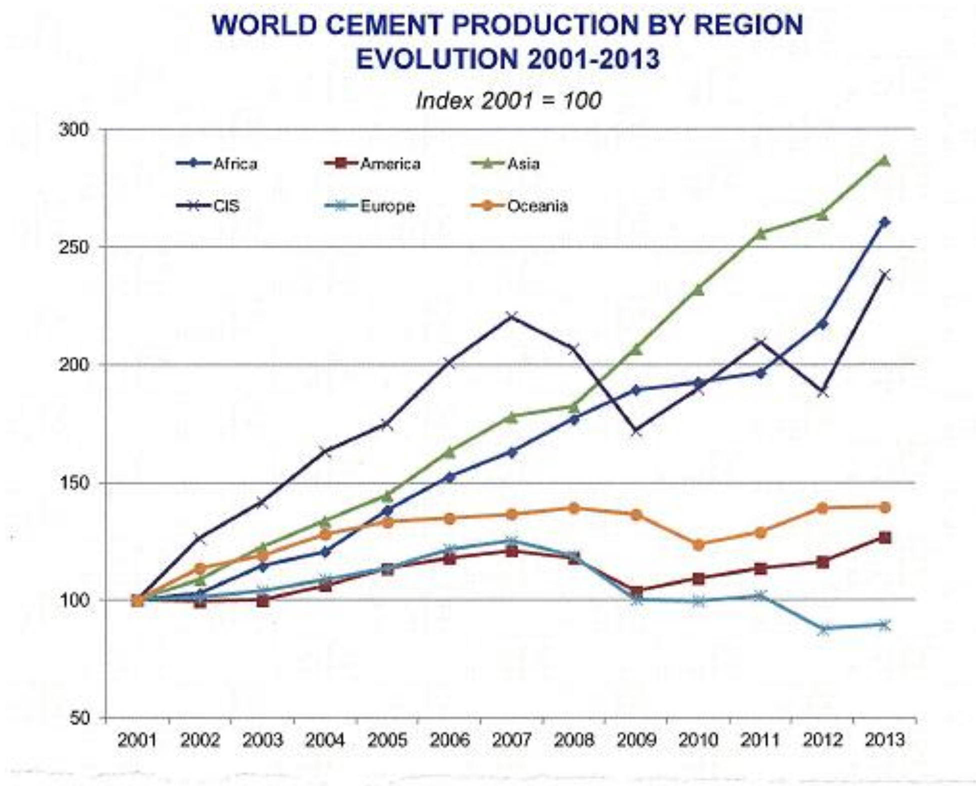

Figure 3: UK greenhouse gas emissions by source, 2014 [4].

Table 1: Embodied CO_2 of UK cement, additions and cementitious materials [5]

Cement additions and Cementitious materials		**Embodied CO_2 (kg/tonne)**
Portland Cement CEM I		930
Addition or cement constituent	Ground granulated blast furnace slag	52
	Fly ash (from coal burning power generation)	4
	Limestone	32
	Minor addition constituent	32
Weighted Average Cement Note 1: this is the weighted average of all CEM I, II, III, and IV factory-made cements supplied by BCA Member Companies in the UK		880
Weighted Average Cement Note 2: Includes all CEM I, II, III, and IV cements, ggbs, and fly ash supplied in the UK Note 3: The weighted average non-clinker cementitious content in the UK is 23%		720

Note 1: Data supplied by a single UK supplier

Note 2: MPA Cement members are Hanson Cement, CEMEX UK, Lafarge Cement UK and Tarmac Buxton Lime and Cement. It is assumed that the material supplied to Northern

Ireland is in the same proportion to that supplied in the UK. Materials imported and sold by companies not manufacturing in the UK are not included.

Note 3: The Weighted Average Cementitious CO_{2e} is the CO_{2e} of the individual cementitious materials i.e. CEM I, CEM II, CEM III, CEM IV and additions, weighted by the relative tonnages of each supplied in the UK. It is a representative number to use to address the CO_{2e} of concrete elements at the design stage where it is not possible to identify or specify a particular cement or equivalent combination.

References

[1] J. Kline, L. Barcelo, Cement and CO2, a victim of success! , 2012, 14p.

[2] C. Meyer, The greening of the concrete industry, Cement & Concrete Composites 31, January 2009, 5p.

[3] Provisional UK greenhouse gas emissions national statistics 2014.

[4] International Energy Agency, 2014.

[5] Fact sheet 18, MPA: Minerals Products Association, 2010.

[6] Higgins D., Parrott L, Sear L., “Defining and improving the environment impacts of the concrete industry”, 2002.

[7] Davidotis J, Soft mineralogy and geopolymers. In technologie Ud (ed) Proceedings of Geopolymer 88 International Concrete, France, 1988.

[8] Davidotis J, Geopolymer Inorganic polymer new materials Journal of Thermal Analysis, Vol. 37, 1991, pp. 1633-1656.

PARAMETERS CONTROLLING SUPERPLASTICIZER CEMENT INTERACTIONS DURING THE CASTING AND HARDENING OF CEMENT BASED SYSTEMS

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Introduction

Concrete of today has only little in common with the traditional concrete used a few decades ago. It has become a high performance material, which can be adjusted for high performance applications and according to ultimate user specifications. The reason for the rapid evolvement was the increasing awareness about how the rheology of concrete can be improved without negatively affecting the mechanical properties of concrete by chemical admixtures.

The incorporation of superplasticizers into concrete mixture compositions eventually facilitated concrete engineers to improve the workability properties without need to increase the water-cement-ratio (w/c) and furthermore to significantly reduce the w/c without loss of workability. This finally resulted in innovative concrete with higher performance and specified properties, such as self-compacting concrete or ultra-high performance concrete. Therefore, understanding how to control the workability of concrete by the use of chemical admixtures is the key to innovations in concrete technology.

The flow behaviour of coarsely dispersed systems can well be described based on rheological models. Each material has a different resistance against applied shear forces, e.g. induced by deformations or a flow process. The material parameter that provides information about the fluid's resistance against a deformation is the plastic viscosity, which is the gradient of the curve of the shear resistance versus the shear rate (deformation velocity). The minimum stress, which has to be applied before viscous flow is initiated, is called the yield stress. For the flowability and the stability of a concrete mixture both parameters play an important role. In order to provide flow without significant agitation, the yield stress has to be adjusted as low as possible. Nevertheless, a sufficiently high yield stress is also required in order to avoid segregation at rest. A high plastic viscosity is required to avoid segregation at flow but the viscosity also has to be low enough to avoid stagnation of flow at obstacles.

Superplasticizers

Modern concrete often contains superplasticizers. These admixtures contain an anionic backbone that can be adsorbed on aluminate and ferrous clinker phases and on the hydration products ettringite and monosulphate [1]. The dispersion of particles takes place either by electrostatic or steric repulsion (Fig. 1), or a combination of both effects.

The first group of superplasticizers (SP) used in concrete were lignosulphonates, later, more efficient polycondensates were introduced into the market such as naphthalene or melamine sulphonates [2, 3]. In the 1980s the first polycarboxylate SPs (PCE) were introduced [4]. They consist of a methacrylic backbone and attached polyethylene oxide graft chains. Upon adsorption of the polymers, the graft chains support a steric repulsion of the particles, however, a charge excess may generate electrostatic repulsion forces as well.

Cement-superplasticizer interactions with regard to workability

Superplasticizers mainly affect the yield stress by minimising attractive forces between particles. Changes in their dosage or conformation have little effect on the plastic viscosity of cementitious systems, since they are added in negligible amounts with no effects on the particle volume fraction [5]. SPs have to be adsorbed to become effective but they compete with sulphate ions in the pore solution for adsorption sites [6, 7]. The charge density of PCEs determines how strongly and how quickly they are adsorbed on positively charged surfaces [8-10]. Non-adsorbed polymers remain in solution and do not contribute to flowability. Therefore, at an identical effective polymer content, highly charged PCEs are more efficient in reducing the yield stress due to their stronger adsorption tendency [5, 10-13]. However, due to ongoing hydration further monosulphate and ettringite are formed, which provide time dependent additional adsorption sites for those polymers that could not be adsorbed initially, so that they can become effective over the course of time [5, 14-16] (Fig. 2). This time dependent adsorption contributes significantly to the flow retention.

Cement-superplasticizer interactions with regard to hydration retardation

Superplasticizers are typically added in order to control the rheology and to modify the water content. However, once added they cannot be withdrawn from the system, and their effects on the ongoing hydration have to be considered. Superplasticizers are known to significantly retard the setting of cementitious systems. The mechanism behind the hydration retardation is not fully clarified today. Two effects have to be considered with regard to the effects induced by PCE superplasticizers:

- Investigations have shown that at identical polymer dosage PCE with higher charge density may have a stronger retarding effect than PCE with lower charge density [17].
- The set retardation is proportional to the amount of effective polymers in the system. Higher charged PCE types are more efficient in their dispersing effect, thus need to be added in lower amounts, causing less retardation.

Hence, the charge density of PCE can have two opposing effects, an accelerating and a retarding effect. Fig. 3 shows that the effect of the molecular architecture retreats into the background since the clearly dominating effect on the set retardation is induced by the pure amount of PCE in the cementitious system. As a result it can be concluded that higher charge density PCE generally cause less retardation.

Conclusions

Workability has become an important design parameter for specific concrete types, where the rheology at fresh state is relevant for the functionality at hardened state.

The major contribution towards the tailored design of sophisticated flowable cement based system comes from the understanding of the interactions between superplasticizers and the hydrating cement.

A parameter of utmost importance for the performance ability of superplasticizers based on PCE is their charge density, which can be linked to their adsorption behaviour.

High charge PCE is immediately very efficient to reduce the yield stress of concrete but becomes ineffective rapidly. It is therefore well suited for pre-cast technology.

Low charge density PCE is less efficient in the beginning but can maintain the yield stress reduction over a long period of time. It is therefore well suited for ready-mixed and onsite concrete.

Since the amount of polymers is the dominating factor that interferes with the early hydration of cement, higher charged PCEs cause less retardation due to their higher effectiveness.

Figures and tables

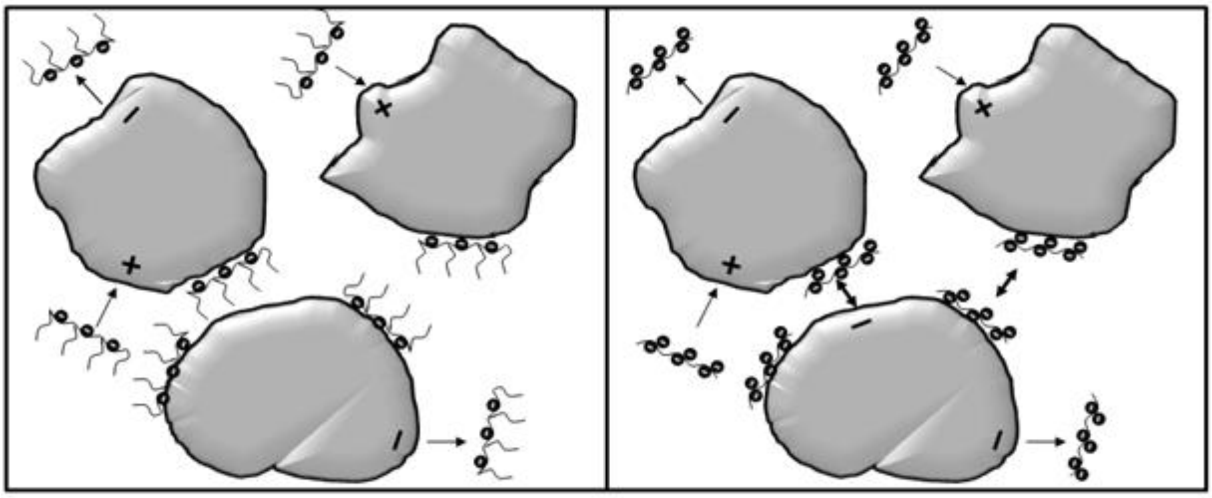

Figure 1: Steric (left) and electrostatic (right) repulsion mechanism [10].

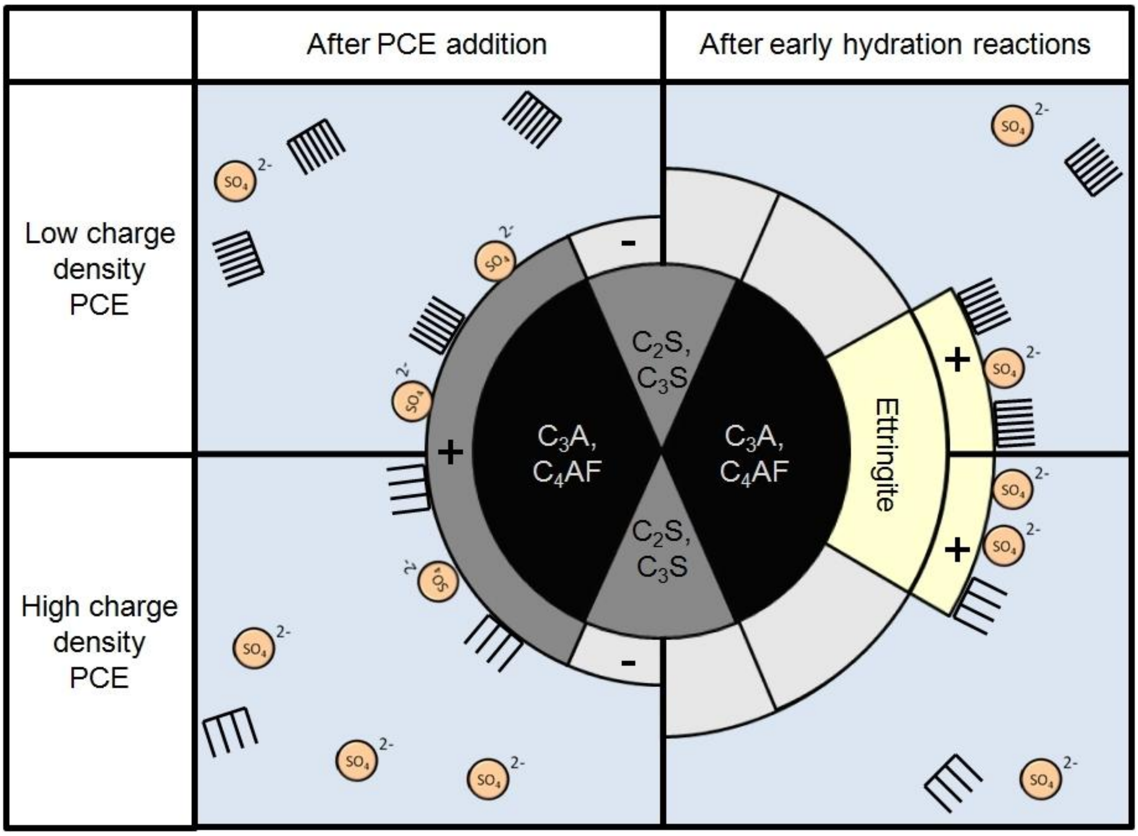

Figure 2: Time dependent effects on the efficiency of superplasticizers depending upon their adsorption properties [16].

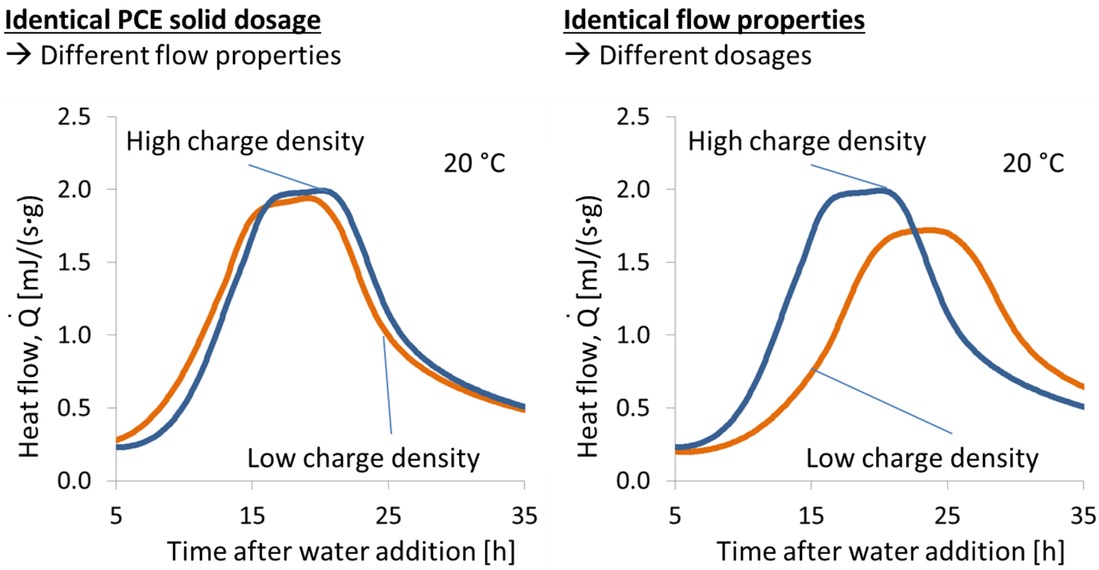

Figure 3: Influence of the charge density and the polymer amount on the hydration retardation.

References

[1] J. Plank, C. Hirsch, Cement and Concrete Research, 37 (2007) 537-542.

[2] J. Plank, Applied Microbiology and Biotechnology, 66 (2004) 1-9.

[3] C. Giraudeau, J.-B. D'Espinose De Lacaillerie, Z. Souguir, A. Nonat, R.J. Flatt, Journal of the American Ceramic Society, 92 (2009) 2471-2488.

[4] C.A.J. Winter, in: Lehrstuhl für Bauchemie der Technischen Universität München, TU-München, München, 2007.

[5] W. Schmidt, H.J.H. Brouwers, H.-C. Kühne, B. Meng, Cement and Concrete Composites, 49 (2014) 111-126.

[6] S. Hanehara, K. Yamada, Cement and Concrete Research, 29 (1999) 1159-1165.

[7] J. Plank, G. Bassioni, Z. Dai, H. Keller, B. Sachsenhauser, N. Zouaoui, in: J. Stark (Ed.) 16th International Conference on Building Materials - ibausil, FIB, Weimar, Germany, 2006, pp. 579-598.

[8] I. Schober, R.J. Flatt, in: V.M. Malhotra (Ed.) 8th CANMET/ACI International Conference on Superplasticizers and other chemical Admixtures in Concrete, American Concrete Institute, Sorrento, Italy, 2006, pp. 169-184.

[9] I. Schober, R.J. Flatt, in: J. Stark (Ed.) 16th International Conference on Building Materials - ibausil, FIB, Weimar, Germany, 2006, pp. 93-100.

[10] W. Schmidt, in: Department of the Built Environment, TU Eindhoven, Eindhoven University of Technology, Eindhoven, Netherlands, 2014, pp. 308.

[11] W. Schmidt, in: ACCTA Pre-Conference Lecturing Courses, University of the Witwatersrand, Johannesburg, South Africa, 2013.

[12] W. Schmidt, in: 22. Workshop und Kolloquium Rheologische Messungen an Baustoffen, Regensburg, Germany, 2013.

[13] W. Schmidt, in: Department of the Built Environment, Eindhoven University of Technology, Eindhoven, Netherlands, 2014, pp. 324.

[14] W. Schmidt, J. Brouwers, H.-C. Kühne, B. Meng, Effects of Superplasticizer and Viscosity-Modifying Agent on Fresh Concrete Performance of SCC at Varied Ambient Temperatures, in: Design, Production and Placement of Self-Consolidating Concrete, Springer Netherlands, 2010, pp. 65-77.

[15] W. Schmidt, H.-C. Kühne, B. Meng, in: A. Rogge, B. Meng (Eds.) 52. DAfStb-Forschungskolloquium, Deutscher Ausschuss für Stahlbeton e. V. (DAfStb), Berlin, Germany, 2011, pp. 40-49.

[16] W. Schmidt, H.J.H. Brouwers, H.-C. Kühne, B. Meng, Advances in Civil Engineering Materials, 3 (2014).

[17] F. Winnefeld, S. Becker, J. Pakusch, T. Gotz, Cement and Concrete Composites, 29 (2007) 251-262.

QUALITY CONTROL OF REINFORCED CONCRETE STRUCTURES FOR DURABILITY

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Introduction

There is concern almost universally about the lack of durability of reinforced concrete (RC) structures. In the main, 'durability' is a concept not well understood by structural engineers, not well specified by designers, and not well executed by contractors in terms of constructing for durability. The consequences are the existence of a substantial amount of poorly–performing structures that require major maintenance to ensure their service lives, or may even need premature demolition before the end of their useful service lives. While the problem might be expected to exist more in developing parts of the world, there are numerous examples of the same in developed economies, particularly for reinforced concrete structures for which corrosion of the reinforcing is a major problem.

The current provisions for durability in the standards [1, 2] outline the exposure conditions, concrete mix requirements, cover depth provisions and execution of concrete practices. The approach in these standards used for quality control is based on a measure of strength on a standard cube or cylinder specimen. However, strength is an inadequate measure of the quality of a reinforced structure (RC) with regard to durability which is dependent on the penetrability of the concrete cover [3]. Penetrability of the concrete cover is influenced by proper execution of construction practices – the placing, compaction and curing of concrete [4].

Regarding specifications for durability, this is tricky precisely because the concept itself is difficult to grasp. Durability has no meaning in isolation of the environment of exposure to which a structure is exposed. The result is that current specifications for RC durability are limited mainly to so-called 'prescriptive' approaches in which limits are set on mix proportions, materials, and possibly concrete strength, for example maximum w/b ratio, minimum cement content, minimum compressive strength.

It has been argued for some time now that prescriptive specifications are inadequate because they require difficult-to-measure aspects, they do not directly address the multiplicity of possible durability issues, and they are not appropriate in an age when binder systems are multiple and complex and ever-changing, and in which alternative and innovative materials are needed. Therefore, a better way is required: modern thinking centres on performance-based specifications in which specific durability-related parameters are specified as needing to be achieved in the structure, or at least in pre-qualification trials, such that a proper handle on durability can be obtained [5].

Linked to an appropriate durability specification is the need for accurate and reliable test methods and a quality control/quality assurance scheme. Simply measuring strength is inadequate in the control of the quality of RC structures, especially with regard to durability. Proposals have been made for a shift to performance-based specifications, as indicated above.

This paper discusses the use of the durability index (DI) performance-based approach which has been implemented in large scale projects in South Africa, drawn largely from a previous publication on this subject [6]. The practicality of the approach has been evaluated in different ways, such as considering variability in DI test results; applicability of the tests in laboratories and on site; and the perception of resident engineers (REs) of this approach. It has been shown that measurement of actual *in situ* values of critical durability parameters – sometimes called durability indicators – can quantify *as-built* variability and general performance of construction in terms of quality. As mentioned, this implies the existence of reliable test methods. The applicability of selected tests in various laboratories is reviewed by references to a laboratory audit, in which variations in test equipment and execution of the tests were observed. From the studies presented, several challenges were observed such as difficulty in use of test panels, poor communication among parties, reluctance to adopt this approach and a need to increase reliability of tests. These challenges will serve as useful guidelines for the improvements of the approach to ensure its successful implementation in quality control.

The Durability index performance-based approach

The durability index (DI) tests were developed to characterize the properties of near surface concrete and its potential resistance to ingress of aggressive substances [7]. The DI tests are oxygen permeability index (OPI), water sorptivity index (WSI) and chloride conductivity index (CCI). These tests are relatively simple to carry out and should be conducted at an early age, ideally at 28 -35 days.

The OPI and CCI tests are used in service life prediction where the OPI test was found to have a strong correlation to carbonation depth, while the CCI has a strong correlation with the diffusion coefficient in the modified Fick's 2nd law of diffusion. These tests have been applied in performance-based specifications which considers several factors such as exposure conditions (adapted from EN-206), cover depth, service life and binder properties [8]. The WSI is used as an internal control in projects to evaluate the effectiveness of curing.

The DI performance-based specifications have been adopted by the South African National Roads Agency Limited (SANRAL) in a major infrastructure project which is further described in the subsequent section.

Practical implementation of the DI performance-based specifications

OPI test values were obtained from five sub-projects (sub-projects 1, 2, 4 and 6 *from in situ* structures; sub-project 9 from precast elements), and statistically analysed to determine average values, compliance with limit value provided in the specifications, magnitude of variation in test values which indicates the degree of control in construction of structures, and proportion of values that fail to comply with the limit value.

A summary of the findings is presented in Figure 1. The average value from all sub-projects complied with the limit OPI value of 9.70 (log scale). Variability as measured *in situ* is also seen to vary widely in the histograms: the lowest variability was from sub-project 9 (precast elements) and the highest from sub-project 6. Further, the proportion of values not complying with the limit is highest for sub-project 1 at 40.1%, representing almost half of the test results; for sub-project 9, all the values complied with the limit, showing that the degree of control here was high. In general, the variability was considerable for the *in situ* structures, indicating poorer quality control for these structures.

Conclusions

Mather [9] strongly emphasised that the owner of a structure gets "what they inspect, not what they expect". To guarantee the durability of RC structures, a measure of the quality (penetrability) of the concrete cover is essential. The paper has illustrated the application of the DI-based performance approach in South Africa which is practical in control of concrete cover quality. The OPI test has been observed to have an acceptable variability and is also a robust test. There was a positive reception of the approach from some REs who highlighted that improvements in construction practices had taken place with its implementation. Several challenges in the implementation of the DI-based performance approach will need to be addressed such as the quality of production of test panels, improved communication among the parties (laboratory staff, contractors and engineers) and reducing test variability e.g. for the water sorptivity test. The implementation of this test on a large scale should be viewed as a first important step in the development of quality control procedures for durability of RC structures. The challenges observed are useful as they highlight areas that need improvement to ensure successful application of the approach.

Figures

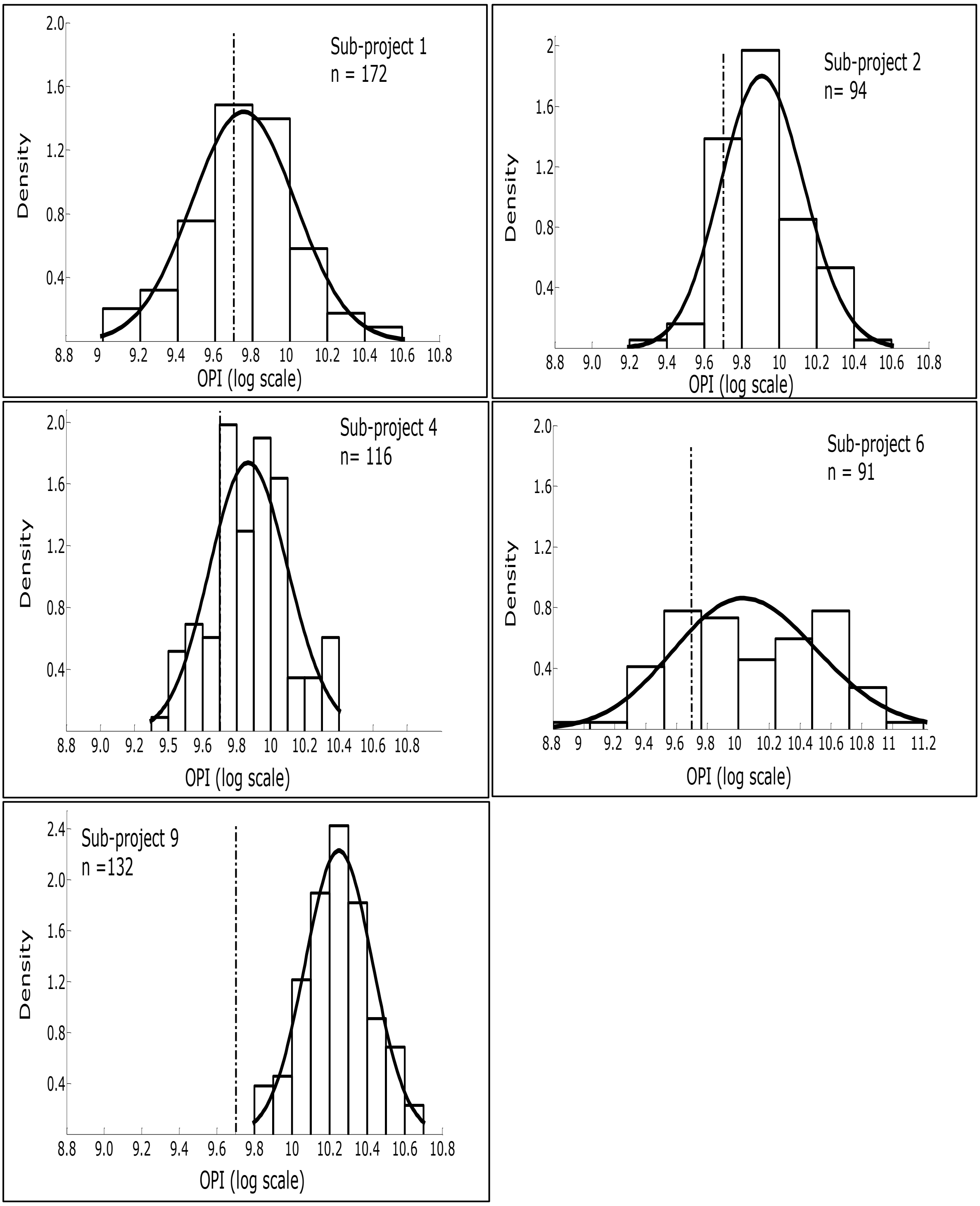

Figure 1: Histogram plots of OPI values from sub-projects of the GFIP

References

[1] BS EN 206-1, 2000, "Concrete – Part 1: Specification, performance, production and conformity", London. British Standard Institute.

[2] SANS 10100-2, 2009, "The Structural use of concrete. Part 2: Materials and execution of work", South African Bureau of Standards. 84pp.

[3] Skalny, J. and Idorn, G.M., 2004, "Thoughts on Concrete Durability", International RILEM Symposium on Concrete Science and Engineering: A Tribute to Arnon Bentur. Weiss, J., Kovler, K., Marchand, J. and Mindess, S., Ed. RILEM.

[4] Bentur, A. and Mitchell, D., 2008, "Material performance lessons", Cement and concrete research. 38(2):259-272.

[5] Somerville, G., 1997, "Engineering design and service life: a framework for the future", In Prediction of concrete durability: Proceedings of STATS 21st Anniversary Conference, Glanville, J.A.N., Ed. London. E & FN SPON: 58-76.

[6] Nganga, G., Alexander, M.G. and Beushausen, H., 2013, "Quality control of reinforced concrete structures using the Durability index performance-based approach", ACCTA conference, Emperors Palace, Johannesburg, 28 – 30th January 2013.

[7] Alexander, M.G. and Mackechnie, J.R., 2001, "Use of durability indexes to achieve durable cover concrete in reinforced concrete structures", In Materials Science of Concrete. J.P. Skalny and S. Mindess, Ed. Westerville: American Ceramic Society. 483-511.

[8] Alexander, M.G., Ballim, Y. and Stanish, K., 2008, "A framework for use of durability indexes in performance-based design and specifications for reinforced concrete structures", Materials and structures. 41(5):921-936.

[9] Mather, B., 2002, "Owner's responsibility in quality verification", Concrete International 24(2):70 -72.

Cementing our future through innovation: novel approaches to enhancing the quality of Concrete

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Brief author biography

Dr. Raissa Ferron earned her BS from Howard University, and she earned her MS and PhD from North-western University. She is an Assistant Professor in the Department of Civil, Architectural and Environmental Engineering at the University of Texas at Austin. Her research group focuses on infrastructure materials, primarily dedicated to researches in characterization of fresh-state hydraulic cements microstructure, rheology, affordable sustainable housing materials, and smart materials. She serves as a member of several technical committees and was a recipient of the 2010 American Society of Civil Engineers New Faces award, an award which recognizes outstanding young civil engineers.

Introduction

Materials development in the field of civil engineering is an area where exciting opportunities exist to tackle the demands of our ever changing society. Whether you are in Africa, North America, Asia, South America, Australia, Antarctica or Europe, concrete materials play an essential role in the livelihood, security and health of one's national infrastructure and economy. In order to achieve the goal of a safer, better and longer life-cycle for our world's infrastructure, a holistic approach which takes into account the interaction among processing, structure, and properties to yield a given technical performance is needed. An overview of some of the research activities occurring within Dr. Ferron's group regarding a systems approach to enhancing the quality of concrete will be presented. Additional details regarding the topics of these research activities are provided below:

- **Role of mixing on concrete:** All concrete, whether it is for the field or the lab, must be mixed; yet the mixing process is probably one of the least areas studied with respect to the life cycle of concrete. Mixing not only homogenizes the composition of concrete; it also plays a significant role on the rheology, strength and durability of concrete. Thus, throughout the history of time, hundreds of researchers all of the world have conducted experimental tests in the lab in order to gain a better understanding of the factors that control concrete performance. Ideally the sample preparation technique used in the experimental test should simulate the processing conditions that would occur in the field. In the lab, concrete is often mixed for approximately 8 minutes [1], however the mixing time and speed of concrete in the field differs drastically. This disconnect between how concrete homogenized in the field versus how it is cement paste and concrete is mixed in the lab, as well as the implications that this has on the properties of concrete, will be discussed.

- **Screening of alternative supplementary cementitious materials via rheology:** Supplementary cementitious materials (SCMs) provide many benefits to the concrete industry due to the cost savings, long-term strength improvements, and enhanced durability that results from incorporting SCMs in portland cement concrete. Fly ash is the most widely used SCM in United States. However concerns about the future availability of fly ash have arisen due to the implentation of pollution control devices in coal combustion plants and increased blending of powder river basin coals, both of which can influence the composition (and hence quality) of the resulting fly ash. Rheology is the study of the flow of deformation of materials. This presentation will present the work of a project that focused on use of rheological methods to screen SCMs that could be used as a potential replacement to fly ash for concrete mixtures.

- **Smart multifunctional cement-based materials:** Today's concrete is no longer a simple combination of Portland cement, aggregates and water. With increased use of various types of waste materials, supplementary cementing materials and chemical admixtures, material incompatibility is an issue that often arises in concrete construction. As a result, some of the greatest problems in concrete manufacturing occur when concrete does not stiffen, set or harden on time. All of which can affect the durability of concrete. However, what if it was possible to create a concrete in which one is able to control in real-time its stiffening behaviour? Cement-based magnetorheological (MR) fluids can potentially be used in civil engineering applications to act as a "set-on-demand" material. MR fluids are a novel class of smart materials that are able to change its viscoelastic properties in the presence of magnetic fields. The development of a cement-based MR suspension would not only allow for greater control during the processing of concrete, but could transform the way that the health monitoring of pavements and structures are conducted. Traditionally, MR methods have not been used on cementitious composites; however recent work shows that cementitious suspensions can display MR properties [2] and will be presented in this talk.

- **Self-healing concrete**: Internal stresses (due to mechanical loads, temperature changes, etc.) may induce microscopic cracks in Portland cement concrete, which will continue to grow upon the application of additional stresses. These cracks can provide pathways for harmful chemicals to ingress, which can lead to a loss of strength and integrity. Recent research in the field of concrete materials suggests that it might be possible to develop a smart cement-based material that is capable of self-healing by leveraging the metabolic activity of microorganisms to induce biogenic calcium carbonate precipitation [3]. In fact, such an approach has been used to repair ornamental stones for restoration [4-5] via external application of a bacterial agent. Some of the approaches to incorporating bacteria into concrete as well as the challenges and advantage of each method will be presented.

References

[1] ASTM International: ASTM C192, Standard practice for making and curing concrete test specimens in the laboratory, ASTM Int. (2013).

[2] Sriramya Duddukiri Nair and Raissa Douglas Ferron, (2014) "Set-on-demand concrete," *Cement and Concrete Research,* v55, pp. 13-27.

[3] Bin Zhang, Zeynep Basaran, Paramita Mondal, and Raissa Douglas Ferron. "*Use of Biomineralization in Developing Smart Concrete Inspired by Nature*". International Journal of Materials and Structural Integrity, in press.

[4] Jimenez-Lopez, C., Rodriguez-Navarro, C., Piñar, G., Carrillo-Rosúa, F.J., Rodriguez-Gallego, M. and Gonzalez-Muñoz, M.T. (2007) 'Consolidation of degraded ornamental porous limestone stone by calcium carbonate precipitation induced by the microbiota inhabiting the stone', *Chemosphere,* vol. 68, no. 10, pp. 1929-1936.

[5] Rodriguez-Navarro, C., Rodriguez-Gallego, M., Chekroun, K.B. and Gonzalez-Muñoz, M.T. (2003) 'Conservation of ornamental stone by Myxococcus Xanthus-induced carbonate biomineralization', *Applied and Environmental Microbiology,* vol. 69, no. 4, pp. 2182-2193.

FROM LAB-CRETE TO REAL-CRETE, THE PEOPLE + PLANET = PROFITABLE PROJECTS APPROACH

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Brief author biography

Boudewijn Piscaer studied mechanical engineering but moved into the industrial application of refractories bricks as a sales engineer. He developed new markets in Europe and North America. In 1984 he became in charge of Lafarge's High Tech Refractory Concrete Division in Paris, implementing patents for low cement concrete. Since 1995 he applies the same technological plus human success factors to the civil concrete. Also Self Compacting Concrete innovation implementation became his link with the move towards more sustainability, which remains his global key objective today for the People, Planet and Profit. He started up the long prepared new Sustainable and Innovative Concrete Quality Assurance activities this year.

Introduction

While science in Europe and North America may be at a higher level than in Africa, progress in Europe is obstructed by out-dated prescriptive standards. The new approach towards sustainable constructions is for Africa a chance to "leap frog" over the mistakes made in Europe. In economies where the cost of materials weighs heavier then cost of man hours, interesting move to improving the engagement op people is both affordable and necessary. Safety of structures and reducing waste of expensive resources are leading. Due to the interests in high tech local micro productions, we count on contribution from our African friends on our common progress, especially for pilots.

Facts

There are only 3 truth; my truth, your truth and THE truths.

Tierno Bokar, Soufi/playwriter, Mali 1939

The writer/speaker acts not from scientific but from practical experience in technical sales, innovation implementations, pioneering in business, and general management in global international settings. He still tries to build bridges between practice and science.

A. Though concrete is for most people just grey and gets hard with water, for scientists lots of mysteries remain. We can say that "Rock Science is more complex then Rocket Science" since we work with natural materials that differ from place to place.

B. There are 4 types of concrete; Book-Crete, Lab-Crete, Real-Crete and Legal-Crete.

C. The basic demands on concrete are;

1. Workability, (from earth dry to Self Compacting Concrete)

2. Strength, (demoulding strength, testing strength, final use strength)

3. Durability, (> 90% is corrosion of steel re-enforcement by carbonation and chlorides)

4. Sustainability, (People, Planet, Profit balance)

5. Aesthetics, (surface, colour)

6. Cost (not just price but Life Cycle Cost)

D. Globally premature failure of concrete structures can be related to; 20 % poor concrete mix, 30 % errors in design, 50 % shortcomings on the job site (lack of curing, reinforcement cover, compacting). So, science and technology is only a part of the solution.

E. Strength and Durability Performance is related to;

I. Particle Packing, II. Adhesion III. Reactivity/Mineralogical transformations of the fines.

F. The Water "Cement" Factor has done a lot of good when cement was only Portland cement, but cannot function anymore as a performance indicator with new binders available. Instead, the Water Powder Ratio can function as a rough guideline.

G. One of the major ingredients for sustainable concrete is; CONSITANCY!

H. A "green" concrete that is not Durable is not Sustainable.

I. The concrete profession emits 4 Billion tons of CO_2 per year, 2.4 Billion coming from Portland cement production. Portland cement is the number 2 in CO_2 product in the world and remains a key ingredient in concrete (for the time being).

J. Other and low environmental impact binders, recognized by the cement industry are; Blast-furnace slag, Natural Pozzolans, Industrial Fly-Ash, Ground Calcium Carbonate, Micro Silica Fume, Oil-Shale Ash.

K. Promising binders are; Reactive Rice Husk Silica, Sugar Cane Bagasse, Meta-Kaolin etc.

L. Demand for tailor made concrete thus tailor made binders will increase, meaning flexible supply of different qualities and optimum use of materials.

M. Regarding the average buying power, people in South Africa pay 30 X to 130 X more for a bag of cement. Will the quality be better?

N. If you ask 10 structural engineers a solution, you get 10 different answers.

O. Education is Knowledge, skills and Attitude. Textbooks should be part of the knowledge inventory, but personal communication skills and attitude will determine if and where you can make use of that knowledge.

P. (to be filled in during the sessions)

Q. etc.

Key Case Story (to be told)

The Self Compacting Concrete development (and the lack thereof) in several European countries late 90th will be presented and discussed as an example how culture and management can make the technological differences.

A Holistic approach towards sustainable concrete structure

Sustainability is a global inspiration but a local obligation. B. Piscaer, Rabat Nov. 2013

I. Basic Infrastructure in the country

Are there building codes and performance based quality standards?

Which one's can we use for the time being, with an eye to better ones?

Are they enforced and by whom and how?

Are there any branch organizations available?

What role do the educational institutions play?

If there is no adequate responsible public structure available, can a private independent structure for quality-assurance be set-up?

II. At the desk (Book-Crete)

1. Identify the project LEADER, not just a project manager

2. Inventory of available human and material resources and have enough samples shipped to the development lab

3. Who are the suppliers of structural engineering, materials, contractors? Early and respectful communication between as many parties involved in the project around the same table is key to success; Customer (end user?) – Specifiers (Architect & especially structural Engineers) - Concrete supplier(s) – Contractor & "specialized" subcontractor – Construction supervisor.

4. What textbooks have people read? Every "master" will have their preferred one so make a list. Mine is from Ken Day; **Concrete Mix Design, Quality Control and Specification, Fourth Edition,** ISBN-13: 978-04155049971.

5. Establish a concrete development program to respond to all 6 demands on concrete with all valid suppliers and sub-suppliers, especially the neutral admixture people.

6. (to be filled in by colleagues)

III. At the Lab (Lab-Crete development);

7. Does it have basic equipment to make and test 16 X 4 X $ prisms from mortars, using simple mixers, flow cones and presses or can we improvise with affordable materials?

8. Select the right amount of materials needed for testing

9. At the production lab site; Send full scale m3 samples away with Real-Crete productions

10. (to be filled in by colleagues)

IV. On the production site (Real-Crete)

11. Establish incoming raw materials and outgoing Quality Control methodology. Check on water demand of the powders.

12. Select the key suppliers and make binding contracts

13. (to be filled in by colleagues)

V. On the job

14. Awareness; Explain on <u>all levels</u> why you want good compacting, cover thickness and curing/after treatment.

15. Organize on-job quality control/inspection and Non Destructive Testing (maturity measurement, strength, cover thickness, permeability)

16 See if there are any private or public quality performance schemes available

17. See if there are Sustainability (LCA) schemes available

18. Make report/fact sheet of the job.

19. Communicate with project partners the plusses and minus of the project as valuable lessons for the future.

20. (to be filled in by colleagues)

Note; All the above will be printed prior to the Knowledge EXCHANGE event and can serve as subjects/materials for a more interactive/exchange session then a one way key-note.

If possible, students may be requested to prepare the topics they would like to elaborate on more.

Boudewijn Piscaer, Toronto 18-5-2015

SUSTAINABLE BINDERS AND NEW WAYS OF CONSTRUCTION

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Brief author biography

Angel Palomo has a PhD in Chemistry. He is involved in research activities since 1982. He has an H-factor of 35 (SCOPUS) or 31 (WOS). His main area of research is chemistry of Portland cement, cementitious materials at cultural heritage and new sustainable cementitious materials (with special focus to alkali activated cements). Angel is a supervisor of 6 doctoral theses, has more than 150 publications in scientific journals and an invited keynote speaker in more than 100 international events. He is the leader of more than 50 research projects (at national and international level). He is also the collaborator and advisor of the international industry in sustainable cement and concrete.

Dr Mario Molina (a well reputable Mexican Nobel Prize in Chemistry) wrote:

"*Scientists may announce the elements affecting the environment based on the available evidences, however the solution to the problems is not a responsibility of scientists but the whole society.*"

Sustainable Binders

Increasing economic growth demands more effective utilization of both renewable and non-renewable resources. If not carefully targeted, this will lead to production of an increased amount of waste. Additionally, waste handling companies treat numerous waste flows generated in different industrial areas which have not yet found major industrial applications. Legislation and taxation are becoming more stringent, and consequently, waste disposal costs are increasing. This has resulted in increasing interest in the search for novel utilization possibilities for the waste flows generated.

There is an increasing environmental need to develop new, more sustainable production technologies to utilize waste as a substitute for raw materials in different industrial areas. Special emphasis here falls upon the construction sector, which produces almost ten percent of global CO2 emissions, while generating around 11% of global GDP [1]. At present, part of the coal fly ash generated by the European energy sector (for example), and much of the blast furnace slag from European iron making, is used as supplementary cementitious materials in cement and concrete production. However, significant fraction of EU ashes and slags are currently land filled; around 7% of blast furnace slag and the vast majority of non-ferrous and specialty steel slags across the EU [2] and as much as 50% of fly ash produced in some EU member states (although much less in others), are not effectively utilized.

Aluminate- and silicate-containing waste materials can react in alkaline conditions, yielding a solid material comparable to hardened Portland cement. The material thus produced is called an alkali-activated material (AAM), or geopolymer. The main advantage of these materials is that compared to traditional Portland cement based concrete (e.g. Ordinary Portland Cement, OPC), geopolymers have been shown to reduce CO2 emissions by up to 80% while offering comparable technical performance in many aspects [3]. Geopolymer technology has also long been recognized to offer high potential for immobilization of hazardous components [4]. This characteristic is essential in safely utilizing industrial waste materials in construction products. The most common alkaline additives ('activators') used in geopolymer technology are commercially produced bulk chemicals (NaOH, KOH, sodium and potassium silicate solutions), which become by far the main cost factor in producing geopolymers. By replacing such chemicals by waste solutions, geopolymers will become much more competitive with conventional binders on a cost basis and their CO2 footprint will further decrease.

Geopolymers have been shown to be suitable for large-scale civil infrastructure materials [5] but their commercial utilization has not yet become common. it is now the right time for building materials companies to take the lead in the market deployment of this innovative and promising technology.

Alkali-activation technology, in fact, has been known for over 100 years [6] and the use of alkali activated industrial waste such as fly ash and ground granulated blast furnace slag (GGBS) as binders for cement substitution has been widely studied ever since. More recently, due to the commitment of the World Climatic Change Conference to reduce the CO2 emissions, geopolymers have received much more attention and represent the most mature alternative to traditional cement based products. However, the utilization of geopolymers in the construction sector is still in an initial phase. So far only a few applications are reported:

- Zeobond Pty Ltd (www.zeobond.com), in Australia has developed and registered a geopolymer-based technology named E-Crete that has been mainly used for producing slabs in form of both precast and ready mix concrete. Very interestingly the ready mix application does not require a heat source, since the reaction occurs at room temperature.
- ACCIONA (www.acciona.com) (Spain) has developed a porous geopolymeric material in form of constructive blocks within the GREEN CAST project. This material is based on fly ash, activated with an alkaline solution. A foaming agent is added into the mixture, generating a porous structure, which provides a cellular structure to the material, keeping a good mechanical performance.
- HASSEL (www.hassellstudio.com), Bligh Tanner (www.blightanner.com.au) and Wagners (www.wagner.com.au) have successfully used geopolymer concrete for structural purposes in the University of Queensland's Global Change Institute (GCI), in Australia. The 4 storey high building, for general public use, comprises 3 suspended geopolymer concrete floors involving 33 precast panels.
- Banah UK Ltd (www.banahuk.co.uk) has developed geopolymer construction elements for external and internal walls as well as geopolymer products for direct PC replacement. The raw material of Banah geopolymer products is a geological resource which is not considered as waste, but is available in large volumes in the area immediately surrounding their production facility.

Geopolymer technology has already been applied and tested in real conditions, in Europe, Australia, North America, and Asia [7]. However, current world market applications are in general only in the very initial stages of maturity. The future development of this technology will likely demonstrate different high value geopolymer products: fibre-reinforced geopolymers, porous geopolymers, self-compacting geopolymers and aesthetic geopolymer products. Currently, these materials are produced with PC concrete:

Fibre-reinforced geopolymers: Adding fibres to PC concrete can improve its mechanical properties and durability. One particular type of application is façade panels, with carefully tailored texture and colour properties. High performance, fibre-reinforced concrete has proved especially valuable for this type of applications with enhanced mechanical properties allowing for audacious shaping (such as very thin panels), and dense granular structure limiting the aesthetically damaging fixation of pollutants on the surface. Recently, the use of fibre-reinforcement in geopolymer materials has been studied successfully [8], but no such products are yet on the market.

Porous geopolymer products: Today, porous concrete products are used for thermal and acoustic insulation. A significant part of the insulation products available on the European market are made with Portland cement mixes, such as autoclaved aerated concrete (AAC) blocks. Porous geopolymer materials are a sustainable option for porous concrete products. ACCIONA has developed a porous geopolymeric material in form of constructive blocks within the GREEN CAST project (Eco-Innovation Initiative). Compared to conventional AAC, the GREEN CAST material presents similar properties. However, to the best of my knowledge, no geopolymer products are yet used as external wall panels for acoustic insulation of noise generated by traffic (acoustic barriers), and only to a small extent for indoor insulating elements.

Hybrid, self-compacting ready mix concrete: Self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions, for remote casting and in sections with congested reinforcement. Use of SCC can also help to minimize noise-related damages on the worksite that are induced by vibration of concrete. Another advantage of SCC is that the time required to place large sections is considerably reduced [9]. The first cases of SCC concrete were reported in Japan in 1986, the volume of SCC in construction has risen steadily over the years, and there is increasing end-user demand for SCC in the whole world [10]. Extensive research has been carried out related to new binders such as Hybrid Cements (HYC) - the result of combining traditional binders (PC, CAC) and geopolymer [11-12] and their use in SCC, but no products have yet appeared on the market.

Aesthetic concrete products: Today, the high value construction on the market contains mainly materials based on PC (e.g. www.lafarge.com/contribute-better-cities/contribute-more-beautiful-cities). Graphic concrete is one of those technologies used for production of the aesthetic concrete products (www.graphicconcrete.fi). In this technology artistic designs are printed on any concrete surface at the time of casting by using a special made membrane. The desired design is printed on the surface by using set retarders.

New ways of construction: 3D printing

Three-dimensional printing, a modern manufacturing technique based on additive deposition (US Patent and Trademark Office –

http://www.uspto.gov/web/patents/classification/cpc/html/defB33Y.html, 2015.02.09), has recently been introduced for use in construction [13 - 14]. The development of large-scale printers to manufacture the sizeable elements and members (or even whole buildings) needed in this industry is one of the major challenges facing robotics. Those large-scale 3D printers are already on the market stands as proof that conventional construction activities (such as design and building) have begun to incorporate new technologies. One of the first applications for 3D printing would obviously be the ability to recover classical architectural elements such as columns and ornaments that are no longer handcrafted. In 3D technology, complexity entails no extra cost, for objects are simply printed from three-dimensional scans. Virtually any shape can be rapidly printed by additive deposition.

The construction materials industry, for cement in particular, cannot shun this technology. New cements must be designed for practical use in large-scale printers as these robots are developed.

At this time two main innovative techniques are being explored for applying large-scale 3D printers to construction. As they are based on two very different approaches to building the objects designed, they are associated with different notions of what a "binder" is.

Contour crafting (developed in the USA)

In this technique a machine drives a printer head in three-dimensional motion to sequentially deposit layers of a previously mixed mortar paste or micro-concrete onto a solid surface.

This is certainly the most widely used and best known technology [13]. Contour crafted print quality is still not wholly satisfactory, however, for the material is deposited in tiers several centimetres thick and the inter-layer joints are highly visible. Moreover, since the printing process takes place from the top down, only small openings, voids or cantilevers can be accommodated (by changing the speed of the printer head). A provisional structure must be built (using the machine itself) to support larger cantilevers or openings. This technology is promising for simple construction processes, given the speed of these printers. It is ideal, for instance, for building rural dwellings or emergency housing after earthquakes or other natural catastrophes and adapts well to traditional binders such as Portland cement pastes or the clay ordinarily used in structural elements such as bricks and roof tiles [15].

While no scientific paper has yet been published on research or development of new binders specifically designed to work with such 3D printers, some of the world's cement majors are known to be engaging in projects primarily geared to developing 3D printers and cements that can be efficiently handled by such robots [16].

3D-shape (developed in Italy)

The approach adopted in 3D-shape differs entirely from the principle underlying the contour crafting model. Much more versatile, it is able to use cementitious material to create complex shapes and geometries. In this technique, the essential binder components need not be mixed in advance. Rather, they are blended outside the printer nozzle (as the "ink" is deposited onto the paper). This prevents the machine from occlusion, enabling it to maintain high printing precision throughout the construction process. More importantly, this 3D printer is not confined to certain shapes. It can print from top down or bottom up, leaving voids and openings of any size, for it uses the binder precursor as formwork for the objects to be printed [17].

In this 3D-shape approach, alkaline activation acquires vital importance as a mature science and technology able to supply binders perfectly adapted to process needs. Portland cement, in contrast, poses a number of practical problems for use in 3D-shape printers due to the characteristic ways that water diffuses and percolates through the complex packing system present in cement and aggregate particles. As a result of those mechanisms [18], when water comes into contact with anhydrous cement (in the early stages of hydration), part of it hydrates the material that is to constitute the formwork, thereby derailing the entire process.

The 3D-shape printer prototypes presently in place in Italy use Sorel-type cements [19] by way of printing paper (see Figure1), since magnesium salt-based products exhibit much more effective diffusion and percolation than water into Portland cement. Such cements have two major drawbacks, however: durability (very low in certain circumstances) and price (extremely costly).

No significant papers on new cements appropriate for 3D-shape printers have been published either, nor has research been reported that associates this technique with alkaline activation. Nonetheless, given their specific rheology, some alkaline cement pastes [20] hold great promise for application in such printers.

Figures and tables

Figure1: 3D-shape prototype printer and printed object using Sorel cement (photos by A. Palomo)

References

[1] http://in.reuters.com/article/2011/03/03/idINIndia-55293920110303

[2] J.F.P. Gomes, C.G. Pinto, Leaching of heavy metals from steelmaking slags, Revista de Metalurgia, 42(2006):409-416

[3] van Deventer JSJ et al. (2012) Minerals Engineering 29: 89–104.

[4] Palomo A, Grutzeck M, Blanco MT "Alkali-activated fly ashes - A cement for the future" Cement And Concrete Research Vol. 29 [8] pp.1323-1329, (1999).

[5] Provis JL et al. (2014) In: Provis JL, van Deventer JSJ, Alkali-Activated Materials: State-of-the-Art Report, RILEM TC 224-AAM, Springer/RILEM, Dordrecht, p. 309–338.

[6] A. Palomo, A. Fernández-Jiménez, G. Kovalchuk, L.M. Ordoñez and M.C. Naranjo "OPC-fly ash cementitious systems. Study of the gel binders produced during alkaline hydration" J. Mat. Sci. 42, pp 2958-2966 (2007)

[7] Wallah SE (2009) Modern Applied Science 3(12): 14–21.

[8] Ambily PS et al. (2014) Magazine of Concrete Research 66(2): 82–89.

[9] A. Skarendahl and O. Petersson, "State of the Art Report of RILEM Technical Committee 174-SCC, Self-Compacting Concrete," Paris, RILEM Publications S.A.R.L, 2000, 154 p.

[10] European Guidelines for self-compacting concrete: Specifications, production and use.2005. BIMBM, CEMBUREAU, ERCO, EFCA.

[11] Shi C, et al. Cem Concr Res 2011; 41:750–63.

[12] Garcia-Lodeiro I. et al. "Cement & Concrete Composites 39 (2013) 82–92.

[13] Behrokh Khoshnevis, Automated construction by contour crafting – related robotics and information technologies, Published in Journal of Automation in Construction – Special Issue: The best of ISARC 2002, 13, (2004), 5-19.

[14] Wilhelm, S; Curbach, M., Review of possible mineral materials and production techniques for a building material on the moon, STRUCTURAL CONCRETE, 15, (2014), 419-428, DOI: 10.1002/suco.201300088.

[15] M. Kornmann and CTTB, "Clay bricks and roof tiles, manufacturing and properties", Soc. industrie minérale, Paris,(2007) ISBN 2-9517765-6-X.

[16] "Desarrollo de un prototipo para impresión 3D de construcciones a gran escala" RTC-2014-1869-5 (MINECO) Government of Spain.

[17] Cesaretti, G; Dini, E (Dini, Enrico); De Kestelier, X; Colla, V; Pambaguian, LBuilding components for an outpost on the Lunar soil by means of a novel 3D printing technology, ACTA ASTRONAUTICA, 93,(2014), 430-450, DOI: 10.1016/j.actaastro.2013.07.034.

[18] Picandet V., Rangeard D., Perrot A., Lecompte T., Permeability measurement of fresh cement paste, Cement and Concrete Research 41 (2011) 330–338.

[19] Zongjin Li, C.K. Chau, Influence of molar ratios on properties of magnesium oxychloride cement, Cement and Concrete Research 37 (2007) 866–870.

[20] A. Palomo, P.F.G. Banfill, A. Fernandez-Jimenez and D.S. Swift "Properties of alkali activated fly ashes determined from rheological measurements" Advances Cem. Research. Vol.17, pp143-151 (2005).

SUSTAINABLE CONCRETE MADE FROM RECYCLED AGGREGATES

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Brief author biography

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Introduction

Debris from demolished and collapsed concrete and masonry structures is currently thrown away as wastes within the city of Dar es Salaam. According to Mfinanga [1], continuous industrial development poses serious problems of construction and demolition wastes disposal. Whereas on the one hand, there may be shortage of natural aggregates for production of new concrete, on the other hand the enormous amounts of demolished concrete produced from deteriorated and obsolete structures creates severe ecological and environmental problem [2]. Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development.

Dar es Salaam city is the Tanzania's largest city and major administrative, commercial, industrial and transportation centre. The city's population grew from 128,742 in 1957([3], to the currently population of around 4.5 million people. Due to this high population growth there is high demand of land for settlement for the people, while the government needs to expand the existing roads so as to meet the demand of the population, by doing so a lot of unplanned houses have to be demolished to pave way for the new roads and buildings in Dar es Salaam [4].

Objectives of the study

The objective of this study was to explore the suitability of recycled aggregates produced from construction and demolished concrete debris in making structural concrete. Basing on this main objective, the specific objectives were:

- To determine the quality of recycled aggregate such as crushing value, absorption and density.
- Establish the structural properties of the fresh as well as the hardened concrete

- Establish the grade of concrete that can be attained.

Concrete

The word "Concrete" comes from a Latin word "Concretus" meaning grow together according to the Concise Oxford Dictionary – 10^{th} Edition [4]. Concrete is one of the important building materials playing part in most if not all building structures for it is possible to be moulded into different shapes required for various structural elements.

The quality of concrete produced on site, depends on the quality of materials which have to meet the minimum specifications set by codes. On top of it is know-how of all personnel involved in production of the concrete. Neville [5] in his book "Properties of concrete" had the following to say: - "*Bad concrete is often a subsistence of the consistence of a soup, hardening in a honey-combed, non-homogeneous mass – is made simply by mixing cement, aggregates and water. Surprisingly, the ingredients of a good concrete are exactly the same, and it is only the know-how, often without additional costs of labour, that is responsible for the difference"*. This is to say that principles of good concrete production should be adhered to. Concrete ingredient materials should be of the required quality and quantity. Several codes have been developed to guide towards production of good concrete in different ways, for example CP110 and BS8110 [6] (Structural use of concrete), and BS 12620[7] (aggregates) and BS EN 197-2000 [8] (Cement). Interpreting these codes, various manuals and books have been printed.

Recycled Aggregates

Recycled aggregates originate from construction and demolition debris and consist mainly of crushed concrete and crushed asphalt pavement. Reusing and recycling of construction and demolition wastes are among principle of sustainable construction that advocate creation on operation of health built environment based on resource efficiency and ecological principles. Reuse refers to using an object again, either of its original purpose or for a similar purpose, without significantly altering the physical form of the object or material. Recycled means using wastes as material to produce a new product, involve altering the physical form of an object or material and making a new object from the altered material. Recycled concrete aggregate could be produced from;

- Recycled precast element and concrete cubes after testing, and
- Demolished concrete buildings such as the debris shown in Figure 2

Sampling Of Concrete Debris Elements and Aggregates Production

As the wastes that are generated in construction sites consist of bricks, blocks, concrete, reinforcements and timbers pieces, this project concentrated with cement composite wastes such as concrete and blocks. Aggregates for this study were obtained from crushed concrete cubes and cement/sand blocks from demolished walls of School of Law that was in vertical extension work and from broken concrete seats known as '***vimbwete'.*** The demolished concrete boulders were in large sizes, so they had to be manually crushed using hammers (figure 1) into small aggregate sizes which were suitable for testing.

Aggregates Tests

The aggregates were tested for grading as shown in graphic form in Figures 3. Then the aggregates were tested for their suitability, the results of which are presented in Table 1***.*** The grading of crushed concrete aggregates showed that almost 95% of all recycled aggregates had sizes ranging from 9.5 mm to 37.5 mm.

Specimens Preparation, Tests and Results

Proportions of concrete ingredients were calculated using data obtained from aggregate tests by a process known as Mix Design. The cement used in making the concrete was Portland cement. Concrete cubes, prisms and cylinders were prepared for concrete grades of C25, C20 and C15, since they are the most common grades of concrete that are applied in the construction of concrete structures in Dar es Salaam. Cubes compressive strength was tested at the ages of 3, 7 and 28 days while the prisms and cylinders were tested after attaining the age of 28 days.

Workability Test

The slump test results showed that the slump value was medium as it was ranging from 30 mm to 60 mm.

Compressive Strength of Concrete

The compressive strength of concrete test was done when the specimens reached the ages of 3, 7 and 28 days. The test results averages for density and compressive strength have been analyzed and are shown in Figures 2 and 3.

Tensile Strength Test

The tensile strength of concrete was determined by using flexural (bending) strength test and tensile splitting test. The E-Modulus values obtained were 10.2 kN/m2 and 12.3 kN/m2, while the bending tensile strength values were 3.3 and 1.7 N/mm2 for crushed concrete aggregates and crushed blocks aggregates concretes respectively. The tensile splitting strengths were 2.8 N/mm2 for crushed aggregates concrete and 1.3 N/mm2 for crushed blocks aggregates concrete.

Discussion

The average compressive strength of 26.8 N/mm^2 obtained for grade C25 crushed concrete is less than target strength of 34.8 N/mm^2. However, the average strength is greater than the required concrete grade; the low strength has been due to much water during mix as can be depicted by the slump of 60mm which is the upper limit for medium workability. Applying research experiment relationship between compressive strength and splitting strength ($f_t = 0.464C.f_c^{2/3}$) [9], it can be shown that with the same ratio one can achieve a target compression strength of 32.7N/mm^2 if slump is 35 mm.

Compressive strength tests performed on cubes have shown compliance with the specifications at 28 days. Cubes were designed to meet characteristic strengths of 25 N/mm^2 and 15 N/mm^2 from the target mean strengths of 34.8 and 24.8N/mm^2 respectively. The compressive strength obtained for grade C25 was 16.8, 22.1 and

26.8N/mm^2 at 3, 7 and 28 days ages respectively. This shows rapid gaining of strength as compared to Table 7.1 of BS 8110: Part 2 [9], which indicates compression strength of 16.5N/mm^2 (62%) in the seventh day of casting, a value which in this study has been reached in the third day. The cement used was Portland composite cement and behaves as a Rapid Hardening Cement. The compressive strength for grade C15 was 17.4, 21.2 and 24.9N/mm^2 at 3, 7 and 28 days respectively.

- The flexural bending strength for concrete grade C25 was acceptable for it reached 3.3 N/mm^2 and the splitting tensile strength was 2.8 N/mm^2.
- Modulus of elasticity of 10.2kN/mm^2 for concrete grade C25 is less than the recommended value in BS8110-2:1985 which ranges between 19 – 31kN/mm^2, and E- Modulus obtained for grade C15 was 12.3kN/mm^2. This is 35% – 45% less than the specification value.
- Concrete made up of crushed blocks was weak and did not reach the characteristic strength designated. An examination on the mode of failure of the cubes when crushed under compression machine reveals that the aggregates crushed, hence an indication that individual aggregates were weak.
- Water absorption of recycled concrete aggregates is a bit higher than natural aggregates form the same parent rock due to the cement-sand paste around the aggregates which absorbed more water.

Concluding Remarks

Basing on the results of this study and discussions made above, following are the concluding remarks:

- Further studies to widen knowledge about all the relevant properties of recycled aggregates concrete are required.
- Further studies should be carried to check suitability of broken blocks in uses such as in bases and making recycled blocks
- The use of recycled aggregates concrete should be encouraged to reduce consumption of natural resources, decreased workload to local authorities whose resources in management of wastes is meagre.
- Developing of proper local standards will give assurance of quality of the material and their resulting structures to the users. Utilization of recycled aggregates for making structural concrete will help improving environmental cleanness and performance of concrete and construction industry at large.
- Use of recycled aggregates diverts substantial quantity of waste from landfill to beneficial resource generating income to the community.

Figures and tables

Figure 1: Local people crushing big concrete debris to aggregate sizes

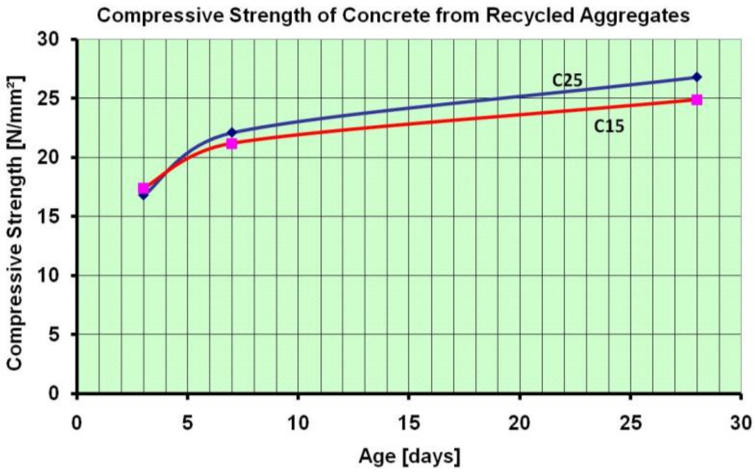

Figure 2: Compressive strength of recycles aggregates concrete

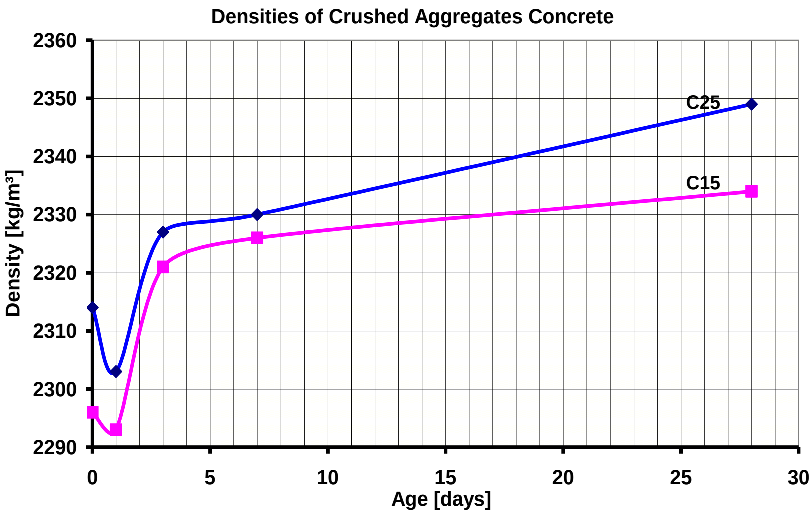

Figure 3: Densities of crushed aggregates concrete

Table 1: Summary materials of test results

Material	**Test**	**Results**	**Specification value**
Crushed Concrete	Sieve test	6.69 (Fineness modulus)	6 – 6.5
	Moisture content	1.0%	
	ACV	23%	<45%
	Gross density	2.5g/cm^3	
	Water absorption	3.6%	0.1 – 4%
Crushed Blocks	Sieve test	6.44 (Fineness modulus)	6 – 6.5
	Moisture content	1.3%	
	Gross density	2.5g/cm^3	
	Water absorption	11.4%	0.1 – 4%
Fine Aggregates (Sand)	Moisture content	1.2%	
	Sieve test	2.2 (Fineness modulus)	1.7 – 2.8
	Gross density	2.5g/cm^3	
Cement	No test done		

References

[1] Mfinanga W., "*Properties of concrete made from recycled aggregates*", PGD Dissertation, Department of Structural and Construction Engineering, University of Dar es Salaam, 2009.

[2] Chandra S, "*Implication of using recycled construction and demolition wastes as aggregates in concrete*", Session lead paper, International Conference on Sustainable Waste Management and Recycling, 2004, Kingston University, London.

[3] Makunza J.K. "*Challenges In Achieving Good Quality Concrete Constructions In Africa Sub-Sahara"*, Paper submitted to Tanzania Journal of Engineering and Technology, College of Engineering and Technology, University of Dar es Salaam, 2013

[4] Rusibamayila M, "Use of recycled aggregates for making concrete", Final Year Report, Department of Structural and Construction Engineering, University of Dar es Salaam, 2012.

[5] Neville A. M., "Properties of Concrete", ISBN-10-0273755803, 5th Edition, Sept 2012.

[6] BS 8110 (1997), *Structural Use of Concrete, Part 1: 1997 – Code of Practice for Design and Construction*, BSI, London, 1997.

[7] BS 12620 -2002: Aggregates for concrete, BSI, London, 2002

[8] BS EN 197-2000, Cement - Part 1: Composition, specifications and conformity criteria for common cements, BSI, London.

[9] BS 8110-2:1985, *Structural use of concrete for special circumstances,* BSI, London.

DRY-STACK AND COMPRESSED STABILISED EARTH-BLOCK CONSTRUCTION: EXPLORING NEW FRONTIERS IN CONSTRUCTION

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Introduction

According to UN-HABITAT 3 billion people lack decent housing in the world. Market share of the major building material in South Africa [10] are shown below.

Material group Rand market share Ranking

1. Cement and reinforced concrete 35%
2. Carbon steel 23%
3. Concrete and clay masonry 12%
4. Wood 10%
5. Ceramic wall and floor tiles and sanitary ware 9%
6. Plastics 4%

It can be seen that the market in building materials is dominated by cement and concrete. The study concluded that to significantly reduce building materials-related costs and environmental burdens in South Africa, R&D efforts need to be focused on the following material groups:

- Cement and concrete
- Lightweight steel construction
- Composite materials (as substitutes for cement, carbon steel, conventional concrete, bricks, blocks and wood)

Cement is expensive in Africa. This is due to lack of adequate cement producing plants in Africa. As an example, Germany has more cement plants than the whole of sub-Sahara Africa put together. This in turn has contributed in making cement expensive, even more so if it is considered that incomes are very low. The most efficient way of dealing with the situation is to use low cement content and possibly high amount of supplementary cementitious materials (SCM). Labour is relatively cheap on the continent and this makes it possible to apply labour intensive techniques such as hand mixing and soil-cement construction. A typical example of earthen house is shown in Figure 1.

Compressed Earth Blocks

Compressed Earth Block (CEB) is earthen blocks compressed by hand-operated or motorized hydraulic machines. CEB does not contain any stabilisation therefore no fossil fuel is required in the production of the CEB. Many example of earth construction exists all over the African continent. This construction has the advantage of:

- Earth buildings provide better noise control.
- Earth construction is economically beneficial.
- Earth construction is environmentally sustainable.
- Earth construction is regarded as a job creation opportunity as it does not require much initial investment to establish.
- Earth construction promotes local culture, heritage, and material.
- Earth is available in large quantities in most regions.
- Earth is very good in fire resistance.
- Earth walls (loam) absorb pollutants.
- Easy to design with and high aesthetical value.
- It balances and improves indoor air humidity and temperature.
- It encourages self-help construction.
- It requires simple tools and less skilled labour.
- Loam preserves timber and other organic materials.

With the advantages come major disadvantage as follows:

- It is well known that earth construction is labour intensive. Although this may not be considered a major disadvantage in Africa, it is so in most other parts of the world.
- It is not as strong as conventional construction materials.
- CEB houses behave poorly in the event of natural disaster such as earthquakes, flooding etc.
- The rate of wear and tear of CEBs is high and therefore need high maintenance.

- There are structural limitations.= due to low mechanical properties.

Compressed Stabilised Earth Blocks (CSEB)

Due to the clay fraction within un-stabilised CEB the soil will swell on taking up water and shrinking on drying (Lunt, 1980). This therefore increases the likelihood of severe cracking and often leads to difficulties in getting renderings to adhere to the walls resulting in eventual disintegration (Lunt, 1980). The aim of a soil stabiliser is therefore to increase the soil's resistance to the destructive properties of the weather as well as increasing the strength and cohesion of the soil. The stabilised form is more suitable for the African situation due to the by-laws and housing standards that exist.

Soil identification and classification

A typical soil profile is shown in Figure 2. There are broadly four different layers or horizons which consist of visually and texturally distinct layers. The top soil layer contains organic matter and is usually dark in colour. This layer is not suitable for stabilised soil-cement block production due to its high content of organic matter. The sub soil layer is an accumulation of iron, clay, aluminium and organic compounds formed through a process referred to as illuviation. It is very sticky if it has high clay content. This layer is the most suitable layer for soil stabilised block production. The weathered rock horizon is the third layer which consists of mostly large broken rocks. This layer usually contains sandy soil that is easier to excavate. It is not suitable for block production due to the size of the gravels and inadequate clay content. The bedrock or parent rock material in bedrock landscapes is a layer of partially weathered bedrock at the base of the soil profile. Unlike the layers above, bedrocks comprise continuous masses of hard rock that cannot be easily excavated.

Soil particles obtained from the sub-soil layer are broadly divided into three size classes: clay, silt and sand. Soil materials intended for CSEB construction designates the basic material made up of carefully controlled proportions of sand, clay and silt before any mixing with additive or with water. Basic soil particle grading is shown in Table 1. Sand components with particle sizes larger than 2 mm are classified as gravel and are generally omitted in the grading of the soil. Gravel is not normally used in soil-cement block production as the large particle size results in poor finishing.

Particles size analysis is used to determine the fraction of each particle size that fall within each of the size ranges. A well graded soil will produce a better packing of the particles resulting in a denser and less permeable product. The distribution of particle sizes that provides the optimum packing of particles is known as the Fuller curve. It is based on the assumption that the smaller particles fill the void between the larger particles to give the highest density. A soil may be considered well graded if the distribution of particles from fine silt to coarse sand is reasonably uniform. Figure 3 shows a standard sieving process for soil using a 5 mm net.

Soil identification and selection

Soil texture is defined as the relative proportions of each class (clay, silt and sand). Sands give the material strength while clays bind it together and silt fulfils a less clear intermediate function. It is important to get the right texture for soil cement block production. Good soil cement blocks can be produced with a sandy soil with clay content between 5 - 20% and silt content of 5 - 25%. Blocks can be produced with higher clay and silt content, but it may be necessary to determine the plasticity index to see if the soil is suitable for block production. Generally soil with clay and silt portions below 10%, will be difficult to handle when coming out the block making machine. Soil with clay and silt content above 40% will need to be blended with a sandy soil since stabilisation of the material with cement is less effective. Commonly used methods to determine soil texture include: hand texture method, separation by sieving and separation by sedimentation.

Soil texture classification by sedimentation is carried out by adding a soil sample to a dispersing solution of sodium hexametaphosphate, (NaPO3)6 in de-ionized water. The sedimentations tests are based on Stoke's law which predicts the free fall of any diameter spherical particle of known specific gravity in a fluid of known viscosity at low concentration. It is assumed that the soil particles have approximately the same specific gravity and that the rate of fall is dependent only on the particle size. The larger diameter particles (sand) fall more quickly and settle at the bottom of the jar, then silt will settle out and finally a clay layer will form on top. Once settled (Figure 4), the relative percentages of sand, silt and clay may then be measured. This test is easily carried out on work site.

The particle size analysis may be used to classify the soil sample into a specific textural class, such as a sand, silt, clay, loam, etc. Soil texture depends on its composition and the relative portions of clay, sand, and silt. The soil textural triangle shown in Figure 10.4 enables one to visually assess textural class based on the three percentage values obtained through particle size analysis. The goal of the particle size analysis may be to classify a soil sample into a specific textural class, such as a sandy clay, sandy silt, clay loam etc. based on the zone of the material in the textural triangle. The major textural classes are shown in Figure 5. The area within and about the circle is centred at approximately 55%:30%:15% sand:clay:silt ratios as shown in Figure 5 and indicates the zone most suitable for stabilisation.

Clay and cement make different contributions to the material properties of soil-cement blocks; in fact the two materials will work against each other if the quantities are not carefully selected. Too much clay in the mix will result in the cement not adequately coating all the mix particles and subsequent wetting will cause expansion of the material and cracking. As a rule of thumb, the most suitable soil for stabilised soil block production should contain approximately 30 - 40% clay+silt and 60-70% sand. Spence et al. (1983) recommended the following ranges for soil-cement block production: sand: 60–90%, silt: 0–25% and clay: 10-25%.

Not all soils are suitable for construction. Soil containing organic matter, highly expansive soils and soils containing excessive soluble salts such as gypsum and chalk should be avoided in the selection of materials for soil-cement block production.

The African Standards Organisation standard ARS 670 of 2014 recommends that the granular composition of the soil for CSEB production should preferably fall within the limits of the shaded area on the diagram of texture in Figure 5 and should be similar in shape. The limits of the recommended shaded area are approximate. Soils with granular composition that fall outside the shaded area may still give acceptable results, but it is recommended that they be subjected to a series of tests enabling their suitability to be assessed.

Stabilisers

Stabilisers when introduced in soil will perform the following functions;

- Bind the soil particles together making the product stronger.
- Reduce the amount of voids and therefore limit the water which can be absorbed by the stabilised soil.
- Reduce the shrinkage and swelling properties of the soil
- Increase the tensile strength of the soil.

Cement

When cement is added to soil, there will be reduction in the following properties with increasing cement content: the liquid limit (LL), the plasticity index (PI) and the potential for volume change. However the compressive and shear strengths are increased with increased cement content. A variety of compounds and gels are formed by hydration reactions of the cement in the presence of moisture. The products of cement hydration are hydrated calcium silicates, hydrated calcium aluminates and hydrated lime. Soil stabilisation is mostly done with the use of cement as the stabilising agent. Ordinary Portland cement (OPC) is mostly used for stabilisation purposes and it works best with sandy soils. Stabilisation may be difficult if the clay content is very high. Generally the combined percentage of silt and clay should not be less than 10% and ideally should not be more than 40 percent. The cement content varies depending on the desired strength of bricks and type of soil, although 5-10% by weight of dry soil is most commonly used.

Lime

Hydrated lime (calcium hydroxide) is also used as a stabiliser. There are two basic types of lime: high calcium and high magnesium lime. Their soil- stabilising efficiency is about the same. Lime will react readily with most plastic soils containing clay but lime does not improve sands or other non-cohesive granular materials. Lime makes a good stabiliser for soil with clay content greater than 40%. It reacts with the clay to form strong bonds between soil particles. The recommended amount of lime for stabilisation ranges from 4% to 8% of the dry weight of soil. Soils ranging in plasticity index from 10 to 50 or higher are suitable for lime stabilisation. Lime stabilisation decreases the plastic index and volume change, and increase the compressive strength of the soil material.

Combination of Lime and Cement

When a soil has clay content in excess of 40%, cement becomes less efficient as a stabilizing agent. A combination of lime and cement stabilisation is recommended. The lime will make the soil easier to work with, and cement will help to improve the strength and water resistance the product.

Combination of Lime and Pozzolans

Pozzolans are materials which contain a significant amount of silica. Volcanic ash, pulverized blast furnace slag, pumices and silica flour are examples of pozzolans. Lime and pozzolan will react and make cement which may be almost as good as Portland cement. The lime becomes the activator for the pozzolanic action. This can be used for both clayey (>40%) and sandy (<10% clay) soils. This combination of stabilisers results in a relatively low strength block.

Conclusions

- Engineers are not all familiar with CSEB blocks. Careful materials selection is recommended.
- Soil differs from region to region; soil testing is required to ensure good block quality.
- Dry stacking is not common, resistance from clients.
- Clay shrinks – Block has clay in it. Ensure there is sufficient curing and drying afterwards about 0.1% wet-dry shrinkage
- Tidal zone – Wet Dry cycles is the most destructive action. Plaster the tidal zone

Figures and tables

Figure 1: Earth Construction (Courtesy J. Makunza)

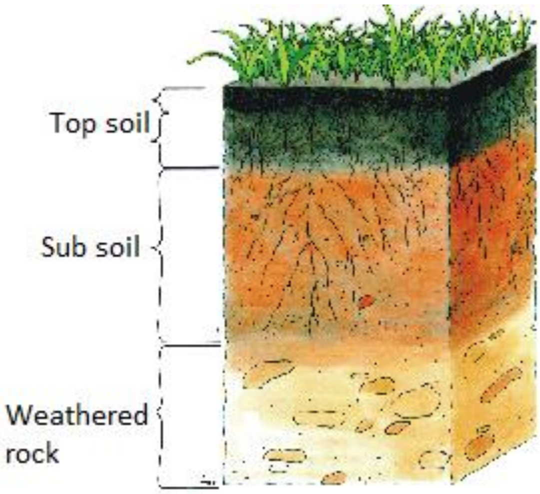


Figure 2: Typical soil profile


Figure 3: Field sieving of soil

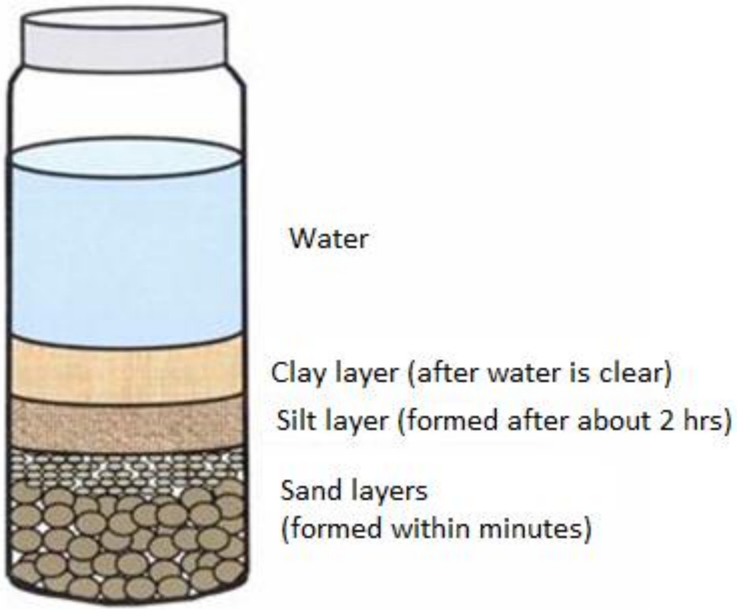


Figure 4: Settlement of soil materials

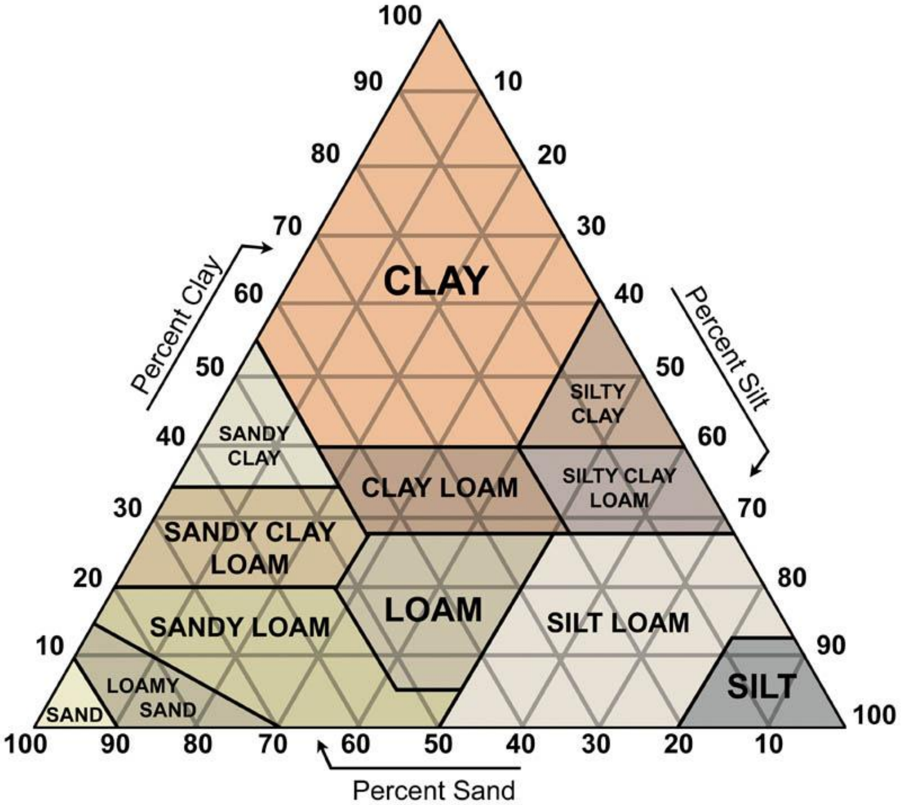


Figure 5: Soil Textural Triangle (source: http://www.Google.co.za)

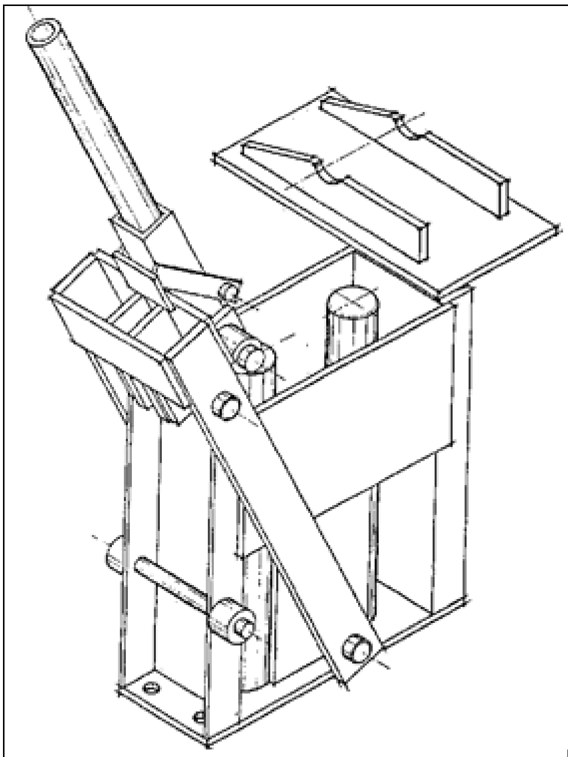
	
a) typical manual press	b) portable mechanized press

Figure 6: Typical presses for compressed soil cement production.

Figure 7: Mixing and production of blocks

Figure 8: The blocks are wetted and then covered with a dark plastic sheeting.

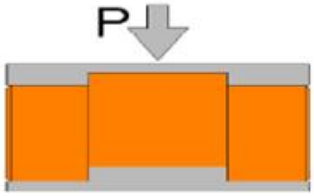
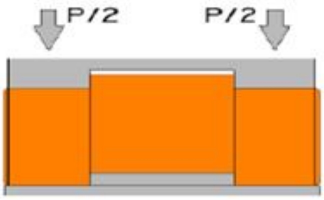
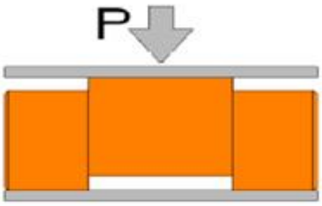
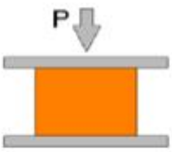
Method of Load Application		Load Regime	Failure Pattern/ Cube Loading Arrangement	Resulting Normalised Strength
1	Load application across the gross area of the block			0.9
2	Load application across the shoulders of the block			0.8
3	Load application across the Tongue of the block			0.6
4	Testing of Cubes			1

Figure 9: Blocks are tested using various techniques and results analysed based on method of testing.

Table 1: Soil particle fractions

GRAVEL FRACTION:	coarse gravel	-	60 to 20 mm
	medium gravel	-	20 to 6 mm
	fine gravel	-	6 to 2 mm
SAND FRACTION:	coarse sand	-	2 to 0.6 mm
	medium sand	-	0.6 to 0.2 mm
	fine sand	-	0.2 to 0.06 mm
SILT FRACTION:	coarse silt	-	0.06 to 0.02 mm
	medium silt	-	0.02 to 0.006 mm
	fine silt	-	0.006 to 0.002 mm
CLAY FRACTION:	passes the	-	0.002 sieve

References

[1] Joe Mapiravana & Naalamkai L Ampofo-Anti, Prioritising building materials research and development in the delivery of subsidised housing in South Africa: NHBRC Housing Conference 2011.

[2] Anifowose, A.Y.B. 2000. Stabilisation of lateritic soils as a raw material for building blocks: Bulletin of Engineering Geology and the Environment, 58: 151-157

[3] Arumala, J. O and Gondal, T. (2007). Compressed earth Building Blocks for Affordable Housing. RICS, London, COBRA 2007. ISBN: 9781842193570

[4] Lunt, G. 1980. Stabilised Soil Blocks for Building. UK: Department of the Environment, overseas division

TECHNICAL PAPERS

CASSAVA PEEL ASH: AN EMERGING POZZOLANIC MATERIAL

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Brief author biography

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Introduction

Recently, there has been growing interest in the use of agricultural wastes as partial substitute of cement in concrete.

The use of pozzolanic materials is found in many ancient civilizations. More recent, in Europe and the USA, there have been numerous massive structures built with the use of pozzolan-cement mixtures [1]. Nevertheless, many researchers have demonstrated the use of different agricultural wastes such as sugar cane straw ash, groundnut husk ash etc. as pozzolans with positive results [2, 3]. However, the use of cassava peel ash (CPA) as pozzolan is novel.

Nigerian cassava production is by far the largest in the world. Its annual production is put at 51 million metric tonnes (mmt) [4]. Cassava peel (CP) is a by-product of cassava processing for domestic or industrial uses. Adesanya et al. [5] reported that cassava peel constitutes between 20-35% of the weight of tuber, especially in the case of hand peeling. Based on 20 per cent estimate, about 10.2 mmt of cassava peels are generated annually and 12 mmt is expected to be produced in the year 2020, when the cassava production would have risen to 60 mmt.

Indiscriminate disposal of cassava peels (CP) due to gross underutilization as well as lack of appropriate technology to recycle them is still a major challenge. Heap of cassava peels ready for burning for no benefit in return is shown in Figure 1. Recycling the CP into a more beneficial use in the construction industry is thus desirable. This will also ensure environmental sustainability.

Materials and methods

Cassava peels were collected and activated by burning in furnace at temperatures of 500, 600, 700, 800, 900 and 1000℃ for 30, 60 and 60 minutes. Chemical content of ash produced from each treatment was determined using XRF technique. Activation condition that produced ash with higher amorphous silica and alumina was noted. This condition was used to produce CPA that was blended with Portland cement at varying percentages of 5 to 25% (5% interval) by weight of cement. Pozzolanic reaction between CPA and calcium hydroxide (CH) was examined using the method used by Dwivedi *et al.* [6] Mortar of mix ratio 1:3 by weight was produced and cast into a prism mould of size 40 × 40 × 160 mm; mortar specimens were tested for strengths (compressive and flexural) as prescribed by BS 4550-3.4-1978. Water binder ratio of 0.5 was used and fine aggregate used was river sand of maximum nominal size of 3.18 mm.

Results and discussion

Chemical composition of CPA

Silica content of CPA increased with increase in both temperature and time of burning (Table 1). Since amorphous silica is required, it was observed that the silica produced from the CPA at temperatures of 800 ℃ and above formed ball-shaped particles that could be considered as crystalline. This finding was similar to what Shinohara and Kohyama [8] reported about RHA. This study found that CPA produced at activation condition of 700 ℃ for 90 minutes produced combined silica and alumina greater that minimum of 70% recommended and could be considered as the appropriate conditions to obtain amorphous silica suitable for pozzolanic activity. The XRD spectrum of CPA at this activation conditions contained one smeared peak with many short bumps and irregular base line, suggesting that CPA was mainly amorphous with traces of crystalline form.

Pozzolanic reactivity of CPA and free lime determination

The reaction between CH and CPA was monitored at different periods of reaction (1, 2, 3, and 4 hours). The results indicated that the amount of CH that reacted with CPA increased as the reaction period increased. This response suggested a pozzolanic reaction. To further confirmed this performance, quantity of free lime present in hydrated cement-CPA mixture at different ages of 1, 3, 7, 14, 21 28 days was monitored. Within 24 hours, there was no appreciable difference in the amount of free lime produced for all the samples when compared with normal cement hydration but the difference became more manifested when the hydration period increased. Reduction in free lime content observed would indicate that CPA reacted with excess lime. However, at 20 and 25% CPA contents, the same quantity of free lime was produced (0.58 mol/dm^3) indicating that pozzolanic reaction between CPA and CH was more active when CPA proportion is not more than 15%.

Compressive and flexural strengths of blended cement-CPA mortar

In Table 2, it is shown that as proportion of CPA in mixes increased, the strength decreased for the first 28 days of curing. However, at 90 days of curing, the compressive strength values of mortar cubes produced from 5, 10 and 15% CPA were 50.9, 50.05, and 49.7 N/mm^2, respectively which were 99.4, 97.7 and 97% of the normal mortar. Since pozzolanic effect is usually appreciated at longer period of curing, there could be further increase in strength for the blended cement - CPA mortar at above 90 days as shown by the trend of the compressive strength of mortar containing up to 15% CPA. Flexural strength characteristics of cement-CPA mortar beams exhibited similar pattern to their corresponding compressive strength behaviour. Furthermore, the strength activity indices of mortar containing up to 15% CPA was about 80%, greater than minimum of 75% recommended for fly ash. This performance further suggested CPA could be considered as pozzolanic.

Conclusion

Tests to investigate pozzolanic properties of CPA were conducted. The following could be concluded from the study:

i. Cassava peels are available in large quantity in Nigeria and disposed for no benefit in return.
ii. Cassava peel ash burnt at temperature of 700℃ for 90 minutes contained amorphous silica in adequate quantity and state for pozzolanic reactivity.
iii. Blended cement-CPA mortar containing 15% proportion of CPA has strength comparable with that of normal mortar.
iv. There is further need to study microstructure of hydrated cement-CPA mixture to make more precise generalization.

Figures and tables

Figure 1: Heaps of cassava peels at a cassava processing centre in Ilaro, Nigeria [6]

Table 1: Effect of Calcining Temperature and Duration on Chemical Composition of Cassava Peel Ash (CPA) and Ordinary Portland Cement (OPC)

Temp. (^{0}C)	**Time (min)**		**Oxides (%)**								
			SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**LOI**
500	**30**	**CPA from unwashed CP**	47.29	6.83	3.78	8.66	4.17	2.97	10.62	0.64	13.66
	60		51.73	9.21	1.17	7.77	4.55	2.26	17.76	0.02	11.07
	90		52.22	6.91	3.84	9.05	4.41	3.01	8.76	0.65	10.10
600	**30**		45.57	6.94	3.78	8.78	4.36	3.10	10.99	0.63	14.54
	60		47.23	7.18	4.03	9.31	4.40	3.04	10.47	0.61	10.88
	90		49.20	7.44	4.20	9.96	4.91	3.33	7.68	1.93	10.88
700	**30**		49.54	7.45	6.09	9.61	4.58	2.89	10.49	0.55	7.30
	60		53.35	7.13	4.02	9.20	4.23	2.56	9.45	0.60	4.56
	90		58.02	12.80	1.41	8.53	5.02	2.18	7.67	0.03	4.18
800	**30**		52.36	6.17	3.24	10.02	4.59	2.56	10.48	0.37	12.03
	60		54.12	7.02	3.52	11.64	5.18	3.34	4.84	0.24	8.49
	90		58.90	7.54	3.79	6.81	5.21	4.21	6.37	0.40	6.11
900	**30**		51.88	7.39	3.71	12.70	5.79	3.99	8.55	0.34	7.35
	60		53.54	7.38	4.02	11.18	3.68	4.07	7.82	1.21	7.37
	90		58.37	7.86	3.94	9.24	6.50	4.44	6.77	0.46	5.28
1000	**30**		51.13	6.89	3.21	8.20	6.50	4.34	7.88	0.03	6.10
	60		52.34	8.45	2.98	9.89	5.67	3.45	6.77	1.23	3.67
	90		59.95	8.71	3.89	8.69	5.38	3.60	7.28	0.37	4.73
700	**90**	***wcp**	52.57	6.94	3.78	8.78	4.36	3.10	10.99	0.63	7.54
OPC			**19.99**	**5.49**	**3.00**	**63.32**	**1.45**	**0.34**	**0.08**	**0.09**	**3.96**

Table 2: Compressive and Flexural strengths of cement-CPA mortar

CPA Content (%)	**Compressive Strength (N/mm^2)**				**Flexural Strength (N/mm^2)**			
	Curing Age (Days)				**Curing Age (Days)**			
	7	**28**	**56**	**90**	**7**	**28**	**56**	**90**
0	34.4	41.1	46.7	51.2	5.7	6.4	6.8	7.1
5	32.2	40.1	45.5	50.9	5.3	6.2	6.7	6.9
10	32.0	39.8	44.4	50.5	5.2	5.9	6.4	6.8
15	29.7	38.7	43.6	49.7	5.1	5.8	6.2	6.7
20	26.1	37.1	39.0	39.5	4.7	5.7	5.8	5.9
25	16.1	19.2	19.4	19.7	2.1	3.5	3.7	3.8

References

[1] Wilson .J.W. and Ding Y.C (2007). "A Comprehensive Report on Pozzolanic Admixtures, the Cement Industry, Market and Economic Trends and Major Companies operating in the Far East, with Reference to Pagan Island" prepared for the Secretary, Department of Public Lands, Commonwealth of Northern Mariana Islands. 4-33.

[2] Frías, M., Villar Cociña, E., Valencia-Morales, E., (2007). "Characterisation of sugar cane straw waste as pozzolanic material for construction: Calcining temperature and kinetic parameters", Journal of Waste Management, 27, 533-538.

[3] Ketkukah, T.S. and Ndububa, E.E. (2006). "Groundnut Husk Ash (GHA) as a Pozzolana Material in Mortar", International Journal of Science and Technological Research, 3(2), 209-214.

[4] Adesina, A. (2012). “Investigating Nigeria’s agricultural value chains”. *A lecture presented at the Bank of Industry’s Nigerian Investment Forum, London*, Federal Ministry of Agriculture and Rural Development, 1-48.

[5] Adesanya, O.A, Oluyemi, K.A., Josiah, S.J., Adesanya, R.A., Shittu, L.A.J., Ofusori, D.A., Bankole, M.A. and Babalola, G.B. (2008). "Ethanol Production by *Saccharomyces Cereviasiae* from cassava peel hydrolysate", *The Internet Journal of Microbiology,* 5(1). 25-35.

[6] Salau, M.A. and Olonade, K.A. (2011) “Pozzolanic Potentials of Cassava Peel Ash” Journal of Engineering Research, 16(1).

[7] Dwivedi, V.N., Singh N.P., Das, S.S. and Singh, N.B. (2006). "A new pozzolanic material for cement industry: Bamboo leaf ash", *International Journal of Physical Sciences* 1(3), 106-111.

[8] Shinohara, Y., and Kohyama, N. (2004). “Quantitative analysis of tridymite and cristobalite crystallized in rice husk ash by heating”. *Industrial Health*. 42, 277-285.

COMPRESSIVE STRENGTH CHARACTERISTICS OF BAMBOO LEAF ASH BLENDED CEMENT CONCRETE

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Introduction

In the cement industry, continuous attempts are being made to reduce the cost of production of Portland cement and consumption of raw materials, energy expense, protect the environment and enhance quality of cement. Ordinary Portland cement is one of the most important building materials in terms of quantity produced [1, 2].

Since it is produced at a high temperature (1500^0C), it consumes a lot of energy, emitting harmful gases and polluting the atmosphere (Metz *et al.,* 2007), therefore, an alternative to its use is a matter of urgency. One way of achieving this is to use certain low cost materials for partial replacement of Portland cement in concrete production [3]. Also, there has been an increase in prices of houses over the last century, arising mainly from escalating prices of building materials and has caused a shortfall in the provision of adequate housing in Nigeria and globally [4]. Hence, alternatives to conventional building materials have been focus of most researches recently and their suitability as local materials for building construction purposes [5, 6, 7].

This work focuses on the use of bamboo leaf ash (BLA) as a partial replacement of the conventional concrete binder namely cement. Also, the recent clamour for green, sustainable buildings and eco-friendly construction materials aims at reducing the production of harmful gases that pollutes the environment and minimizing waste that litters the environment. Utilization of such agricultural waste like bamboo leaves serve as an effective method of minimizing waste generated, saving energy and ensuring sustainability in the built environment.

Materials and method

This research aimed at investigating the compressive strength properties of bamboo leaf ash blended cement concrete with a view to ascertaining the suitability of bamboo leaf ash as a pozzolanic material in concrete. The study experimentally determined the characteristics of bamboo leaf ash, assessed the effects of varying percentage composition of BLA and curing age on the compressive strength characteristics of BLA blended cement concrete.

In determining the compressive strength, a total of 72, 100mm x 100mm x 100mm concrete cubes were cast from mixes containing BLA contents of 0%, 5%, 10%, 15%, 20% and 25% as partial replacement for ordinary Portland cement (OPC). Bamboo leafs collected were sun dried and thereafter burnt into ashes in a drum and spread on a clean removable surface for quick cooling. The resulting ashes was then grinded and sift with 212 µm sieve and thereafter burnt further in a furnace up to 800^0C. A targeted strength of 25 N/mm^2 was adopted to determine the proportion of the different components. Manual mixing was done after which slump test was carried out in testing the workability of the mixed concrete before casting. Water curing was done for 7, 14, 28 and 56 days. Three replicates were used. Experimental results gotten were analyzed using tables, graphs and analysis of variance (ANOVA).

Various tests carried out include aggregates' sample grading, moisture content and relative density, BLA X-ray diffraction analysis, chemical properties of BLA, workability of freshly mixed concrete and compressive strength test of cube specimens.

Results and discussion

A relative density of 1.50 was gotten for the used sand while 2.00 was gotten for the granite. An X-ray diffractometer (XRD) using CuK_α radiation based on De Bragg's principle was used allowing an error margin of ± 0.03, compounds detected include KO_3, Fe_2O_3, SiO_2, TiO_2 and TiO_3. BLA chemical properties were also determined using X-ray fluorescence (XRF), result gotten is displayed in Table 1. The result of the XRF is far better than that of XRD.

Slump test carried out was to ensure that the mixed concrete achieves a desired medium workability of value between 50 mm and 100 mm. It was done in accordance to the requirement of BS EN 12350-2: 2009. No admixture was used to enhance workability. It was observed that the higher OPC partial replacement with BLA, the higher the water required to achieve required slump. This implies that BLA as a pozzolanic material requires more water to facilitate its hydration. The average results of compressive strengths gotten for various OPC partial replacements with BLA and different curing ages in water are summarized in Table 2.

Table 2 shows that for all the cement replacement levels, there is an increase in compressive strength with time (curing age). This is due to the fact that concrete strength increases with age and BLA as a pozzolan reacts with lime [$Ca(OH)_2$] produced from the hydration process of cement to form Calcium Silicate Hydrate (CSH) mainly responsible for concrete strength. In contrary, compressive strength of the blended cement concrete reduces generally as the BLA content increase. However, concrete with 5% and 10% BLA content performed favourably than other replacement levels. Likewise, Fig. 1 below affirms these statements. But BLA content of 10% performs best after that of the control with its plotline slightly above that of 5% and a R^2 of 0.984. Hence, 10%

BLA can be taken as optimum, implying that ordinary Portland cement can be effectively replaced with 10% bamboo leaf ash in concrete production.

Conclusion

By and large, observed results showed that:

- The higher the BLA content, the higher the water/cement ratio required to achieve required workability.
- The higher the percentage replacement of cement with BLA, the lower the compressive strength characteristics of the resulting concrete.
- The optimum replacement percentage is 10% and the pozzolanic effect of the BLA takes maximum effect at the later days of hydration (28 and 56 days).
- Hence, BLA blended cement concrete is suitable for construction purposes when later days strength is required.

Figures and tables

Table 1: Chemical properties of bamboo leaf ash (BLA) used.

Elemental Oxides	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	K_2O (%)	Na_2O (%)	Mn_2O_3 (%)	Cr_2O_3 (%)	P_2O_5 (%)	TiO_2 (%)	LOI (%)
BLA	72.97	2.85	2.31	4.98	1.23	0.55	6.07	0.00	0.41	0.05	2.37	0.41	4.20

Table 2: Compressive strengths of BLA blended cement concrete at various ages.

BLA (%)	Compressive strength (N/mm^2)			
	7 days	14 days	28 days	56 days
0	17.96	22.68	26.46	28.46
5	16.42	19.70	22.72	26.22
10	18.34	19.90	22.78	26.46
15	12.08	14.46	16.42	20.10
20	9.34	11.16	13.54	16.48
25	5.36	7.10	10.26	12.74

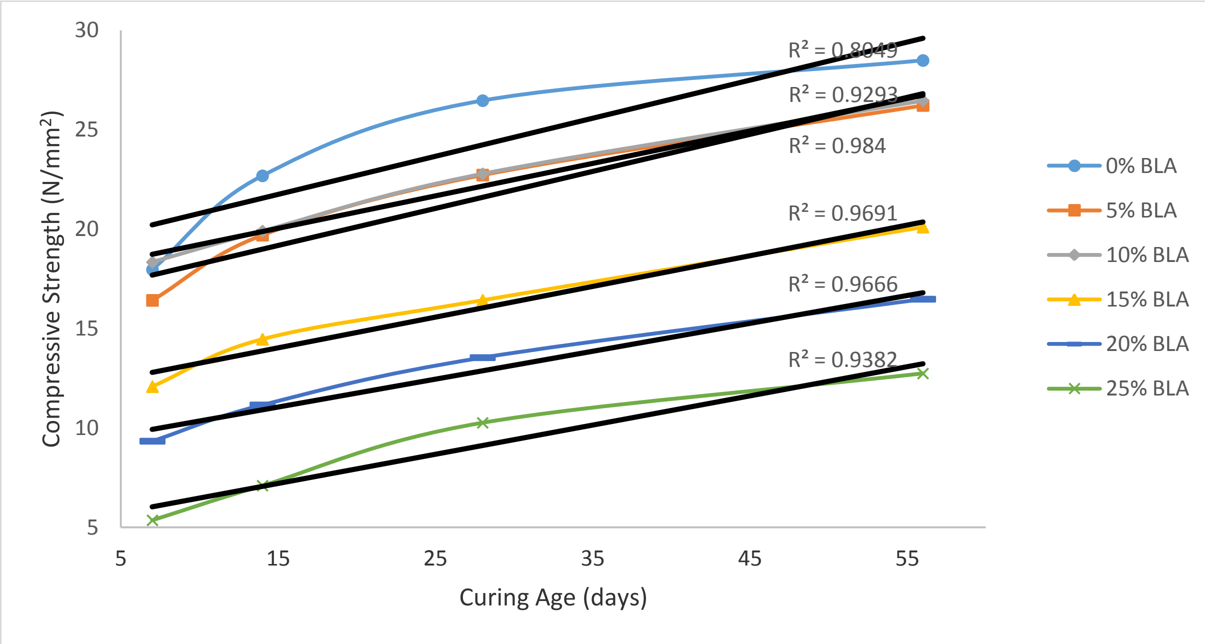

Figure 1: Variation of compressive strength with curing age at various BLA content.

References

[1] Mehta, P.K. and Monteiro, P.J.M. (2006) *Concrete: microstructure, properties and materials*, 3rd edn, McGraw-Hill, New Delhi.

[2] Hosseini, M.M., Yixin, S. and Whalen, J.K. (2011) Biocement production from silicon-rich plant residues: perspectives and future potential in Canada. *Biosystems Engineering*, 110(4).

[3] Dwivedi, V.N., Singh, N.P., Das, S.S., Singh, N.B. (2006) A new pozzolanic material for cement industry: bamboo leaf ash. *International Journal of Physical Sciences*, 1(3), 106-11.

[4] Olusola, K.O. and Adesanya, D.A. (2004) Public acceptability and evaluation of local building materials for housing construction in Nigeria. *Journal of property research and construction*, 1, 83-98.

[5] Dipayan, J. (2007). A new look to an old pozzolan: clinoptilolite-a promising pozzolan in concrete. *Paper presented at the 29th annual conference of cement microscopy*, Quebec city, Canada.

[6] Metz, B., Davidson, O., Bosch, P., Dave, R., & Meyer, L. (2007). *Climate change 2007 Mitigation of climate change*, Intergovernmental Panel on Climate Change, Geneva (Switzerland), (Working Group III).

[7] Umoh, A.A., Alake, O., Babafemi, A.J., Olasunkanmi, O.F. (2013). Assessing the performance of ternary blended cement concrete incorporating periwinkle shell and bamboo leaf ashes. *Civil and Environmental Research*, 3(1), 26-35.

PHYSICAL AND MECHANICAL PROPERTIES OF A PORTLAND CEMENT BLENDED WITH SILICA UNDER SATURATED CARBONATITIC LAVAS AS NATURAL POZZOLANS

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Introduction

As part of a PhD study into characterisation of natural pozzolana from the East African rift system, this study aims to evaluate the physical and mechanical characteristics of silica undersaturated ultrapotassic kamafugites and carbonatitic lavas of the Toro-Ankore geological region when used as supplementary cementitious materials in Portland cement concrete. Toro-Ankore geological region is located in the Albertine rift, of the East African rift system (Fig. 1). The East African rift system (Fig. 1a) is composed of the Eastern arm running from the Red sea up to Southern Africa and the Western arm that starts from the North Western Uganda and joining the Eastern arm in the South of Tanzania.

Petrology of volcanic rocks in East Africa

The petrology and geochemistry of volcanic deposits in the different volcanic zones of the East African rift system has been extensively studied [1-6, 13-14]. The deposits were found to be predominantly carbonatites and alkali volcanic rocks. The Western arm shows a variation in the chemistry of volcanic deposits from basaltic volcanic deposits that are weak in alkalinity to strongly silica undersaturated high potassium carbonate-rich carbonatites and kamafugites. The Eastern arm of the rift system is dominated by sodium-rich dolomite and calcite deposits of carbonatite complexes with carbonatite, nephelinite, nepheline syenite, ijolite and phonolite rock series. The Western rift is dominated by katungite, mafurite, ugandite, basanite, leucitite, nephelinite, and melilitite rock series. The occurrence and location of these deposits is mainly associated with the rift system [3]. The deposits are distinctly different form each other following their individual points of volcanic eruption. The estimated volume of volcanic deposits in the western branch of the East African rift system is approximately 100,000 cubic kilometres [4] while that for the eastern branch ranges from 220,000 to over 900,000 cubic kilometres [5, 6].

Justification for the study

The pressure of an increasing housing infrastructure demand experienced in developing regions of the world is characteristic of increased stress on the environment as manifested in the rates of deforestation, degradation of natural resources, growth of informal settlements, to mention but a few. Most of sub-Saharan Africa lies in this classification. Portland cement concrete is still the preferred option to meeting the housing infrastructure deficit obtaining in sub-Sahara Africa. Concrete is however still unaffordable by the majority in sub-Sahara Africa partly because the manufacture of the active ingredient in concrete, Portland cement, is costly due to its association with high energy consumption [7, 8]. A number of researches have shown that utilisation of easily accessible supplementary cementitious materials (SCMs) that require minimal processing significantly reduces the cost of cement [8, 9, 10]. The impetus of this study is that the abundant volcanic deposits in the East African rift system can be explored (characterised and tested) to provide a viable and affordable option to make concrete for addressing the challenge of providing housing infrastructure in the region.

For a material to qualify as an SCM, it should have a suitable chemical and mineralogical composition, be easily accessible, environmentally responsive and of relatively low cost [9]. The problem of high variability of important physicochemical properties in volcanic rocks has been addressed partly by the availability of highly pozzolanic industrial by-products such as fly ash, silica fume and blast furnace slag. The production of these materials is a controlled process that delivers SCMs with largely consistent physicochemical characteristics [9]. The increase in demand for SCMs coupled with a conflicting reduction in their production due to technological advancements in manufacturing processes and adaptation to more sustainable policies [7, 8] has led to a renewed demand for research to characterise natural pozzolana deposits. Recent research trends on alkali-activation of pozzolanic industrial waste such as silica fume and GGBS [9, 11] postulates a future shortage of these materials. Furthermore, most developing and under-developed countries around the world are deficient of the highly pozzolanic industrial waste yet sufficient in volcanic rocks deposits that can be put to use as SCMs [12].

Much of published research characterising the volcanic deposits in the East African rift system is in a geological domain [1-6, 13, 14]. Not much has been published on the engineering applications of these materials that are already being utilised by cement companies operating in the East African region to produce pozzolanic cements. In the majority of cases, research findings of multi-national cement companies are hoarded by individual companies and hence do not support the growth of local skills and competences. The few existing studies on characterisation of natural pozzolana as SCMs in East Africa are limited in scope and have empirical observations that limit the extent of their beneficial application. This has therefore led to limited beneficiation of the abundant natural material in the region. The natural pozzolana blended cements produced in the East Africa region are mainly used in relatively simple structures with no significant public importance that would demand actual field performance studies of the pozzolana blended cements. Major infrastructure developments in the East African region rely mainly on imported cements and there is a general disdain for structural application of the locally produced pozzolanic cement by design consultants. Concrete technology practices in the East African region further complicate any intention to evaluate actual performance of these blended cements and therefore the consumer only relies on the information supplied by the manufacturer or his agents to apply these cements. This level of uncertainty leads to expensive designs, a factor that contributes to the high cost of construction.

Materials and methods

A study of physical and mechanical properties of volcanic materials that influence their performance as SCMs in Portland cement concrete is partly petrological and partly engineering. Understanding the physicochemical characteristics from the petrological perspective and then projecting the observed characteristics to performance of the SCMs in Portland cement concrete presents an opportunity for prognosis in application of the volcanic materials as SCMs. Four samples of the volcanic tuff sourced from different locations in the study area have been pulverised to Blaine fineness ranging from 3000 to 5000 cm^2/g. Characterisation tests have been conducted on the samples to evaluate grindability, chemical composition, pozzolanic activity, water demand, setting time and fineness optimisation for strength development. Pozzolanicity has been tested according to EN 196-5 (Frattini test) and strength activity index tests (ASTM C 311) for mortar prisms at 7, 28, 56 and 90 days is ongoing. Isothermal conduction calorimetry was utilised to advance more understanding of the interaction of the different natural pozzolana samples with Portland cement. Laser diffraction technique was utilised in particle size analysis of the different powder samples. A polarised light microscope (Eclipse LV100 polarizing) was used to characterise particle shape and texture and together with X-ray Diffraction (XRD) analysis to evaluate the glass content, mineralogical composition and mineralogical changes due to thermal destabilisation of the volcanic tuffs.

Conclusions

The presence of the volcanic materials increased water demand while the setting time was reduced.

Preliminary results show the Frattini test to be unreliable in testing pozzolanicity of the samples. Moreover, samples 1 and 2 (Table 1) fail the ASTM C618 [15] minimum requirement of the sum of silica, alumina and iron oxide composition of 70% but exceed the minimum strength activity minimum requirement.

The silica undersaturated samples are characteristically high in CaO reaching 25% of total oxide composition in studies conducted with XRF. The role of limestone and soluble alkalis in influencing hydration will be investigated and is not part of the current scope.

The study advances the need to evaluate cement extenders more on the basis of their resulting performance in concrete.

Figures and tables

Table 1: Chemical analysis and physical characteristics of kamafugites and carbonatites

Parameters/% oxide composition	Sample 1 (S1)	Sample 2 (S2)	Sample 3 (S3)	Sample 4 (S4)	CEM 1 52.5R
Source	Fort Portal	Katwe-Kikorongo	Kataara - Bunyaruguru	Rushasha - Bunyaruguru	Afrisam
Loss on Ignition (LOI)	13.57	16.55	10.43	10.38	0.09
SiO_2	35.81	41.59	56.78	52.06	20.33
Al_2O_3	9.29	8.87	8.67	9.29	4.41
Fe_2O_3	13.73	12.35	8.19	8.99	2.53
CaO	25.19	19.78	8.87	11.19	65.19
MgO	5.49	6.44	6.95	7.37	1.80
K_2O	1.07	2.82	4.69	4.39	0.48
Na_2O	1.8	1.13	0.3	1.01	0.09
P_2O_5	2.75	1.97	1.07	1.24	0.08
TiO_2	2.31	3.33	2.78	2.44	0.41
Mn_2O_3	0.42	0.27	0.16	0.17	0.10
Cr_2O_3	0.02	0.02	0.05	0.03	0.01
V_2O_5	0.05	0.06	0.05	0.05	0.01
Total XRF	97.93	98.65	98.56	98.23	95.42
Specific gravity	2.75	2.63	2.38	2.55	3.14
Water demand	30.75	32.00	30.70	33.14	30.70
Initial Setting time (min) 80:20 ratio	200	200	190	200	200
Final Setting time (min) 80:20 ratio	245	255	246	256	286
Initial Setting time (min) 65:35 ratio	180	180	170	191	201
Final setting time (min) 65:35 ratio	245	255	225	306	261
7 day mortar strength	38.9	42.6	40.0	40.7	44.0
d(10%)	0,85	0,68	0,85	0,67	1,42
d(50%)	14,70	11,39	21,90	10,23	12,53
d(90%)	99,81	82,19	178,72	81,69	32,07

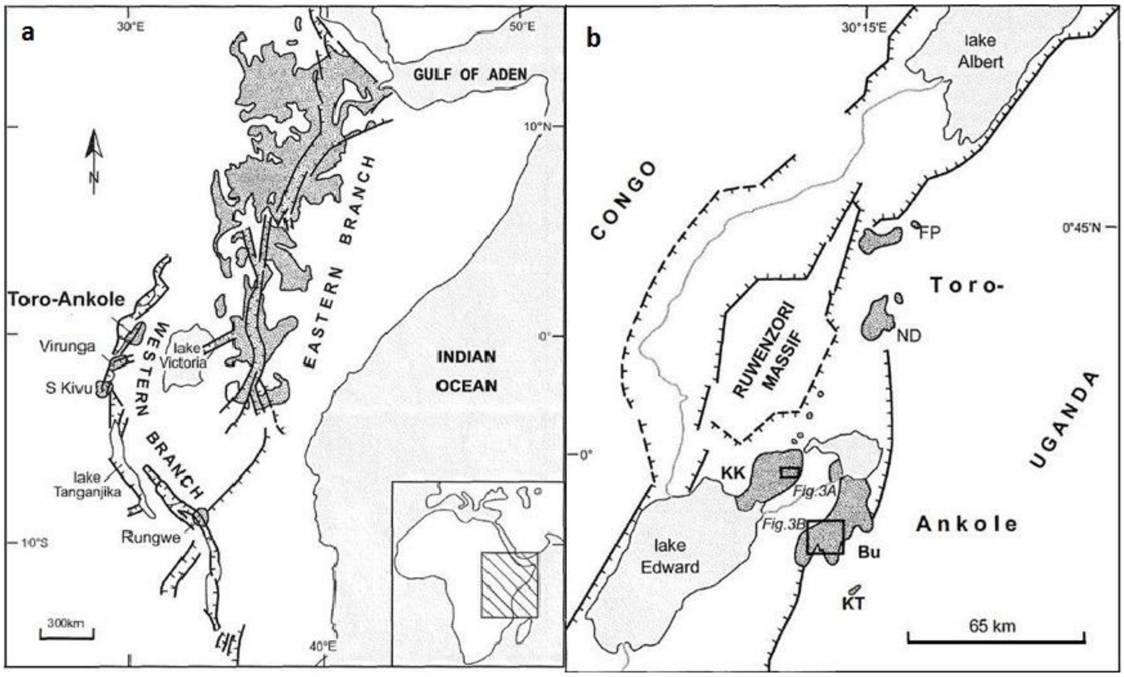

Figure 1: (a) A sketch map of eastern Africa showing the rift system and occurrence of lava deposits. The Albertine rift or the western branch is composed of Toro-Ankore, Birunga and South Kivu series. The hairy lines represent the main rift faults. (Map adapted from Tappe et al [13]) (b) Location of volcanic tuff deposits in the Toro-Ankore series (after Tappe et al [13]). Carbonatites are mainly located in the northern deposits of Fort Portal (FP) and Ndale (ND) (tappe et al [13]) while Kamafugites occupy Katwe_Kikorongo (KK), Bunyaruguru (Bu) and Katunga (KT) deposits.

References

[1] Rosenthal A., Foley S. F., Pearson G. D., Nowell M. G., Tappe S., (2009), "Petrogenesis of strongly alkaline primitive volcanic rocks at the propagating tip of the western branch of the East African Rift", Earth and Planetary Science Letters 284, Elsevier B. V., pp 236-248.

[2] Barker D. S, and Nixon P. H, (1989), "High-Ca, low-alkali carbonatite volcanism at Fort Portal, Uganda; Contrib. Mineral. Petrol. 103: pp 166-177; Springer.

[3] Jones P. Adrian, Genge Mathew, Carmody Laura, (2013), "Carbon in Earth: Carbonate melts and Carbonatites", Reviews in Mineralogy and Geochemistry, Vol. 75 pp 289-322; The Mineralogy Society of America, ISBN 978-0-939950-90-4.

[4] Kampunzu A. B., Mohr P., (1991), "Magmatic evolution and petrogenesis in the East African Rift system", in Kampunzu A. B., Lubala R. T.; Magmatism in Extensional Structural Settings: the Phanerozoic African Plate. Springer, Berlin, pp 85-136.

[5] Williams L.A.J., (1972), "The Kenya Rift volcanic: a note on volumes and chemical compositions", Tectonophysics Vol. 15 pp 83-96.

[6] Morley C.K., (1999), "Tectonic evolution of the East African Rift system and the modifying influence of magmatism", a review, Acta vulcanologica Vol. 11 (1), pp 1-19.

[7] Damtoft J S., Lukasik J., Herfort D., Sorrentino D., Gartner E M., (2008), "Sustainable development and climate change initiatives", Cem Concr Res, 38, 115-127. http://dx.doi.org/10.1016/j.cemconres.2007.09.008.

[8] Schneider M., Romer M., Tschudin M., Bolio H., (2011), "Sustainable cement production- present and future", Cem Concr Res, 41, 642-650.

[9] Snellings R., Mertens G., Elsen J., (2012), "Reviews in Mineralogy and Geochemistry: Supplementary Cementitious Materials"; Applied Mineralogy of Cement & Concrete, Vol. 74. Pp. 211-278, Mineralogical Society of America.
[10] ACI committee 232 report, (2001), "Use of raw or processed natural pozzolans in concrete", ACI 232.1R-00, American Concrete Institute, Farmington Hills, Mich.
[11] RILEM TC224 AAM (2014), "Alkali-Activated Materials: State-of-the-Art Report", Springer ISBN978-94-007-7671-5.
[12] Blanco Varela M.T., Martinez Ramirez S., Erena I., Gener M., Carmona P., (2006) "Characterisation and pozzolanicity of Zeolitic rocks from two Cuban deposits. Applied Clay Sciences 33 pg 149 - 159, Elsevier.
[13] Tappe S., Foley S. F., and Pearson D. G., (2003), The Kamafugites of Uganda: a mineralogical and geochemical comparison with their Italian and Brazilian analogues, Period. Mineral. 72 pp51-77.
[14] Holmes A. (1942), "A suite of volcanic rocks from south-west Uganda containing kalsilite (a polymorph of $KAlSiO_4$)", the Mineralogical Magazine and Journal of the Mineralogical Society, Vol.XXVI, No.177, pp 197-217.
[15] ASTM C618, (2005) "Standard specification for coal fly ash and raw or Calcined natural pozzolan for use in concrete", American society for testing and materials. West Conshohocken, PA, ASTM International.

PERFORMANCE OF TERNARY CEMENTITIOUS BINDER SYSTEMS INCORPORATING UNTREATED AND TREATED POZZOLANIC MATERIALS

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Brief author biography

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Introduction

The way concrete is used changed rapidly in the last decades. Originally concrete consisted of three components (cement, water, gravel/sand mixture). Nowadays it has evolved to a 5 component system (cement, water, gravel/sand mixture, supplementary cementitious materials and additives) which do not only concentrate on strength but also aspects like workability, durability and sustainability.

Concrete is the most used material in the world. Out of the 29 countries with the highest growth in the demand for concrete, 16 nations are located on the African continent. Particularly Sub-Saharan Africa shows massively emerging markets, where only concrete can satisfy the demand for decent housing and infrastructure.

Use of cement in Africa

The origin of Portland cement was around 170 years ago in Great Britain. Since then, concrete technology has spread out to Europe, the United States, and Japan. Except for South Africa, most Sub-Saharan African Countries where not involved in the development and research on cement and concrete. As a consequence the standards for concrete were assimilated to the needs of the above mentioned initial countries, underestimating some specialities like the infrastructure, high temperatures and humidity in African countries. Even the existing standards and guidelines are yet relatively low implemented in construction activities. Furthermore many common practices like ready-mix concrete can’t be used due to a shortage of sufficient concrete mixing plants and the missing infrastructure in most parts of Africa. On-site mixing can be considered as the usual way to work on construction sites.

The commonly used supplementary cementitious materials, are based on inert, pozzolanic hydraulic active materials, they often derive from industrial processes. Unfortunately most Sub-Saharan African countries do not have enough of the needed industries at the moment to provide the by-products needed for the cement industry.

The main ingredient for concrete will still be ordinary Portland cement. Cement plants are scarce in Africa. Prices for cements are extremely high and demands cannot be covered. Most sub-Saharan countries need to import cement from countries like China, Indonesia and South Africa. The price can be as high as in Europe and locally even three times higher. Due to Chinas powerful dominance on the market, it is doubtful that new industry cement production can compete in price and quality. The worldwide use of Portland cement concludes in an emission of over 2.6 Billion tons of CO^2 per year – with an increasing tendency. Every year, 15 Billion tons of raw materials are used for concrete aggregates and cement making. The production of one ton cement nearly equals one ton of Carbon dioxide that disperses into the environment and therefore noticeably contributes to an environmental pollution.

Creating an alternative

All those aspects force African economy to consider more modern standards, which incorporate the best and newest technology in an adequate way. Therefore it should be considered a unique opportunity to develop innovative African concrete technologies.

Consequently, in Africa there is pressure to save as much cement as possible. One option could be the reduction of clinker content by using local supplements.

Africa is endowed with huge deposits of natural pozzolans, limestone or gypsum, most of it existing along the eastern and western lift valleys of central Africa. By-products from the agricultural industry like rice-husk ash, bagasse ash or stabilizers like Cassava, maize, or potato starch can also be used as a supplement.

Blending reduces the costs and produces more environment friendly material, but also improves the concrete performance by synergetic combination of the constituents.

One of the possible promising supplements is rice husk ash (RHA). After harvesting and milling of rice, there is one main residue: the husk. Tanzania for example, the leading rice producer in East Africa, produces about 1.1 million tonnes of rice, which equals over 300,000 tonnes classified as waste, not knowing about the commercial value. The by-product has negligible protein content and therefore is not considered for livestock feeding, RHA at proper incineration conditions is found to contain 85 – 95% amorphous silica with high pozzolanic properties suitable for cement replacement. This available natural resource could be utilized to improve the livelihoods of many people. In very small scale projects rice husk is already used for burning bricks, create affordable building material by mixing clay or cement with RHA

A set of studies have been realised using RHA in concrete made with recycled concrete aggregates. With the use of approximately 50% of recycled concrete and 15% RHA almost the same compressive strength was achieved as the representative sample using a conventional concrete mix with natural aggregates and without RHA. Other studies using RHA incinerated in different temperatures showed similar outcomes. The maximum compressive and flexural strength could be seen at a reduction of around 10-15% of OPC by RHA. Diverse side effects have been found using concrete containing RHA, like reduced permeability, increased corrosion resistance and increased durability. Furthermore it was found that this concrete has a high water demand because it has a higher surface area than OPC, hence tends to absorb water faster.

Objective of the Master thesis

Those works on RHA concrete offer a high potential for further investigation. Within the context of the master thesis the performance of rice husk-ash (RHA) will be evaluated with regards to its use as a binder replacement for ordinary Portland cement (OPC). Since RHA is assumed to show superior behaviour to OPC, it should further be evaluated how far the use of RHA can help to reduce even higher amounts of OPC by replacing it with an inert limestone filler material. The performance should also be compared to other alternative materials that can be feasible for Sub-Saharan Africa.

The study will comprise evaluations of the cementitious systems containing RHA with regards to:

- Mechanical properties and pozzolanic reactivity

- Early hydration

- Workability

- Interactions with water reducing admixtures

Adopted solutions for the African market could be in future cementitious pre-mix binder compounds for concrete or even pre-mix binder compounds for self-compacting concrete. These solutions already include cement, well-adjusted fines and admixtures as required. They would need some more effort on site, which is considering the low labour costs no big problem. But they do not require high labour skills and are able to perform reliable regardless of most negative factors.

Knowing more about this interesting supplementary cementitious material RHA, could help as well to thrive the development of those very practicable and suitable solutions for the African continent.

References

[1] P.Padma Rao, Pradhan Kumar, Bhaskar Singh (2014): A Study on Use of Rice Husk Ash in Concrete. In: International Journal of Education and applied research, Vol. 4, Issue Spl-2, p. 75-81.

[2] Wolfram Schmidt, Charles Nmai, Apollo Buregyeya, u.a. (2013): Why does Africa need African concrete? An observation of concrete in Europe, America, and Asia – and conclusions for Africa. In: International Conference on Advances in Cement and Concrete Technology in Africa, January 28-30, p. 1139 – 1147

[3] Akinkurolere O. O. (2013): Effects of Rice-Husk Ash as Partial Replacement for Cement on Compressive Strength of Recycled Aggregate Concrete. In: International Journal of Engineering and Technology, Vol. 3, No. 8, p. 777-780

[4] Noah Lusaka (2013): Various Uses of Rice Residues Across the East African Region. In: Baobab, OPEN COLUMN2, March, p. 26-27

[5] Dr. Dipl.-Ing. Wolfram Schmidt and MSc. Nsesheye S Msinjili (2014): SCC: a solution to the challenges of concrete construction in Africa. In: CONCRETE TRENDS African Focus, p. 18-20

[6] MSc. Nsesheye Susan Msinjili, Dr. Dipl.-Ing Wolfram Schmidt (2014): Rice husk ash as a constituent material for low-cost housing in Africa. In: CONCRETE TRENDS, November, p. 46-47

[7] R. Nassingwa, N. M. Nangoku, W. Balu-Tabaaro, u.a. (2011): Workshop Cement and Concrete for Africa – Proceedings. In: Spearhead Network for Innovative, Clean and Safe Cement and Concrete Technologies, Berlin, 17th August 2011
[8] RAMADHANSYAH PUTRA JAYA, MOHD AL AMIN MUHAMAD NOR, ZAINAL ARIFIN AHMAD, u.a. (2013): Properties of Mortar Containing Rice Husk Ash at Different Temperature and Exposed to Aggressive Environment. In: Trans Tech Publications, Advanced Materials Research, Vol. 620, p. 87-93
[9] Wolfram Schmidt, Naomi N. M. Hirya, Dubravka Bjegovic, u.a. (2012): Cement technology in sub-Saharan Africa—Practical and scientific experiences. In: American Ceramic Society Bulletin, Vol. 91, No. 5, p. 52-56
[10] Peter Wray (2012): Straight talk with Karen Scrivener on cements, CO2 and sustainable development. In: American Ceramic Society Bulletin, Vol. 91, No. 5, p. 47-50

Utilisation of gum acacia Karoo as set-retarding water-reducing admixture in cement mortar and concrete at optimum dosage

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Introduction

Concrete Admixtures have found wide application in construction industries. Globally, this market is expected to be worthy $18.26 billion by 2019. Unlike Asia pacific region, which is currently the leading consumer of chemical admixtures, usage of admixtures in Africa is currently very low. However, it is expected to increase due to increase in construction of new infrastructures, new residential buildings, roads, bridges and water retention structures. Admixtures improve quality of construction producing more durable structures. There is an opportunity to increase growth in usage of chemical admixtures which is slow due to their high prices and lack of awareness in construction industry.

Ingredients that are added to the concrete batch other than water, aggregate or Portland cement, in order to improve the properties of concrete, immediately before or during mixing are known as admixtures. Admixtures have many beneficial effects on concrete which include increased workability, hydration kinetics, water demand, improved strength and better durability [1]. Chemical admixtures are commonly classified depending on the function and effect on concrete. Type of admixture and extent of interaction will influence the mechanical and physic-chemical properties of concrete. Among the seven categories included in ASTM C494 [2] is type D which are set retarding water reducing admixtures (SRWR). In this study, the effect of Gum Acacia Karroo (GAK) as SRWR admixture in cement mortar and concrete was investigated. SRWR admixtures are important for production of concrete in hot weather when placing and pumping. They reduce water content by at least 5% but maintain a certain slump. Reduction in amount of cement used can be realized by reducing water-cement-ratio (w/c).

GAK is a sticky natural gum which oozes from Acacia Karroo Haynes species. Acacia Karroo grows wildly in Southern African countries and produces lower grade of gum. Other species producing gum Arabic (GA) are Acacia Seyal or Senegal and comes mainly from gum belt in Sub-Sahara countries in Africa [3]. It is of high quality and mostly used in food industry.

GA is polysaccharide [4, 5] which contains similar sugars [6] like most lignosulphates [7]. Khayat, [5] listed GA, xanthan gum and welan gum as natural polymers which are soluble in water and increase cohesion and stability. GAK easily dissolves in water, has low reactivity, does not interfere with blended product due to its pale colouration and does not react with most minerals. Study conducted by [8] using Acacia gum from Seyal species reported increase in compressive strength. Soluble sugar content of GAK yielded 70% of the precipitating mass which contained soluble sugars like glucose, fructose and sucrose. Researchers have carried out studies using most of the natural gums but literature on use of Acacia Karroo gum in concrete is scarce.

Significance of this study was to determine the effect of GAK on some mechanical properties of cement mortar and concrete. Dosages of GAK at 0.7% and 0.8%wt (weight of cement), identified to be within the optimum dosage, were used for the test and compared with the control (sample without GAK).

Effect on compressive strength

Ordinary Portland cement CEM-I (grade 52.5) donated by Pretoria Portland Cement (PPC) was used. GAK was picked from Pretoria Botanical Garden (GAKP). The tears were picked, cleaned and sieved through a 200 µm sieve for cement mortar samples. For concrete samples GAK was dissolved in part of gauge water for a night. Compressive strength was performed on mortar samples according to South African Standard [SANS 50196-1]. The 0.7 and 0.8%wt dosage were chosen since they showed maximum strength even without reduction of water. For all the dosages there was increase in strength with age. Figure 1a illustrates compressive strength for 0.7% and 0.8% dosages of GAK with w/c ratio of 0.5 while 0.7% RW and 0.8% RW represent w/c ratio of 0.4 for cement mortars. For concrete (Figure 1b) 0.7% and 0.8% samples were prepared with w/b ratio of 0.61 while 0.7RW and 0.8RW were prepared with w/b (water-bidder-ratio) of 0.5. The results indicate the dominate effect of water reduction on compressive strength both in cement mortar and concrete. For cement mortar, there was a marginal difference in compressive strength between the control, 0.7%wt and 0.8%wt dosages at 28 days. However decreasing the w/c from 0.5 to 0.4 showed increase in strength by 3.4% and 8.3% for 0.7 and 0.8% dosages at 28 days. On the other hand, decreasing w/b ratio from 0.61 to 0.5 increased compressive strength by 33.5% and 39.1% for 0.7RW and 0.8RW respectively for concrete samples. This increase in strength showed that GAK can be used as a water reducer while maintaining certain slump for concrete and cement mortar.

Rate of hydration by GAK

Retarding admixtures are basically in the same category as SRWR admixtures. Many retarders reduce mixing water and many water reducers retard the setting of concrete

[9]. Tricalcium Silicate (C_3S) and Tricalcium Aluminate (C_3A) are the fastest hydrating cement reactant groups and retarding admixtures are used to interfere with this reaction delaying the setting time [10]. Delay can be attributed to adsorption of GAK on polymer chains of cement grains and interference with the precipitation of various minerals into solutions which can cause retarding effect on the rate of hydration and setting. GAK delayed initial setting time by 1.7 hrs and 1.8 hrs for 0.7 and 0.8%wt dosage above control respectively (Table 1). Final setting time increased by 4.6 and 4.4 hrs respectively for 0.7 and 0.8% dosages at 23^0C

Setting time indicates the rate of hydration of cement. To have an idea of hydration process TGA studies were carried out on cement mortars at 7 days at optimum dosages (Figure 2). [11] carried out TGA tests to study hydration. Samples were heated between 30 ^{0}C to 1000 ^{0}C in Nitrogen at 10^0C per minute. Peaks below 300^0C (Figure 2) were due to decomposition of ettringite (C-H-S) and gypsum, between 450^0 and 515 ^{0}C – decomposition of Calcium Hydroxide (CH) (Hydration product) and 740^0 to 850 ^{0}C was decarbonation of calcium carbonate coming from clinker. Percentage of CH content, calculated straight from TGA curves [12], was found to be 1.25% for 0.8% while 0.7% dosage was at 1.58%. Lower percentage of CH at 0.8% dosage was an indication of increased rate of hydration at that dosage as compared to 0.7% and thus higher compressive strength. However the control had lower CH content at 0.92%.

Conclusions

Inclusion of GAK in cement pastes increased both initial and final the setting time thereby affecting the rate of hydration. However further research should be carried out at different conditions with different cements

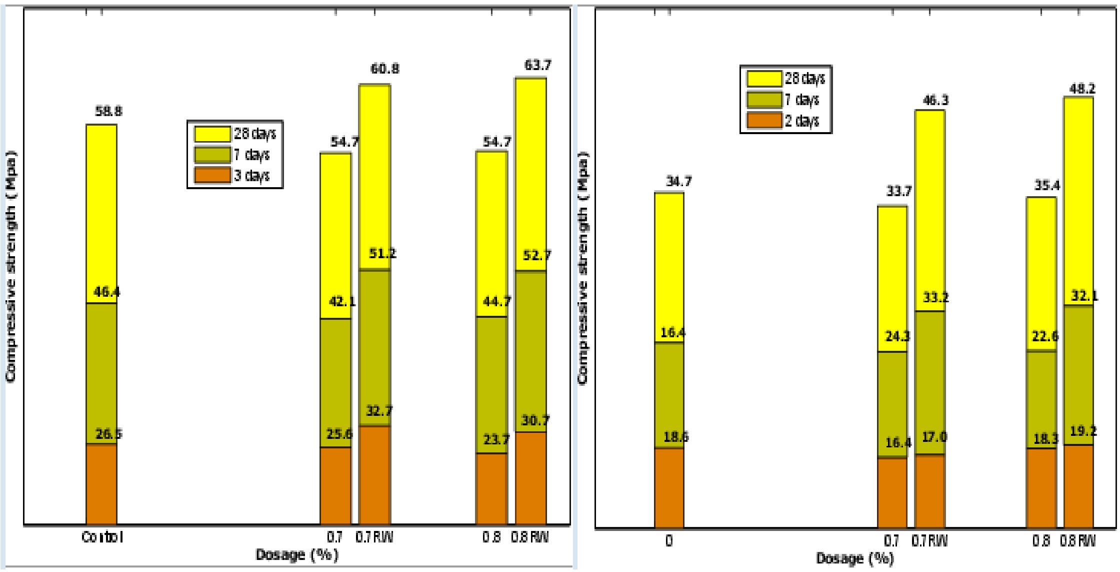
Reducing w/c ratio by reducing the amount of mixing water increased compressive strength of both concrete and cement mortar. This will result in reduced cost of concrete with higher performance which leads to reduction of negative effects on environment by reducing consumption of cement.

GAK is a good candidate for a SRWR admixture which is environmental friendly, non-toxic and biodegradable producing green concrete.

Figures and tables

Table 1: Setting time of cement pastes.

Sample dosage (% wt. Cement)	**Initial setting time (min)**	**Final setting time (min)**
No GAK	191	261
0.7%	291	536
0.8%	301	525



*RW= w/c of o.4

*RW=w/b 0f 0.5

Figure 1: Compressive strength: (a) mortar (b) concrete with different dosages and different w/c ratio.

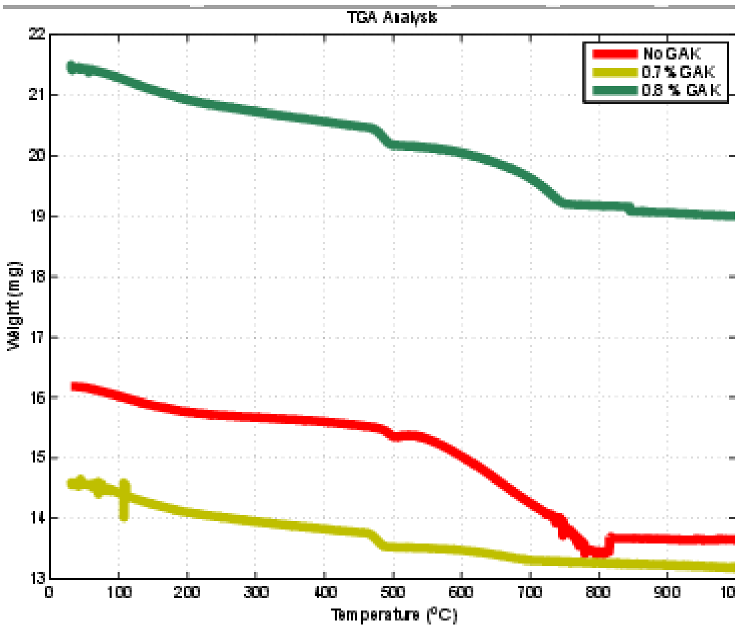


Figure 2: Thermogravemetric (TGA) analysis for cement mortar using different dosages of GAK.

References

[1] V.S. Ramachandran, Concrete Admixtures Handbook, Second Edition ed., Noyes Publication, U.S.A, 1995.

[2] ASTM C494 / C494M-13, ASTM International,West Conshohocken, PA, 2013, www.astm.org.

[3] D. Verbeken, S. Dierckx, K. Dewettinck, Applied Microbiology and Biotechnology, 63 (2003) 10-21.

[4] N.A. Ademoh, A. Abdullahi, Research Journal of Applied Sciences, Engineering and Technology, 1 (2009) 107-111.

[5] K.H. Khayat, Cement and Concrete Composites, 20 (1998) 171-188.

[6] S. Al-Assaf, G.O. Phillips, P.A. Williams, Food Hydrocolloids, 19 (2005) 661-667.

[7] V.S. Ramachandran, Concrete admixtures handbook: properties, science and technology, Cambridge University Press, 1996.

[8] N.S. Abdeljaleel, Hassaballa, A.E. & Rahman, A. M., Innovative Systems Design Engineering, 3 (2012).

[9] N.P. Mailvaganam, M. Rixom, Chemical admixtures for concrete, CRC Press, 2002.

[10] A.M. Neville, J.J. Brooks, Concrete technology, Longman Scientific & Technical Harlow, 1987.

[11] Q. Zeng, K. Li, T. Fen-Chong, P. Dangla, Construction and Building Materials, 28 (2012) 468-475.

[12] A. Peschard, A. Govin, P. Grosseau, B. Guilhot, R. Guyonnet, Cement and Concrete Research, 34 (2004) 2153-2158.

EFFECT OF FLY ASH-β-CYCLODEXTRIN COMPOSITES ON CONCRETE PROPERTIES

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Introduction

The need for using industrial wastes as construction materials cannot be over emphasized. The advantages range from the reduction in environmental pollution caused by the industrial wastes to the reduction of construction cost as a result of the incorporation of these wastes in construction. Fly ash (FA) is a promising industrial waste, which has been used in concrete technology as a cement replacement and is abundant in South Africa. However, its utilization is still limited compared to the quantity (approximately 36 million tons per year) of the FA being generated by ESKOM (the major South African electricity producer) as industrial waste. Therefore, there is a need to increase the utilisation of the large amount of unused FA (approximately 94% of ash generated) [1]. The exploitation of the unique chemistry of FA and modification of its chemical structure are needed to make it more applicable in concrete, especially with a view to improve early strength and durability developed when FA is used in concrete. This study investigated the effectiveness of using cyclodextrin (an enzymatic modification of starch) to beneficially modifies FA structure and hence increase the FA usage in concrete technology.

In the previous studies reported by the author [2, 3], the chemical compatibility of FA and cyclodextrin was confirmed and it was concluded that certain composites were formed with fly ash-cyclodextrin interaction, which was envisaged to be useful in improving fly ash behaviour in concrete production. Since these composites are relatively new materials in concrete technology, indicative tests were performed using two composites synthesis methods with different percentages of *β*-cyclodextrin (0.1%, 0.2% and 0.5%) and 30% FA on concrete strengths (compressive and split tensile) and durability (permeability, sorptivity and porosity) [4, 5]. Based on these tests results, further investigations were carried out using the physical mixture composite, lower percentages of β-cyclodextrin (0.025%, 0.05% and 0.1%), 30% FA and 50% FA. This paper presents the effect of fly ash-*β*-cyclodextrin composites on setting time, workability, compressive strength and permeability of concrete.

Materials and Experimental procedures

The main materials used are Class F FA, CEM152.5N cement and β-cyclodextrin (β-CD). The FA was obtained from Matla ESKOM power station, South Africa. β-CD was obtained from Industrial Urethanes (Pty) Ltd, South Africa. The cement type (CEMI52.5N) was obtained from Pretoria Portland Cement Company (PPC), South Africa. FA-β-CD composites mixtures were synthesized based on physical mixtures as explained elsewhere [2]. The quantity of water used for the setting time test depends on the amount of water that produced a consistent mix for each sample as described in SANS50196-3 [6]. The concrete was mixed according to SANS 5861-1:2006. The mixture proportion is shown in Table 1. Immediately after mixture, the slump test was performed according to SANS 5862-1:2006 [7].

The setting time test was performed on cement paste based on the procedure described in SANS 50196-3 [8] standard. Samples were mixed in a HOBART mixer, conforming to SANS 50196-1 [9]. The compressive strength tests were performed according to SANS 5863: 2006 [10] on each 100 x 100 mm cube sample at 7, 14, 28, 90 and 180 curing days. The permeability test was based on the durability index approach, which was developed by Ballim and Alexander [11-13] at 28 and 90 days curing ages using discs having a diameter of 68 mm and thickness of 30 ± 2 mm.

Results and discussions

The initial and final setting times of the cement pastes were affected by FA, β-CD and FA-β-CD composites (Figure 1). An increase in both the initial and final setting times was observed in binary samples while a further increase in both initial and final setting times was observed in ternary samples. The β-CD showed a higher effect in increasing setting time than FA. The higher the FA and β-CD contents, the greater the setting times observed (Figure 1), with the highest of 696 minutes and 1420 minutes initial and final setting times, respectively, observed for C50FA0.1CD sample.

The slump results presented in Table 1 show increase in slump with an increase in FA and β-CD contents. Figure 2 shows that compressive strength increased with an increase in curing age. The samples with 50% FA exhibited lower compressive strengths than other samples. The C30FA sample showed increased compressive strength compared to the control sample at 180 days curing period. A reduced compressive strength was observed for C50FA samples at all curing ages compared to the control sample. The β-CD samples (C0.025CD, C0.05CD and C0.1CD) showed an increase in concrete compressive strength at all ages of curing, compared to the control sample. The composite samples containing 30% FA showed greater compressive strengths than the control sample at later curing ages (90 and 180 days). However, composite samples containing 50% FA showed less compressive strengths than the control sample at all curing ages.

The samples containing 0.1β-CD showed invalid permeability results and therefore excluded from the discussion. The FA and FA-β-CD composite samples had a positive effect on permeability as shown in Figure 3; decreased permeability was observed for these samples at both curing ages, when compared to the control sample. The C50FA sample showed a greater decrease in permeability than C30FA sample. Generally, the FA and FA-β-CD composite samples had a better influence on concrete permeability at the 90 days curing age than at the 28 days curing age, which can be attributed to slower pozzolanic reaction in these samples.

Conclusions

In general, the chemical structure of FA was improved with its interaction with cyclodextrin. The FA-β-CD composite at lower percentages of FA (30%) and β-CD (0.05%) improved FA concrete's compressive strength at all ages. The study contributed to the knowledge of FA structure modification using cyclodextrin and promoted the continued inclusion of FA in concrete, which in turn should reduce the environmental pollution resulting from FA on ash dams and carbon dioxide emitted during cement production.

Figures and tables

Table 1: Mixture proportions for 1 m^3 of concrete SA

Samples	Cement	Crusher sand (Kg)	Coarse aggregate (Kg)	FA (Kg)	β-CD (Kg)	Water (Kg)	W/B	Slump (mm)
C	520.00	650	1000	0.00	0.00	208	0.4	30
C30FA	364.00	650	1000	156.00	0.00	208	0.4	40
C50FA	260.00	650	1000	260.00	0.00	208	0.4	55
C0.025CD	519.87	650	1000	0.00	0.13	208	0.4	40
C0.05CD	519.74	650	1000	0.00	0.26	208	0.4	55
C0.1CD	519.48	650	1000	0.00	0.52	208	0.4	135
C30FA0.025CD	364.00	650	1000	155.87	0.13	208	0.4	55
C30FA0.05CD	364.00	650	1000	155.74	0.26	208	0.4	70
C30FA0.1CD	364.00	650	1000	155.48	0.52	208	0.4	180
C50FA0.025CD	260.00	650	1000	259.87	0.13	208	0.4	80
C50FA0.05CD	260.00	650	1000	259.74	0.26	208	0.4	115
C50FA0.1CD	260.00	650	1000	259.48	0.52	208	0.4	200

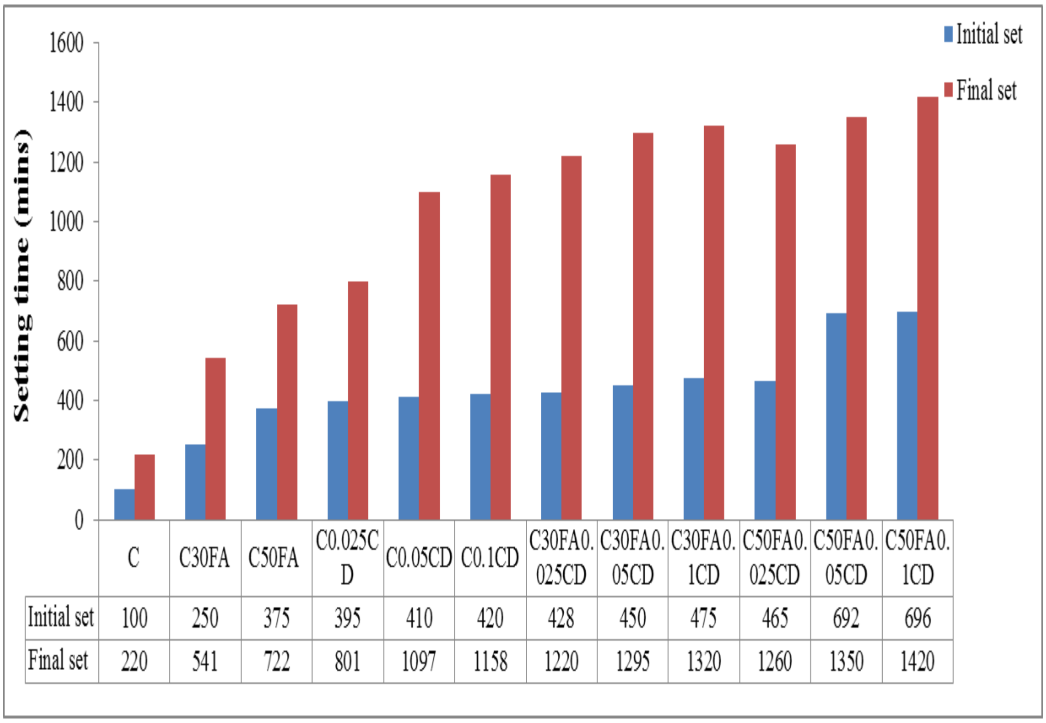

Figure 1: Setting times of cement paste samples.

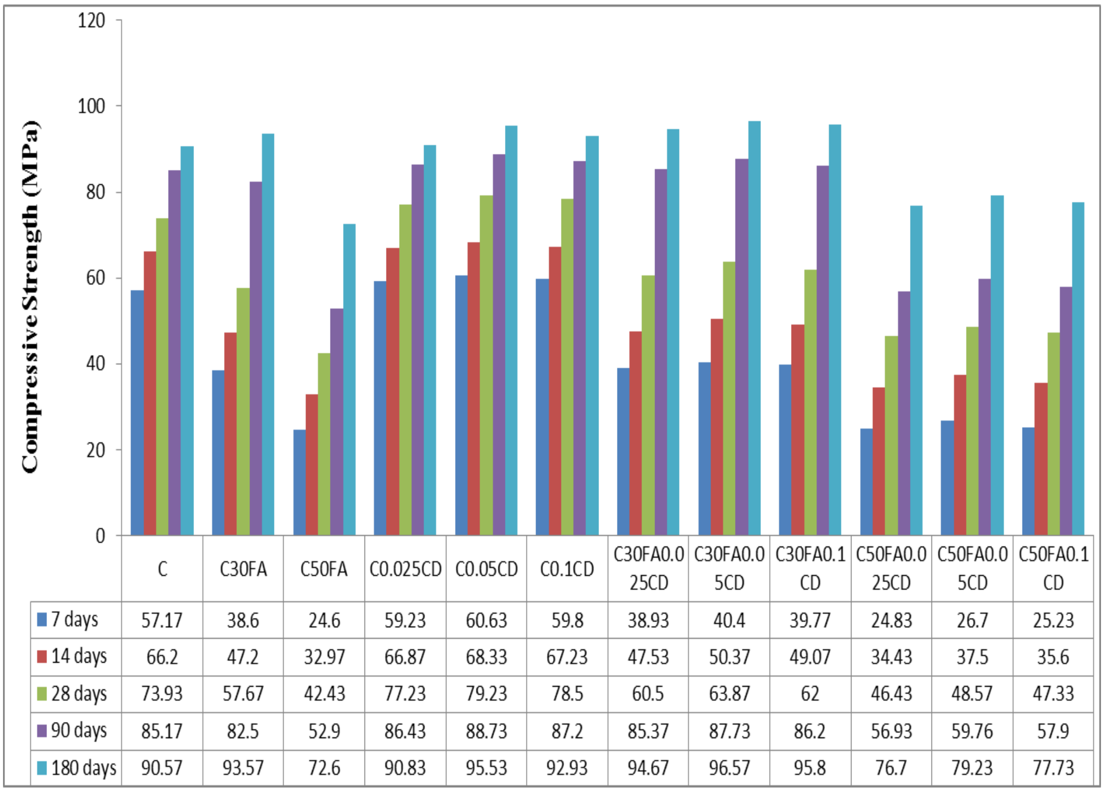

Figure 2: Compressive strength of concrete samples with 0.4 W/B.

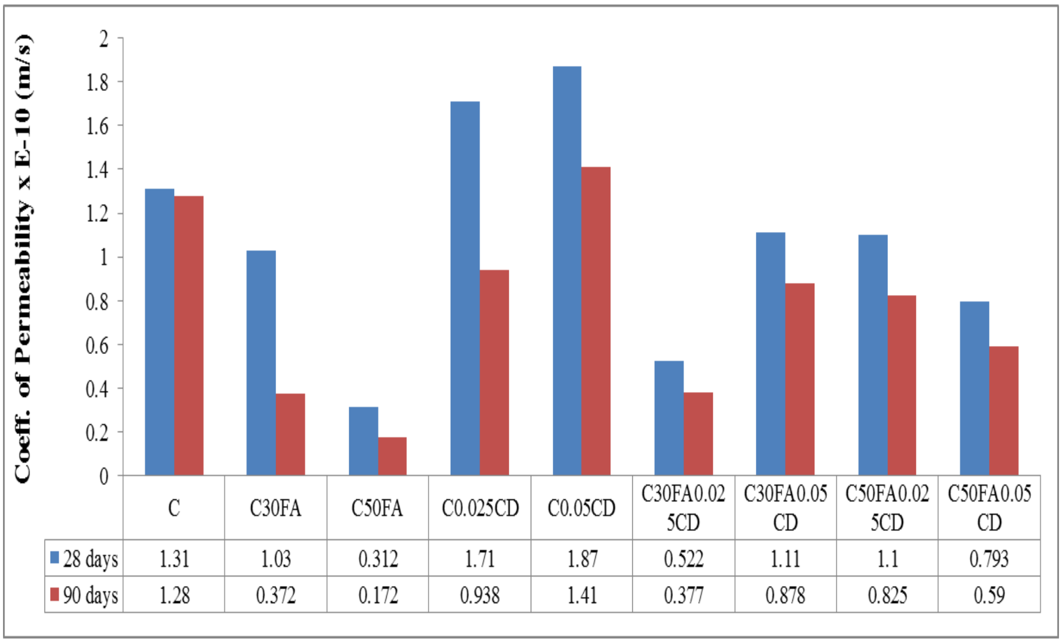

Figure 3: Coefficient of permeability of samples.

References

[1] ESKOM 2014. ESKOM integrated report 2014, http://integratedreport.ESKOM.co.za/pdf/full-integrated.pdf (CITED: 28/11/2014).

[2] Ikotun B.D., Mishra S., Fanourakis G.C.: Journal of Inclusion Phenomena and Macrocyclic Chemistry 79, 311-317 (2014).

[3] Ikotun B. D., Mishra S., Fanourakis G. C.: Particulate Science and Technology, Imprint: Taylor and Francis, Vol. 32, 360-365 (2014).

[4] Ikotun B. D., Fanourakis G. C., Mishra S.: RILEM proceedings PRO 95, conference at Germany from 14-17/09/14. ISBN 978-2-35158-147-6, 55 – 64(2014).

[5] Ikotun B. D., Fanourakis G. C., Mishra S.: Proceedings of the first International Conference on Construction Materials and Structures, 24-26/11/14, Johannesburg, South Africa. ISBN 978-1-61499-465-7, 825 – 834 (2014).

[6] SANS50196-3:2006: Methods of testing cement Part 3: Determination of setting times and soundness, ISBN 0-626-17598-4. Edition 2.

[7] SANS 5862-1:2006, Concrete tests-consistence of freshly mixed concrete – slump test, Pretoria: South Africa Bureau of Standards.

[8] SANS50196-3:2006: Methods of testing cement Part 3: Determination of setting times and soundness, ISBN 0-626-17598-4. Ed. 2.

[9] SANS 50196-1:2006: Methods of testing cement Part 1: Determination of strength, ISBN 0-626-17596-8. Ed. 2.

[10] SANS 5863:2006: Concrete tests-compressive strength of hardened concrete, Pretoria: South Africa Bureau of Standards.

[11] M.G. Alexander, Y. Ballim, J.M. Mackechnie, Concrete durability index testing manual, Research monograph no. 4, (1999).

[12] M.G. Alexander, J.R. Mackechnie, Y. Ballim, Guide to the use of durability indexes for achieving durability in concrete structures, Research monograph no 2, (2001), 5-25.

[13] M.G. Alexander, Durability indexes and their use in concrete engineering, International RILEM Symposium on Concrete Science and Engineering: Print-ISBN: 2-912143-46-2, e-ISBN: 2912143586, 9 – 22.

DETERMINATION OF SUSTAINABLE ADDITIVES TO IMPROVE LOCAL PORTLAND CEMENT FOR OFFSHORE CONSTRUCTION

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Brief author biography

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Introduction

The construction industry is increasingly turning to the use of environmentally friendly materials in order to meet the sustainable aspect required by marine infrastructures. This is due inability of the ordinary Portland cement not performing well when subjected to harsh environment. Hence, the development of suitable supplementary materials (fly ash, natural Pozzolan or limestone powder) to improve Portland cement offers promising signs for a change in the way of producing concrete which will sustain marine environment [1].

Objectives of the research

The main objective of this study was to determine suitable additive to improve local Portland cement to be used for construction of structures subjected to the marine environment. To achieve this goal, the following specific objectives were done:

- To determine the properties of the ingredients of mortar, fine aggregates, cement, water, fly ash, pozzolan and limestone powder
- To investigate unit weight of each prescribed mortar mix
- To develop various cement sand mortars and determine the strength development pattern, compressive strength through partial replacement of cement, water permeability and determine the carbonation penetration.

The investigation and its findings can encourage the use of the new approach in use of existing cement with readily available cementitious materials for casting specialized onshore structures. This will result in promoting better quality construction and innovative system in our construction industry.

The investigation undertaken will:

- Confirm that, the partial replacement of fly ash, pozzolan and limestone will lead to cheaper mortar/concrete than conventional plaster/concrete.

- To help solve the problem of importing corrosion resistance chemical and special cement for sea construction like geo polymer cement.

Compression test results

Compression strength test samples of size 70x70x70 mm were prepared of 1:3 mortar of different proportional of blended Portland cement with different additives of 30%, 20% and 10% replacement of cement. Distilled water was used for preparing mortar but samples were cured in sea water. Their strength was determined for 2,7,14 and 28days.

The ratios of replacement cement were obtained experimentally where 20% replacement by fly ash, 30%by natural pozzolan and 20% by limestone powder gave high compressive strength compare to other replacement.

Then comparison of compressive strength of cement only and cement with partial replacement by additive were done graphical as shown in the graph no 1.

The results shows that specimen containing 30% replacement contains high compressive strength development compare to other. This is due to the content of SiO_2 which dissolve into water and form H_2SiO_4 which react with calcium hydroxide (the end product of hydration reaction of cement) to form the grout paste of cement (calcium silicate hydrate) which develop high strength to the specimen [2].

Also it shows the decrease of strength of the specimen containing cement only at day 14 this is due to the high amount of sulphate ion from the sea water which attacks the constituent of cement like C_3S and C_3A.

Water permeability test results

This test was done to each proportion of mortar sample of 150x150x150 mm, this helps to determine durability of mortar. Since the structure to be constructed in the sea water has to be of low permeability of aggressive chemicals and to avoid the corrosion of reinforced bar. Specimen were cured in normal water for 28days and left to dry for one day then place in the water permeability machine for 48 hours. Then the specimens were broken into two parts to determine the depth of penetration.

The experimental observations were done to the samples containing fly ash, natural pozzolan and cement only and the result are shown in table 1.

The results show that the specimen containing natural pozzolan of 30% has low permeability compare to other specimens followed by 30% replacement by fly ash and this is due to the pozzolanic reaction which uses all calcium hydroxide which cause porosity to the specimen.

But specimen containing cement only shows high permeability due to high amount of porosity facilitated by high end product of hydration which is calcium hydroxide.

Carbonation test result

Each mix proportion sample of 28days carbonation test was conducted by using phenolphthalein to determine the depth of penetration of carbon into the sample. This helps to determine ability of the additive to resist the penetration of carbon-dioxide gas which may cause corrosion of reinforcement. This test depends on the age of the specimen and environments exposure. This test was conducted on the water permeability sample after they had been tested for water penetration and being broken into two parts to determine the depth of penetration of water, the solution was spread on the sample to observe the change of colour.

If the sample turn into pink means sample is not carbonate but if does not turn into any colour means the sample is carbonated.

Results shows that all specimen containing additive shows the change of colour to pink soon after spreading the solution, where the colour remain unchanged for approximate one month. But for the specimen containing cement only, the change of colour to pink occur immediately after spread the solution but the next day the sample return to its normal colour as shown in the picture no 1. This shows that cement only has low resistance to carbon dioxide reaction compare to one containing additives. This is due to high quantity of calcium hydroxide which reacts with carbon dioxide gas.

Analysis of result

According to the test observation above the following were the analyses

- The use of natural pozzolan as additive of cement with replacement of 30% gives the high compressive strength of 33N/mm^2 at 28days of curing in sea and there was the development of strength as the time increases.

- Also limestone powder can be opted as additive, since it shows the high compressive strength of 27.1N/mmm^2 at 28 days of curing in sea and the strength development pattern where increasing as time of curing increases.

- Also during chemical reaction taking place between magnesium sulphate from sea water and C_3S (tricalcium silicate) and also with calcium hydroxide. There is the production of gypsum (calcium sulphate) which has the role in cement to during hydration to avoid the generation of high amount of heat and to prevent the C_3S to form mono-sulphate aluminates [2]. Hence there is possibility of reducing amount of gypsum during the production of cement for off shore construction.

- According to permeability test which were observed for natural pozzolan and fly ash. Fly ash of 30% replacement shows small coefficient of permeability compare to other followed by 30% replacement by natural pozzolan. But that does not draw up conclusion that fly ash is suitable additive since it had small compressive strength compare to natural pozzolan

Conclusion

Since the investigation is still in the progress, the conclusion cannot be done but there is advantage of the expected result which is to obtain additive which will lower permeability of Aggressive agents like chloride and sulphates and to increase performance of Portland cement in concrete for offshore construction. Also to come up with ratio of most effective additive partially to replace cement, this can be done on site or at the industry, hence produce concrete structure which will be durable in that harsh environment.

Figures and tables

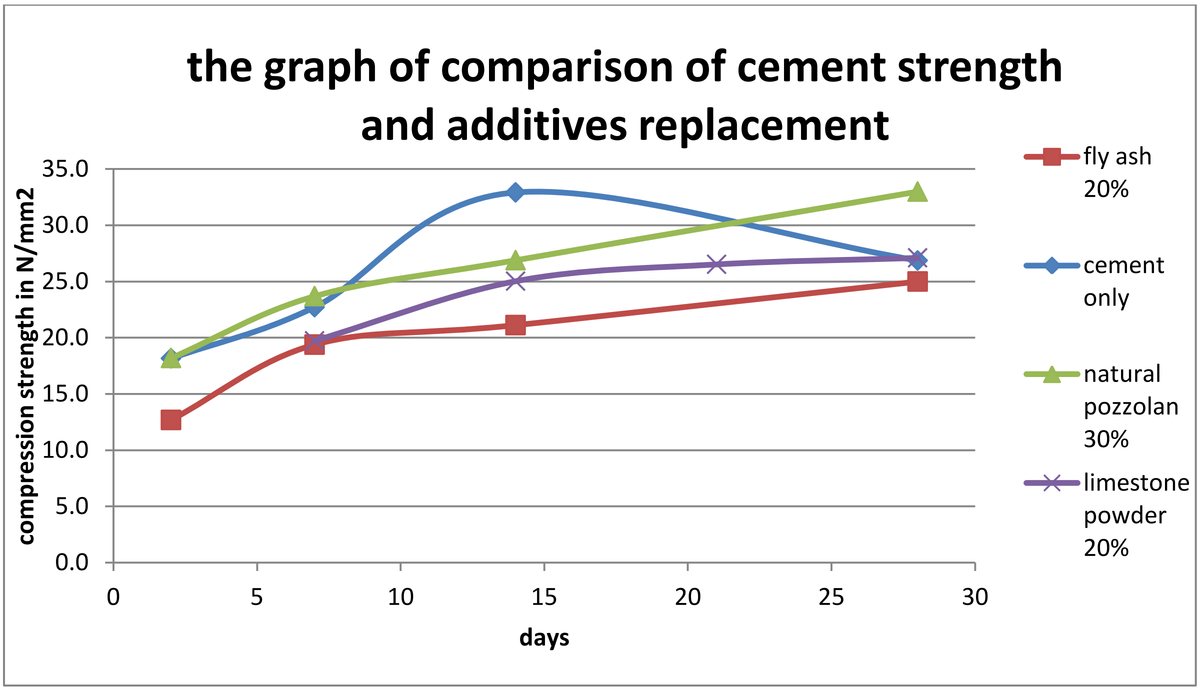

Figure 1: Comparison of strength of cement and additives replacement

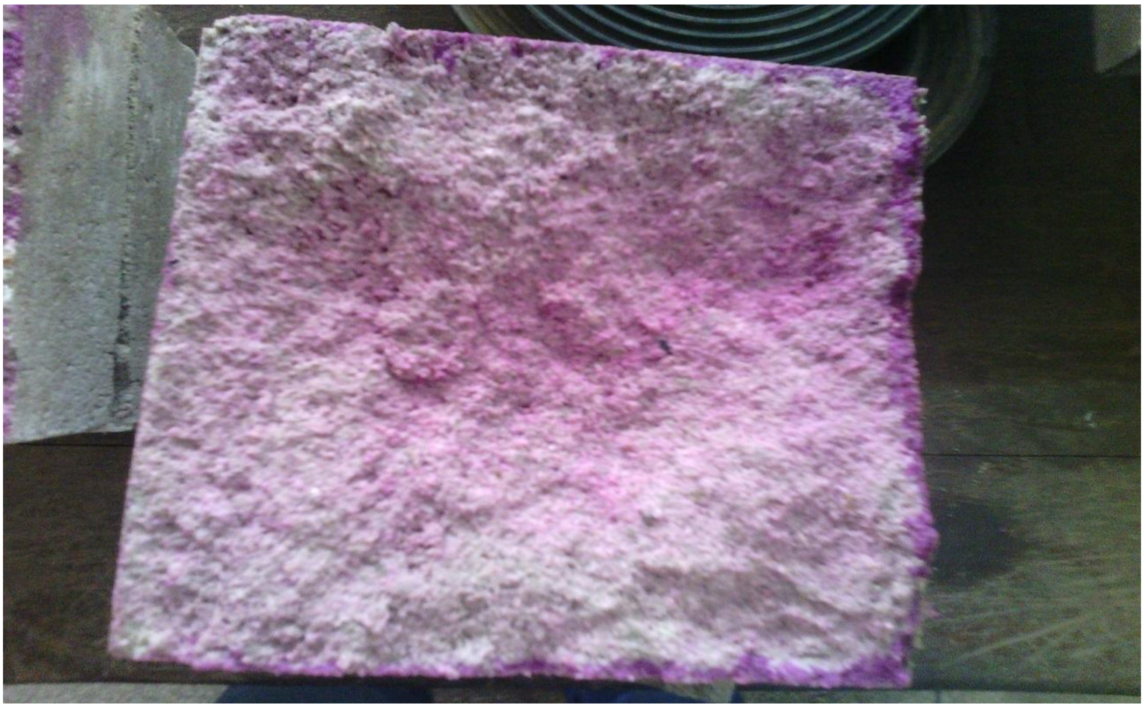

Figure 2: shows unchanged colour specimen after carbonation test

Table 1: Water permeability test result

material type	sample	density after test	depth of penetration in cm	coefficient of penetration K cm/sec x10^-5	average coefficient of penetration K cm/sec x10^-5
cement 42.5N	1	2.09	12.5	7.2	7.7
	2	2.02	14.1	8.2	
natural pozzolan 10%	1	1.98	2.6	1.5	1.4
	2	2.03	2.2	1.3	
natural pozzolan 20%	1	1.95	3.0	1.7	1.6
	2	2.01	2.5	1.4	
natural pozzolan 30%	1	2.04	2.0	1.2	1.0
	2	2.07	1.6	0.9	
fly ash 10%	1	2.12	3.5	2.0	1.9
	2	2.13	3.0	1.7	
fly ash 20%	1	2.13	3.0	1.7	1.7
	2	2.12	2.9	1.7	
fly ash 30%	1	2.08	1.2	0.7	0.6
	2	2.07	0.9	0.5	

References

[1] P.K.Mehta. *concrete in marine environment.*

[2] JayantD.Bapat. *Mineral Admixtures in Cement and Concrete.*

[3] Dr. Jeff Thomas, A. R. *science of concrete.*

PROPERTIES OF FRESH SELF-COMPACTING CONCRETE CONTAINING SLAG

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Introduction

Self-compacting concrete (SCC), is a highly flowable concrete with minimal segregation that can flow into place under its own weight and no consolidation work at site [1]. One of the most important differences between SCC and conventional concrete is the incorporation of mineral admixtures such as fly ash, silica fume, and ground granulated blast furnace slag (GBFS) [2-5]. As these mineral additives replace part of the Portland cement, the cost of SCC will be reduced especially as most mineral additives are industrial by-products. GBFS is being widely used as a cement replacement in Portland cement concrete because of its low heat of hydration, high sulphate and acid resistance and higher ultimate strength[6, 7]. The improvement in strength and durability of GBFS concrete is very sensitive to the fineness of GBFS and its glass content [8-10]. Higher slag fineness increases the strength and significantly reduces the concrete permeability and can greatly provide higher sulphate and acid resistance. However, few studies have been investigated so far on the influence of GBFS fineness on the workability of self-compacting concrete.

Experimental Program

This study, is aimed to investigate the effect of the slag content and its fineness on the rheological properties of self compacting concrete. A total of ten concrete mixes including the control mixes were prepared with 0, 10, 15, 20 and 25% of slag as cement replacement with two different finenesses. The water to binder ratio was kept low at 0.40 and binder content was maintained constant for all concrete mixtures. The filling ability and deformability of SCC was determined with respect to slump flow. The passing ability of SCC was assessed by L-box test. The segregation resistance was also quantified by sieve test.

Results and discussion

Slump flow for self compacting concrete mixtures containing GBFS as partial cement replacement with different finenesses are shown in Figure 1. It can be seen, from this figure that slump flow values varied from 775 to 800 mm and 660 to 680 mm for SCC mixtures with slag fineness 350 m²/kg and 420 m²/kg respectively. There is a slight increase of slump flow of SCC mixes with increasing slag content in the case of lower fineness (350 m²/kg). However, the contrary is noticed for higher slag fineness (420 m²/kg). It should be noted that increasing slag content from 10 to 25% improves the workability of concrete. The higher slump flow values are given by SCC mixes with lower slag fineness. This increase of the fineness of slag lowers the slump flow of all concrete mixtures containing slag. This reduction in slump flow may be attributed to the high demand for the w/b ratio by the finer particles of slag. Figure 2 shows the L-box test results filling and passing ability of SCC mixtures with and without slag for different finenesses. It can be seen from this figure that only SCC mixes content of 15 to 25 % with lower slag fineness (350 m²/kg) could be used to produce SCC with an adequate passing ability. However, all the remained SCC mixtures including SCC control present a risk of blocking. It should be noted that the passing ability is more sensitive to the fineness of slag. Increasing the slag fineness increased the risk of blocking of SCC mixtures as can be seen in this Figure. This could be explained by the increase of the viscosity of the SCC mixes with increasing slag fineness. The increase in viscosity tends to block the passing capacity of SCC mixes through the three reinforcement bars of the L-box test setup. The results of the resistance to segregation of SCC mixtures containing various amounts of GBFS with different finenesses of 350 kg/m² and 420 kg/m² are illustrated in Figure 3. It can be seen from this figure, that resistance to segregation of all SCC mixtures with lower slag fineness decreases with increasing GBFS content. The results revealed that SCC mixes content of 0 to 15 % with slag fineness 350 m²/kg possessed adequate segregation resistance. An increase of fineness of slag led to segregation problem for all SCC mixes as can be seen in Figure 3. This could be attributed to the higher fineness of slag used in this investigation.

Conclusions

There is a slight increase of slump flow of SCC mixes with increasing slag content in the case of lower fineness (350 m²/kg). However, the contrary is noticed for higher slag fineness (420m²/kg)

Slag content of 15 to 20 % with lower slag fineness (350 m²/kg) could be used to produce SCC with an adequate filling ability, passing ability and stability.

Increasing slag fineness affects significantly the rheology of self compacting concrete mixes.

Figures and tables

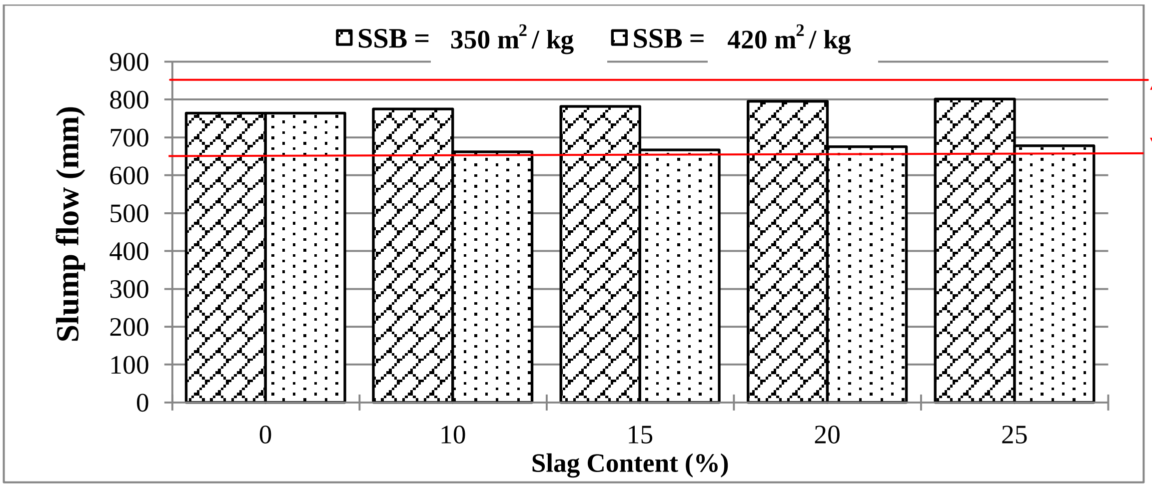

Figure 1: Slump flow of SCC mixtures with different slag fineness.

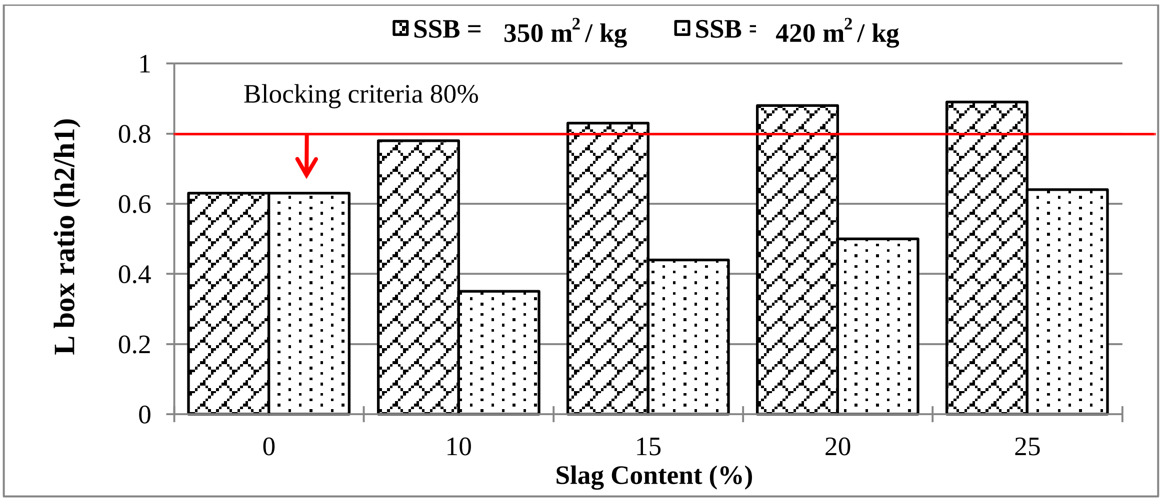

Figure 2: L-box ratio of SCC mixes with different slag fineness.

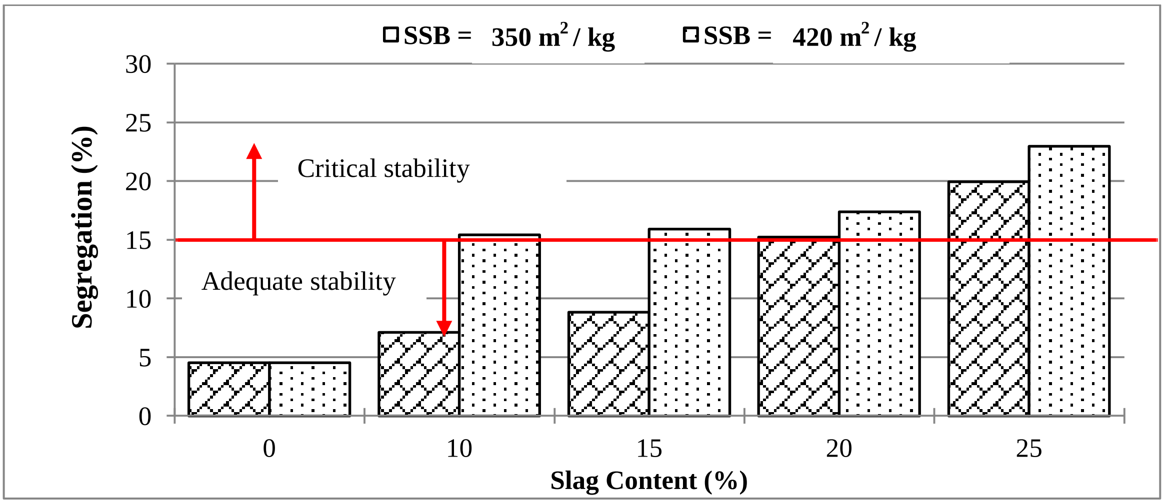

Figure 3: Resistance to segregation of SCC mixtures with different slag fineness.

References

[1] Okamura H, and Ozawa K. Self-Compacting high Performance Concrete in Japan. Second CANMET/ACI International Symposium on Advances In Concrete Technology. Las Vegas, ACI, SP 159-2, 1995, pp 31- 44.

[2] Vejmelkováa E., Kepperta M, Grzeszczykb S, Skalin skib B, Cˇerny´B. Properties of self-compacting concrete mixtures containing metakaolin and blast furnace slag. Constr Build Mater,2011,25:1325–31.

[3] Boukendakdji O, Kenai S, Kadri E.H. and Rouis F. Effect of slag on the rheology of fresh self-compacted concrete. Constr Build Mater, 2009, 23: 2593–2598.

[4] Guneyisi E, Gesogˇlu M.O. and Zbay E. Effects of marble powder and slag on the properties of self-compacting mortars. Mater Struct, 2009, 42:813–826.

[5] Gesoglu M, Guneyisi E, Ozbay E . Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. Constr Build Mater,2009, 23, pp. 1847-1854.

[6] Khatib, J.M, Hibbert, J.J. Selected engineering properties of concrete incorporating slag and metakaolin. Constr Build Mater;2005, 19:460–72.

[7] Kenai S, Hadj Sadok A, Menadi, B. Durability of concretes containing Algerian slag. Tenth international conference on non-conventional materials and technologies. Cali, Colombia; 2008, 12–14 November.

[8] Nakamura N, Sakai M, Swamy RN. Effect of slag fineness on the development of concrete strength and microstructure. ACI Publication SP-132; 1992, p. 1343–66.

[9] Oner M, Erdogˇdu K, Günlü A. Effect of components fineness on strength of blast furnace slag cement. Cem Concr. Res;2003, 33:463–9.

[10] Neville, A. Properties of Concrete. 4th ed. London. Longman, London, 1995.

SHOTCRETE

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Brief author biography

Maria Thumann holds a Master's degree in civil engineering from the OTH University of Sciences Regensburg, Germany. She is currently working on a research project which is called "Reduction of the potential for precipitations of shotcrete". Her Co-author Dr. Wolfgang Kusterle is Professor for building materials at the OTH Regensburg and he is a well-known shotcrete expert.

General information about shotcrete

In general the term shotcrete describes shotcrete as material (sprayed concrete), shotcreting as placing process as well as shotcrete as construction method. Shotcrete as material is defined as a concrete conveyed through a hose and pneumatically projected at high velocity onto a surface [1–3]. Compared to conventional concrete, which usually has to be compacted by vibration, shotcrete is applied under pressure and consolidated through the high velocity impact of the incoming sprayed particles. This pneumatical method allows vertical and overhead applications on irregular surfaces without formwork.

Typical applications for shotcrete are:

- concrete replacement and strengthening (Fig. 1)
- concreting complex geometries without formwork
- slope stabilization
- support of tunnels and underground constructions [4]

Wet-mix and dry-mix process

Two different processes are available for the application of shotcrete: wet-mix process and dry-mix process (Fig. 2).

Dry mix process means that the dry constituent materials (aggregates, cement, further additions and admixtures) are placed in a shotcrete gun and the material is transported through the hose using compressed air (thin flow process). At the nozzle water and liquid admixtures, if necessary, are added. The amount of water is only controlled by the nozzleman, indeed his skills affect the quality of the shotcrete. Dry-mix sprayed concrete is used when smaller quantities and outputs are required. The system is very flexible; it allows start and stop operations and an easy handling of the light weight hose. The compact and robust machines can be even used in confined space conditions. But with dry-mix sprayed concrete the economics are affected by the high rebound quantities and wear costs as well as the working conditions because of high dust generation.

Higher volumes of shotcrete in less time compared to dry-mix process can be applied with the wet-mix process. The wet mix-process uses ready-mixed concrete. The concrete is usually transported to the nozzle using a concrete pump (dense flow process). At the nozzle admixtures, e.g. accelerator, are added. The addition of accelerator provides sufficient early strength development of the shotcrete. At the nozzle compressed air is introduced to provide sufficient velocity for placement. Thin flow process is less commonly used for wet sprayed concrete. Compared to dry mix-process the wet mix method produces less rebound and dust, the content of water is constant and higher volumes can be placed in less time.

Sprayed concrete requirements

Beside the regular requirements for concrete like compressive strength and workability, the setting and the early strength development of shotcrete plays an important role. The risk of fresh concrete falling onto workers is one of the most serious hazards, especially in case of overhead applications.

The mix design of shotcrete has to be adapted for this purpose. But of course general basics regarding durability are still valid, e.g. the lower the water-cement ratio, the better the durability. The mix-design of concrete usually consists of three components (water, cement and aggregates). To extend its properties and potential applications, five components can be necessary (water, cement, aggregates, additions and admixtures). Combined with the application parameters for shotcrete, it becomes a complex system. For example, due to the addition of accelerator sufficient early strength can be achieved, but the chemical matching of cement and accelerator must be well adjusted.

Furthermore, the application of shotcrete influences the quality. Sprayed concrete is applied in layers. Some application rules for spraying have to be considered to achieve good adhesion to the substrate and good compaction and small amounts of rebound, e.g. cleaning substrate from dust, optimized nozzle distance to keep dust generation and rebound at low level, application of the sprayed concrete rectangular to the substrate etc.

Aspects concerning durability have to be determined depending on the different requirements, e.g. resistance against water penetration, chemical attack etc. In general they are equivalent to those for cast-in-situ concrete. But the very special applications of shotcrete result sometimes specific requirements.

Research project

The aim of a German research project is the improvement of shotcrete mix-designs regarding reduced precipitations. The context is easily explained. For the serviceability and durability of the tunnel it is necessary, that the construction is protected against water ingress. One possibility is to drain off the water depressurized ("umbrella insulation"). The groundwater is collected at the edges of the tunnel sidewalls in drainage pipes, so that the tunnel lining is relieved from water pressure (Fig. 3).

On its way from the surrounding ground to the drainage pipe the groundwater gets in contact with cement bound materials, changes pressure and temperature and finally gets in contact with the atmosphere. Chemical reactions between the groundwater and the cement bound material occur, which are influenced by the chemical composition and the hydro-geological conditions of the groundwater [6]. Precipitations in the drainage pipes are a common seen phenomenon resulting from these reactions. With time the drainage pipes are getting clogged. Subsequently the pressure on the tunnel wall increases and the construction can be damaged. The cleaning of drainage pipes during operation of traffic tunnels is possible, but very costly and time consuming. To minimize the tunnel maintenance work in traffic tunnels it is therefore crucial that precipitations are reduced to a minimum. The shotcrete mix design has to be adapted for this purpose. Early age compressive strength development, compressive strength and aspects concerning durability of shotcrete as well as costs for shotcrete should not be influenced substantially. The leaching behaviour of new and already known binder-compositions will be studied. It is acknowledged that the process of calcium leaching cannot be avoided completely because of durability aspects like the corrosion protection. However, there is a good chance to minimize it. Most common change in mix-design is the reduction in clinker content, by using a lower amount of ordinary Portland cement together with cementitious materials as slag and fly ash to fill up the required binder-content. Additions in general can improve the durability and the fines matrix. But especially in case of shotcrete, application parameters and sufficient early strength development influence the mix-design. Within the research project new and already known binder compositions are studied [7; 8]. These baseline investigations create new possibilities for mix design of shotcrete.

Conclusion

To sum up shotcrete is a flexible, economic and rapid construction method. It requires a high degree of mechanization, specialist workers, experience and technical knowledge. The variation of possible applications offers a lot of opportunities.

Figures and tables

Figure 1: Shotcrete application for bridge column repair. Here shotcrete is embedding the anode grid of a cathodic protection (picture Kusterle)

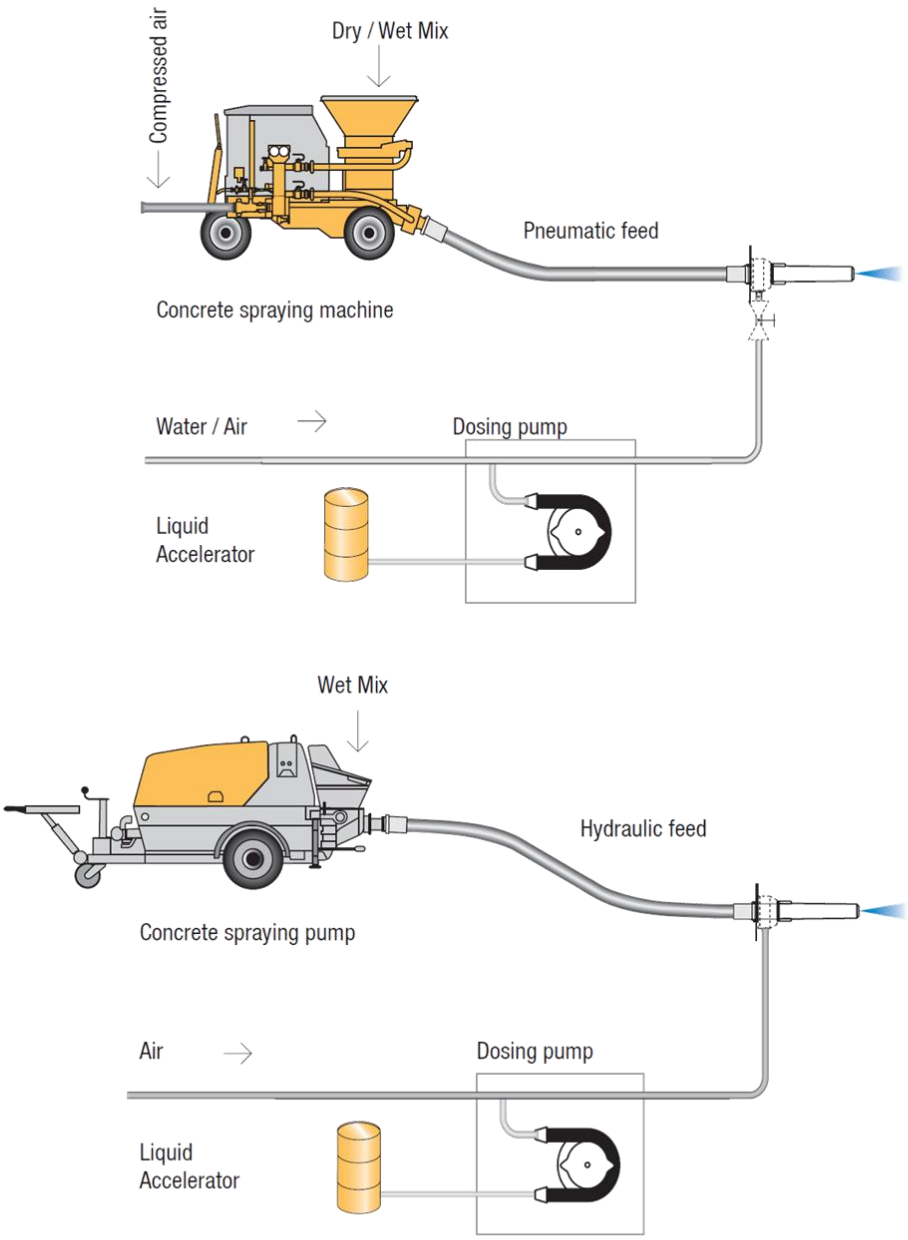

Figure 2: Thin-flow process for dry mix or wet mix sprayed concrete (above) and dense flow process for wet mix sprayed concrete (below) [5]

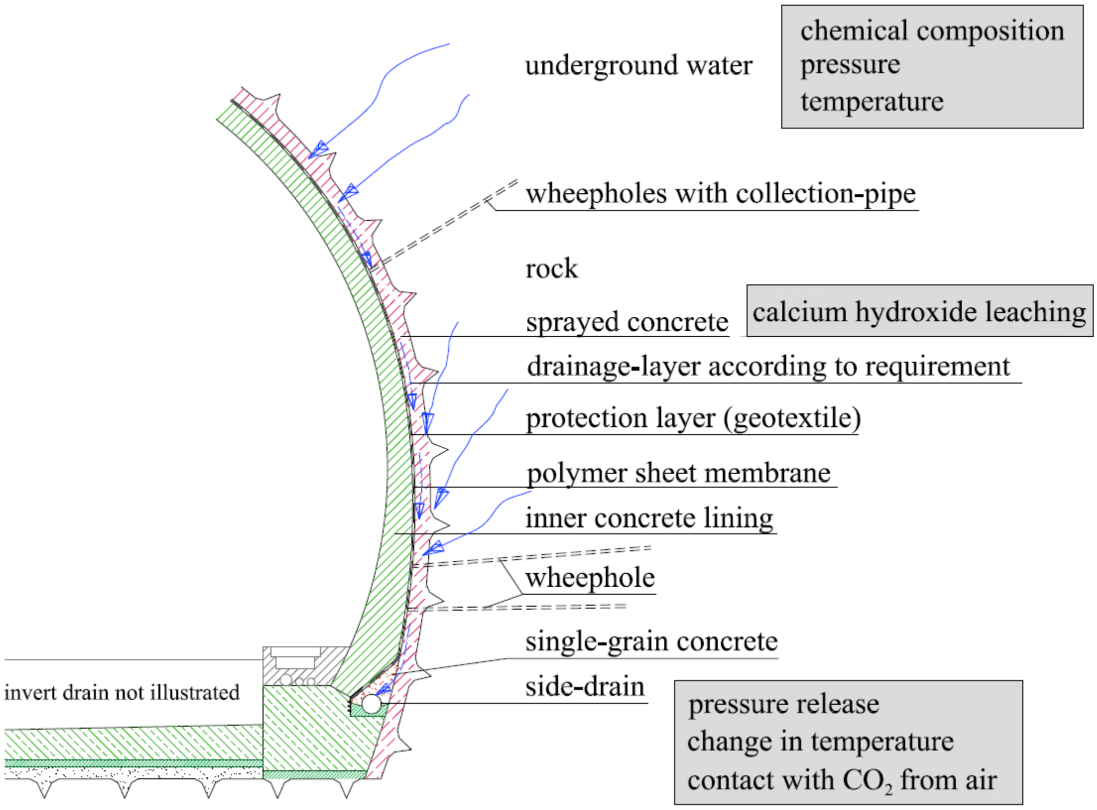

Figure 3: The way of the water from the rock to the drainage pipe [6]

References

[1] Österreichische Bautechnik Vereinigung: Guideline "Sprayed Concrete". Vienna (04/2013).

[2] DIN Deutsches Institut für Normung: DIN EN 14487-2: Spritzbeton - Teil 2: Ausführung (Sprayed concrete - Part 2: Execution). Berlin: Beuth Verlag GmbH (01/2007).

[3] DIN Deutsches Institut für Normung: DIN EN 14487-1: Spritzbeton -Teil 1: Begriffe, Festlegungen und Konformität (Sprayed concrete - Part 1: Definitions, specifications and conformity). Berlin: Beuth Verlag GmbH (03/2006).

[4] Kusterle, W., Jäger, J., John, M., Neumann, C., Röck, R.: Spritzbeton im Tunnelbau. In: Bergmeister, K., Fingerloos, F., Wörner, J.-D. (Eds.): Betonkalender 2014. Unterirdisches Bauen, Grundbau, Eurocode 7: Ernst & Sohn, p. 303–390.

[5] Höfler, J., Schlumpf, J., Jahn, M.: Sika Sprayed Concrete Handbook (08/2011).

[6] Österreichische Vereinigung für Beton- und Bautechnik: Richtlinie Tunnelentwässerung (Guideline tunnel drainage). Vienna (04/2010).

[7] Thumann, M., Saxer, A., Hartmaier, M., Kusterle, W.: Versinterungspotential von Spritzbeton - Laboruntersuchungen und Kleinspritzversuche zur Reduzierung der Calciumfreisetzung. In: Kusterle, W. (Ed.): Spritzbeton-Technologie 2015: (01/2015).

[8] Thumann, M., Saxer, A., Kusterle, W.: Precipitations in the Tunnel Drainage System. The Influence of Sprayed Concrete and Other Cement Bound Materials. In: Beck, T., Woldmo, O., Engen, S. (Eds.): Seventh International Symposium on Sprayed Concrete. Modern Use of Wet Mix Sprayed Concrete for Underground Support,p.375–386.

Rice husk ash as source of soluble silicate in the design of metakaolin based inorganic polymer cement and mortars

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Brief author biography

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Introduction

Despite the promising properties of the geopolymer binders, and the particular interest manifested by researchers and industries, there are technological challenges associated with the variability of the raw materials from different sources, and the low sustainability of the current alkali-activators used [1-3]. During the alkaline activation of aluminosilicate precursors, the nature of the activator solution plays a key role in determining structural and mechanical performance. The production of sodium silicate involves the calcination of sodium carbonate (Na2CO3) and quartz sand (SiO2) at temperatures between 1400–1500 °C, producing large amounts of CO2 as a secondary product [1]. This substantially increases the embodied energy of silicate-activated binders, reducing significantly their sustainability. However, sodium silicate (Na2SiO3, sometimes referred to as 'waterglass') is the activator which generally provides the highest compressive strength development at early ages of curing, and exhibits some technological advantages compared with other activators such as NaOH.

This then provides motivation for the examination of the current activators used in geopolymerisation processes in terms of their sustainability, and the assessment of alternatives that can contribute to decrease the embodied energy of these binders. Some studies assessing alternative activators based on modified silica fume (MSF) have been conducted [1]. Likewise, agro-industrial wastes, as well as other silica sources, have been studied as alternative sources for alkali-activators in order to obtain a more environmentally friendly alkali-activated binder with lower cost [1-3]. These results reveal that this alternative activator promotes similar or even better mechanical performance when compared with conventional activators.

Rice husk ash

Rice husk ash is an agricultural by-product with annual production estimated to more than 300 millions of tons. RHA in turn contains around 85 % - 90 % amorphous silica. Due to their amorphous structure and small particle size, RHA can be used to replace amorphous silica in many applications. In the cement and concretes technology, RHA is a good super-pozzolan. There are growing demands for fine amorphous silica in the production of special cement and concrete mixes, high performance concrete, high strength, low permeability concrete, for use in bridges, marine environments, nuclear power plants, etc… and the RHA particles can be suitable to play the role. Industries also use rice husk as fuel in boilers and for power generation. Among the different types of biomass used for gasification, rice husk account for 18 – 20 %.

Dissolution, formation of colloidal silicate and geopolymer synthesis

Amorphous silica from RHA can be extracted using low temperature alkali extraction. The solubility of amorphous silica is very low at pH< 10 and increases sharply above pH 10. This unique solubility behaviour makes silica extractable in pure form from RHA by solubilising it under alkaline conditions[5, 6]. In the case of the sodium silicate for use in geopolymers, the solution is designed with a simply process in which fine particles of RHA are dissolved into highly concentrated sodium hydroxide solution (5M to 12M). The high SiO2/Na2O molar ratio is applied to maintain under control the bulk Na_2O content into the final geopolymer binder.

The structure of the produced gelatinous silicate phases is modified by the presence of alkaline ions. Due to the strong deprotonation reactions taking place in high alkaline solutions, the oligomers contain singly-negatively charged oxygen anions that attract alkaline cations, creating thus alkaline NBO sites. Therefore, the incorporation of alkali metal ions on interstitial sites is unavoidable during silicon polycondensation in the presence of alkali metal ions[6-7]. The amount of NBO sites is a function of the SiO_2/Na_2O molar ratio in the prepared silicate gels. Low SiO_2/Na_2O molar ratio is equivalent with increased number of NBO sites and thus with structures consisting principally of SiQ^2, SiQ^1 structural units which form silicate chains, dimers, and monomers. On the contrary, high SiO_2/Na_2O molar ratio is equivalent with decreased number of NBO sites and thus with structures consisting principally of SiQ^3, SiQ^4 structural units which form silicate 3D frameworks and sheets. In the case of the gelatinous silicate phase with the highest molar ratio $SiO_2/Na_2O \geq 5$, the position of the halo peak indicates the predominance of SiQ^3 units which create a mixed structure consisting of silicate sheets and 3D frameworks [6-7]. The position of the halo peak (Figure 1) in the gelatinous silicate phase with the lowest molar ratio SiO2/Na2O $\leq$ 2.86 indicates the predominance of SiQ_2 units that create a mixed silicate chains and sheets structure [6-7]. The IR spectra of gelatinous silicate phases at different SiO_2/Na_2O molar ratios showed bands in the range 370–1300 cm^{-1} attributed to different vibrations in the –Si–O–Si– units[4,5]: (a) 1000–1100 cm^{-1} due to asymmetric stretching, (b) 750–800 cm^{-1} due to symmetric stretching, and (c) ~ 460 cm^{-1} due to bending.

The geopolymerisation process involves a heterogeneous chemical reaction between two phases: a fine solid aluminosilicate precursor and an aqueous alkali silicate solution. Geopolymers are normally composite materials consisting of non-dissolved solid grains and embedded by gelatinous binder. The non-dissolved solids are attributed either to insoluble solid phases existing in the initial solid aluminosilicate raw material or to incomplete dissolution due to slow reaction kinetics. The gelatinous phase binding the non-dissolved solid grains is principally of aluminosilicate nature although other metals such as Ca, Fe, etc., could be found as minor constituents in the gel. A good geopolymer has to have at least two properties: high hydrolytic stability and satisfactory mechanical strength (compressive, flexural, etc.) depending on the type of application. Both properties depend on the structure of the gelatinous binder. Comparative results is obtained considering conventional geopolymer with sodium silicate and sustainable geopolymer with up to 75 vol% of sodium silicate replaced by the in-situ produced RHA-NaOH gel.

Physic-mechanical properties and Microstructure

The effects of bulk composition and microstructure on strengthening mechanisms and fracture resistance of geopolymer binder and mortars were demonstrated and are related to the Si/Al which can be controlled with the amount of soluble silica presents into the composite system (Figures 2 and 3). Based on IR spectra and porosity analysis, it was observed that capillary pores and the nature of alkali-aluminosilicate hydrated named polysialates (H–M–A–S) determine cracks initiation site in the Al-rich geopolymer samples with low Si/Al molar ratio (range 1.23–1.5). These samples exhibited low flexural strength, Young modulus and Impact toughness as well as delayed failure under environmental stresses. Increasing the Si/Al molar ratio (range 1.79–2.42) improved the flexural strength and Impact toughness. Formation of more polymerized H–M–A–S phases contributed to strengthening the matrices and hinder axial cracks; consequence of toughening mechanisms developed by the coarsening on molecular scale of H–M–A–S.

The increase of the flexural strength is interpreted as the results of the extension of N-A-S-H phase formation in the matrix and at the interfacial zone [7]. However the strengthening mechanisms are focused to the enhancement of the volume of N-A-S-H easily developed into amorphous silica based formulations while the reactions at interfaces between geopolymer gels and the incongruent dissolved particles play significant role in matrix strengthening phenomenon. The decrease into the number of contact points due to the low reactivity (poor dissolution and reduction of the soluble silica) is considered to explain the reduction of the flexural strength over the limit soluble silicate content.

Conclusions

The sodium silicate is the principal binder component used during the geopolymerisation process of the amorphous to semi-crystalline aluminosilicates. The high temperature process for the preparation of the sodium silicate has appeared as limited factor for the geopolymer in the perspective of its classification as green materials. In this project, the rice husk ash is activated in sodium hydroxide solutions with various concentrations to assess the effectiveness of the rice husk-NaOH system to substitute sodium silicate in the formulations of inorganic polymer cement and composites. It was concluded that appropriate process method applied to the geopolymerisation using the system RHA-NaOH can allow the obtained products to compete with the standard metakaolin based geopolymer with conventional sodium silicate. The products are more compatible with the environmental issues and gain in sustainability.

Figures and tables

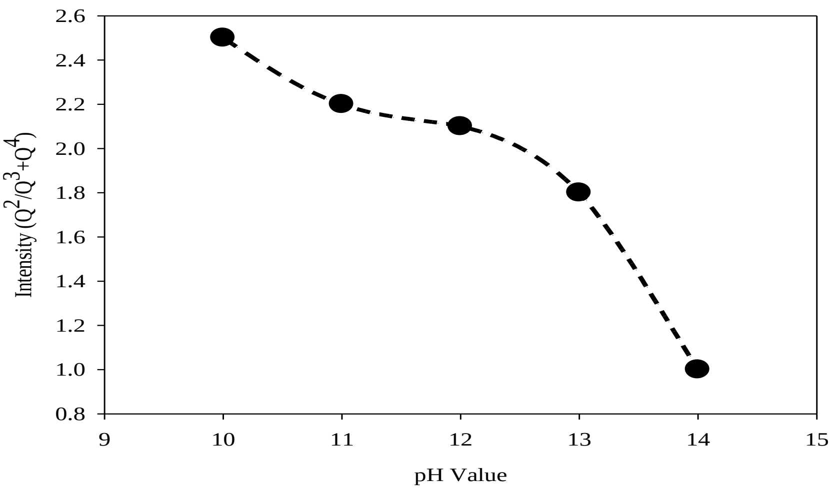

Figure 1: Variation of the position of ϑ_{as}Si-O-Si asymmetric strectching vibration band as function of the pH value.

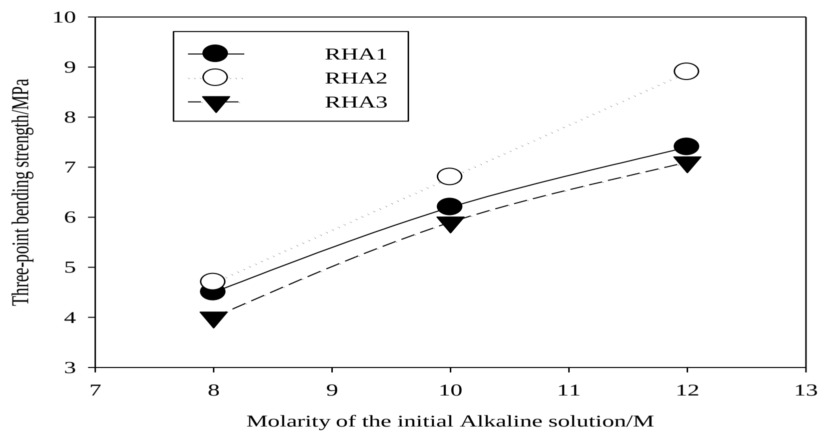

Figure 2: Effects of the RHA content and the initial alkalinity on the flexural strength of the inorganic polymer binders.

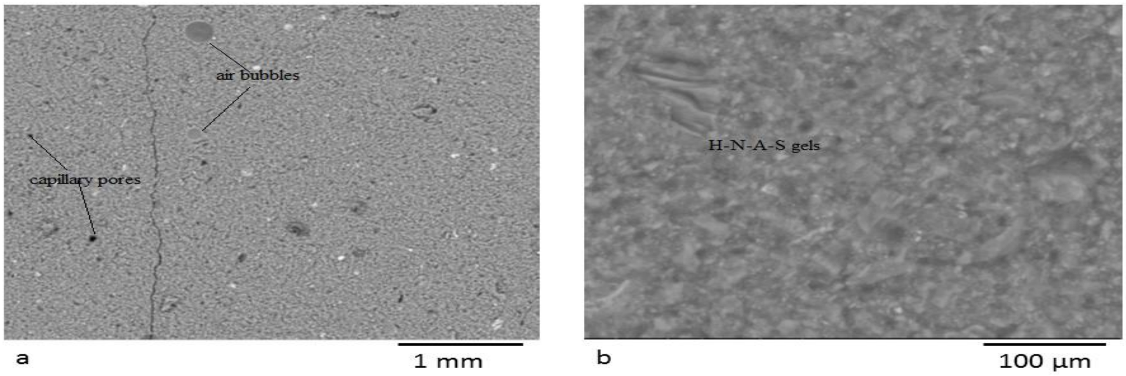

Figure 3: Microstructure of the inorganic polymer binder with 75 vol.% of sodium silicate replaced by NaOH-RHA solution.

References

[1] Erich D. Rodríguez, Susan A. Bernal, John L. Provis, Jordi Paya, José M. Monzo, María Victoria Borrachero, Effect of nanosilica-based activators on the performance of an alkali-activated fly ash binder, Cement & Concrete Composites 35 (2013) 1–11.

[2] van Jaarsveld JGS, van Deventer JSJ. Effect of the alkali metal activator on the properties of fly ash-based geopolymers. Ind Eng Chem Res 1999;38(10):3932–41.

[3] G. Habert, J.B. d'Espinose de Lacaillerie, N. Roussel, An environmental evaluation of geopolymer based concrete production: reviewing current research trends, Journal of Cleaner Production, 19, (11) (2011) 1229-1238.

[4] Ralph K. Iler, The Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties and Biochemistry of Silica, Willey 1979, 896p.

[5] U. Kalapathy , A. Proctor, J. Shultz, An improved method for production of silica from rice hull ash, Bioresource Technology 85 (2002) 285–289.

[6] D. Dimas I. Giannopoulou D. Panias, Polymerization in sodium silicate solutions: a fundamental process in geopolymerization technology, J Mater Sci (2009) 44:3719–3730.

[7] Elie Kamseu, Maria Chiara Bignozzi, U.C. Melo, Cristina Leonelli, Vincenzo M. Sglavo, Design of inorganic polymer cements: Effects of matrix strengthening on microstructure, Construction and Building Materials, 38 (2013) 1135-1145.

THE STRUCTURAL BEHAVIOUR OF POZZOLAN-LIME CEMENT AS A POTENTIAL SUBSTITUTE TO PORTLAND CEMENT IN LOW-STRENGTH CONSTRUCTION APPLICATIONS

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Introduction

A number of studies [1, 2, 3] have indicated that construction materials constitute a high proportion of construction cost. This is bound to be higher for remote areas where most of the materials have to be transported for longer distances. Traditionally, Portland cement has been a major construction material in most forms of building construction, mainly as a binding agent in concrete, mortar, renders, walling blocks, roofing tiles and pavers. However, it is a relatively expensive material mainly due to high production energy requirements, transportation costs, and artificial price fixing. When used for small buildings and low-strength applications, Portland cement makes construction unnecessarily more expensive than it ought to be. Habitat [3] estimates that up to 80% of the world-wide use of cement does not require strength levels of Portland cement. According to Spence [4], the continued demand for OPC, even where unnecessary, can be attributed to its high 'status value' and limited knowledge of viable alternatives.

A pozzolan is a material which when finely ground and mixed with lime in the presence of water, reacts to form a cement-like product [5]. Natural pozzolans activated with lime have been tried as an alternative or supplement to Portland cement. However, their use is not widespread because of being associated with inferior products and low social-status. Day [2] attributes the little confidence in the use of such alternative binders to lack of sufficient information on their qualities that influence their performance.

There are vast deposits of natural pozzolans in Uganda especially in form of volcanic soils and other natural earth deposits of similar origin in rift valley areas [6]. Rudimentary methods have been tried to exploit and use pozzolans in rural areas. However, their extensive use has been hindered by the suspect quality of their products and lack of adequate information about their performance.

Problem statement and research aim

Whereas there is a vast potential for natural pozzolans in several parts of Uganda with good qualities for use in construction, there has been no rigorous examination of such qualities in relation to their potential to substitute OPC in low-strength applications to reduce the cost of housing. As a result, there is lack of confidence in extensive use of the pozzolan materials because of limited knowledge to demonstrate their structural performance. There is also limited demand for their appropriate application in construction due to lack of information on cost saving possibilities and other economic benefits.

This research was carried out to examine the structural behaviour of natural pozzolans mixed with lime as a potential substitute to Portland cement in low-strength construction applications. This, it is believed, would reduce the cost of housing construction to address the problem if inadequate housing in rural Uganda. The exploitation of natural pozzolans is also bound to empower the rural communities with the required skills to process and utilise the material. It can be a stimulant for local micro-industrial developments and employment opportunities, for the betterment of the quality of life and living standards of the local communities.

Materials and methods

The key materials used include volcanic ash, hydrated lime (to BS 890/1972), and stone dust. The volcanic ash was pulverized to nine different grades of particle size, i.e. 45μm, 63μm, 75μm, 90μm, 106μm, 125μm, 150μm, 180μm and 212μm. Each grade was used to prepare five different blends with lime, containing 10%, 30%, 50%, 70% and 90% of the volcanic ash. For each of these blends, nine 50mm mortar cubes were prepared. Each treated portion was mixed thoroughly in a motorised mixer, and the same quantity of water added to each.

The moulds were made of nine compartment gangs and hence, nine replicates of experimental units (50mm mortar cubes) were made out of each blended portion and labelled accordingly. All the cubes were subjected to the same humid environment for curing at room temperature. Three cubes were picked randomly without replacement from each batch of 9 cubes and tested for compressive strength after 7 days. This was also done from the remaining six, after 28 days of curing. The remainder were tested after 90 days of curing. This procedure was aimed at achieving pre-treatment equality of the sample portions by random assignment. The compressive tests were guided by the test procedure prescribed in ASTM311 detailed under Test Method C109/C109M.

Data analysis and discussion

The effect of pozzolan grade was assessed to determine whether the changes in the pozzolan particle size would produce respective significant changes in compressive strength of the pozzolan – lime system for a given level of lime content. The assessment also examined the nature and extent of this effect. Single factor ANOVA was performed to explain variability based on the degrees of freedom (F-statistic), and the plausibility value (P-Value) of the various pozzolan grades and fixed blends. The F statistic for all combinations was much greater than critical F-value. Similarly, the P-value was found to be very small for all combinations. This is a clear reflection of variability in the sample means, and hence a strong indication that the compressive strength changes with the pozzolan grade. The nature of the effect was determined by observing the trend of compressive strength with grade variations for the different experiments. This is given in Figure 1 below.

The results show an inverse relationship between the compressive strength and pozzolan grade. It can therefore be postulated that the finer the pozzolan, the higher the compressive strength for a given content of pozzolan/lime, and curing duration. The observations also indicate that the highest strength values are obtained for both the finest pozzolan grades and longer curing durations. The plots indicate a relatively linear relationship between strength development and pozzolan grade. As such, a linear regression model was used to determine a mathematical function that relates the two variables and gives the best fit possible between them.

The mathematical relationships of the linear equivalents were derived by linear regression methods and used to determine the sensitivity of each experimental set. The functions for the various experiments were used to determine the rates of strength development from which the optimum values were derived. The 50% and 70% experiments exhibited the highest possible compressive strength attainable of any of the experimental units under consideration.

The 50% experiment had the highest negative gradient, while the 70% experiment had the smallest at 7 days. In this case the 70% experiment exhibits the most stable treatment that is least sensitive to changes in pozzolan grade, while the 50% experiment presents the most sensitive, hence least stable. At 28 days, the gradient is smallest for the 50% experiment followed by the 70% experiment. This is also the case for the 90-day experiments. As such, the two sets of experiments exhibit the highest stability and least sensitivity to changes in pozzolan grade.

The interchange in performance between 50% and 70% mixes with respect to maximum attainable compressive strength and stability against changes in grade over time implies that in between the two mixes lies the mix that would yield optimum performance in terms of functionality and cost. This mix was established by examining the variation of compressive strength with respect to the pozzolan content in the mix. The findings are presented in Figure 2 below.

The trend of variations in compressive strength with pozzolan content exhibited peaks and valleys. The peaks imply that the compressive strength increases with the pozzolan content up to a certain point, beyond which it begins to reduce. The existence of valleys for low pozzolan contents could be an indication of the dilution effect of pozzolan to the latent strength properties of lime until such a point when the contribution to strength values by the pozzolan-lime reaction outweighs the dilution effect. The existence of peaks and valleys suggests polynomial relations between compressive strength and pozzolan blend. As such, polynomial functions were assumed for data from the various experiments, which were then adjusted using computer software to attain a fitting relation.

The derived polynomial functions were adjusted as much as possible to maintain the same maximum peak attained with the observed data. The absolute critical values of the independent variables were determined from the first derivative of the derived functions at which the derivative is equivalent to zero. The critical points were checked using the second derivative to confirm whether the turning point is the required absolute maximum critical point. The results indicate that for all pozzolan grades, the maximum attainable compressive strength is attainable for higher pozzolan contents, in this case above 50%. The values did not seem to follow any particular trend, probably suggesting no clear link between the blend that gives maximum strength values and the grade of the pozzolans.

The maximum blending values attainable did not indicate a clear bearing of varying pozzolan blends on the actual strength attained. This comparison was revealed by working out the actual strength attained by substituting the absolute critical values in the derived polynomial expressions for each experiment. The values obtained are presented in Table 1.

The comparison between critical blends and attainable maximum strength reveals that while the strength increases as the grade reduces, the critical blends do not seem to follow the same trend. This could be a suggestion of greater stability for the pozzolan content in the variation of attainable compressive strength. On this basis, it can therefore be assumed that provided the pozzolans are available in adequate but not excessive quantities, the compressive strength will be less sensitive to variations in the actual pozzolan content. The derived critical blend and maximum strength values are comparable with the observed values. Therefore, the derived mathematical functions can be considered to predict the trend of compressive strength variation with pozzolan content close enough to the expected real values. The mid-range grades of 106μm, 125μm and 150μm exhibited more stability and predictability in strength development which was attributed to an ideal balance between the filler effect and the reaction between pozzolans and lime for these grades. Hence, while the finest grades could give high compressive strength values, the mid-range grades presented the most stable materials that can be used with consistent results.

The comparison shows that for the finest grades, the pozzolan content yielding peak strength values for the various pozzolan grades decreases with time. While this shows a greater significance of lime in strength development over time, it also depicts a high level of sensitivity and instability of pozzolan-lime mix designs for the finest pozzolan grades. The wider range of pozzolan contents that give peak strength values after 28 days and 90 days makes it difficult to design an appropriate mix for these grades, which will yield predictable and consistent strength results.

Conclusions and recommendations

The research generated strong evidence of strength development with varying proportions of natural pozzolans and lime. The results also confirmed that in addition to pozzolan content, the pozzolan grade also has influence on the strength development process of the pozzolan – lime system. It can also safely be deduced that the best results of compressive strength values can be obtained in the pozzolan-lime system if the predominant pozzolan particle size is in the range of 125μm, and the pozzolan content between 54% and 60%.

The compressive strength values registered by natural pozzolans with lime in the presence of water were too low for use in structure elements of housing construction.

The highest observed value was 0.9MPa, while the most likely value generated from the developed mathematical models is 0.5MPa. However, there is a wide range of low-strength applications where such compressive strength values may be acceptable. These include mass concrete for small structures, masonry mortar, plasters, renders, light weight bricks, and soil stabilisation. These applications may constitute a substantial portion of materials used in small housing structures. Hence, the use of pozzolans can significantly reduce the construction cost of such houses. Addition of limited quantities of Portland cement may be considered to enhance the structural performance of the material.

Figures and tables

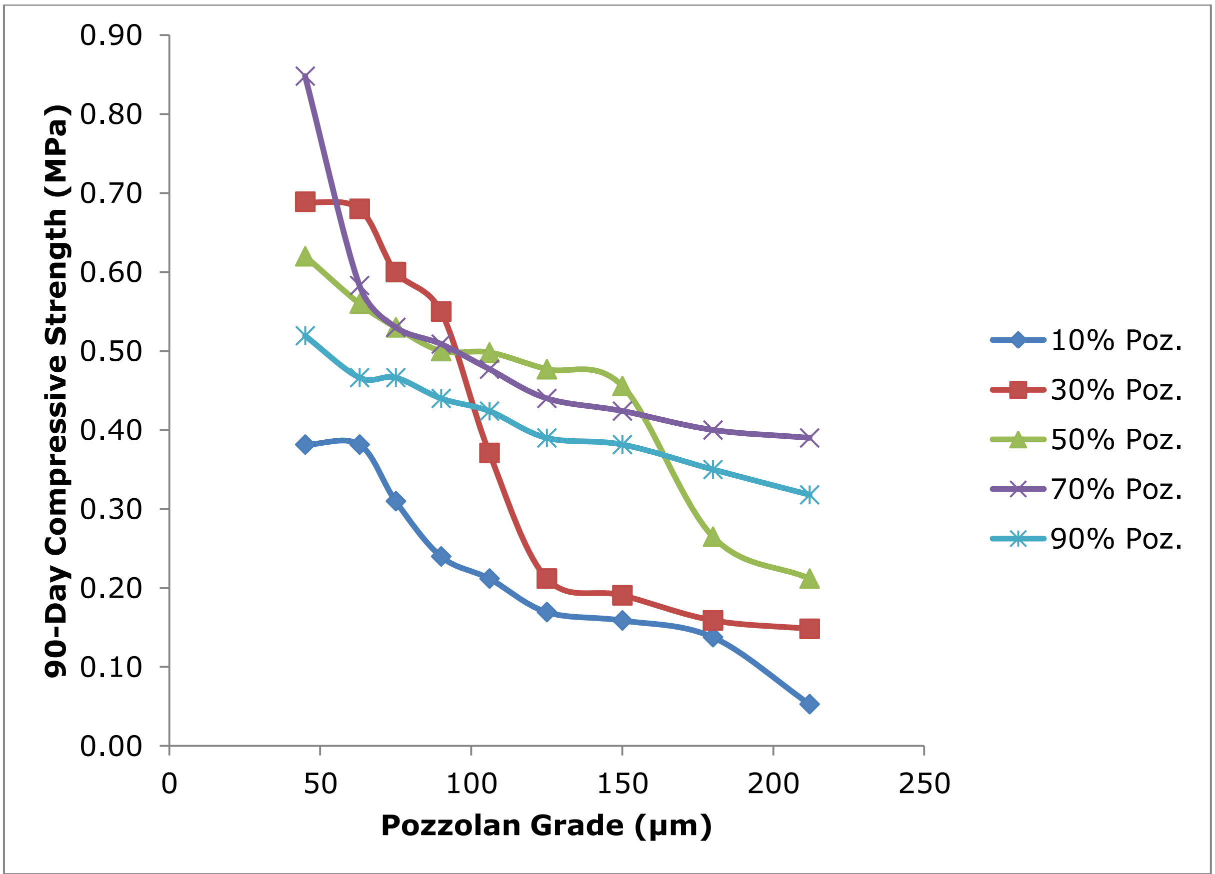

Figure 1: Variation of compressive strength with pozzolan particle size

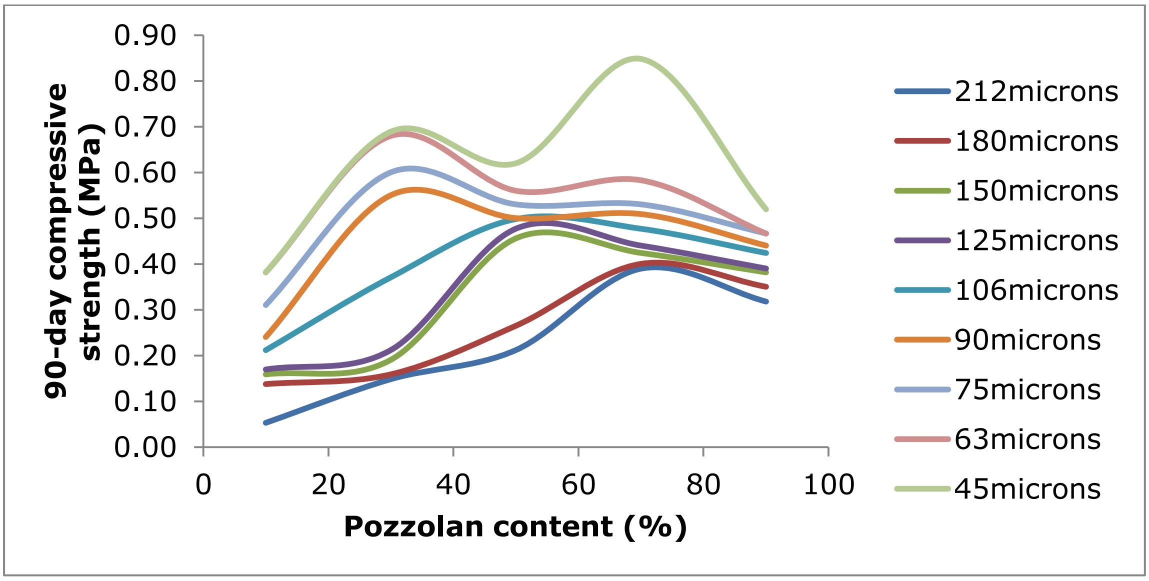

Figure 1: Variation of compressive strength with pozzolan:lime content

Table 1: Critical pozzolan/lime blends and attainable maximum strength

	7-Day		**28-Day**		***90-Day***	
Experiment	*Critical Blend Values (%)*	*Max. Strength (MPa)*	*Critical Blend Values (%)*	*Max. Strength (MPa)*	*Critical Blend Values (%)*	*Peak Strength (MPa)*
45µm	54.602	0.4315	62.793	0.723	61.452	0.779
63µm	62.838	0.3687	59.993	0.534	39.385	0.653
75µm	53.621	0.3102	52.606	0.478	29.462	0.600
90µm	78.146	0.2435	56.014	0.451	30.934	0.550
106µm	70.415	0.2332	55.046	0.454	56.420	0.506
125µm	59.579	0.2077	57.597	0.409	57.176	0.501
150µm	75.523	0.0841	71.827	0.372	57.468	0.482
180µm	74.522	0.1726	68.753	0.338	76.816	0.402
212µm	62.658	0.1349	64.404	0.286	76.670	0.370

References

[1] Berhane Z. (1987), Local building materials and low cost housing. Proceedings of the IAHS World Congress on Housing Innovations in Science and Technology for the Future, pp58-62, Berlin.

[2] Day R. L. (1990), Pozzolans for use in low-cost housing. A report for the International Development Research Centre, Ottawa.

[3] Habitat (1985), The use of selected indigenous building materials with potential for wide application in developing countries. United Nations Centre for Human Settlements, Nairobi.

[4] Spence R. C. S. (1980), Small scale production of cementitious materials. Intermediate Technology Publications, London, United Kingdom.

[5] Kerali A.G., Mwakali, J.A., and Okure, M.E. (2007), Development and application of construction materials in Uganda. Fountain Publishers, Kampala.

[6] Department of Geological Surveys and Mines (1992), Pozzolan housing project. A report for the International Development Research Centre, Ottawa.

Properties of FaL-G Bricks

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Brief author biography

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Introduction

Although there is many variety of construction materials, ranging from modern to traditional construction materials, including steel, concrete, aluminium, plastic, timber, composite, stone, , thatches, masonry and earth; engineering has greater influence with the provision of the everyday infrastructure in which society works. This includes transportation networks, water and sewerage systems, communication and power transmission systems, harbours and all types of buildings, in which people live, learn, worship, work, play, and store their belongings. The choice of materials to be used in constructing these facilities is a big challenge, these materials behave differently, after it has been subjected into different environmental condition and loading.

It is therefore important that structures are to be constructed by materials that fulfil all requirements in terms of strength, safety, durability and heat/fire resistance. However, since materials used in the construction of different structures except timber are from non-renewable resources must not only be used wisely but also there is a need to find alternative materials that will help to conserve or reduce exploitation of traditional materials. The choice of such materials depend much on the available technology, type of the structure to be constructed, strength, safety, durability and heat/fire resistance requirement, construction methods, environmental and social impact.

Different alternatives have been suggested to solve above problems, the innovation of utilizing industrial by-product has sound a lot as the feasible solution as it has many advantages such as reduces exploitation of tradition resource while it also conserve environment. Utilization of Fly ash and gypsum is considered in this research. In presence of water, fly ash reacts with lime at ordinary temperature forming a compound possessing cementitious property. The reaction between lime and fly ash produce calcium silicate hydrate (C-S-H) and calcium aluminates hydrates (C-A-H) which are responsible for strength development in the FaL-G bricks [1]. Strength development in lime pozzolanic reaction takes in a slow rate in normal temperature condition. Hence a long curing duration is required to achieve a meaningful strength. Thus there is a need to accelerate the reaction in this compact, which is achieved either by steam curing or by addition of gypsum [2].

Fly ash is an industrial by product obtained after burning coals, it exhibit pozzolanic properties in nature. Fly ash can be classified into two classes, class F and class C depends on the type of coals burnt. Fly ash class C is obtained from lignite and sub-bituminous coals and itself possess cementitious property while class F is produced from burning anthracite and bituminous coals, these classes can be distinguished by looking the amount of calcium and the silica, alumina and iron content [3]. Gypsum is also by product but it does not exist in its natural form $CaSO_4.2H_2O$, it contains some impurities which prevent direct use as building materials, it includes alkalis and organic matters but it is rich in sulphate.

The Fal-G is the mixture of Fly ash, Lime and Gypsum, it is environmental friendly materials and the substitute potential to cement and in making bricks, as it use locally available materials, thus it is not only economical solution but also it conserve environment by minimizing the use of fuel in production of burnt clay bricks and then it will minimizing the amount of CO_2 produced from the cement industries, the amount of carbon dioxide produced is approximately equal to the amount of cement produced, the FaL-G is an alternative material to cement as it is sustainable and cost effective technology [3,4].

It has same properties as those of hydraulic cement, it hardens in presence of water, it is water resistant and it gains strength with time.

Materials

Fly ash was procured from Mufindi Paper Mills (MPM), it consists some materials (wood chips) that was mixed with the coals during burning process; it therefore sieved using o.150µm to remove wood particles. Gypsum can either be procured from the same place or bought from other source while Hydraulic lime was used, it is commercially available in the market. Table 1 shows the chemical compositions of Fly ash, Lime and Gypsum.

Mix proportion

The mixture were composed of varying percentage of Fly ash and lime while holding the gypsum constant as 10%, it is summarised in Table 2. The required quantity of gypsum and lime mixed in dry condition, fly ash was added to the mixture to obtain uniform mix and this mixture was termed as FaL-G binder.

The FaL-G mortar was prepared using sand as fine aggregates and FaL-G as binder, the procedure adopted was the same as that of convectional cement. Tap water was used to mix the ingredients. The ingredients mixed thoroughly in the pan mixer till the uniformity in colour homogeneous mix was obtained.

Testing, results and discussion

The specimens with 300x150x70 mm were prepared from each mix for strength and water absorption tests. The specimens for compressive strength test were tested at different days of curing, this test was done using compressive machine of 3000kN capacity at rate of 25kN/mm2/s, and the results are as shown in the figure 1.

The water absorption test was determined also, it was conducted at 25±2°C, the specimen used was one cured for 28 days. 110°C oven and 0.01g balance were used.

On studying the properties of FaL-G bricks parameters were varied as follows:

- Age 7, 14 and 28 days.
- Binder to aggregate ratio 1:1.
- Fly ash content 40, 45, 50, 55 and 60%.
- Lime content 50, 45, 40, 35, and 30%.

The strength development of FaL-G bricks increases with age of curing, it is due to continues reaction between binder and water. The compressive strength was around 3 MPa.

Conclusions

It is found that the FaL-G brick has a maximum strength after 28 days, which is 3.1 N/mm2, at this point the fly ash content is 45% and that of lime is 45%, gypsum has no important role to play, which means this is an optimal binder proportion.

The water absorption of FaL-G bricks increases with the increases in fly ash content, it is in the range of 15.365% to 18.131% which is smaller than 20%.

It is lighter in weight and therefore FaL-G bricks reduce dead weight and materials handling cost in multi-stored construction. In the view of the above it can be concluded that masonry bricks can be prepared using FaL-G binder economically. By using marginal materials, sustainability can be achieved in the process.

Figures and tables

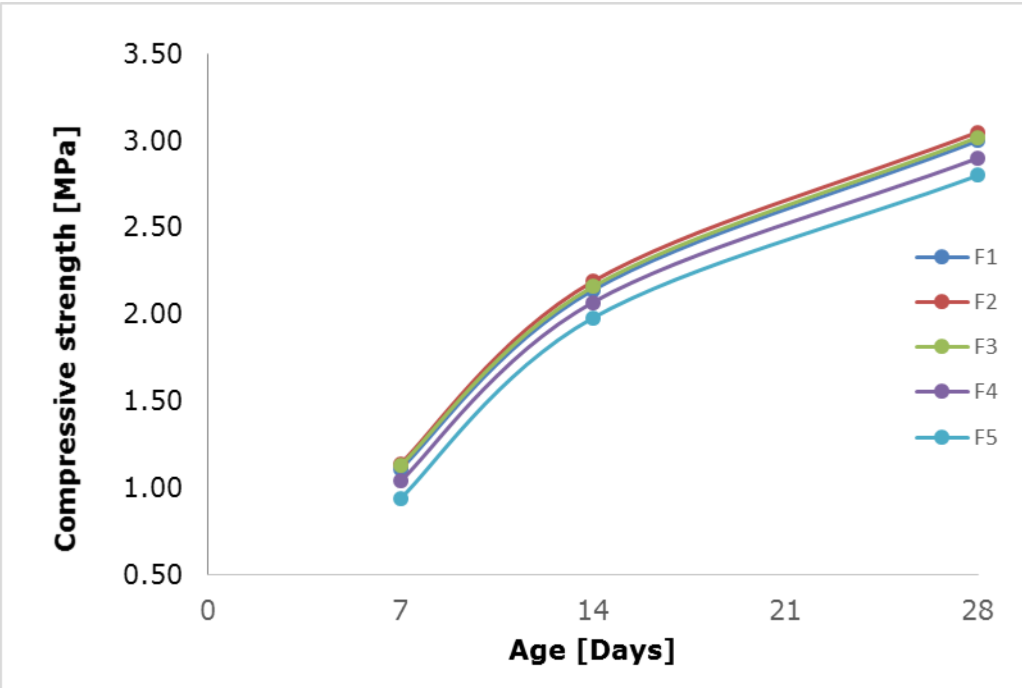

Figure 1: Variation of compressive strength with age of curing

Table 1: Chemical composition of lime and fly ash

Compound %	fly ash	lime
SiO2	0.3683	1.2
Al2O3	0.257	
CaO	0.1867	
Fe2O3	0.0678	0.4
SO3	0.0293	
TiO2	0.0135	
K2O	0.0099	
MgO	0.0035	1.4
P2O5	0.003	
ZrO2	0.0019	
MnO	0.0015	
Cr2O3	0.0014	
Cl	0.0014	
Na2O	0.0013	
CaCO3		5.9
Ca(OH)2	-	89.4
LoI	0.0535	1.7

Table 2: Mix proportion of Fly ash, Lime and Gypsum

Fly ash	**Lime**	**Gypsum**	**Binder to aggregate ratio**
40%	50%	10	1:1
45%	45%	10	1:1
50%	40%	10	1:1
55%	35%	10	1:1
60%	30%	10	1:1

References

[1] A. Basumajumdar, A.K. Das, N. Bandyopadhyay and S. Matra, Some Studies on the Reaction Between Fly ash and Lime,28 (2005) 131-136.

[2] R.K. Jayasudha, Radhakrishna and P.S. Niranjan, Properties of FaL-G Hollow Blocks, International Journal of Research in Engineering and Technology (2013) 384-389.

[3] ASTM C 67-12, Standard Test Methods For Sampling and Testing Bricks and Structural Clay Tile.

[4] Radhakrishna, P.S. Niranjan, P.P. Raj and V.S. Kumar, International Conference on Advances in ARchitecture and Civil Engineering, 1 (2012) 56-61.

Earthen building materials: hydraulic lime based grout for retrofitting and CEBs stabilised with geopolymer binders

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Introduction

From the last decades the earth construction has a growing interest due to the high sustainability (low CO_2 emissions), thermal and acoustic performance, fire resistance and cost of the raw material (soil) [1]. In fact, earth construction can constitute a feasible solution for a more sustainable construction industry in developed countries.

Nowadays the research areas on earthen construction focus from one side on the improvement of the materials for new buildings, on the other side on the conservation of existing architectural heritage.

Historical earthen buildings are often damaged by static or dynamic loads in form of extensive cracking. All too often these cracks are insufficiently or inappropriately repaired, if at all, because of lack of knowledge and/or technology. In particular, the behaviour of crack repair by grouting poses a challenge in earthen materials and demands specific requirements for the grouting mortar, such as low water content, good water retention, low shrinkage, etc. Cracks in earthen construction can be repaired by grouting to re-establish structural continuity, and can also be used to consolidate voids and gaps, or as a complement to other strengthening techniques such as the introduction of tie-rods.

In the framework of earthen materials for new constructions, the major drawback is that traditional earthen materials are typically considered as non-standard. The great variability and heterogeneity of the properties of the available soils, the lack of quality control in the manufacturing of the earthen materials and in the construction process can be pointed out as the main reasons behind this situation. Furthermore, only few countries issued standards and recommendations supporting earth construction, discouraging the design of earth construction by the technical community in countries where these documents are absent.

Hydraulic lime based grout for the repair of cracks

Grout requirements are workability, low shrinkage, a good bond to the original material, chemical and mechanical compatibility with, and durability. The effectiveness of grouting for earthen materials is limited by shrinkage/swelling behaviour of the grout [2]. The quantity of water present in the grout may compromise the integrity and bond between the repair grout itself and the original material: during injection by causing the earthen crack surfaces to swell and/or shrink, resulting in cracking at the interface. Therefore, the determination of suitable water/binder ratio for lime and hydraulic grouts and the water/soil ratio for earthen grouts are critical factors as far as shrinkage behaviour, bond to the crack surface and mechanical performance are concerned.

Foreseen difficulties in grouting are the achievement of adhesion, long term effectiveness, and more generally the restoration of structural integrity and continuity of a damaged structure in the long term. Thus, the correct grout selection should take into account characteristics such as chemical and mineral composition, porosity, water retention, shrinkage, durability, adhesion, mechanical strengths, etc. In addition, grouts should be fluid with sufficiently low viscosity to be injectable and should have stable consistency for a given time in order to allow the voids to be filled. As a consequence the rheological behaviour should be well understood and controlled so that the fluid grout may be pumped and flow correctly inside the porous environment. The main disadvantage of earthen grouts is their high shrinkage [3].

Due to the nature of earthen materials the hydraulic lime grout has to meet considerable demands on a variety of properties, which are related to injectability, compatibility and durability. The grout developed can be used to re-establish structural continuity in cracked earthen masonry or other massive earth walls (rammed earth and cob) with the focus grouting cracks. The grout material was based on hydrated lime (calcium hydroxide) with addition of pozzolana and lime stone filler. Environmental conditions are important as well. Temperature is significantly influencing the hardening process of grouts based on hydraulic lime. If the temperature is too low, the hardening, i.e. hydration and carbonation processes, might be delayed significantly or even stopped completely. The temperature might also influence the performance of super plasticisers and thus affect negatively flow capacity and water retention of the fresh grout.

CEBs stabilised with alkaline activation

Masonry built with compressed earth blocks (CEBs) is probably the most relevant case of improvement introduced in the earth construction technology, as these blocks can be seen as an upgrade of the adobes. They were mostly stabilised by cement or lime. For CEB a soil moist earth is used which is mechanically compacted in a mould with a higher pressure producing a material with a higher strength and better durability.

This procedure is particularly interesting in the cases where the available soil does not meet adequate properties. Nevertheless, the chemical stabilisation is systematically used, even in soils with adequate properties. On the other hand, the addition of cement and lime increases substantially the cost and the embodied energy of the CEBs, making this solution less competitive [4]. The use of geopolymeric binders obtained from alkaline activation has shown lower CO2 emissions than cement based binders, without compromising properties such as strength and durability [5]. A similar result is expected when applying this technique in the stabilisation of soils. Roughly speaking, the stabilisation process consists in the mixing of the soil with a geopolymer binder, which hardens and forms a matrix that involves and binds the particles in a soil-binder interface that usually delivers strength levels higher than the soil alone. In general terms, the alkaline activation process consists in a reaction between alumina-silicate materials and alkali or alkali earth substances (constituting the alkaline activator). Fly ash is probably the most popular alumina-silicate raw source used in alkaline activation, but others can be mentioned such as high-furnace slag and metakaolin [6]. The first two are industrial by-products, meaning that they produce zero CO2 emissions and their use is a way to valorise them in the building industry. Therefore, most of the environmental impact of the alkaline activation technique resides in the production of the alkaline activator compounds, namely sodium hydroxide and sodium silicate.

Previous studies [7] have been able to demonstrate that the stabilisation of soils with this technique can deliver similar or higher mechanical performance than that obtained from the addition of lime or cement. Therefore, the integration of the alkaline activation of fly ash in the production of CEBs contributes for the mitigation of the environmental impact associated with more traditional chemical stabilisation (usually achieved with cement), while maintaining the mechanical performance standards. In practical terms, this means that the use of this industrial by-product associated to a control of the incorporated alkaline activator compounds is expected to result in CEBs with lower embodied energy.

Conclusions

The results of the grout development show good properties with the addition of different admixtures. In particular, shrinkage and strength development are well adjusted for earthen materials and it seems that they guarantee mechanical compatibility requirements for use on historical earthen substrates. However, adhesion to earthen substrates needs to be increased. This has to be done by optimising water retention of the grout.

It is important to underline that grouting cannot be considered, when isolated, as an effective strengthening intervention. It is strongly suggested its use in combination with other interventions such as confinement, mesh reinforcement or external reinforcement [8]. As an isolated intervention, grouting can just partially contribute to re-establish the initial bearing capacity of the wall.

The alkaline activation of fly ash was shown to promote excellent results regarding the improvement of the mechanical performance of CEBs. This means that a large margin for optimization of the mixtures exists, namely with respect to the environmental impact and cost of the solution.

References

[1] H. Houben, H. Guillaud, Earth Construction: A Comprehensive Guide. Intermediate Technology Development Group, 2008.

[2] R.A. Silva, L. Schueremans, D.V. Oliveira, K. Dekoning, T. Gyssels, On the development of unmodified mud grouts for repairing earth constructions: rheology, strength and adhesion, Materials and Structures 45 (2012) 1497-1512.

[3] N. Roselund, Repair of cracked walls by injection of modified mud. VI International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las

Cruces, New Mexico, U.S.A., 14-19 October 1990, The Getty Conservation Institute, Los Angeles, pp. 336-41.

[4] B.V.V. Reddy, P.P. Kumar, Embodied energy in cement stabilised rammed earth walls. Energy and Buildings, 42 (2010) 380-385.

[5] R.A. Silva, E. Soares, D.V. Oliveira, T. Miranda, N.M. Cristelo, D. Leitão, Mechanical characterization of dry-stack masonry made of CEBs stabilised with alkaline activation, Construction and Building Materials, 75 (2015) 349-358.

[6] D.M. Roy, Alkali-activated cements opportunities and challenges, Cement and Concrete Research, 9 (1999) 249-254.

[7] N. Cristelo, S. Glendinning, T.F. Miranda, D.V. Oliveira, R.A. Silva, Soil stabilisation using alkaline activation of fly ash for self compacting rammed earth construction, Construction and Building Materials, 36 (2012) 727-735.

[8] S. Bhattacharya, S. Nayak, S.C. Dutta, A critical review of retrofitting methods for unreinforced masonry structures. International Journal of Disaster Risk Reduction, 7 (2014) 51-67.

MAKING DURABLE CONCRETE THROUGH INHIBITION OF CHLORIDE ION PENETRATION BY POZZOLANIC ACTION

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Introduction

Concrete is the most widely used construction material on earth and hence its performance and effects on the environment are of great importance[1,2] .Permeability in concrete negatively affects strength as well as durability in dense concrete; these negative effects can be mitigated through the use of pozzolanic materials [3]. One of the main forms of attack from the environment is the ingress of chloride ions, which leads to corrosion of steel reinforcement and subsequent reduction in the resistance, utility, and aesthetics of the structures which are often expected to last for long period of time [4].

Corrosion is the loss of material that occurs as a result of the interaction between chemical and biological agents when metals are exposed to the environment [5]. Corrosion of reinforced steel has two principal problems that affect the service life of concrete reinforced structures: metal lost in the reinforced steel rods reduces the mechanical properties of the structure and corrosion products occupy a higher volume than the base metal and this produces internal stresses, which may cause the concrete to crack. One method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of reinforcing steel bar by using relatively impenetrable concrete which can be achieved through the use of cement pozzolans. Use of pozzolanic materials reduces the permeability of concrete due to conversion of calcium hydroxide $\{Ca(OH)_2\}$ into stable cementitious compounds called calcium silicate hydrate ($C_3S_2H_8$) which in turn increases the concrete corrosion resistance [6,7].

Materials and methods

The materials used in this research work were groundnut shell ash (GSA), locust beans pod ash (LBPA), bamboo leaf ash (BLA), sugarcane bagasse ash (SBA), sand (fine aggregate), granite (coarse aggregate), cement (Ordinary Portland Cement) and clean water as the curing medium. GSA was gotten from groundnut shell by drying and burning the shell at a temperature of 500^{o}C, LBPA was obtained from locust beans pod of the fruit of the African locust bean tree (*Parkia Biglobosa*) by burning at a temperature of 600^{o}C. SBA was obtained by burning sugar cane bagasse at 650^{o}C while BLA was produced by drying and burning Bamboo leaf to a temperature of 650^{o}C.

Chloride ion penetration test

Permeability of Chloride ion was determined for various mixes of concrete when partially replaced with GSA, LBPA, BLA, SBA using Rapid Migration Test (RMT). A migration cell was set up with a concrete disc specimen 50mm thick and 100mm in diameter with an applied voltage of 10V. The volume of the NaCl solution was 750 ml and that of NaOH was 300 ml. After 8 hours the specimen was removed and split and the depth of chloride penetration was determined in one half of the specimen using colorimetric technique in which 0.1N silver nitrate was used as colorimetric indicator [8,9].

Results, analysis and discussion

The chloride ion penetration depth result obtained after 30 days of curing concrete specimen with (Ordinary Portland Cement) OPC, GSA (4%), GSA (12%), BLA (12%), LPBA (12%) and SBA (12%) is shown in Fig. 1. The curve shows that GSA (4%) is most durable with a final depth of 18mm followed by SBA (12%) with final depth of 20mm and then GSA (12%) with a final depth of 21mm; therefore the addition of these 3 pozzolans will improve the permeability resistance of their corresponding concrete beyond that of OPC. The curve further shows that BLA (12%) has the same permeability resistance as that of OPC with the final depth of 24mm whereas permeability of LPBA (12%) is lower than that of OPC with a final depth of 26mm.

The result of the chloride ion penetration depth obtained for 56 days of curing the concrete specimen with OPC, GSA (4%), GSA (12%), BLA (12%), LPBA (12%) and SBA (12%) is also shown in Fig. 2. At 56 curing days SBA (12%) and GSA (12%) emerge the most durable with the final penetration depth of 15 mm, follow by BLA (12%) with a final penetration depth of 16 mm and then LBPA (12%) with final penetration depth of 17 mm and GSA (4%) has a final depth of 18 mm, OPC (control) has a final depth of 20 mm .The result shows that all the pozzolans have better penetration resistance to chloride ion than the OPC and are therefore more durable than the control. Their use to partially replace cement in concrete production will improve the durability properties of such concrete. It is observed that results for both 30 days curing (Fig. 1) and 56 days curing (Fig. 2) show that for all the specimen there is increase in the penetration resistance as the curing days increases, therefore durability of concrete increases with increase in curing days.

The ANOVA test as well as the least significant difference (LSD) test was also done for the 56 days curing and the result is shown in Table 1. The Table shows that when OPC was compared with GSA (4%), with GSA (12%) and with LPBA (12%) there were significant differences ($p<0.05$) between the permeability of OPC and these 3 pozzolans. Consequently, the durability property of GSA (4%), GSA (12%) and LPBA (12%) is significantly higher than that of OPC and therefore will perform better in terms of durability than OPC and therefore could replace OPC in concrete production giving a better durable concrete. On the other hand, there is no significant difference OPC and BLA (12%) or OPC and SBA (12%); consequently BLA (12%) and SBA (12%) could be substituted for OPC without significantly altering the permeability property of the concrete.

Conclusions and recommendations

Partial replacement of GSA, LPBA and BLA with OPC at 12% will give a better durable concrete in terms of chloride ion penetration resistance provided the curing age is up 56 days. While partial replacement of SBA with OPC at 12% will give an equal durable concrete in terms of chloride ion penetration resistance provided the curing age is up 56 days.

Figures and tables

Table 1: LSD test for chloride ion penetration depth for 56 days curing. 1-OPC (control), 2-GSA (4%), 3-GSA (12%), 4-BLA (12%), 5-LPBA (12%), 6-SBA (12%)

i	j	MD(i-j)	p	Remark
1.00	2.00	2.100	.043	*
	3.00	3.100	.004	**
	4.00	1.100	.283	NS
	5.00	2.200	.035	*
	6.00	1.400	.174	NS
2.00	3.00	1.000	.329	NS
	4.00	-1.000	.329	NS
	5.00	.100	.922	NS
	6.00	-.700	.493	NS
3.00	4.00	-2.000	.054	NS
	5.00	-.900	.379	NS
	6.00	-1.700	.100	NS
4.00	5.00	1.100	.283	NS
	6.00	.300	.769	NS
5.00	6.00	-.800	.434	NS

**Mean Difference is significant at $p< 0.01$,*Mean Difference is significant at $p<0.05$, NS= Not Significant

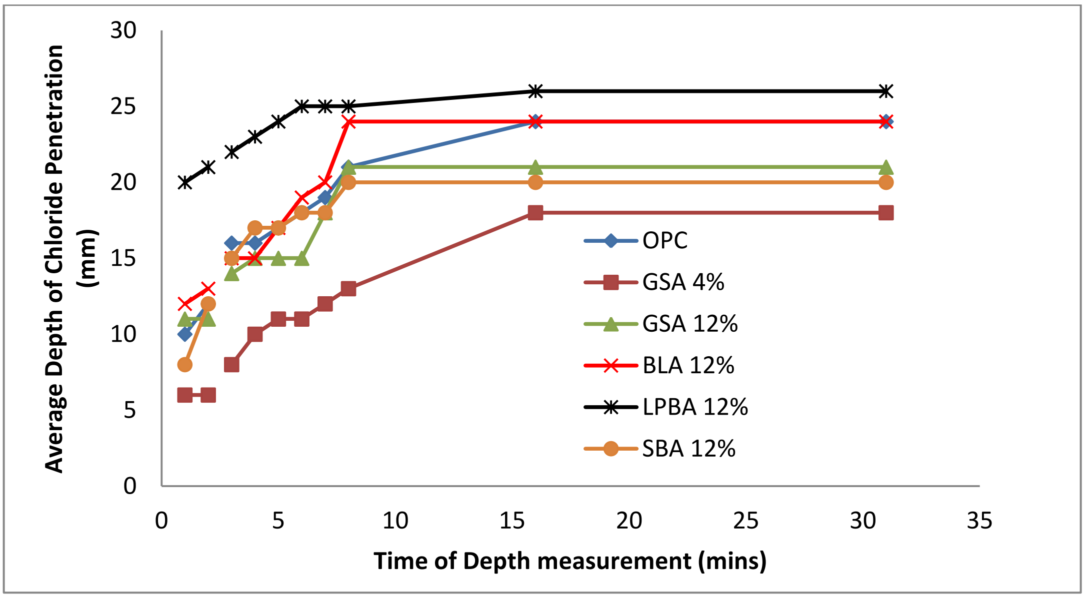

Figure 1: Average Depth of Chloride Penetration against Time of depth measurement for 30 days concrete specimen

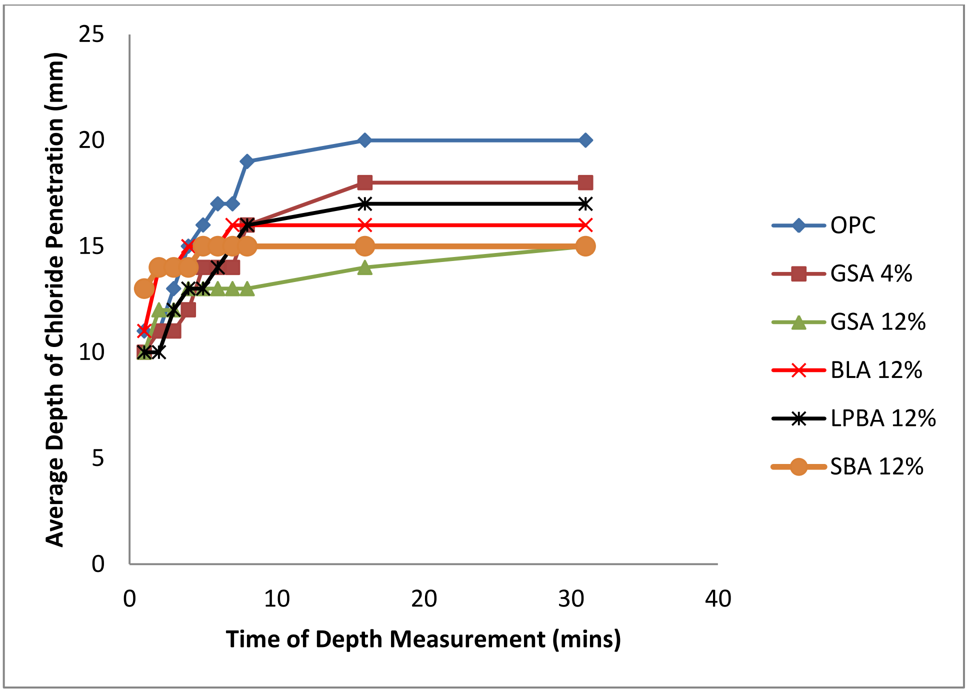

Figure 2: Average Depth of Chloride Penetration against Time of depth measurement for 56 days concrete specimen

References

[1] Glavind, M. and Munch-Petersen, C., (September, 2002) "Green Concrete-A life cycle Approach", Proceedings of Challenges of Concrete Construction, University of Dundee

[2] Mehta, P.K., (2001),"Reducing the Environmental Impact of Concrete," as cited by A.K.H Kwan, P.L Ng and W. W. S Fung,(2011), *Research Directions for High Performance Concrete*, Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong.

[3] Zaki, A. (2006). Concrete Corrosion: Introduction to corrosion. *In Principles of Corrosion Engineering and Corrosion Control,* 616–617, Butterworth-Heinemann.

[4] Chandramouli,K., Srinivasa Rao,P., Pannirselvam,N., Seshadri Sekhar,T.S & Sravana,P. (2010). Chloride Penetration Resistance Studies on Concretes Modified with Alkali Resistant Glass Fibres. *American Journal of Applied Sciences*, 7, (3), 371–375 as cited by Núñez-Jaquez *et al.,* 2012

[5] Neville, A.M., (2003). Properties of Concrete. *Pearson Education (Singapore) Pte Ltd*.,483-497.

[6] Shetty, M.S. (1992). Concrete Technology. *S. Chand and Company, New Delhi,Indian,* 343-346

[7] Mindess, S., Young, J.F & Darwin D. (2003). *Concrete, Second edition*, Prentice Hall, New Jersey, USA.

[8] Otsuki, N., Nagataki, S., & Nakashita, K., (1992). Evaluation of AgNO3 Solution Spray Method for Measurement of Chloride Penetration into Hardened Cementitious Matrix Materials", *ACI Materials Journal*, 89 (6), 587-592.

[9] Tang L. & Nilsson L.O.,(1992). Chloride Diffusivity in High Strength Concrete. *Nordic Concrete Research,*11, 162-170.

DEVELOPMENT OF PREDICTION MODELS FOR THE CARBONATION OF REINFORCED CONCRETE

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Introduction

The service life of reinforced concrete structures affected by steel reinforcement corrosion is marked by two stages i.e. initiation and propagation stages. The initiation period is commonly associated with either - chloride penetration and accumulation of chloride ions in the vicinity of the reinforcement or the ingress of carbon dioxide and associated reduction of pH in the concrete up to the level of the reinforcement. The duration of the initiation period depends on the quality of the concrete, particularly the cover concrete and the environmental exposure condition of the concrete.

In the case of carbonation, the rate of advance of the reaction front between carbon dioxide and calcium hydroxide in concrete depends directly on the permeability of the concrete and the quantity of the hydroxides, which are, in turn, controlled by the characteristics of the concrete making material and its processing, for example curing and compaction. In addition, carbonation rates depend on the concrete exposure condition environments [1, 2, 3, and 4]. While the permeability of concrete depends on many factors among which are the water/binder ratio and processing of the concrete which influences its hydration. The amount of calcium hydroxides available in the concrete depends on the type and content of the binder used.

The service life of a reinforced concrete structure can be defined with respect to the relevant limit state- which for this study is the initiation limit state and marked by corrosion initiation period. The initiation limit state is defined as the time it takes the aggressive agents (carbon dioxide) to get to the level of the steel reinforcement in sufficient quantity or form to initiate active corrosion. During this time, the structure is also expected to be able to meet its specified durability requirements with an acceptable level of safety [5].

In South Africa, an approach to improving the durability performance of reinforced concrete construction has been developed (See Figure 1). The philosophy involves the understanding that durability will be improved only when measurements of appropriate cover concrete properties can be made. Such measurements must reflect the in-situ properties of concrete, influenced by the dual aspect of material potential and construction quality [6]

This approach involves a series of tests that measure the fluid transport properties of concrete at a relatively early age, usually 28 days. Additionally, the approach quantifies the concrete deterioration mechanism, and by relating the mechanism of deterioration to its early-age characteristics parameters, control of concrete quality or predictions of its performance can be achieved [7, 8].

Materials, methods and analytical approach aimed at predictions of carbonation

This study assessed the carbonation of concretes exposed to a range of micro-climate variations in Johannesburg, particularly with variations in carbon dioxide content, temperature and relative humidity conditions. Concretes samples were prepared using five binder types representing variations of blends with GGBS, FA and CSF and four w/b ratios ranging from 0,4 to 0,75 and subjected to different degrees of initial water curing (3, 7 and 28 days). These samples were then placed in three exposure conditions: indoors in laboratory air, outdoors sheltered from rain and sun and outdoors fully exposed to the elements. The depths of carbonation of these samples were monitored over a period of 24 months in order to determine the rates of carbonation. The calculated rates were then correlated to the compressive strength, 28-day durability index (permeability and Sorptivity) values, binder type, curing duration and exposure condition.

The correlation analysis was performed using regression analysis; this is a method for investigating functional relationships that may exist among variables [9, 10]. The relationship is expressed in the form of an equation or a model connecting the response variable(s) and one or more predictor variables. This approach has been used in a variety of applications [4, 11, 12, 13, 14, 15, and 16].

The individual models for the prediction of the natural carbonation rate of concrete in the inland environment are presented in Models 1 to 5, (See Table 1). These models are obtained by multiple linear regression analysis on the obtained experimental data, performed in the Statistical Package of Social Science (SPSS) 20 software. The method of analysis was based on the Ordinary Least Squares (*OLS*) procedure to estimate the regression parameters (coefficients).

The presented models in Table 1 are for the prediction of carbonation rate in reinforced concrete structures located in the inland environment. These models can be used at the planning, design and construction stages as well as for the service life prediction of proposed concrete structures. In addition, the models can be used for maintenance and repair schedules and residual service life prediction of existing concrete structures.

Conclusion

Through the carbonation study and model development, it can be stated that:

- The micro-climate condition, especially the relative humidity, dictates the rate of carbonation of concrete in the inland environment. Thus, concrete samples in the outdoor sheltered sites presented the highest rate of carbonation. Although samples in this exposure site carbonate faster, the risk of reinforcement corrosion is likely to be low because the samples are protected from direct moisture effect;

- The developed prediction models are sensitive to the initial curing period of the concrete as well as the micro-climate of the exposure condition surrounding the concrete. Contrary to the other reported results [4, 13, 16], it was found that binder type, on its own is not statistically significant as a variable for the prediction of carbonation in concrete. This is based on the fact that the early-age characterisation parameters vary with binder types.

Figures and tables

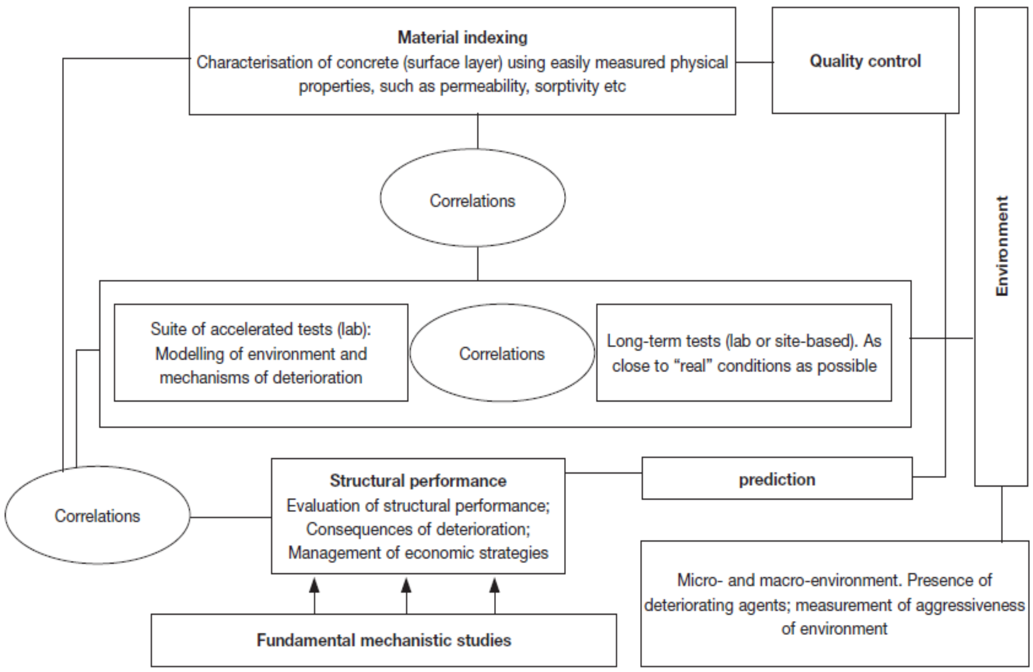

Figure 1: Framework for carrying out durability studies [7, 8].

Table 1: Recommended models for use.

Model	Prediction Equation
Model 1: Mixture Design	$K_{nat}.=5.63+10.01((w/b))-0.02(C)+\alpha_1+\beta$
Model 2: Compressive Strength	$K_{nat}.=14.26-0.18(fc)+\alpha_2+\beta$
Model 3: Oxygen Permeability Index	$K_{nat}.=41.24-0.07(f_c)-2.53(OPI)-0.57(CH)+\beta$
Model 4: Water Sorptivity	$K_{nat}.=13.75-0.06(f_c)+0.34(WS)-0.63(CH)+\beta$
Model 5: Accelerated Carbonation Rate	$K_{nat}.=1.44+1.15(K_{acc}.)+\alpha_3+\beta$

Table 2: Model coefficients for curing duration.

Curing duration	α_1	α_2	α_3
28 days	0	0	0
7 days	+1.61	-1.56	+0.74
3 days	+2.90	-1.79	+1.31

Table 3: Model coefficients for exposure condition.

Exposure condition	β
Indoor	0
Outdoor sheltered	+1.07
Outdoor exposed	-2.07

Where,

K_{nat} = natural carbonation rate, in mm/√years;
w/b = water/binder ratio;
C = cement content, in kg/m^3;
f_c = 28 day compressive strength of concrete, in MPa;
OPI = 28 day oxygen permeability of concrete;
WS = 28 day water sorptivity of the concrete;
CH = 28 day calcium hydroxide content of the concrete;
K_{acc} = 28 day accelerated carbonation rate of the concrete.
α = curing duration given to concrete and obtained from Table 2.
β = exposure condition of the concrete and obtained from Table 3.

References

[1] Kobayashi, K., & Uno, Y. (1990). *Influence of alkali on carbonation of concrete, part 2-Influence of alkali in cement on rate of carbonation of concrete*. Cement and Concrete Research, 20(4), 619-622.
[2] Neville, A. (1981). *Properties of Concrete (3rd edn.)* Pitman. London, UK.
[3] Roberts, M. H. (1981). *Carbonation of concrete made with dense national aggregates*. Watford, Building Research Establishment., Information Paper IP 6/81.
[4] Wierig, H. (1984). *Long-time studies on the carbonation of concrete under normal outdoor exposure.* Proceedings of the RILEM, Hannover University, 239-249.
[5] Richardson, M. G. (2004). *Fundamentals of durable reinforced concrete*: Taylor & Francis.
[6] Ballim, Y., Alexander, M., & Beushausen, H. (2009). *In: Owens G (ed) Fulton's concrete technology*. 9th edn Cement and Concrete Institute, Midrand.pp. 155-188.
[7] Alexander, M. G., & Ballim, Y. (1993). *Experiences with durability testing of concrete: A suggested framework incorporating parameters and results from accelerated durability tests*. 3rd Canadian Symposium on: Cement and Concrete. Ottawa, Canada. pp. 248-263.
[8] Ballim, Y., Alexander, M., & Beushausen, H. (2009). *In: Owens G (ed) Fulton's concrete technology*. 9th edn Cement and Concrete Institute, Midrand.pp. 155-188.
[9] Chatterjee, S., & Hadi, A. S. (2009). *Sensitivity analysis in linear regression* (Vol. 327): Wiley. com.
[10] Chatterjee, S., & Hadi, A. S. (2013). *Regression analysis by example*: John Wiley & Sons.

[11] Alexander, M. G., Mackechnie, J., & Yam, W. (2007). *Carbonation of concrete bridge structures in three South African localities*. Cement and Concrete Composites, 29(10), 750-759

[12] Gaylard, P., Ballim, Y., & Fatti, L. (2013). *A model for the drying shrinkage of South African concretes*. Journal of the South African Institution of Civil Engineering, *55*(1), 45-59.

[13] Dhir, R. K., Hewlett, P. C., Byars, E. A., & Bai, J. P. (1994). *Estimating the durability of concrete in structures*. Concretes Society, London, Vol. 28, No. 6, pp. 25-30.

[14] Jean-Marie, K. O. (2011). *Land use Impacts on Water Resources Management in a Data-Scarce Watershed of the Equatorial Nile: Case Study of the Semliki.* PhD Thesis, University of the Witwatersrand, Johannesburg.

[15] Mackechnie, J. R. (1996). *Predictions of reinforced concrete durability in the marine environment.* PhD thesis, University of Cape Town, Cape Town.

[16] Parrott, L. J. (1994). *Design for avoiding damage due to carbonation-induced corrosion*, Durability of Concrete- 3rd International Conference, Nice, France 1994, pp.283-298.

Durability characteristics of concrete containing sugarcane waste fibre ash (SWFA)

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Introduction

When bagasse from sugar processing is burnt, sugarcane waste fibre ash (SWFA) is produced. In the recent past interest has arisen on the potential of using SWFA as cementing material, due to its high pozzolanic activity [1 - 8].

In a recent study of SWFA-cement mixes [9], it was found that when SWFA was used to partially replace cement by weight percentage of up to 20%, the chemical composition was significantly affected, with the content of CaO falling from 60.87% for pure cement to 49.29% at 20% replacement. SWFA was also found to have a silica content of 67%, with a LOI of 9.34%, with a dark grey colour.

Concretes made of blended cements generally have lower permeability and more discontinuous pore structure than plain Portland cement concretes [10]. This slows down ingress of chloride ions, thereby slowing down deterioration of concrete and corrosion of reinforcement steel. Slag has been seen to be a very effective cement replacement material for marine environments with 60% cement replacement by slag being the optimum mix with respect to strength development and resistance to chloride penetration [10, 11]. Fly ash has been found to improve resistance to chloride penetration in concrete. Mixes containing finer fly ash showed greater resistance to chloride penetration than those with coarser fly ash [12].

RHA concretes have been found to have good resistance to sulphate attack [10]. Fly ash and RHA mortar are of lower pH levels and thus less susceptible to sulphate attack [10, 13]. Up to 40% of Portland cement can be replaced with fly ash and RHA to make blended cement [10]. Better resistance to sulphate attack in finer fly ash blended cement has also been observed. This has been attributed to the higher reactivity of the finer fly ash with $Ca(OH)_2$ resulting in less $Ca(OH)_2$ being available for sulphate attack [13].

Bagasse Ash, cement and concrete mix

SWFA was collected from Mumias Sugar Factory in Western Kenya where it is produced as a waste product of burning sugarcane bagasse for electricity generation. Usually bagasse with a moisture content of about 50% is fed into boilers where it is burnt at 1000°C to convert water into steam that drives turbines to generate electricity

Cement-SWFA paste samples containing between 0 – 20% SWFA, with a water cement ratio of 0.53 were prepared. These pastes were spread on polythene sheets to a thickness of approximately 3mm. These were observed on a scanning electron microscope at 18 hours and 90 days age.

A concrete mix of target strength 25N/mm^2 with a w/c ratio of 0.53 and with coarse aggregates consisting of two sizes: 20mm and 10mm, and Ordinary Portland Cement class 32.5 was used to make cubes of 100 x 100 x 100mm.

These samples were exposed for a period of 90 days to: (i) sea water; (ii) concentrated hydrochloric acid (iii) dilute carbonic acid (iv) ultraviolet light.

Exposure to sea water

During the curing period, a white 'crust' formed on the surface of the curing water. A chemical analysis of this crust and the sea water before and after the 90 day curing period is as given in Table 1. The formation of the crust was not as pronounced in a basin containing 12 – 20% ash concrete cubes.

Cube strengths after exposure suggested 36% higher strength at 6% SWFA content than that of the control cubes.

Exposure to concentrated hydrochloric acid

Some effervescence was observed in the earlier days of later and later bubbling on the surface of the samples. This activity was observed to be more in the lower SWFA content samples than in the ones with higher SWFA content. A white substance was deposited on the sample surface. This was observed after the 24 hour draining prior to weighing and testing for strength. The samples showed some cracks, similar to those of early stages of spalling.

The control cubes showed the highest resistance to attack by concentrated hydrochloric acid.

Exposure to dilute carbonic acid

Concrete containing 6% SWFA had approximately 16% higher strength than the control and generally the strength of the samples was not affected by the dilute acid in the exposure period.

Exposure to ultraviolet light

All samples were lost some mass during the exposure. This is thought to have been due to loss of moisture. However, the samples containing 6% SWFA showed the least moisture loss, thought to have been due to smaller pore sizes within the samples as observed on the micrographs Figure 1.

None of the samples were able to achieve the target strength of 25N/mm^2, though once again the concrete containing 6% SWFA was observed to have the highest strength.

Conclusions

SWFA content in concrete has no clear effect on corrosion resistance from concentrated hydrochloric acid.

Inclusion of SWFA as part of the cementing material in concrete improves the concrete’s resistance to attack by dilute carbonic acid with the highest resistance occurring at 6% content of SWFA.

Inclusion of SWFA as part of the cementing material in concrete improves the concrete’s resistance to attack by UV light. The optimum of this resistance occurs at 6% content of SWFA.

Concrete strength is generally reduced when cured under UV light. In 90 days, this reduction is observed to be approximately 20%.

Figures and tables

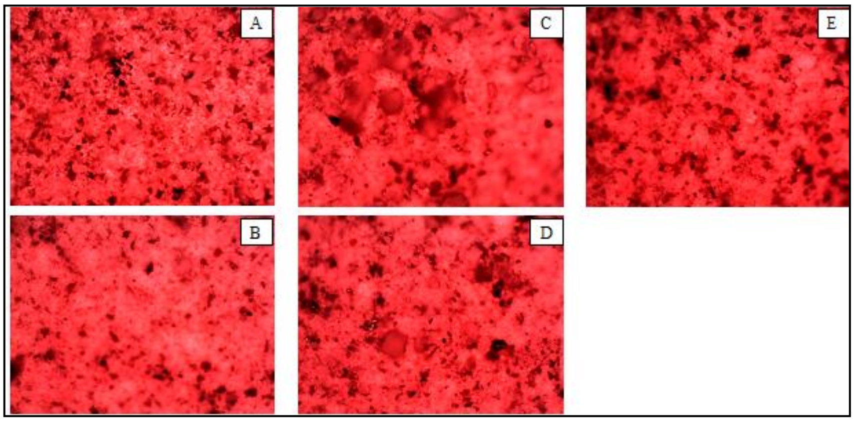

Figure 1 (a): 90 day SWFA – Cement Paste Micrographs (x200): (A) 0% Replacement, (B) 5% Replacement, (C) 10% Replacement, (D) 15% Replacement & (E) 20% Replacement

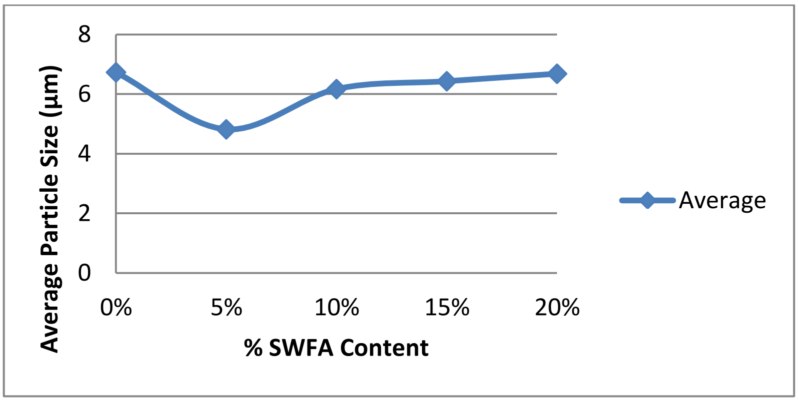

Figure 2: average grain sizes versus % SWFA content (90 day paste)

Table 1: Precipitate and curing water analyses - before and after curing

Sample	**%SO_4**	**%Cl**	**pH**
Sea Water Before	4.69	2.31	6.81
Sea Water After (Basin A containing concrete of 0 – 10% SWFA)	7.73	4.41	9.71
Sea Water After (Basin B – Containing concrete of 12 – 20% SWFA)	6.79	5.02	8.26
Precipitate (Basin A)	4.46	11.3	9.45

References

[1] Villa-Cocina, E., ValenciaMorales, Gonzalez-Rodriguez, R., Hernandez-Ruiz, J. (2003). Kinetics of the Pozzolanic Reaction Between Lime and Sugar Cane Straw Ash by Electrical Conductivity Measurement: A Kinetic–Diffusive Model. Cement and Concrete Research, Volume 33 (4), Pp 517-524.

[2] Chusilp, N., Likhitsripaiboon, N., Jaturapitakkul, C. (2009) Development of Bagasse Ash as a Pozzolanic Material in Concrete. Asian Journal on Energy and Environment, Vol. 10(3), Pp 149-159.

[3] Amu, O. O., Ogunniyi, S. A., Oladeji, O. O. (2011). Geotechnical Properties of Lateritic Soil Stabilized with Sugarcane Straw Ash. American Journal of Scientific and Industrial Research, Vol. 2(2), Pp 323-331.

[4] Osinubi, K. J., Ayuba, S. T., (2007). Influence of Compactive Efforts on Bagasse Ash Treated Black Cotton Soil. Nigerian Journal of Soil and Environmental Research Vol. 7, Pp. 92-101.

[5] Singh, N. B., Das, S. S., Singh, N. P., Dwivedi, V. N. (2009). Studies on SCLA Composite Portland Cement. Indian Journal of Engineering and Materials Sciences. Vol. 16, Pp. 415 – 422.

[6] Govindarajan, D., Jayalakshmi, G., (2011). XRD, FTIR and Microstructure Studies of Calcined Sugarcane Bagasse Ash. Advances in Applied Science Research, Vol. 2 (3), Pp. 544 – 549.

[7] Cordeiro, G. C., Filho, R. D., Eduardo, T. (2008). Use of Ultra-Fine Sugar Cane Bagasse Ash as Mineral Admixture for Concrete. ACI Materials Journal, Vol. 105(5), Pp. 487 – 493.
[8] Singh, N. B., Singh V. D., Rai, S. (2000). Hydration of Bagasse Ash-Blended Portland Cement. Cement and Concrete Research, Vol. 30(9), Pp. 1485 – 1488.
[9] Mwero, J. N., Abuodha, S. O., Mumenya, S. W., Rading, G. O., Kavishe, F. P. L. (2011). Sugarcane Waste Fibre Ash: Composition, Particle Size Distribution and Pozzolanic Properties. ICASTOR Journal of Engineering, Vol. 4 (2), Pp 137-144.
[10] Givi, A. N., Rashid, S. A., Aziz, F. N. A., Salleh, M. A. M. (2010). Contribution of Rice Husk Ash to the Properties of Mortar and Concrete: A Review. Journal of American Science, Vol. 6(3), Pp. 157 – 165.
[11] Cook, J. D., Jedy, M., Cao, H. T., (1989). Behaviour of Slag Cement Concretes in Marine-Environment Chloride Ion Penetration. Third International Conference Proceedings. Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Trodheim, Norway, 18th – 23rd June, 1989.
[12] Chindaprasirt, P., Chotithanorm, C., Cao, H. T., Srivivatnanon, V., (2007) Influence of Fly Ash Fineness on the Chloride Penetration of Concrete. Construction and Building Materials, Vol. 21, Pp 356-361.
[13] Chindaprasirt, P., Homwuttiwong, S., Sirivivatnanon, V., (2004). Influence of Fly Ash Fineness on Strength, Drying Shrinkage and Sulphate Resistance of Blended Cement Mortar. Cement and Concrete Research, Vol. 34, Pp. 1087 – 1092.

THE INFLUENCE OF CONCRETE MIX DESIGN ON SHEAR STRENGTH OF REINFORCED CONCRETE FLAT SLABS

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Introduction

Reinforced concrete frames are widely used world over and even more so in Africa. Typically, slabs are supported by beams which are in turn supported by columns. However, there are instances when slabs are supported directly by columns and are referred to as a flat slab. The flat slab may be used where it is necessary to maximise the height of clear span between floors, as beams tend to reduce this by their depth and also allows for an unsymmetrical arrangement of columns. Concrete flat slabs are commonly used in buildings such as hospitals, shopping malls, or multi-storey parking areas where columns usually support wide spans and the sight of deep beams may make the structure aesthetically unpleasant. There are different types of flat slabs which can be distinguished by the slab to column connection (Fig. 1).

However, because of this direct slab to column connection, the shear capacity of the reinforced concrete flat slab is most critical as it is susceptible to punching shear at those connection points (Fig. 2). This in turn subjects reinforced concrete flat slabs to early failure and may reduce its performance well before intended design life span.

Background to the study

Punching shear strength in concrete slabs may be improved by increasing the thickness of the slab, providing drop panels at the slab – column connections, reducing the effective length of the slab, reducing applied loads and/or providing shear reinforcement. However, increasing the thickness of the slab and drop panels reduces the clear floor height and reducing the effective length of slab and applied load maybe impractical depending on the intended use of the building.

It can therefore be envisaged that there is a certain influence of concrete mix design with regards the shear capacity of reinforced concrete flat slabs. Various studies have been carried out to investigate increasing the shear capacity by adjusting or alternative reinforcement. However, not much has been done on the investigation of the performance of the concrete itself with regards to its shear strength.

Patil, Gore and Salunke (2013) described the optimum design of reinforced concrete flat slabs with drop panels. They found that the cost of flat slabs increased with respect concrete grade and steel reinforcement grade increases, whereas the cost of flat slab decreases as the number of span increases by keeping total length of slab constant [4]. Ericson and Farahaninia (2010) discussed punching shear in reinforced concrete slabs supported on edge steel columns [1]. Pilakoutas and Li presented alternative shear reinforcement for reinforced concrete flat slabs [5].

Methodology

In this study we will consider reinforced concrete flat slabs of the same depth and columns without column heads or drop panels. A direct inelastic small scale micro-concrete model of only the slab and columns supporting it will be used and will reproduce the effects of nonlinear stress-strain relation and tensile cracking of concrete. Materials and aggregates used for the model will be scaled down, but ratios and proportions will be maintained as of those that would be used in site construction. A mixture of suitably graded sand, Portland cement and water will be used to simulate concrete in the small scale model. Usually laboratory trials do not portray a full picture of mix design performance and on-site conditions differ with those of a laboratory. Modelling gives a better understanding and allows for adjustments to mix proportions and re-testing where needed. Typically, concrete with a compressive strength of 30MPa is used in construction of flat slabs and the same will be adopted in this study. However, for the purpose of this study, the water-cement ratio and volume of aggregate used will vary between models in order for us to assess the effect of these on the shear strength on the concrete. Because it is difficult to satisfy all these concrete properties and still maintain workability, an available additive will be used.

In order to obtain good predictions of onsite concrete behaviour from the results of model tests, material properties should be similar to those of the prototype concrete of a similar compressive strength. Super set Portland cement will be used and aggregates measured for water absorption and porosity. Since concrete consistency is governed by free water content only, this is an important parameter to assess. The concrete for the model will be cast in formwork that will be scaled to model size and cured with hessian sacks and water. Once it is fully cured loads will be applied to it until the concrete fails in shear at the slab-column connections in such a manner as that shown in figure 2.

Conclusion

The importance of concrete mix design cannot be overstated. It is the basis of all structural designs and works to be carried out. For reinforced concrete flat slabs, the shear capacity is a quintessential parameter to be considered in one's design as this is the most likely failure to occur first. However, the required compressive strength is usually the basis of most mix designs and the steel reinforcement making up for the punching shear to increase its capacity. This study will seek to investigate whether the concrete mix design itself can be used to increase the shear capacity of the structural element. This may also in turn help the design remain economic as the thickness of the slab will not need to be increased and no significant increase in reinforcement. In the past, parameters such as water-cement ratio were considered constraints in concrete mix design. But evolving technologies in mix design, concrete workability and the increased use of superplasticisers and additives allows for different considerations.

Figures and tables

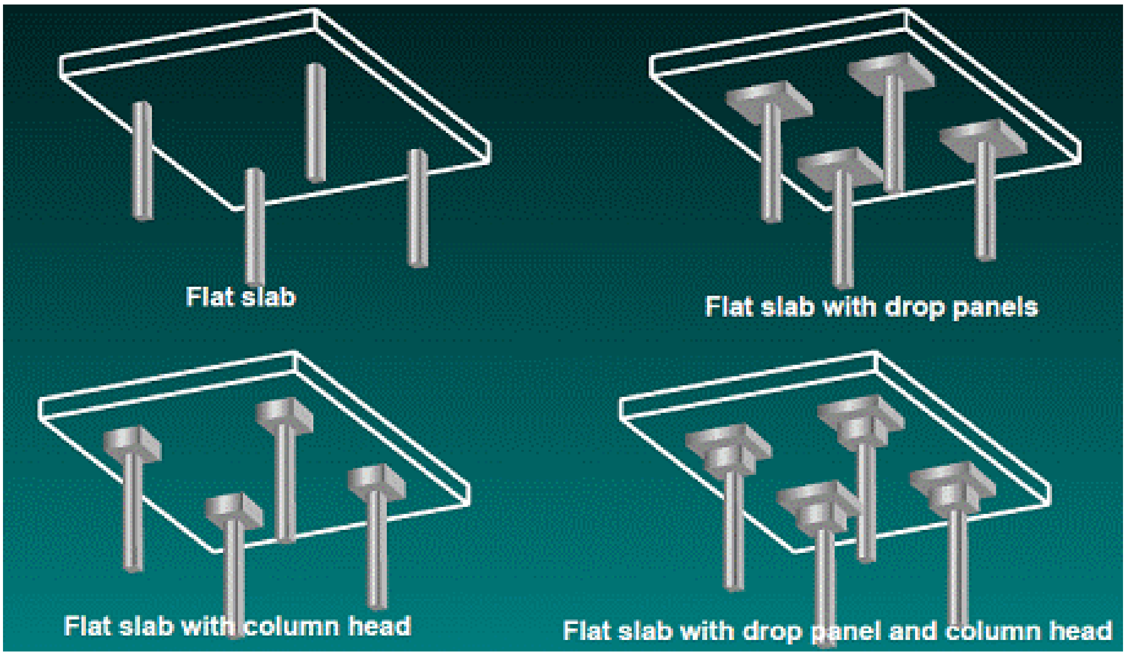

Figure 1: Typical flat slab arrangements

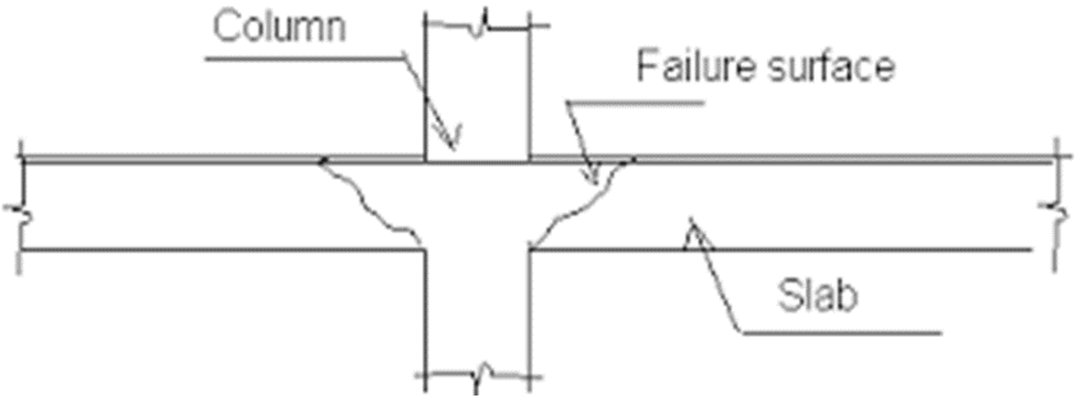

Figure 2: Flat slab punching shear failure

References

[1] Ericsson, S. and Farahaninia, K. (2010) *Punching Shear in Reinforced Concrete Slabs Supported on Edge Steel Columns.* Unpublished Masters' Thesis. Chalmers University of Technology.

[2] Londhe, R.S. (2011) Shear Strength Analysis and Prediction of Reinforced Concrete Transfer Beams in High-Rise Buildings. *Structural Engineering and Mechanics.* Vol. 37, p. 39-59.

[3] Mosley, W.H. and Bungey, J.H. (1987) *Reinforced Concrete Design.* 3rd Edition. Southampton: Macmillan Books.

[4] Muttoni, A. (2008) Punching Shear Strength of Reinforced Concrete Slabs without Transverse Reinforcement. *ACI Structural Journal.* 105 (8). p. 440-450.

[5] Patil, K.S., Gore, N.G. and Salunke, P.J. (2013) Optimum Design of Reinforced Concrete Flat Slab with Drop Panel. *International Journal of Recent Technology and Engineering.* Vol. 2 (9). p. 37-39.
[6] Pilakoutas, K. and Li, X. (2003) Alternative Shear Reinforcement for Reinforced Concrete Flat Slabs. *Journal of Structural Engineering.* 129 (9). p. 1164-1172.
[7] Ruiz, M.F., and Muttoni, A. (2009) Applications of Critical Shear Crack Theory to Punching of Reinforced Concrete Slabs with Transverse Reinforcement. *ACI Structural Journal.*106 (8). p. 485-494.

DURABILITY OF LOCALLY PRODUCED BURNT CLAY BRICKS

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Introduction

Sustainable economic growth for every country and Ghana for that matter is dependent on infrastructural development, public development projects and the provision of affordable houses for the average populace. Construction is costly due to the heavy reliance on imported clinker for cement production; moreover, the use of cement in the construction industry is much extensive and more widespread. The use of locally-produced burnt clay bricks has been envisaged as the best alternative. However, locally-produced burnt clay bricks are perceived to lose their properties depending on service conditions.

The Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR) in Ghana has been conducting research into the development and promotion of locally-developed building materials. One of such material is burnt clay bricks [1, 2]. Burnt clay bricks have been much-admired to have several technical, economic and environmental advantages. They are durable and have good aesthetic appeal. Their use in construction also encourages sustainable economic gain through the reduction of clinker consumption and construction cost [3].

Developers expect burnt clay bricks to be strong, inexpensive and durable in aggressive environment [4]. For instance, in marine environment, bricks come under salt attack which causes efflorescence, scaling, crumbling, and cracking causing material damage [5, 6]. According to Lubelli et al. [7], the effect of sodium chloride (NaCl) is either direct or indirect. Direct damage by NaCl is due to crystallization which generates pressure to cause material damage and hygroscopicity, whilst indirect damage is due to the catalytic role of halite. Careful control of clay composition and firing temperature can produce durable burnt clay bricks that remain unaltered in the process of their service life even in aggressive environment. The effect of salt attack can be seen in diverse forms which include scaling, crumbling, softening, splits, cracks and granular disintegration which ultimately cause failure of the masonry material. If damage to the microstructure of the material is allowed to continue it will lead to reduced compressive strength of the burnt clay bricks causing failure [8].

Hence, the study investigated the durability of locally-produced burnt clay bricks. Properties of laboratory-produced burnt bricks from Mfensi (MF), Mankranso (MK) and Nyamebekyre (NK) (known clay deposit sites in Ghana) clays were compared with burnt bricks available on the market but produced from the same clay source. The wet-dry cycle as experienced in Ghana during alternating sunny and rainy periods makes the country prone to salt attack along the coastal areas. Therefore studying the factors affecting durability of burnt clay bricks produced and used locally is vital. Durability properties like porosity pore size distribution, bulk density and mechanical strength dependents on the types of raw material, the forming process and firing condition used in manufacturing. These when evaluated will inform proper selection of building materials in construction, ensure strength and performance during service life when subjected to aggressive environment.

Method

A flow diagram describing the process of production and characterization of burnt clay bricks is shown in Figure 1. Burnt clay bricks samples were obtained from three factories namely BRRI, Vicalix and Rock Brick and Tile Factories. Mfensi, Mankranso and Nyamebekyre clays were obtained from the Ashanti Region of Ghana. A total of 450 bricks were moulded after clay has been mixed with water, tempered and thoroughly worked into a plastic state.

The mineralogical compositions of the clay sample were studied using X-ray diffraction (Siemens D5000). X-ray fluorescence (Spectro X-lab 2000) was used for the chemical analysis of the clay samples. The particle size distribution of the clay samples were determined by the hydrometer method of sedimentation as specified by British Standard BS 1377:90. The specific gravity of the clay samples was determined as specified by the British Standard BS 1377:90.

Burnt bricks produced in the laboratory were fired at 800, 900 and 1050 ^{o}C to investigate the effect of firing temperature on brick durability. The burnt clay bricks were characterized by determining their, linear firing shrinkage, apparent porosity, water of absorption, bulk density and cold crushing strength. The burnt bricks were subjected to salt attack tests and durability assessed by measuring degradation. The bricks were exposed by soaking in 0.5 M NaCl and 0.5 M Na_2SO_4 for 7, 15, 30, 60 and 90 days, respectively. Samples were removed at the end of exposure periods and then oven dried for 22 hours at 110 ^{o}C. Deterioration as well as the amount of damage was assessed by comparing the compressive strengths, apparent porosities, bulk densities and absorption before and after exposure tests.

Results

In all the clay samples, quartz (SiO_2) was identified as the major mineralogical phase with minor fractions of kaolinite. The specific gravities of the various clays were determined to be of an average of 2.60 g/cm^3. The particle size analysis of the clay samples showed a varied distribution of clay, silt, sand and gravel in average percentage composition of 36.06, 36.93, and 1.1 respectively.

The results for bulk density, apparent porosity, water absorption, and cold crushing strength are summarized in Table 1. Figure 2 shows a picture of the laboratory moulded clay bricks. The bulk densities of laboratory-produced samples decreased slightly from 800 °C to 900 °C and increased slightly at 1050 °C. Increase in bulk density results in a corresponding decrease in water absorption (Table 1). At lower temperatures, bricks exhibit larger pore sizes which results in lower density and a corresponding increase in water absorption which is not desirable for brick durability. It was observed that apparent porosity decreased with increasing firing temperature for all investigated clays. Higher apparent porosity causes greater water absorption which is not desirable. This is because, the lower the negative influence of water on the bricks the better the quality of bricks and consequently, the higher the durability [9]. It is also observed that the water absorption decreased with increasing firing temperature, however, the water absorption in commercially-produced bricks were higher than those produced in the laboratory. Studies carried out by Cardiano et al. [10] showed that vitrification begins above 900 °C with formation of glassy phase. This decreased the total pore size and consequently water absorption. Generally, strength values of laboratory-produced bricks were higher than those produced commercially. The relatively low strength values could be due to variations in firing temperatures.

The effect of exposure time on the apparent porosity, water absorption, apparent porosity and cold crushing strength of burnt bricks produced from different clay materials in the above mentioned media, showed varied results. Mfensi (MF) bricks fired at 1050 ^{o}C performed very well in seawater and Na_2SO_4 with an increase in strength of 10.4 % and 35.4 %, respectively. Nevertheless, the performances of bricks fired at 900 ^{o}C were better than bricks fired at 800 ^{o}C. Mankranso (MK) bricks fired at 1050 ^{o}C also performed very well in seawater and NaCl with a corresponding increase in strength of 18.2 % and 14.0 %, respectively. Bricks fired at 800 and 900 ^{o}C had reduction in strength values in all media with more damaging effect in Na_2SO_4. The results show that burnt bricks fired at high temperatures are more durable and have better chances of survival in aggressive environments than bricks fired at low temperatures. Nyamebekyre (NK) bricks also showed similar behaviour with bricks fired at 1050 ^{o}C demonstrating high durability in seawater and NaCl environments. It can therefore be concluded that brunt bricks fired at high temperatures have high durability in aggressive environments.

Conclusions

The following conclusions were drawn based on the results:

- The cold crushing strength values of laboratory-produced burnt bricks were higher than that produced commercially. Variations in other properties were also observed, with laboratory-produced bricks having better properties than commercially available bricks.

- Generally, the results show that burnt bricks fired at high temperatures are more durable and have better chances of survival in aggressive environments than bricks fired at low temperatures.

Figures and tables

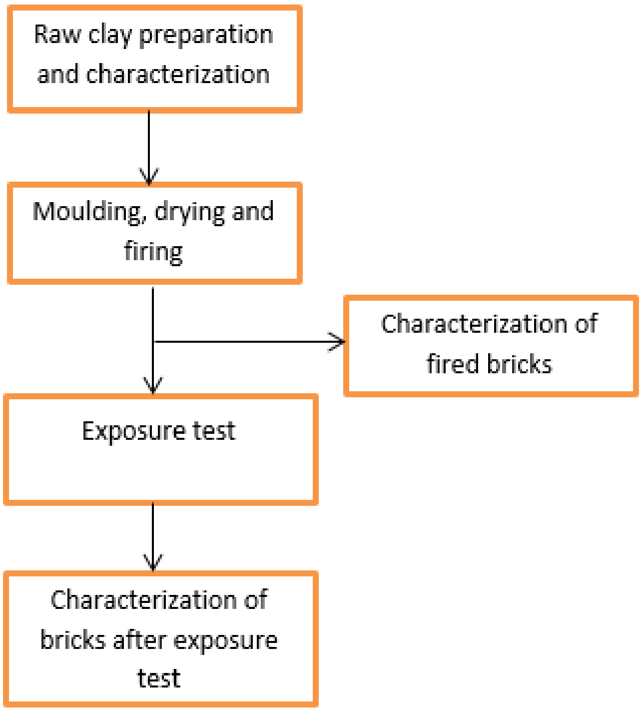

Figure 1: Flow diagram showing the processes involved in assessing the durability of locally-produced burnt clay bricks.

(a) (b)

Figure 2: Images of burnt bricks before (a) and after (b) exposure to seawater showing efflorescence.

Table 1: Summary of bulk density, apparent porosity, water absorption, and cold crushing strength.

	Bulk Density (g/cm^3)	Apparent Porosity (%)	Water Absorption (%)	Cold Crushing Strength (MPa)
MF - lab				
800	3.33	50.00	25.00	1.28
900	1.99	43.70	21.87	1.93
1050	2.41	31.64	13.17	2.02
MK - lab				
800	1.91	26.79	14.08	1.21
900	1.55	21.38	12.67	1.25
1050	1.65	20.96	12.53	1.10
NK - lab				
800	1.72	22.34	13.01	1.61
900	1.56	19.96	12.69	1.93
1050	1.65	16.66	10.15	1.53
BBRI				
MF	1.51	31.83	31.83	0.25
MK	1.80	26.53	26.52	0.24
NK	1.40	21.34	21.34	0.20

References

[1] Ayetey J. K. (1977) Clays and their evaluation for bricks manufacture; Ghana clay report, BRRI current note 11, p.42.

[2] Kesse G. O. (1985) The mineral and rock resources of Ghana. AA Rotterdam, p.437-439.

[3] Atiemo E. (1998) Clay as pozzolana for building purposes, Journal of Building and Road research, 2 (1&2), p.10.

[4] Winslow D. N. Kilgour C. L. Crooks R. W. (1988) Predicting the durability of bricks. ASTM Journal of Testing and Evaluation, 16(6), p.527–531.

[5] DeVekey R. C. (2006) The durability of masonry mortar, stone and ancillary components, In: Durability of material and structures in building and civil engineering, Scotland, United Kingdom, p.246 – 267

[6] Bucea L. Sirivivatnanom V. Khatri R. (2005) Building materials deterioration due to salts attack laboratory experimental program, Internal Technical Report. CSIRO Manufacturing and Infrastructure Technology, CMIT, p.165.

[7] Lubelli B. van Hees R. P. J. Groo J. W. P. (2004) Construction and Building Materials, 18, p.119–124.

[8] Zsembery S. (2001) Manual 2: The Properties of Clay Masonry Units, Clay Brick and Paver Institute (CBPI), Australia.

[9] Scherer G. W. (2004) Stress from crystallization of salt. Cement and Concrete Research, 34(9), p.1613-1624.

[10] Cardiano P. Ioppolo S. Stefano C. Pettignano A. Sergi S. Piraino P. (2004) Study and characterization of the ancient bricks of monastery of "San Filippo di Fragalà" in Frazzanò (Sicily), Ana-lytica Chimica Acta, 519 (1), p.103–111.

INFLUENCE OF METAKAOLIN ON THE PERFORMANCE OF CONCRETES

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Introduction

The impact of Portland cement on the environment is of concern, as the manufacture of cement is responsible for about 5% of total global emissions from industrial sources. An effective way to reduce the impact on the environment is to use supplementary cementitious materials (SCM) as a partial substitute to cement. The use of SCM in cement for the manufacture of mortar and concrete offers economic and ecological advantages. The main SCM are limestone, tuff, slag and natural pozzolana. Several studies have analysed the effect of these additions on mechanical properties, and durability of concrete. However, few studies have been realised on the performance of concrete with local metakaolin (MK). Metakaolin is produced by controlled thermal treatment of kaolin, which is known of its high pozzolanic reactivity.

The main purpose of this study is to analyse the performance of mortar and concrete with local metakaolin. The preparation of the metakaolin was carried out by calcination of kaolin at a temperature of 850 ° C for a period of 3 hours. The cement used in this study is CEMI 42.5 type. Kaolin was originated from the region of Mila (Algeria). The sand is a siliceous sand and the gravel is a quarry crushed stone. To get a constant workability of mortar and concrete, a superplasticizer based polycarboxylates was added.

Experiments and methods

The composition of the concrete has been established on the method of Dreux Gorisse with a compressive strength after 28 days under 30 MPa (C30 / 37) and a plastic consistency class S2. The binders used are obtained by partial substitution of the cement mass by different percentages of metakaolin (0, 10, and 15%). For all the binders used, the ratio is held constant. The tests carried out on the concrete are compressive strength, water absorption by capillarity, water permeability and gas permeability. For mortars, the level of cement substitution by metakaolin was 0, 10, 15, 20 and 30%. The water binder ratio was kept constant at 0.5. Compression and bending tests were realized as well as durability tests in aggressive environments under (sodium sulphate solution, magnesium sulphate) at 5% concentration and also sea water.

Results and analyses

The workability test shows that of the need for superplasticizer increases with increasing MK content to compensate for the loss of workability of concrete. Figure 1 shows that MK plays an important role in increasing the compressive strength of concrete, especially at 10% of MK where a compressive strength of 41.5 MPa at 60 days is achieved compared to 34.50 for concrete mix without MK (MK0). Three basic factors affect the contribution of MK to the compressive strength of concrete when it partially replaces cement in concrete. These are the filler effect, accelerating the hydration of CEM I and the pozzolanic reaction of MK with CH. The effect of filler results in a more efficient packaging of the paste. The acceleration of the hydration of CEM I has maximum impact within the first 24 hours and the pozzolanic reaction provides the largest contribution to the compressive strength between 7 and 14 days.

Figure 2 shows that the water absorption decreases with increasing the dosage of metakaolin. This means that the incorporation of metakaolin has a very positive effect on the absorption of water. It was also noted that the capillary absorption coefficient decreases with the increase in the percentage of metakaolin. Concrete mixes with 10 and 15% of MK reduce the absorption coefficient with respect to reference concrete respectively by 25 and 30 %. This reduction in absorption could be explained by the finer pore structure.

The incorporation of metakaolin has a very positive effect on the permeability of water. Mixes with 10% MK have the best results with a decrease in water permeability of about 25%. However, the mix with 15% MK decreases the permeability by about 15%. The metakaolin plays a less important role in the permeability to gas. The higher the level of cement substitution by MK, the higher the coefficient of gas permeability. The values of the measured coefficients of gas permeability are respectively 3.27×10^{-17} m², 4.37×10^{-17} m² and $6,80 \times 10^{-17}$ m² for MK0, MK10 and MK15.

Conclusions

The importance of incorporating metakaolin in concrete was demonstrated. Concrete suffer a loss of workability due to the incorporation of metakaolin hence the need to add a superplasticizer. The Compressive strength was improved after 7 days of age and at long term. All durability parameters were improved after the incorporation of 10 and 15% metakaolin except gas permeability.

Figures and tables

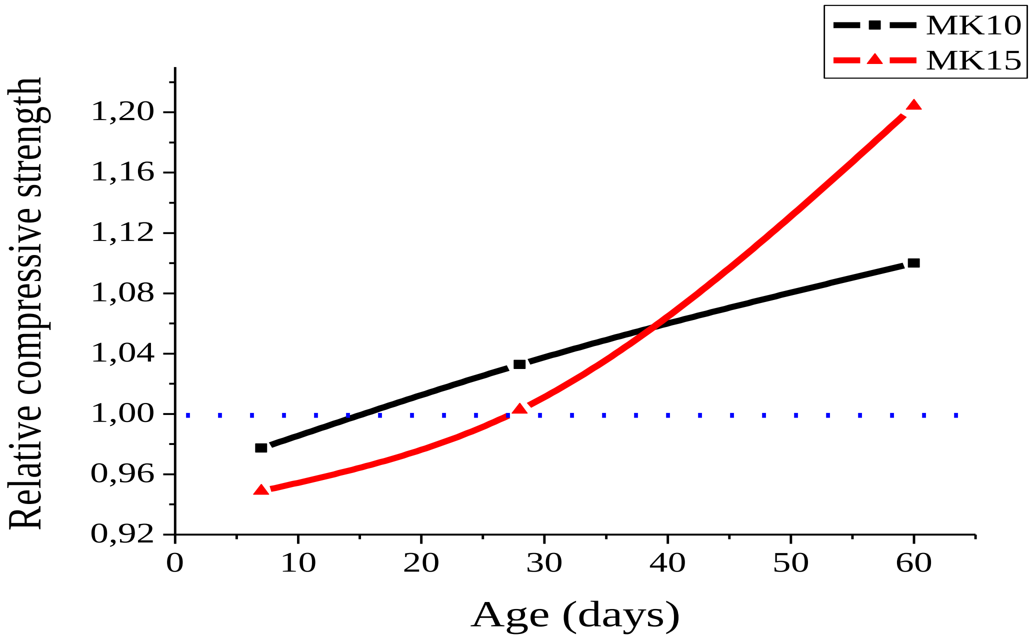

Figure 1: Compressive strength relative ($\frac{Rc\ \ concrete\ with\ additions}{Rc\ reference\ concrete}$).

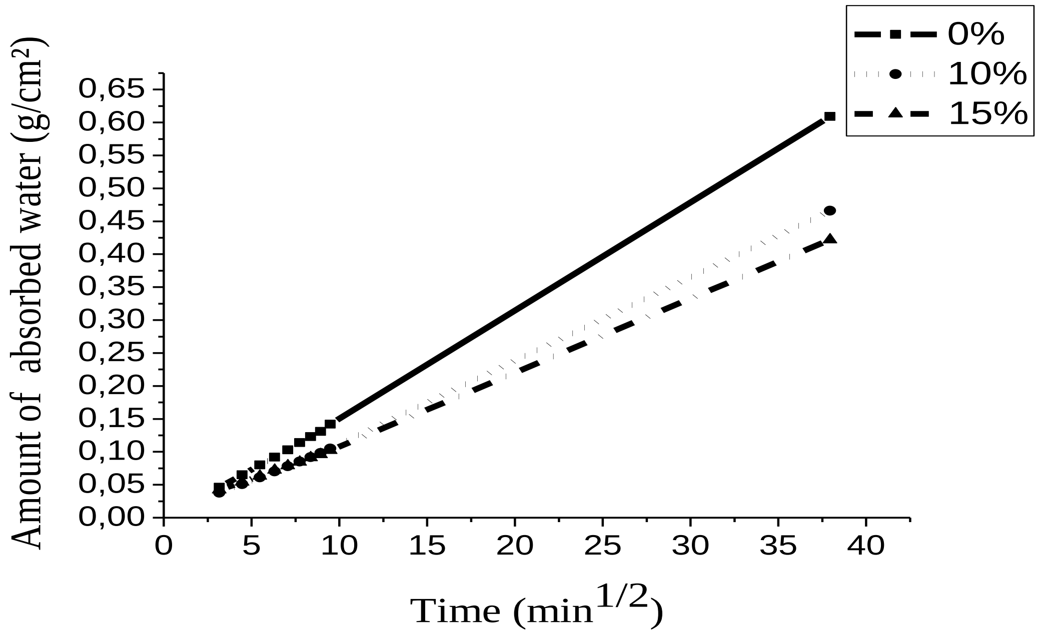

Figure 2: Effect of MK on the absorption of water by capillarity on 24h.

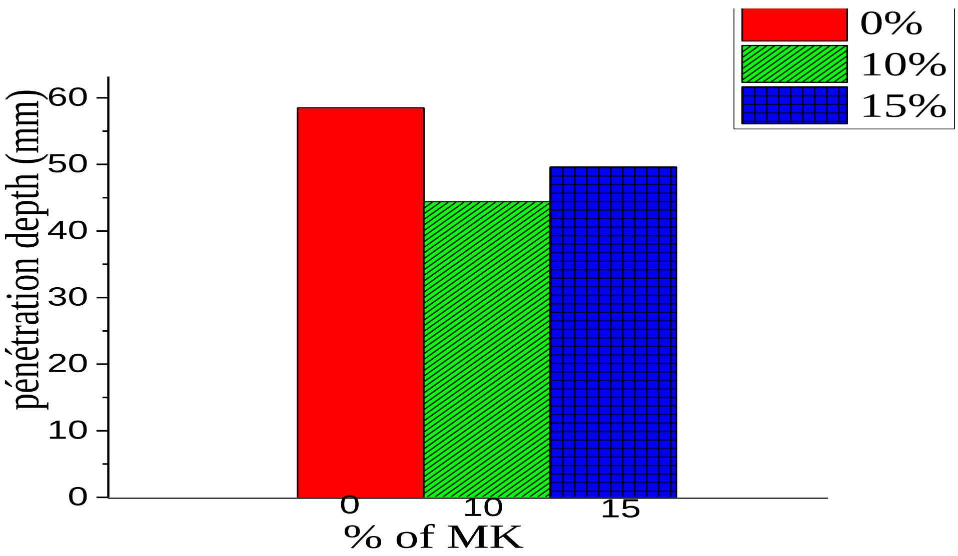

Figure 3: Effect of metakaolin on the depth of water penetration.

THE EFFECTIVENESS OF RECYCLED WASTE NYLON IN THE PARTIAL REPLACEMENT OF FINE AGGREGATE IN REINFORCED CONCRETE SLAB

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Introduction

The rate at which natural resources are consumed in concrete production is becoming alarming. This has significantly led to increase in cost of construction. The most widely used fine aggregate utilised in production of concrete is the natural sand mined from riverbeds. However, the availability of river sand for the preparation of concrete is scarce due to the excessive non-scientific methods of mining these sands, lowering of water table, sinking of the bridge piers, etc. are main repercussions of using natural sands [1].

The problem of disposing used synthetic materials, specifically nylon has remained incompletely solved especially in underdeveloped and developing countries rendering a challenge of controlling this waste. Some materials have substantial effect when utilised effectively in the production of concrete. In essence apt attention should be given to such materials to discover their compatibility with other constituents utilised in concrete production.

To meet the requirements of globalization, in the construction of buildings and other structures, concrete plays the rightful role and a large quantum of concrete is being utilized. River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive and also scarce. In the backdrop of such a bleak atmosphere, there is large demand for alternative materials from industrial waste. An alternative source of material is the use of waste materials [2].

This study examines the properties of concrete produced from the replacement of fine aggregate (sand) with varying percentages of recycled nylon waste. It also intends to determine the amount of nylon corresponding to fine aggregate required to produce same quality or increased quality concrete and to effectively utilize the waste material from the domestic industries and to reduce the problem of disposal of inorganic waste.

Material and methods

Materials

Ordinary Portland cement, locally available sand, coarse aggregate of maximum of 12mm diameter, natural underground water and recycled nylon which was ground into particles and made to pass through no. 4 sieve was used.

Methodology

Slab design and production

Reinforced concrete slabs with the dimension 600mm X 400mm X 50mm were made from the mixture of the recycled nylon at different percentages of 0%, 4%, 8%, 12% and 16%.

Concrete mix

Proper proportioning of individual constituents were done as shown in Table 1. Water cement ratio of 0.75 was used.

Test

Compressive test

Standard cubes of 150mm X 150mm X 150mm were produced from each mix and cured for 28 days and subjected to compressive strength test using the standard of BS 1881: part 116:1983.

Flexural Test

The slabs were all subjected to flexural test under the universal testing machine. A third point loading was considered.

Results and discussion

Based on the research carried out, the following are the results acquired from various test carried out on all specimens. Results were obtained from the average of similar specimens for the tests carried out.

Compressive strength test

Compressive strength being the failure load of a concrete cube or cylinder per unit area indicates the mechanical and durability properties of the concrete mix. After 28days of curing, the cubes were subjected to crushing under the UTM. The resulting compressive strength of individual cubes was recorded as shown in Table 1.

Flexural test

In a simply supported two-way slab subjected to concentrated loading at its centre, the central point is subjected to maximum punching and shear as well as maximum bending moment. Failure may therefore be due to combination of flexure and shear with the former generally dominating. The largest flexural strains therefore occur at the point of load application, consequently, cracking initiates at the soffit of the region, from where the cracks then spread rapidly to the edges of the slab with increasing load to collapse [3]. The measurement of the resistance to bending of the slabs was carried out following the third point loading.

This test indicates that the bending strength of the slab reduced at a lower rate from the beginning but after some time, the bending was accompanied with great deflections corresponding to low forces.

The equation $F.S = \frac{(F*L)}{bd^2}$ was used in calculating the flexural strength and recorded as shown in Table 1.

Deflection and cracks

Crack width was minimal and gradually increases but insignificant values at the early stage of aggregate replacement and with further increase in waste material, cracks occurring became significant (Figure 2).

Results revealed that, at 4% and 8% recycled nylon in concrete mix revealed close proximity in strength to the conventional concrete at 0% under similar exposure and conditions from both compressive strength and flexural strengths. The water demand for proper mix of the concrete increases as the percentage of the recycled waste increases. The weight of the cubes and slabs decreases gradually with increase in recycled waste in the mix. There was no very large difference between concrete slab and cube without replacement and slabs and cubes with replacement of 4% and 8%. With large increase in parentage of recycled waste, there was drastic reduction in strength of concrete.

Conclusion

With the overwhelming increase in nylon waste around, and the significant response of the concrete with 4% to 8% replaced fine aggregate, the use of such concrete should be adopted in construction to aid waste management around the world.

However, the water demand was discovered to increase as the percentage of the recycled waste increases. This certainly continues to reduce the workability of the concrete. The work concluded that at 4%, the recycled waste can be used to partially replace fine aggregate in reinforced concrete slabs with no critical loading conditions.

Figures and tables

Figure 1: Flexural strength test

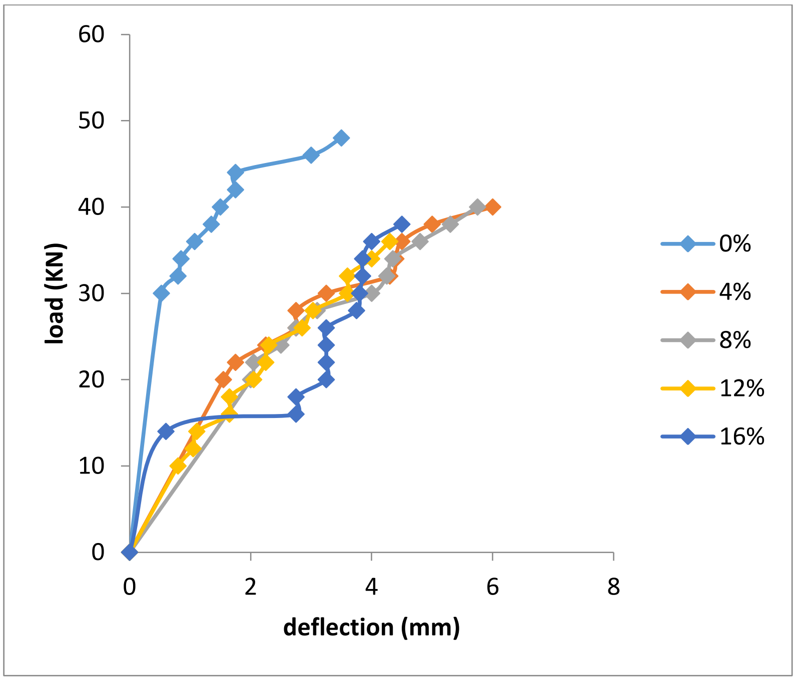

Figure 2: Load deflection response of specimens.

Table 1: Compressive strength and Flexural strength at age 28days.

% of nylon waste	Average compressive strength N/mm^2	Average flexural strength N/mm^2
0	19.07	38.40
4	16.28	32.00
8	15.74	33.60
12	12.59	32.00
14	9.62	38.40

References

[1] Job Thomas, "Utilization of quarry powder as a substitute for the river sand in concrete", Journal of Structural Engineering., vol.32, no.5, pp. 401-407, December 2005.

[2] Sachin B. K, Amol J. M, Vijayshree A. A 2012, "Strength of Concrete Containing Different Types Of Fine Aggregate" International Journal Of Scientific & Engineering Research Volume 3, Issue 9, September-2012 1 ISSN 2229-5518.

[3] Kankam C.K, Odum-Ewuakye B. 2006. Flexural behaviour of babadua reinforced one-way slabs subjected to third-point loading construction of building materials 20 (2006) 279-285.

USE OF SUGARCANE BAGASSE FIBRE AS A SOIL REINFORCEMENT MATERIAL

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Vincent Oderah obtained a BSc (Eng) in Environmental and Biosystems engineering at the University of Nairobi and is currently pursuing his MSc (Eng) in Geotechnical Engineering at the University of Cape Town. His research focus is on sustainable re-use of waste materials and natural fibres as reinforcement inclusions in soil aimed at establishing their viability in ground improvement schemes. He is a member of the geotechnical research group at the University of Cape Town.

Introduction

Sugarcane is the most lignocellulosic crop produced in the tropical countries. 30% of the total sugarcane produced is sugarcane bagasse [1]. South Africa for instance, produces about 22 million tonnes of sugarcane annually amounting to 7.5 million tonnes of sugarcane bagasse [2]. The bagasse produced (which is considered an industrial waste in the sugar industries) presents handling problems. It ferments and decays and at the same time is susceptible to combustion in stockpiles. To solve these problems, projects such as cogeneration, paper, furfural, animal feed production have been explored as an alternative solution [2, 3]. At any rate, the disposal of bagasse is still a major problem in sugar factories especially in countries that are yet to embrace these diversification projects. This condition is aggravated by the urge to reduce the waste material destined to landfills, landfills which some countries do not have.

A study program was therefore initiated at the University of Cape Town to investigate the possible use of sugarcane bagasse fibre as a reinforcement material. This was in a bid of reducing the menace posed by handling sugarcane bagasse by using the fibres in improving the shear strength of soils. Furthermore, it was envisaged that the structural components of bagasse such as lignin, cellulose, and hemicellulose would make it an ideal reinforcing material [4]. The study focussed mostly on the effect of bagasse volumetric concentrations.

Methodology

A sandy soil was reinforced with sugarcane bagasse of different volumetric concentration and tested in a fully automated large direct shear apparatus of 305x305mm. The extent of strength and stiffness response due to the inclusion of bagasse was compared with the unreinforced soil strength. In the investigation, both pithed and de-pithed bagasse were used in reinforcing at a concentration of 0.3-1.7% of dry unit weight. 50, 100, and 200kPa normal loads were applied at a shear rate of 1.2mm/min corresponding to the recommendation from previous studies [5-8]. A maximum of 60mm horizontal displacement was achieved for both normal pressures and the corresponding peak shear strengths used in calculating the cohesion and angle of internal friction as shown in figure 2.

Results

The results showed an increase in both strength and stiffness of the reinforced sandy soil with increasing concentration of bagasse, figure 1 and 2. The strength improved non-linearly up to an asymptotic upper value of 1% concentration beyond which further addition of fibre reduced the strength as shown in figure 3. The increase was more pronounced in the de-pithed bagasse compared to millrun due to increased surface friction between the fibres and soil, figure 3. This was attributed to the increased surface friction between the fibres and soil [9-11]. In both millrun and pith, the cohesion was much increased compared to angle of internal friction. A factor attributed to the cementitious nature of the residual sugars existing in pithed bagasse which binds together the soil particle and consequently improving cohesion and angle of internal friction slightly [5].

Conclusions

Using sugarcane bagasse as a reinforcing element is feasible. Including these materials randomly in the soil improves the soil's shear strength.

This gives an indication that using sugarcane bagasse as a reinforcing material could provide an alternative way of using bagasse, and replace part of the soil stabilization materials like cement, lime and bitumen used in improving the engineering properties of soils.

For the sugarcane bagasse reinforcement to be effective all the residual sugars must be screened out.

This notwithstanding, pithed bagasse in as much as it contain a higher percentage of organic matter could be used as an additive in cementitious applications. The mechanism and the results thereof were however beyond the scope of the investigation.

Figures and tables

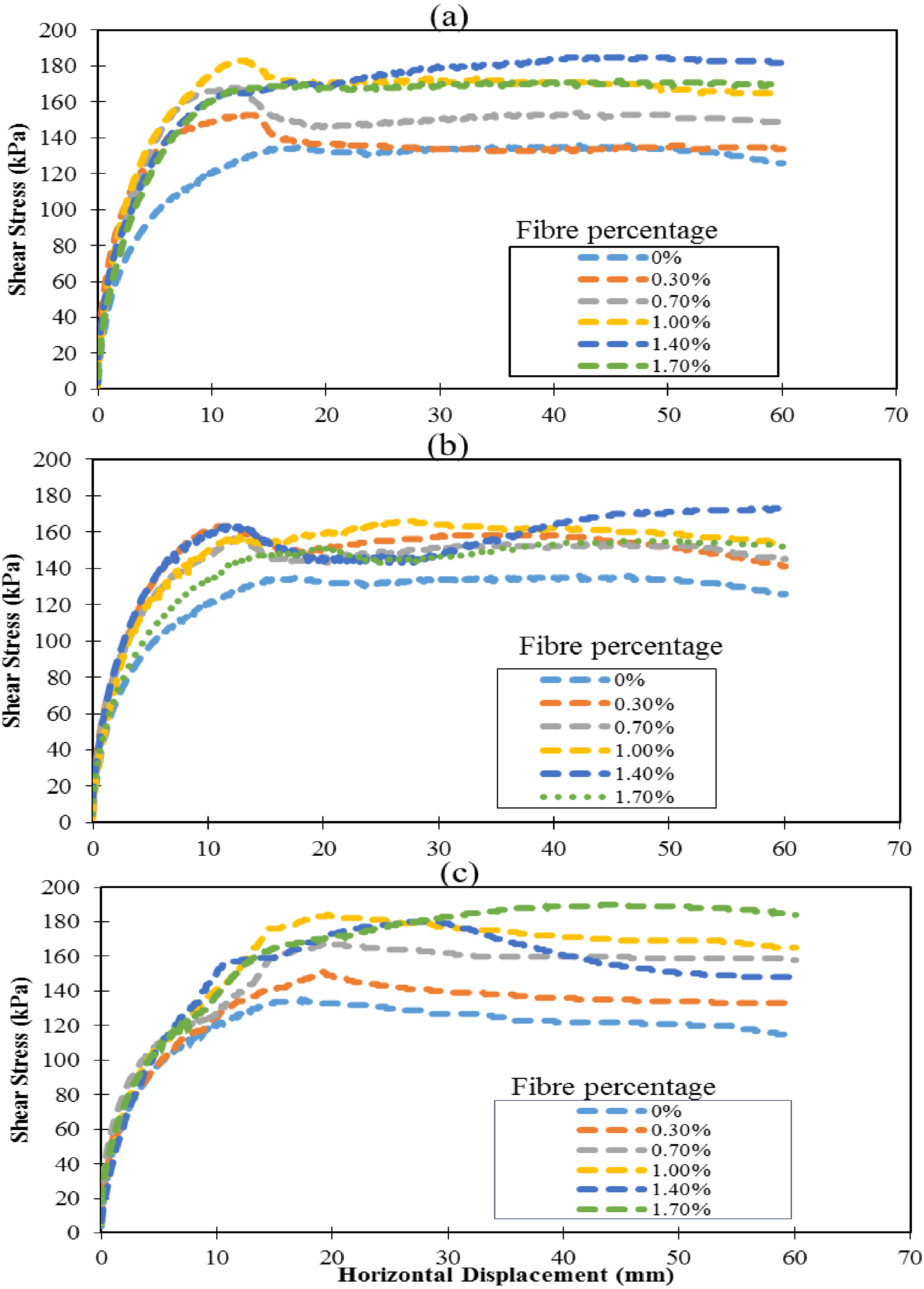

Figure 1: Showing the increase in strength with increasing percentage of (a) fibre (b) Mill-run (c) Pith at 200kPa normal stress

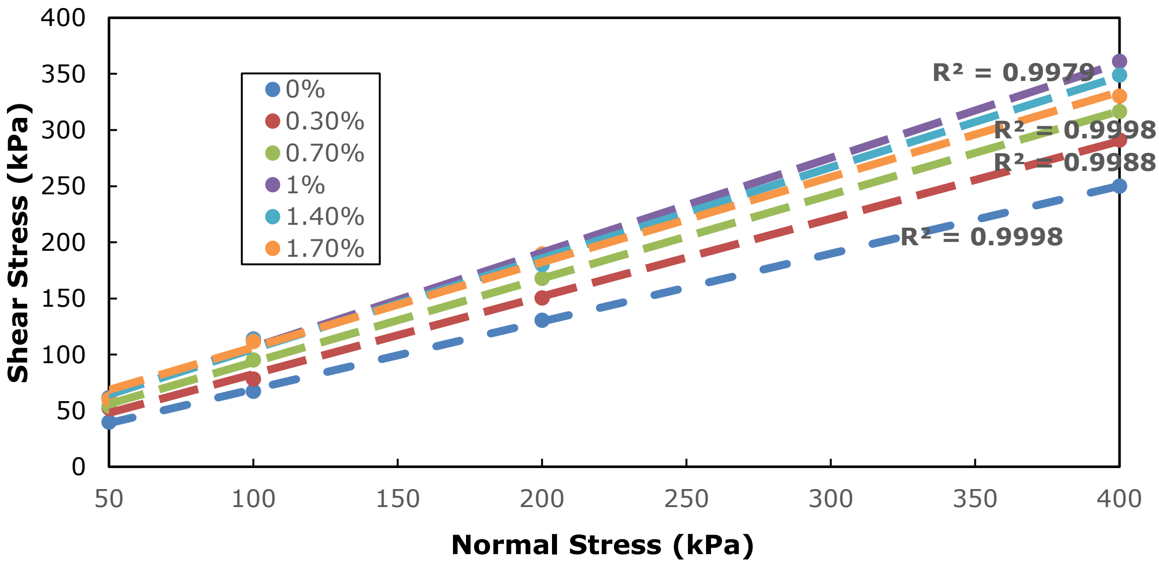

Figure 2: Linear shear envelope, showing upper asymptotic value of 1% fibre concentration.

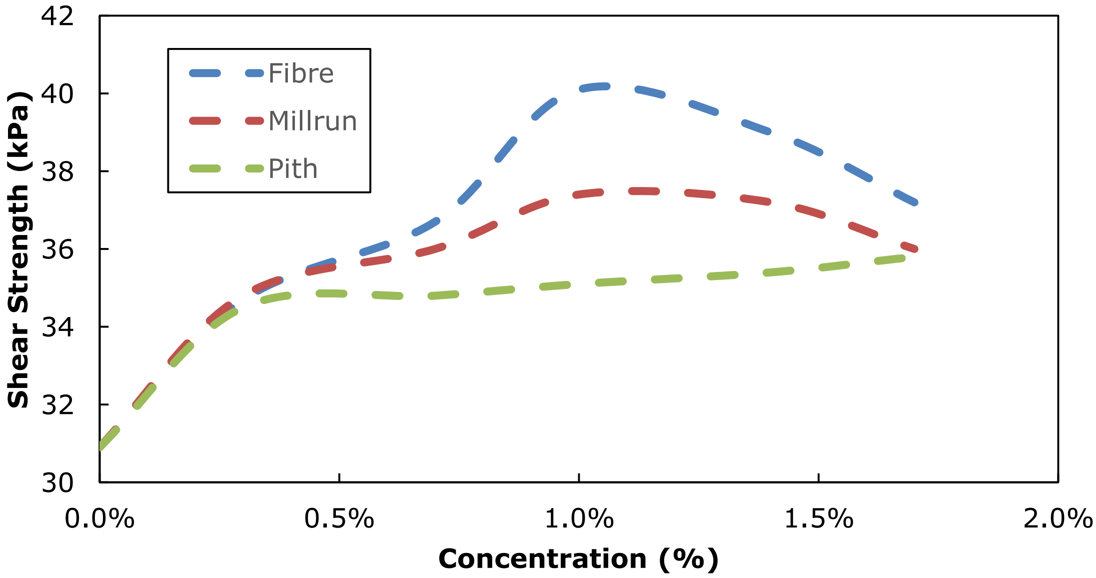

Figure 3: Effect of bagasse concentration of shear strength.

References

[1] National Agricultural Marketing Council. Document 5: Investigation and Evaluation of Alternative Uses and Products from Sugarcane: A Cost Benefit and Macro-Economic Impact Analysis. 2013.Web. 5 June 2014.

[2] United Nations Data. Bagasse Production in South Africa. 2010. Web. June 5, 2014

[3] Mwasiswebe, Denny. Production of Activated Carbon from South African Sugarcane Bagasse. (M.Sc.Eng.) Chemical Engineering -University of KwaZulu-Natal, 2005.

[4] Walford, S. Sugarcane bagasse: How easy is it to measure its constituents? Proceedings of the South African Sugar Technologists Association, 2008, vol. 81, pp. 266-273.

[5] Loh, Y.R., Sujan, D., Rahman, M.E. & Das, C.A. Sugarcane bagasse -The future composite material: A literature review. Resources, Conservation and Recycling. 75(0): 2013 14-22.
[6] Hejazi, S.M., Sheikhzadeh, M., Abtahi, S.M. & Zadhoush, A. A Simple Review of Soil Reinforcement by using Natural and Synthetic Fibers." Construction and Building Materials 30 (2012): 100-16.
[7] Anagnostopoulos, C. a. et al. Shear Strength of Sands Reinforced with Polypropylene Fibers. Geotechnical and Geological Engineering, 2013, 31(2), pp.401–423.
[8] Gray, D.H. & Ohashi, H. Mechanics of Fiber Reinforcement in Sand. Journal of Geotechnical Engineering, 109(3), 1983, pp.335–353.
[9] Sadek, S. et al., 2010. Shear Strength of Fiber-Reinforced Sands. , (March), pp.490–499.
[10] Shao, W. et al. Experimental Investigation of Mechanical Properties of Sands Reinforced with Discrete Randomly Distributed Fiber. Geotechnical and Geological Engineering, 32(4), 2014, pp.901–910.
[11] Yetimoglu, T. & Salbas, O. A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotextiles and Geomembranes, 21(2), 2003, pp.103–110.

EARTHEN PANELS – QUALITY CONTROL FOR AN INDUSTRIALLY PREFABRICATED BUILDING COMPONENT MADE OF NATURAL RAW MATERIALS

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Introduction

In the past few years, the share of earthen building materials used in constructions in Central Europe has increased. That is due to growing acknowledgement of its qualities regarding balancing of humidity, absorption of odours and acoustical insulation.

To regulate these (mostly indoor) uses, the German Institute for Standardization (DIN) has published norms for adobe [1], earth mortar for masonry [2] and earth plaster [3]. In addition to these traditional building materials, earthen panels have been developed. As an ecological alternative to gypsum plaster boards, they combine climatic advantages of traditional materials with economic advantages of industrial processing, i.e. prefabrication and drywall techniques. Earthen panels are a composite layered material, comparable to Textile Reinforced Concrete (TRC). Most products contain an inner layer of reed tubes which improve the tensile strength and reduce the weight. Often, one or both surfaces are reinforced with a fibrous net to prevent cracks in the plastering that is usually applied on top. Additives range from straw to expanded clay. Special panels contain waxes that improve their heat storage capacity or water pipes to allow the usage as flat heating and cooling systems.

Test programme

The product development, however, is still a work in progress. Several cases of cracks and other damages have shown a need for quality control and a lack of knowledge and experience. Therefore, the BAM Federal Institute for Materials Research and Testing and the German producer Conluto have launched the project "Standard Board" supported by the German Association for Building with Earth (DVL). Its aim is to create a basis for another DIN standard that defines requirements of earthen panels. Special panels as mentioned above are going to be subject of this new standard as well, but without consideration of their special qualities. The test programme has been designed following the testing of comparable materials as gypsum plaster boards, wooden panels etc. It is designed to ensure that panels meet with the requirements related to the limit state of usability as defined in DIN 1055 [4]:

- Distortions and shifts that disturb the effective usage, damage not load-bearing parts or change the appearance
- Vibrations that cause discomfort, damage the construction or reduce its usability
- Damages (including cracks) that prospectively will impair the operability, durance or appearance of the construction
- Visible damages caused by material fatigue or other time-dependent effects

Currently the programme includes tests to estimate:

- Dimensional accuracy and stability
- Bending tensile strength
- Resistance to horizontal loads
- Resistance to impacts caused by soft or hard bodies
- Tensile surface strength and/or surface hardness
- Length variation caused by humidity changes, absorption of water vapour
- Reaction to contact with water

The latter is going to be one of the main issues. Earthen panels with certain humidity that dry faster on one surface than on the other one may cup during the drying process, thus causing cracks. In analogy to gypsum plaster boards it will be unavoidable to define a maximum for shrinkage strain in accordance to the environmental temperature and a maximum distance for joint gaps.

Preliminary Results

Dimensional accuracy

The accuracy of length, width and angular dimensions is very high, with a maximum variance of 0.3 mm from the nominal size of 62.5 cm. Nevertheless, large divergences of thickness have been measured. Measurements have been taken on every edge of 5 panels and led to differences form -2 mm to +5 mm from the nominal size (See Fig. 1). In this case, high differences of adjacent panels fixed to a substructure would add up to more than 7 mm. Thus, the maximum plaster thickness of 4 or 5 mm recommended by most manufacturers could not be abided.

The requirement of a maximum plaster height is explained by the necessity of controlling the quantity of water that enters from the fresh plaster into the panel and is therefore an important matter in terms of quality control. That is why the reason for this high variation and a solution are urgent issues. The reason may be found in an inappropriate production process, which will be investigated in a subsequent phase of the project. Should it not be possible to ensure a maximum variety of 2-3 mm, either different instructions concerning type and thickness of earth plaster applied on the surfaces, mechanical equalization techniques or a combination of both must be introduced.

Tensile surface strength

To determine the tensile strength of the surface, steel cylinders with a diameter of 50 mm were glued with an epoxy resin on the earthen panels and then pulled off. The results cover a very large range from approx. 150 to 300 N/mm². The scattered results are probably due to the inhomogeneity of the material and the large mesh size of the reinforcement net or the position of the reinforcement net in the cross section of the panels.

The test results however have led to another observation. Areas with average ultimate loads larger or smaller than 200 N are located on different areas of the panels. The reason of this asymmetry may lie in the fabrication process and will be further investigated.

Humidity-induced length variation

Cracks in a plaster, caused by humidity-induced deformation of panels are the most frequent damage claimed by customers. The large vapour adsorption capacity of earthen materials is on one hand one of its most advertised features, but on the other hand leads to the mentioned damage as the deformation of the panels is directly proportional to the vapour adsorption.

To investigate this phenomenon, samples of 160 mm x 40 mm have been suspended to a climate of changing relative humidity. With a start value of 23 °C and 50% RH, the relative humidity has been increased to 80% and then decreased to 30%, each step starting after mass equilibrium had been reached.

First results show an expansion up to approx. 0.3 mm/m, larger values are to be expected because of the quality range of available products. This means that panels with a length of 1.25 m can show plaster cracks in the joints with a width of 0.3 mm which are clearly visible to the human eye.

It is possible that the application of reinforced plasters reduces that effect. Still, there is need for additional, more reliable solutions. The proceeding of the project may lead to more satisfying approaches.

Conclusions

The introduction of the new DIN standard will bring several advantages not only to planers and manufacturers but also to craftspeople. While nowadays the earth building industry enjoys many liberties but lacks quality control, regimentation will establish a compulsory minimum standard and thus ensure quality and competitiveness. This development - as it is attended with additional costs for quality surveillance tests - is not welcome to all who are concerned but presents the only opportunity to establish earthen building materials as a serious alternative to conventional products on a highly regulated market. But presently there is a need for further, more intense and detailed investigations. This project offers the opportunity not only to meet with the aims of reaching the comparability between earth panels and other panels but also to extend the understanding of the panels system as well.

Figures and tables

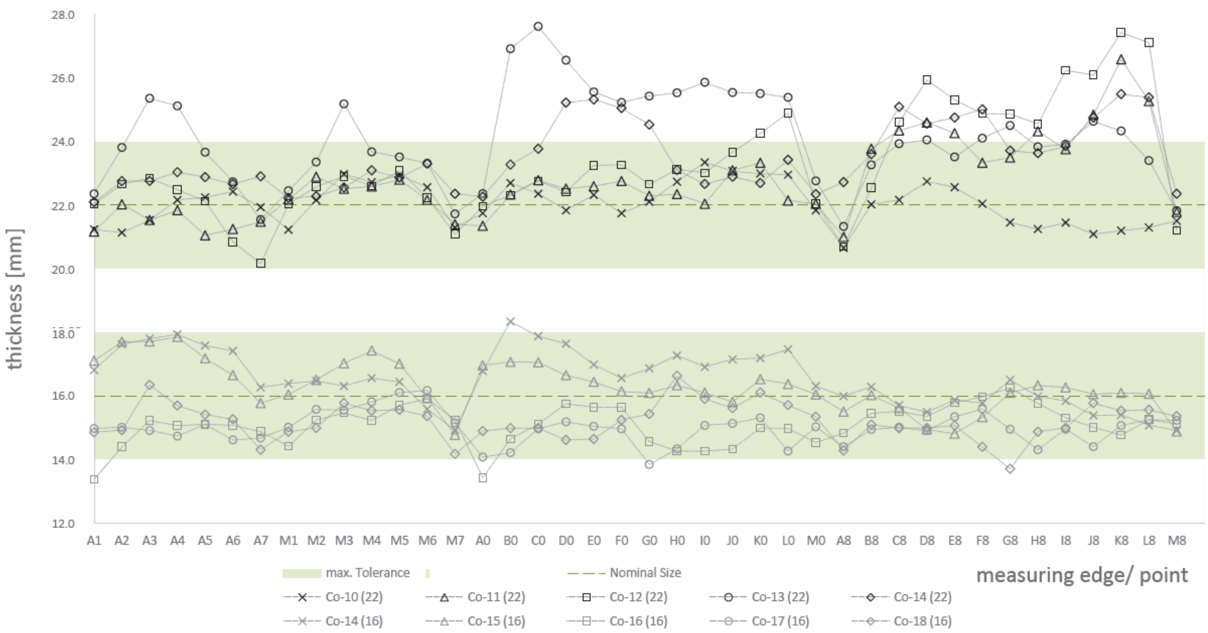

Figure 1: Thickness variation in contrast to nominal size and maximum tolerance defined by producer.

References

[1] DIN 18945: Earth blocks – Terms and definitions, requirements, test methods: 2013.

[2] DIN 18946: Earth masonry mortar - Terms and definitions, requirements, test methods: 2013.

[3] DIN 18947: Earth plasters – Terms and definitions, requirements, test methods: 2013.

[4] DIN 1055-100: Actions on structures. Part 100: Basis of design, safety concept and design rules: 2001, p. 26.

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