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Study of the laboratory Vane test on mortars

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Abstract

The Vane method (Vane test) is a simple but efficient method to measure the yield stress among other properties of non-Newtonian fluids. These fluids exhibit big flow effects in flat surfaces which are common in rheometers devices of different types (parallel disk or coaxial cylinder types). The yield stress values obtained with Vane method, in pastes, gels, soils and concentrated suspensions, have presented good agreement with results found elsewhere by most of the rheologic methods shown in the literature. The aim of this work is presenting a discussion on the capabilities of the Vane method, highlighting the theoretical basis, the functioning principle with some operational particularities, and some applications of the method in investigating the properties of fresh rendering mortars.

Works of several authors that used the same method for fresh mortars were reviewed and experimental results of tests done by the authors of this paper using the method are also presented and discussed, focusing on the desirable workability for mortars.

The Vane test method is an important tool in studying rheological properties in freshly applied mortar. It is able to define clear conditions in the applying of this material.

Keywords: Rendering mortar; Workability; Rheology; Vane test

1. Introduction

The study of fresh mortar properties is of great interest for researchers and engineers because this material is applied in this situation. This approach holds a certain complexity in accordance with the several factors to be considered and outlined in Table 1.

In field applications what stands out is the high level of empiricism regarding freshly set material. For example, it must be pointed out that in studying concrete, the consistency is the parameter for characterising potentially useful workable concrete mixes. This holds in spite of there being a number of different testing forms. For rendering mortars, the same concept proves difficult in characterising these materials under the same application conditions. Within this context, merely knowledge of consistency is insufficient in defining whether or not a mortar type is workable. At present, one of the most used ways for defining their characteristics is the empirical assessment made by masons having experience in handling and applying mortars.

Another relevant factor is that mortars are tested using tools that provide hardly representative results. For, these results are highly influenced by specific operational factors for each experiment. For example, there is the flow table test. This provides as a result the mean diameter after the application of a specific number of vertical impacts in the test sample (according to the procedure described in NBR 13276/95 [1] and ASTM C1437/01 [2] standards). It is more and more commonly agreed among specialists that this type of testing produces insufficient results to define the workability condition for a specific type of mortar.

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The Vane test has proven to be a simple but effective method in measuring non-Newtonian fluid properties since they have a flow on smooth surfaces and are common in devices used in different types of rheometers (parallel disc rheometers or coaxial cylinders). The value of the yield stress obtained by the Vane test coincides to a great extent with the majority of currently available rheological methods [3,4]. All the same, it is obvious that determining rheological parameters (such as yield stress and viscosity) is not a simple task, especially when it comes to concentrated suspensions, as is the case with concretes and mortars. Within this context, most of the existing methods are limited in their applications. Thus, for the same material, it is common to find variations in values dependent on the experiment conditions adopted [1]. This affirmation is shown in Table 2 in which there is considerable variation in yield stress and viscosity results, obtained from different rheometers [5].

The Vane test is a tool that has been used in rheology studies of material in different fields. This method has been highly developed in soil mechanics and it is used to determine a parameter defined as ‘‘undrained shear stress soils’’. In recent years, with the development of instrumentation techniques, geared especially towards rheometry, these techniques have become more diffused and so are used in the study of foods, concentrated suspensions, polymers, among others. In the study of construction materials, it is possible to find research in which the Vane test is used to characterise concrete and mortars. For instance, in work conducted by Austin [6], Alves [7] and Santos [8], this method was applied to assess fresh mortar consistency. Alves [7] defined yield stress values as that characterised the consistency of specific mortars, having air entraining admixtures. Santos [8] used the same equipment and here a minimum yield stress value was found in pumpability of sprayed mortars.

Table 1
Influential factors in mortar workability

Internal factors	The water content is defined in many instances according to the consistency required. Agglomerate and aggregate ratio. Granulometric distribution, shape and texture of aggregate grains. Nature and ratio of additives (air entraining admixtures, water retention agents,…).
External factors	Type of transport. Type of application. Plastering operations. Characteristics of substrate—preparation, rugosity, absorption, etc.

Although some progress has been identified in the application of this method in the study of mortar, it still needs to be further explored given that there is a lack of methodological specificity regarding the definition of adequate experiment procedures for studying materials and for taking into account the distinct specificities. Given this scenario then, this study’s aim is to discuss parameters for a methodological framework, important operational issues as well as comparisons of experiment results obtained through different testing methodologies commonly applied in the study of fresh mortar. It is hoped that this study to contribute for research on other different types of mortars such as, repair mortar, adhesive mortar, among others.

2. Experimental details

2.1. Experimental theoretical basis

2.1.1. Methodological principles

The method concept involves basically inserting the Vane probe in a sample of the material to be tested (Fig. 1). Subsequently, the vane is turned slowly according to a

Table 2
Viscosity and yield stress, obtained through different rheometers [5]

Compositions	Types of rheometers available							
	BML		BTRHEOM		CEMAGREF-IMG		Two-point	
	τ_o (Pa)	μ (Pa/s)	τ_o (Pa)	μ (Pa/s)	τ_o (Pa)	μ (Pa/s)	τ_o (Pa)	μ (Pa/s)
1	738	114	1619	181	1832	—	919	61
2	76	17,4	406	18	437	3	80	13
3	408	82,4	771	136	—	—	314	83
4	840	72	2139	51	2138		1059	—
5	910	108	1753	94	—	—	698	19
6	139	45	505	78	487	63	145	41
7	90	32,7	549	54	410	43	98	38
8	717	29	1662	67	1417	—	689	22
9	125	15	624	25	504	3	159	19
10	248	35,9	740	50	535	43	253	19
11	442	29	1189	27	1034	21	516	16
12	584	39	1503	38	929	47	525	22

OBS.: τ_o—yield stress, μ—viscosity.

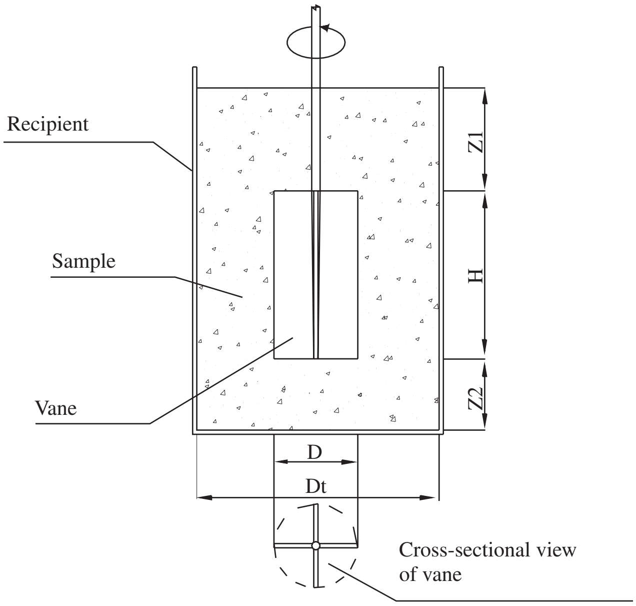

Fig. 1. Vane scheme and recipient used in the Vane test method (modified from [3]).

constant strain rate (constant angular velocity). The flow beginning is defined when the torque used reaches the maximum value and so causes shearing of the material in the area around the vane as illustrated in Fig. 1.

The maximum torque obtained in the experiment can be defined as the algebraic sum of shear stress exercised by the lateral area (T_s) and the vane's upper and lower area (T_e), as shown in Eq. (1).

$$T = T_s + 2T_e. \quad (1)$$

In terms of shear stress the torque is defined as

$$T = \left(\frac{\pi}{2} D^2 H\right)\tau_s + 2\left(2\pi \int_0^{D/2} \tau_e r^2 \, \mathrm{d}r\right), \quad (2)$$

where T is the torque, D is the diameter of the sheared cylinder, H is the height of the sheared cylinder, r is the radius of the sheared cylinder, τ_e is the shear stress in the upper and lower part of the cylinder and τ_s is the shear stress in the cylinder's lateral.

In order to calculate yield stress from the maximum torque, knowledge of the yield area geometry and distribution of shear stress on this surface are necessary. Given that τ_e is unknown, it is not possible to solve the second term of the Eq. (2). Thus, an approximation is adopted that is reasonable for small-diameter vanes. In this way, τ_e is distributed evenly over both surfaces and τ_e is equal to τ_s. Therefore, in the conventional approach used in soil mechanics, it is taken that material yield occurs along the cylindrical surface of the area $\pi D H + 2(\pi D^2/4)$, where D and H are the diameter and the height of the vane, respectively. Also, it is assumed that the shear stress is evenly distributed along the cylinder and is equal to the yield stress (τ_o) where the torque is a maximum (T_m). Given these considerations, a simple relation between τ_o, T_m and the vane dimensions (H and D) is obtained by Eq. (3):

$$T_m = \frac{\pi D^3}{2}\left(\frac{H}{D} + \frac{1}{3}\right)\tau_o, \quad (3)$$

where T_m is the torque maximum and τ_o is the yield stress.

If the rupture surface occurs in a region outside of the interface with the vane, it will not be possible to determine yield stress from that equation. In most cases, application of this formula has provided satisfactory yield stress results for low shear rates.

2.1.2. *Aspects of Vane test*

Measuring devices are developed from mechanical systems that use calibrated torsion springs, having rigidity constants adequate for each type of material, that is, defined basically in terms of the maximum rupture stress for each material (as seen in Figs. 2(a) and (c)). It is also possible to use more sophisticatedly equipped electric devices (torque transducers) that have been previously calibrated and are able to have their input and output data automated through a control and data acquisition system (Fig. 2(b)).

2.1.3. *Vane probe dimensions*

Another parameter that must be observed when defining vanes is to choose the smallest Vane probe dimension, this must be at least 20 times the maximum dimension characteristic of particles present in suspension (this is based upon test procedure recommendations in soils evaluation). This consideration must be followed in order to avoid important disturbances in the material during probe insertion in the sample as well as when defining the sheared surface so as to not influence the result.

2.1.4. *Recipient dimension*

Nguyen [3] recommends that recipient dimensions must adhere to the following ratios: Dt/D > 2.0, Z1/D > 1.0 and Z2/D > 0.5 (as shown in Fig. 1).

In studies conducted on rendering mortars in the Testing and Materials Laboratory at the Universidade de Brasília, major problems regarding the sheared region's position were not identified since the aforementioned relations were respected. In some cases in which these relations were not followed, dislocation of the strained region was observed in the mortar/recipient interface.

2.1.5. *Preparation of the test sample*

In testing rendering mortars, work conducted by Alves [7], serves as a reference in sample preparation. In this work, test material was placed in a cylindrical recipient and distributed in three equal layers, spading each layer 20 times with the spatula (15 × 20 mm) in one complete revolution around the inner surface of the sample. Although this procedure may cause some interference to the material's internal structure, it is a standard procedure, common in mortar testing, as is the case with the

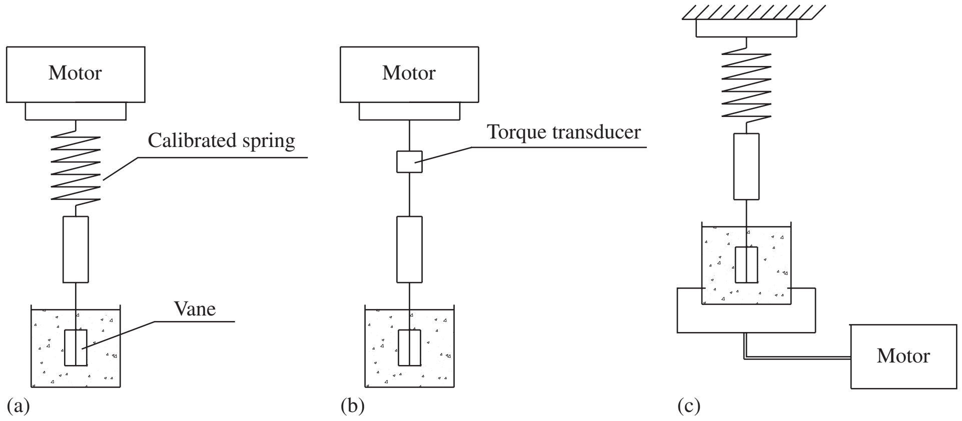

Fig. 2. Measuring bases used in Vane tester equipment (modified from [16]).

Table 3
Description of study series

Type		Consistency		Mortar composition (% mortar)		
		% Water	Cone penetration (mm)	% Cement	% Lime	% Sand
Mixed mortar (cement and lime)	AM-1	19.00	35	10	6	84
	AM-2	21.00	50	10	6	84
	AM-3	22.00	65	10	6	84
Pre-packaged	AI-1	15.00	35	—	—	—
	AI-2	16.00	50	—	—	—
	AI-3	18.60	65	—	—	—

procedures used in the tests to determine the consistency by cone penetration (ASTM C780-96 [9]).

2.1.6. Shear rate

It is recommended that the vane's rotation speed should be less than 10 rpm so as to avoid any influence on viscosity resistance and the instrument's inertia in maximum torque determination [10]. It is usual a velocity of 0.1 rpm (36 °/min) in many studies. It must be pointed out that in some preliminary studies developed by the authors of this paper, on rendering mortars at the Testing and Material Laboratory at the Universidade de Brasília, it was observed that in velocities between 30° and 90°/min, the maximum shear values did not undergo major alterations.

2.2. Experimental research

In this item an experimental study will be presented in which the aim was to study yield stress results obtained from the Vane test in comparison with commonly used methods in characterising fresh mortar, that is, the flow table (NBR 13276/95 [1] and ASTM C1437/01 [2]) and the cone penetration test (ASTM C780/96 [9]).

2.2.1. Study variables

In this study the following variables were defined:

- Types of rendering mortars—two different types of mortars were tested: a mortar of cement, hydrated lime and sand according to the ratio volume 1:1:6 (1:0,60:8,57 in mass), and a pre-packaged mortar. Both are commonly used in rendering production, the compositions of the mortar used are described in Table 3 and the physical characteristics in Table 4. These fresh state mortars were used given that they show different properties for the same workability when tested under different methods;
- Mortar consistency—each mortar was tested under three consistency conditions, defined according to the static cone penetration test (ASTM C780/96 [9]), which is: 35 mm, 50 mm and 65 mm. These values were established because they represent conditions in which the rendering mortars present suitable workability.

These variations sought to investigate initially how alterations to mortar composition as well as to their fresh state, can influence results obtained by different testing methods.

Table 4
Physical characteristics of aggregate use in AM mortar composition and pre-packaged AI mortar grading

Unit mass (g/cm^3)	Specific mass (g/cm^3)	Fineness modulus	Co-efficient uniformity
1.40	2.84	1.09	2.70

Aggregate grading											
Sieves (mm)	2.4	1.68	1.2	0.84	0.6	0.42	0.3	0.21	0.15	0.105	0.075
Cumulative percentage passed (%)	100	100	100	100	99	91	69	48	22	12	8
Pre-packaged mortar grading											
Sieves (mm)	2.4	1.68	1.2	0.84	0.6	0.42	0.3	0.21	0.15	0.105	0.075
Cumulative percentage passed (%)	100	100	100	92	84	72	59	43	26	20	14

Table 5
Operational specificities for vane test method employed

Characteristic	Equipment characteristics
Equipment measuring	Similar to the device presented in Fig. 2(a). Spring constant = 0.0231 kgf/cm/°
Vane	Vane with two lamina in cross form. Height = 50 mm and width = 25 mm
Recipient dimensions	Cylindrical recipient. Diameter = 100 mm and height = 100 mm
Sample preparation	After mixing the material, it was placed in the test recipient in three equal layers, each one spading 20 times with the spatula.
Shear rate	Angular velocity = 0.1 rpm

The procedure used during the study was following:

- Homogenisation of anhydrous materials, water addition and manual homogenisation using a spatula, mixing in planetary mortar mixer for a 1.5 min interval, bearing in mind that after the first 30 s mixing was interrupted and there was more manual homogenisation, using a spatula, after completing the mixture, the mortar was tested through the cone penetration test (ASTM C780/91 [9]), flow table (NBR 13276/95 [1]) and Vane test, mortars were still assessed in a fresh state during testing: mass density (NBR 13278/95 [11]), water retention (NBR 13277/95 [12]) and air entrained content (NM 47:95 [13]).

The operational specificities of the Vane test method are presented in Table 5. For other methods, the procedures employed were the same as those recommended under the respective standard test.

3. Results and discussion

Some additional results to characterise fresh mortars are presented in Table 6.

It is noted that the two mortar types tested (mixed AM mortars and pre-packaged AI mortars) indicate, for the same consistency, (based upon the cone penetration test) quite distinct fresh state properties. These differences are more marked under the following parameters:

- Water content, the AM series requires a higher water demand in comparison to that required by the AI type, under the same consistency for the cone penetration test (previously defined);
- Air entrained content reflects directly upon the specific mass. What is taken into account here is the presence of air entraining admixtures in pre-packaged mortars (AI type), which have this additive as a main plasticity agent.

Further, results indicate that the mortars tested meet the necessary conditions for conducting this study, which, in short seeks to assess mortars in terms of different consistency testing methods and according to workability parameters.

For the relation between consistency results measured according to the cone penetration test and the flow table (Fig. 3), it can be noted that in analysing the same mortar series (AM series or AI), the values reflect the same tendency whilst there are alterations in consistency conditions.

However, in analysing results between two mortar series, it can be observed that for the same values obtained through the cone penetration test, the consistency results obtained through the flow table test are different. This observation can be explained according to the following:

- According to Ferraris [14], in the rheology study of concretes and mortars, results produced through static cone penetration are influenced by the rheological yield stress parameter considerably. At the same time, the flow table test is influenced both by viscosity as well as by yield stress and so it is difficult to characterise the isolated influence of each parameter. This notion may therefore be affecting the aforementioned results to a certain extent;
- Sousa and Bauer [15], an assessment of flow table results indicates that this parameter is highly influenced by mortar plasticity, quite prevalent in mortars with air

Table 6
Summary of results obtained in mortar's characterisation

Mortar	Cone penetration (mm)	Water content (%)	Specific mass (g/cm^3)	Entrained air content (%)	Water retention (%)
AM-1	35	19.00	2.05	3.20	92.34
AM-2	50	21.00	1.91	4.30	90.53
AM-3	65	22.00	1.91	4.20	89.25
AI-1	35	15.00	1.74	16.40	95.20
AI-2	50	16.00	1.65	19.00	93.15
AI-3	65	18.60	1.68	18.60	93.47

Consistency results are presented in Figs. 3–5.

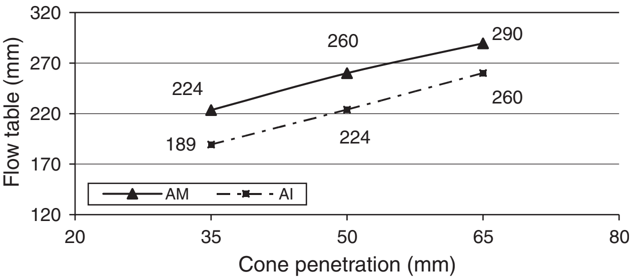

Fig. 3. Relation between the cone penetration test and flow table results.

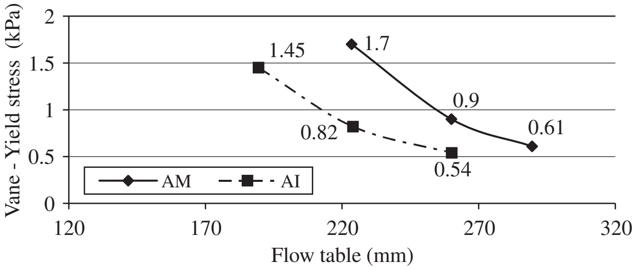

Fig. 5. Relation between flow table and Vane test results.

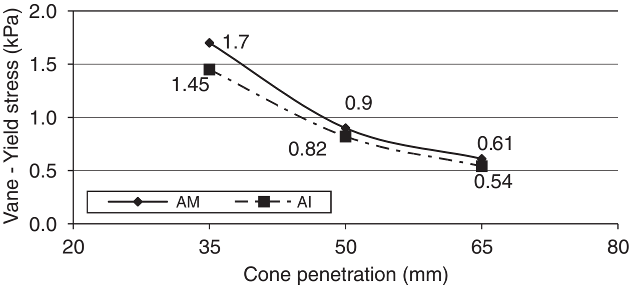

Fig. 4. Relation between cone penetration test and Vane test results.

entraining admixtures. This leads to lesser flow table values under the same workability condition.

Moreover, it can be imagined that the material's internal structuring, resulting from air entraining generates an adequate condition to absorb impacts suffered during the flow table tests. This results in lesser spread values for the cone test. This structuring is not pronounced in AM mortars in which close contact between particles is more prevalent (low entrained air volume), material spread is favoured here during the vertical impacts.

The factors discussed above reinforce the hypothesis that flow table testing should not be seen as the sole parameter when assessing workability.

In assessing the results of the relation between the penetration cone and Vane test results for measuring consistency (Fig. 4), it can be noted that different from the flow table, differences among yield stress measures for a single cone penetration are not greatly marked. This can imply that both parameters have a strong co-relation. This notion contributes to the consideration that the penetration cone test result has a strong relation with the rheological parameter yield stress. All the same, isolated testing of both parameters (penetration cone test and/or Vane test) is insufficient to define workability since only a rheological parameter is being tested (yield stress), viscosity testing would need to be conducted.

Fig. 5 outlines the relation between yield stress results (Vane test) and flow table test. In this test, differences between consistency parameters are also pronounced. All the same, similar to the assessment of the relation between cone penetration test results and flow table ones (Fig. 3), an isolated analysis leads to the conclusion that both parameters are highly inter-dependent. It must be pointed out that flow table results should not be discarded given that this test is applied in the majority of construction materials laboratories and is one of the most known parameters among specialists. It is believed that this test should be complemented with other tests considered in this study (the cone penetration test and the Vane test).

4. Conclusions

Based upon this study, it can be concluded that:

- the Vane test method is an important tool in studying rheological properties in freshly applied mortar. It is able to define clear conditions in the applying of this material;

- the method can help to interpret results in other traditional methods, common in assessing mortars, for example, the flow table that provides a result that is hardly representative of the workability condition;
- differences in results for yield stress (Vane test) and the cone penetration test are not highly marked as is the case with the flow table and this can indicate that both parameters have a strong correlation;
- an isolated evaluation of both parameters (cone penetration test and/or yield stress—Vane test) is still inadequate to define workability since only one rheological parameter is being assessed (yield stress) and there is still the need to study viscosity.

In general, it can be noted that most of this method's potential needs to be further explored. It is hoped that the methodological specificities discussed in this study can be better tested by interested specialists and that the same be adapted to the specific reality of all materials and equipment.

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