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A Vane Rheometer for Fresh Mortar: Development and Validation

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Abstract:
This paper presents the development of a vane rheometer to estimate mortar plastic viscosity and yield stress. The rheological parameters were developed from measurements using a procedure to convert the vane torque and rotational velocity data into shear stress versus shear rate relationships. The used procedure considered the locally sheared material as a Bingham fluid and computed the characteristic shear rate from Couette analogy. The apparatus was tested with three experimental programs in which many rheological parameters of mortar compositions were calculated. The obtained results validated the rheometer test procedure and confirmed that the test results are reproducible.

Key words:
mortar, rheology, plastic viscosity, yield stress, vane rheometer

1 INTRODUCTION

Rheology is the study of material flow, or deformation, under stress. Nowadays, along with the latest development of the construction technique using cementitious materials (concrete and mortar), understanding the rheological behavior of cementitious materials is also very important. Rheology can be applied to describe the ease in which mortar or concrete can be used in the fresh state, including workability, placeability, compactability, finishability, flowability, pumpability and extrudability. In this paper, the rheological behavior of the fresh concrete and mortar is considered similar to that of Bingham fluids [1–9], which is given by:

$$\tau = \tau_o + \mu\dot{\gamma} \quad (1)$$

where τ_o (Pa) is the Bingham yield stress, describing the stress needed to initiate flow, μ (Pas) is the Bingham plastic viscosity, which is the resistance of the material to flow, and τ (Pa) and $\dot{\gamma}$ (1/s) are the shear stress and shear rate, respectively.

The rheological parameters (yield stress and plastic viscosity) of the materials are measured by rheometers. Currently, there are two types of rheometers. The first type is for concrete such as the IBB and Two-Point [10, 11], coaxial as the BML and CEMAGREF-IMG [12, 13], the rheometer developed at the University of Illinois at Urbana-Champaign [14], the vane rheometer as reported in [15–22] which can be fitted with hydraulic pressure transducers and Haake RS150 rheometer for mortar with very fine sand. Another vane apparatus was recently developed by Khayat et al. [23] to evaluate in situ shear strength (yield stress) of clay soils and mortar. The second type is a parallel plate type as the BTRHEOM rheometer [24]. Nowadays, with the development of new mortars and new techniques such as pumping and spraying, the control of rheological behavior of mortars is crucial on construction sites. In this paper, the authors present the development and validation of a vane rheometer to estimate the rheological parameters of mortar at steady-state. The developed rheometer aims to meet the industrial requirements "allowing mobility, simple on-site usage and good precision without having parasitic frictions at a reasonable cost".

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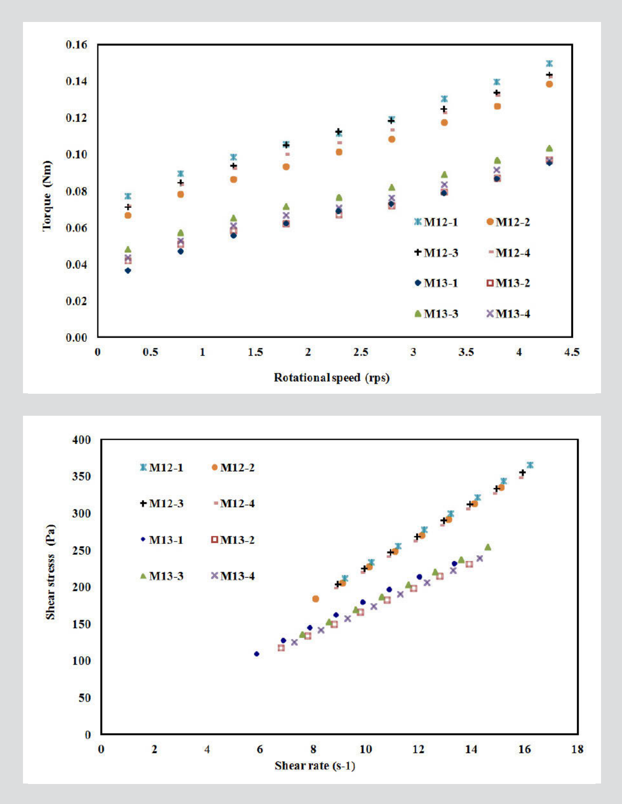

Figure 13: (a) Variation of torque with rotational speed and (b) variation of shear stress with shear rate of the 2nd program for mortars 1 and 2.

The shear rate $\dot{\gamma}_i$ corresponding to the rotation speed Ω_j ($i = j$) can thus be calculated:

$$\dot{\gamma}_i = max\left(\dot{\gamma}_{1j};\dot{\gamma}_{2j}\right) \text{ where } i = j \text{ and } j = \overline{1,n} \tag{8}$$

Once the shear rate has been estimated by Equation 8, it is deemed to correspond to the following wall shear stress:

$$\tau_i = \frac{1}{2}\left(\tau_j + \tau_{j+1}\right) \text{ where } \tau_{j\ or\ j+1} = \frac{M_{j\ or\ j+1}}{2\pi h R_b^2}\ ;\ i = j \text{ and } j = \overline{1,n} \tag{9}$$

where $M_{j\ or\ j+1}$ is calculated by Equation 3. Equations 8 and 9 allow drawing the shear stress curves τ (Pa) according to the shear rate $\dot{\gamma}$ (1/s) and estimating then the rheological parameters τ_0 and μ.

3 VALIDATION OF THE RHEOMETER

After choosing the final version and defining the rheometer test procedure, two experimental programs were carried out. Details of these programs are presented in the following section: The first program aims to determine whether or not the rheometer test procedure allows differentiating the rheological parameters of different mortar compositions. The tested mortar compositions in this program are presented in Table 2.

Mortar	W/C	V_{paste} (m^3)	Cement (Kg)	Water (Kg)	SP (%)	Sand 0/4 (Kg)	Spread flow (cm)
M4	0.4	0.434	600	240	0.3	1526	21
M5		0.470	650	260	0.3	1430	32
M6		0.506	700	280	0.3	1334	40
M7		0.542	750	300	0.3	1238	45
M8	0.50	0.490	600	300	0	1366	39
M9	0.45		640	288	0.3	1364	36
M10	0.40		683	273.2	0.5	1367	41
M11	0.35		735	257.25	0.7	1365	36

Table 2: Mortars composition of the 1st program.

Mortar	W/C	V_{paste} (m^3)	Cement (Kg)	Water (Kg)	SP (%)	Sand 0/4 (Kg)	Slump (cm)
M12	0.5	0.45	550	225	0.8	1423	7
M13	0.5	0.45	550	225	1	1423	11

Table 3: Mortars composition of the 2nd program.

Rheological parameters	Test 1	Test 2	Test 3	Test 4	Standard deviation	Variation coefficient
Mortar 12						
Yield stress (Pa)	10.98	10.77	10.86	10.71	0.12	**0.01**
Plastique viscosity (Pa.s)	21.97	21.54	21.73	21.42	0.24	**0.01**
Mortar 13						
Yield stress (Pa)	15.16	9.53	8.44	8.11	3.29	**0.32**
Plastique viscosity (Pa.s)	16.59	16.06	16.89	16.23	0.37	**0.02**

Table 4: Variation coefficients of the rheological parameters calculated from the repetitive tests.

The second program aims to verify whether the obtained rheological measurements are repetitive and stable with the same mortar composition. Table 3, summarizes the tested mortar composition of this program.

3.1 PROGRAM 1

The used sand size range was 0/4 with a density of 2.5. The cement was CEM I 52.5 type and a modified polycarboxylate based superplasticiser was used. Figures 11 and 12 show the variation of torques with the speed of rotation and the evolution of the shear stress with shear rate for each tested mortar. The results show that the tested mortars behave as Bingham materials (Figures 11 and 12) and the test can differentiate the rheological behavior of different mortars. When the paste volume decreases, the viscosity and yield stress of the mortar increase (Figure 11). This is due to the fact that the paste serves as a lubricant between the sand particles and when it decreases, the maximum distance between the particles decreases and the friction between the components of the mortar increases. The decrease in the W/C causes an increase in the plastic viscosity and also in the yield stress (Figure 12). This is explained by the fact of having the same amount of paste but with a decreasing consistency mortar flow becomes more difficult.

3.2 PROGRAM 2

The sand size range used was 0/4 with a density of 2.5. The cement used was CEM I 52.5 type and a polycarbo-

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xylic ether based superplasticiser was used. In the second program, repetitive tests were carried out in order to check the results' stability over time with the same mortar compositions. In this program, each mortar was made 4 times and tested with the rheometer at the same age. Figure 13 represents the obtained results and shows that the rheometer produced reliable results when measuring shear stress of the same mortar at the same age. The variation coefficient of the rheological parameters is very small (lower than 0.02) as seen in Table 4. The results shown in the table confirm the repeatability of the tests.

4 CONCLUSIONS

In this study, the authors developed a reliable rheometer to characterize the rheological parameters of mortar. The rheometer is compact, easy to use and convenient to carry to the construction and building sites. The results of this study showed the significant influence of the parasite friction on the rheological measurements. In order to minimize this influence, the authors proposed a test procedure adapted to the rheometer. After defining the test procedure, two experimental programs were carried out to validate the tests. The results of the first program showed that the obtained tests measurements allow distinguishing clearly the rheological parameters of different mortar compositions. The tests results also confirmed the assumption that the rheological behavior of mortar is similar to that of Bingham fluids. The results of the last program showed that the rheometer produced reliable results when measuring shear stress of the same mortar over a period of time. The variation coefficient of the rheological parameters is very small hence confirming the repeatability of the tests.

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