Influence of Tack Speed on The Rheological Properties of Mortar in Fresh State

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***Abstract*-In the present work, squeeze flow techniques were used to investigate the influence of tack speed to the rheological properties of mortar in fresh sate, including yield stress and extensional viscosity. The tested samples were prepared under similar conditions of room temperature and atmospheric pressure. Compositions of mortars were tested at two different squeezing rates (20 and 200mm/s) 15min after mixing. The results indicate that mortar's yield stress increases with increasing pulling speed. This increase is evident at low tensile speeds. At high tack speeds, this increase is not obvious, especially in the case of high squeeze speed of 200mm/s. It can be concluded that the optimal speed for removing the mortar and the upper surface is lower than 20mm/s. The extensional viscosity of fresh mortars significantly decreases as the tack speed increases. Also, the elongation viscosity decreases as the gap increases. The increase of the gap during the tack experiment stimulates different units causing the observed decrease of the mortars' elongation viscosity.**

Keywords-squeeze flow technique; tack speed; fresh mortar

I. INTRODUCTION

The fresh state of a cement-based material corresponds to only a minor part of its lifetime, nevertheless, the behavior of the material within this frame has major consequences on its hardened properties. The currently applied methods for testing these materials during the fresh state are simple but limited. Flow table (ASTM-C1437, EN-1015-3) and dropping ball (BS-4551) methods investigate fresh mortar by using single point measurements [1]. These methods are unable to dissociate the contribution of the yield stress or the viscosity on the resulting measurements [1, 2]. In order to overcome the limitations of the traditional methods, rotational rheometers have been used, in which the mortar's rheological behavior and parameters such as yield stress and viscosity were determined in either shear stress or shear rate-controlled procedures [3, 4]. This technique is an important tool for controlling and developing cementitious materials formulations, including mortar, especially for the simulation of mixing and pumping. During the application, the mortar is spread over a substrate and then squeezed between bricks (masonry and tile adhesive mortar) or projected and spread over a surface for internal and external rendering purposes. The mortar fraction of a concrete mix is also squeezed locally between coarse aggregates during the flow of the fresh concrete [5]. Therefore, the rotational rheometry is not suitable in these cases. The behavior of the material after squeezing under different tack speeds provides important information of its rheological performance. The main objective of the current research was to investigate the influence of tack speed on the rheological properties of fresh mortar, including yield stress and extensional viscosity.

II. SQUEEZE FLOW EXPERIMENT

The squeeze test is widely used to determine the flow properties of highly viscous pastes (food, cosmetic, polymers, composites, ceramic pastes and others) [6-10], as it overcomes some of the common problems of conventional rheometry such as slip, disruption of plastic materials, and the difficulty to load very thick and fiber-containing fluids in rotational devices [5].

Fig. 1. A squeezing experiment of mortar in process.

Squeezing technique characterizes cementitious materials by compressing a cylindrical specimen between two parallel surfaces by controlled force or displacement rate. This method has been used for characterizing the rheological behavior of cement pastes [11], Herschel Bulkley fluids [12], Bingham plastic [13], etc. The typical load versus displacement profile of a constant velocity squeeze flow experiment was determined in [11] and it is used to determine the rheological parameters of

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testing materials, including yield stress and viscosity. Direct measurements of yield stress are uniquely performed by stress-controlled rheometry [3, 4]. Squeeze flow tests carried out with constant displacement velocity do not allow such direct measurements [5] since the material flow occurs regardless of the existence of the material yield stress, unless the force required to overcome this value exceeds the load limit of the testing device. In the current study, the testing material was firstly compressed/squeezed between two parallel surfaces until a predefined thickness, followed by a relaxation period of 1.5min, and the surfaces were finally separated with a predefined tack velocity (Figure 1). A typical curve of squeeze-tack experiment is presented in Figure 2 of [14], in which three periods can be observed, compression, relaxation and traction.

It is possible to conduct indirect yield stress determination by the extrapolation of the flow curves in the squeeze stage of the experiment. The yield stress is calculated by dividing the maximum force recorded by the area at that time:

$$\sigma_s = \frac{F_s^{max}}{A_s} \quad (1)$$

in which A_s is the average area of the testing sample at the moment that the recorded load is max:

$$A_s = \frac{V}{h'} = \frac{\pi R^2 h}{h'} \quad (2)$$

where h is the predefine thickness of the test mortar, R is the radius of the sample and h' is the mortar's thickness at the moment of the maximum tack force.

During the third stage of the squeeze flow experiments conducted with a constant upward velocity of the upper plate, the sample height increased linearly, as:

$$h = h_0 + vt \quad (3)$$

where h is the momentary height of the sample, h_0 is the initial sample height at the beginning of the tack step, v is the tack speed of the upper plate and t is the time elapsed after the beginning of the tack period [6].

The biaxial extensional strain rate or elongational strain rate is equal to one-half the vertical Hencky strain rate [6]:

$$\dot{\varepsilon}_B = \frac{\dot{\varepsilon}_H}{2} = \frac{v}{(2h)} \quad (3)$$

The extensional viscosity (η_B) is defined as the ratio between the biaxial extensional stress (σ_B), which is calculated by (1), and the extensional strain rate:

$$\eta_B = \frac{\sigma_B}{\dot{\varepsilon}_B} = 2L\left[\frac{h+(vt)}{v\pi R^2}\right] \quad (4)$$

where L is the load and R is the radius of the sample [6].

III. Experimental Set-up

The material used in this investigation is referenced in [5, 15]. The detailed composition of the tested material is presented in Table I. In order to minimize the effect of sand grading on the rheological properties of concrete, strict grading, normalized CEN 196-1 sand, was used. This is European standard sand (ISO 679), which is very clean, with particles of the same size and round shape. It is dried, screened and prepared in a factory, ensuring quality and consistency, packed in bags containing 1350 ± 5g. Walocel™ MKX 70000 PP01 hydroxyethyl methyl cellulose has been added in the composition of mortar with fixed percentage of dry mixture (0.5%). It is characterized by well-balanced properties, including open time, adhesion, and shear strength, adds good workability and enhances water retention. The selected particle size distribution provides quick, lump-free dissolution. It is compatible with all conventional mineral and organic binders. For evaluating the influence of the squeezing rate to the yield stress of the mortar, the testing samples were squeezed at 20 and 200mm/s speed. After the relaxation time, the testing samples were pulled out at different speeds. By analyzing the recorded flow curves during the experiments, the variation of the yield stress of the testing material can be calculated. The height of the sample should be at least 10 times greater than the maximum particle size in order to avoid wall effects [5]. Hence, the predefined thickness of the testing material is taken as 3.5mm.

TABLE I. MATERIAL'S COMPOSITION

Constituents	White cement	Normalized sand	MKX 70000 PP01	Water
% wt. of dry mixture	30	70	0.5	25

IV. Results and Discussion

A typical flow curve obtained in the squeeze tack experiment is presented in Figure 2. The maximum calculated stress is considered as the yield value of the material. From the flow curves, the value F_{max} is recorded and given in Table II. The yield stress of the materials is calculated (1) and is presented in Table III.

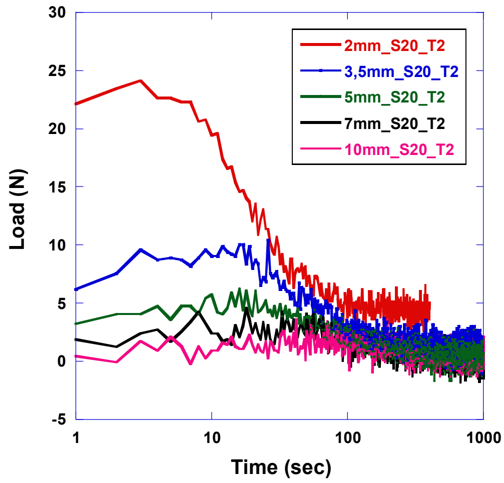

Fig. 2. A typical curve obtained in the tack period of squeeze flow test.

TABLE II. RECORDED MAXIMUM LOAD)

	Traction velocity		
	V_t=2mm/s	V_t=20mm/s	V_t=200mm/s
Squeeze velocity V_s=20mm/s	8.5604	14.603	25.513
Squeeze velocity V_s=200mm/s	8.0569	14.771	18.128

TABLE III. YIELD STRESS OF TESTING MATERIALS

Squeeze – Tack velocity	S20 T2	S20 T20	S20 T200	S200 T2	S200 T20	S200 T200
Yield value	0.0045	0.0068	0.01156	0.00367	0.0067	0.0079

The variation of mortars' yield stress in tension versus the tack velocity is plotted in Figure 3 for two values of squeeze speed, 20mm/s and 200mm/s. It can be seen that at a constant squeeze velocity, the mortar's yield stress increases with the increase of pulling speed. This increase is evident at low tensile speeds (2mm/s and 20mm/s). At high tack speed of 20mm/s, this increase is not obvious, especially in the case of high squeeze speed of 200mm/s. The result indicates that the optima speed for removing the mortar and the upper surface (masonry bricks, tiles adhesive, etc.) is lower than 20mm/s.

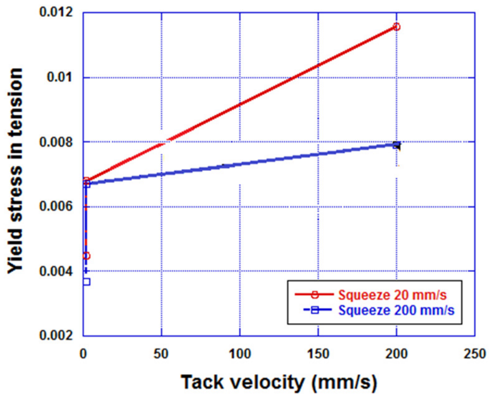

Fig. 3. Yield stress in tension of mortars versus tack velocity at different squeeze speeds.

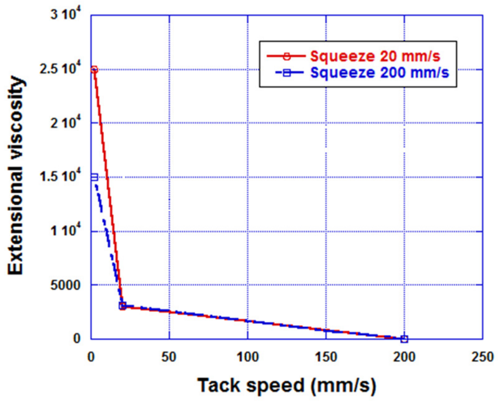

Fig. 4. Extensional viscosity of mortars versus tack speed.

The behavior of mortars' extensional viscosity versus the tack speed is represented in Figure 4. The interpretation of viscosity results obtained by squeeze flow must consider that, although the squeeze velocity remains constant (20 and 200mm/s), the extensional viscosity of fresh mortars significantly decrease as the tack speed increases. Similar observations were recorded at different experiments with squeeze speeds of 20mm/s and 200mm/s. Elongation viscosity values decreased as a result of gap increasing for all the tested samples. Furthermore, unlike in rotational rheometry, where the gap is constant and the decrease of viscosity with the strain rate in fact represents shrinkage, the increase of the gap during the tack experiment stimulates different units (grains getting far apart to each other) causing the observed decrease of the mortars' elongation viscosity. This finding is similar to the findings in [4].

V. CONCLUSIONS

The squeeze flow is a simple and versatile method for the rheological characterization of mortars in a wide range of consistencies, providing important information of the rheological behavior of materials in practical applications. From the obtained flow curves from the squeeze tack experiments, the rheological parameters, including yield stress in tension and mortar's extensional viscosity, have been investigated. The results indicate that mortar's yield stress increases with increasing pulling speed. This increase is evident at low tensile speed values. At high tack speed, this increase is not obvious, especially in the high squeeze speed of 200mm/s. It can be concluded that the optima speed for removing the mortar and the upper surface (masonry bricks, tiles adhesive, etc) is lower than 20mm/s. The extensional viscosity of fresh mortars significantly decreases as the tack speed increases. Elongation viscosity values decreased as a result of increasing gap. The increase of the gap during tack experiment stimulates different units (grains getting far apart to each other) causing the observed decrease of the mortars' elongation viscosity.

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