RELEVANCE of STAR 266-MRP

Properties of fresh concrete are regularly prescribed, especially for specialty concrete mixtures. Fresh concrete properties need to be tailored in order to fulfill requirements related to transportation, placement, consolidation and finishing. Although empirical test methods are continuously developed, they lack the fundamental aspects of science; a more fundamental approach is essential to fully measure, predict and control fresh properties and placement processes. With the aim of collecting the state-of-the-art knowledge on the measurement of rheological properties of complex materials such as concrete, the Committee 266-MRP *Measuring Rheological Properties of Cement-based Materials* was formed in 2015; STAR 266-MRP was published in 2023.

STAR in a nutshell 266-MRP
"Measuring Rheological Properties of Cement-based Materials"

Overview

Typically, rheology classifies materials as elastic, viscous, viscoplastic or viscoelastic. While concrete, and any cement-based material, can technically be described by each of these states, the focus of this STAR is on the viscous/viscoplastic response. This report is focused on the rheometry of concrete and mortar and it excludes cement pastes; instead, a separate contribution in RILEM Technical Letters was published on rheometry of cement pastes [1]. This STAR does not discuss how to relate mix design and rheology, and which range of rheological properties are best for specific applications. This report does not provide recommendations on how to measure rheological properties, but it rather delivers a comprehensive overview of:

- Rheology definitions, behavior, and parameters
- Rheometers
- Measuring and analysis procedures
- Difficulties and challenges during measurements
- Relationships with specific empirical tests
- Behavior of concrete near a surface.

Rheology definitions, behavior, and parameters

Rheometers offer enormous potentials for material developments and quality control on site. However, their use also demands for a higher level of understanding of the flow phenomena. The rheological behavior is in most cases described by a linear relationship between shear stress and shear rate; accurate models exist to fit the linear flow curve of mortar or concrete. In more exceptional circumstances though, non-linearity in the flow curve can be observed, and both shear-thinning and shear-thickening have been reported. This chapter presents several different rheological models, and it explains how basic rheological effects are linked to flow phenomena in cementitious systems.

Rheometers

In this chapter, four types of rheometers are presented: 1) the free flow rheometers for which the flow are induced by gravity (i.e. monitored slump or spread flow); 2) the rotational rheometers which are the most used and directly refers to conventional rheometry (i.e. concentric cylinders and plate-plate rheometers); 3) the confined flow rheometers that can be useful for no slump concretes (i.e. capillary extrusion and squeeze flow); 4) the static rheometers where shear is induced by the concrete own settlement and deformation (i.e. the plate test geometry). This rheometers review shows that there is a large range of devices able to capture and describe a part of, or the entire rheological behavior of concrete mixtures. However, each rheometer is typically dedicated to the measurement of specific parameters, it is suitable for a certain range of concrete consistencies, and it has to be chosen in relation to the targeted parameters and measured concrete type.

Measuring and analysis procedures

The most appropriate way to study the rheological behavior of cementitious paste is to determine the relationships between shear stress and shear rate, referred to as the flow curve. However, none of the rheometers measure directly shear stress and shear rate. Instead, torque or force, linear or rotational velocity measurements are registered and transformed into shear stress and shear rate values. Various mathematical models exist to adequately describe the flow curve of cement-based materials. This chapter presents a summary of some measuring systems including, but not limited to, the concentric cylinders, cone-plate (even if this geometry has not been applied at the concrete scale), plate-plate, and vane geometries, as well as uniaxial compression (squeeze flow rheometer). For all these, a special focus on the generated flow and governing equations is provided. The second part of this chapter deals with the measurement of viscoplastic properties, i.e. flow curves and static yield stress, of cement-based materials.

Difficulties and challenges during measurements

This chapter describes some measurement artefacts, and ways to avoid or minimize the impact of these artefacts on test results. If mortar or concrete behave as a granular material, one is more suited to refer to squeeze flow and penetration test; if they behave as suspension, rotational rheometry can be applied. In case of suspension flows, one can adjust the rheometer, the measuring, and interpretation procedure to avoid the effects of:

- non-equilibrium, causing apparent shear-thickening behavior
- plug flow, under-estimating yield stress and over-estimating viscosity
- the selected data transformation procedure and rheological model, altering the rheological values
- pressure, as the assumed shearing behavior is not fully satisfied
- slippage, due to a lack of roughness that invalidates the measurement.

Other challenges are represented by *i*) gravity and shear-induced particle migration, rendering the sample non-homogeneous, both for dynamic and static measurements and *ii*) heat of vaporization, changing the temperature of the sample. The main protective action is to limit the exposure of the sample to shearing.

A last effect, difficult to control, is the air content and air-void distribution of the material which can have a tremendous, and variable, effect on the rheological properties.

There is no one-fits-all procedure for rheological measurements, but procedures should be adapted based on the descriptions in this chapter and in this report overall.

Relationships with specific empirical tests

The mathematical equations that correlate the responses from some of the main empirical test methods (slump, slump flow, V-funnel, L-box, LCPC-box, portable vane and inclined plane) for mortar and concrete, and their rheological parameters (including static and dynamic yield stress, viscosity, and structural build-up) are discussed in this chapter. The most important drawbacks of these empirical test methods are identified as:

- Limited applicability - by mixture designs, rheological characteristics, and application areas.
- Human influence, i.e. executor's errors.
- Difficulties in achieving correct test sut-up conditions, especially on-site.

Some observations on the squeeze and penetratuion tests for extrusion and 3DP are also presented.

One last discussion is dedicated to the main test methods used to monitor the output of the concrete mixing truck, by adjusting the load imposed on the drive motor in Watt or the hydraulic pressure needed to turn the drum, and the correlations between these methods and rheological parameters. Truck mixers can also be equipped with certain sensors that predict rheological properties of concrete by analyzing the measured force acting on an internal probe or the hydraulic pressure during the rotation of the drum at various rotation speeds.

Behavior of concrete near a surface

The tribometer, a tool designed to investigate the friction of fresh concrete against different types of surfaces, measures tribological quantities such as friction coefficient, friction force, lubrication (release agent application) and wear between two surfaces. It is used to understand the direct contact between pressure-driven concrete and the inner pipe wall of a pipe, but it does not characterize the deformation behavior of concrete in the vicinity of the wall. In this chapter, an overview of two devices, tribometers and interface rheometers, is given in tabular form, including the field of study, principles, test parameters and references.

The interface rheometers allow a better understanding of the lubricating layer between the wall and the actual concrete by providing magnitudes for the interface yield stress and viscosity. The results of tribometers are of importance for the realistic prediction of formwork pressure.

Concluding remarks

Measuring the rheological properties of mortar and concrete is not a straightforward task. STAR 266-MRP is a document created to help the reader in understanding the applicable concepts of rheology, in describing the availability of different tools for homogeneous and heterogeneous materials characterization, in discussing measurement procedures and challenges, as well as providing equations and models to derive rheological values from other tests.

RELATED DOCUMENTS:

1. Feys, D.; Cepuritis, R.; Jacobsen, S., *et al*. Measuring Rheological Properties of Cement Pastes: Most Common Techniques, Procedures and Challenges. *RILEM Tech Lett* **2**, 129-135 (2017).
2. Feys, D., Sonebi, M., Amziane, S. *et al*. RILEM TC 266-MRP: round-robin rheological tests on high performance mortar and concrete with adapted rheology—rheometers, mixtures and procedures. *Mater Struct* **56**, 90 (2023).
3. Feys, D., Keller, H., El Cheikh, K., *et al.* RILEM TC 266-MRP: round-robin rheological tests on high performance mortar and concrete with adapted rheology—a comprehensive flow curve analysis. *Mater Struct* **56**, 105 (2023).
4. Amziane, S., Khayat, K., Sonebi, M., *et al.* RILEM TC 266-MRP: Round-Robin rheological tests on high performance mortar and concrete with adapted rheology—evaluating structural build-up at rest of mortar and concrete. *Mater Struct* **56**, 150 (2023).
5. Yahia, A., Perrot, A., Feys, D., *et al*. Viscoelastic Properties of Fresh Cement Paste: Measuring Procedures and Influencing Parameters. *RILEM Tech Lett*, **8**, 23-30 (2023).
6. Mikhalev, D., Fakhrayee Nejad, S., Ng, S., *et al.* Practical Insights and Advances in Concrete Pumping. *RILEM Tech Lett*, **9**, 1-9 (2024).