Approaches and Challenges in Investigation of Cement Paste Characteristics

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Abstract

Concrete is a widely used man-made complex material in the construction industry. Fresh properties of concrete have a tremendous effect on the durability and quality of structures. The workability is the crucial fresh property of concrete which is highly influenced by the composition of concrete. Cement paste being one of the most essential constituents of concrete, is highly discussed in this literature review paper. Hence, in order to obtain the desired mix of workable concrete, it is mandatory to determine the cement paste properties such as yield stress and plastic viscosity. This leads to determine the workability of cement paste which will be influenced by the various parameters such as the water cement ratio (W/C), type and dosage of admixtures, temperature and mixing methods. Excess addition of water leads to segregation and decrease the strength of the mix which demands the usage of superplasticizers. This state of art paper aims to describe the standard methods to investigate the cement paste characteristics, as well as the guidelines and vital parameters to rectify the errors during measurement of fresh properties of cement paste.
Keyword- Rheological Properties, Cement Paste Characteristics, Admixtures, Workability

I. INTRODUCTION

Cement paste is a Bingham fluid which is a combination of cement and water, formed by mixing the same. The cement paste shows, as a rule, the thixotropic behavior. The properties of cement paste such as yield stress and plastic viscosity arouse much concern as they have major impact on the fresh concrete quality. The critical point at which the material will begin to flow is defined as the yield stress. The plastic viscosity is described by the slope of the shear stress and shear rate curve. The consistency, flowability, workability, and setting time of concrete mixture are dependent on the rheological properties of fresh cement paste. These properties are mainly governing by various parameters such as water to cement ratio (W/C), admixture, and temperature, mixing methodology, and mixing time. Bingham and Hershel–Bulkely models are relatively used to present the flow of paste. Therefore, the understanding of the rheology of cement paste seems to be a basic requirement for preparing good cement paste for concrete.

The influence of admixtures can be measured using a parameter called workability of cement paste. The workability is defined as producing a cohesive mix of concrete or paste by reducing internal friction and voids between internal particles. Workability of cement paste is dependent on the proportion of ingredients of concrete or paste and existence of varieties and dosage of admixtures added to it. Workability can be achieved by adding suitable amount of water but the addition of excess water results into segregation and reduction in strength, which indirectly demands the use of admixtures. The chemical admixture such as super plasticizers are used to increase the workability and maintain cohesiveness in the mixture. The admixture is a material other than major constituents of concrete or mortar which when added to the batch immediately before or during mixing, improves or modifies the properties of fresh concrete.

II. LITERATURE REVIEW

In November 2001,P A Claisse ,J P Lorimer and M H Omari worked on the "Workability of cement pastes". This research work described an insight to all problems which occur when superplasticizers have been used with different types of cement and also investigated compatibility problems. This was achieved by carrying experimental work which consisted of a comprehensive analysis of 14 different types of cement and 3 different super plasticizers named as Sulphonated Melamine Formaldehyde (SMF), Sulphonated Naphthalene Formaldehyde (SNF), and Lignosulphonate (LS).

A rheological test was done using the viscometer which measures the viscosity and the shear stress of a cement paste. The instrument had a medium spring which provides more accurate data at low speeds. To obtain the plastic viscosity and the yield stress, Bingham model was taken into account.

It was observed that temperature plays an important role in affecting the rate of change of rheology with respect to time in a chemically reacting system. This helped in deciding the proportion of cement and water in the mix. A vane spindle was also used. The shear stress was calculated from the torque produced in this test. (Refer Equation 1)

$$\tau=3T/(2\pi(R_v^3+3R_v^3h)) \quad (1)$$

Where,
τ =shear stress
T=torque

From the research, it was found that cement paste has a property called specific surface area which has the greatest influence on the workability. It can be elaborated in a manner that more the surface area more amount of water will be required to cover and lubricate the concrete mix. It has been observed that SNF admixture was not added, workability climbed up with an increase in its chromate content, whereas in a mix containing the SNF, workability increases with a decrease in aluminate content.

In 2005, N.Roussel and P.Coussot carried out the research work "Fifty-cent rheometer" for yield stress measurements: From slump to spreading flow". The authors clarified the divergence between different solutions proposed and experimental results of the slump cone test. They found a solution showing the reality in the proposed and experimental results.

Initially, two analytical solutions for two different regimes i.e. H>R and R>H were defined, Where H is the height of slumped cone and R is the final diameter of the collapsed sample. Experimental results of Mini cone test for slump and spread were presented. Numerical simulations of the slump cone test for Abrams cone and Mini-cone were carried out.

The authors declared that analytical solutions represented the actual derivation showing the relation between the yield stress and spread of the material (Refer Equation 2 and Equation 3). Secondly, the results were also very helpful to predict the experimental outcomes efficiently with the use of numerical simulations. The clarity about the range of validity of analytical expressions were also made feasible to be obtained. Therefore, this was an approach that can be used to provide yield stress by comparing the same with experimental data.

For pure shear flow i.e. R>H,

$$\tau_c=\frac{225\rho g\Omega^2}{128\pi^2R^5} \quad (2)$$

Where,
τ_c=yield stress
ρ=density of paste
g=accelerational gravity=9.81m/s^2
Ω=volume of mini-slump cone
R=spread diameter

For pure elongational flow i.e. R<H,

$$\tau'_c=\frac{(1-S')}{\sqrt{3}} \quad (3)$$

τ'_c=yield stress
s'=$\frac{S}{H_0}$ (Refer Figure 1)

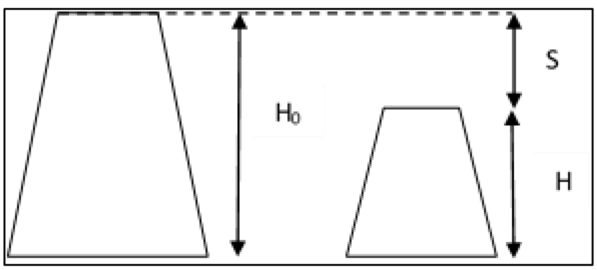

Fig. 1: Defining parameters of slump

In 2006, P. Chindaprasirt et al. studied "The cement paste characteristics and porous concrete properties". They aimed to examine the change of rheology of cement paste due to the impact of method and sequence of mixing and compaction. This objective was achieved by conducting Flow table test directly after the mixing of cement paste and flow value was measured. Similarly, rotating viscosity measuring equipment was employed to measure the yield stress and plastic viscosity. The cement paste is prepared with different types and dosages of admixtures (series N, R, S, P) and different water cement ratio.

The relationship between flow value and w/c ratio is established by plotting a line graph. It was clearly observed that using super-plasticizer seemed to be very effective in accelerating viscosity and yield stress of paste and thus reducing w/c ratio. Agglomerating the entire research work, it was also found that various factors such as mixing methods, mixing time, and the dosage of admixtures which were highly affect the characteristics of cement paste.

In 2017, Zhijun Tan, Susan A. Bernal, and John L. Provis carried out the research to show "The reliability of mini-slump cone test to test the workability of cement paste". The Mini-slump cone test was used to conduct the experimentation on cement paste containing a set of alkali-activated fly ash slag, spanning from 1 to 75 Pa yield stresses. The calculated yield stress from mini-slump test was compared with the results obtained from conventional viscometer. In addition to this, they also stated the significance of preparation for always testing each batch once at the same time after mixing rather than conducting numerous tests on a single batch of material.

For the tests, a total of 27 paste formulations were prepared. Three cells containing a specified water binder ratio and corresponding slag to fly ash ratio were proposed. Each cell would contain 3 different activator doses (in wt% relative to the mass of binder). Therefore, for each water cement ratio of 0.40,0.44 and 0.48 and each slag:FA ratio specified as 100:0,75:25 and 50:50, there will be 3 different activator doses as 4%,8%, and 12%. The Mini-slump cone test was then performed using downscaled Abrams cone. The mechanism stated that the green mixed paste was instantly poured into the cone and then the cone was lifted as gently as possible. The slump diameter was calculated from the slump area measured using ImageJ software by taking a digital photograph. Using Roussel and Coussot formula (stated in Equation 2), the yield stress of the paste was calculated. A HAAKE viscometer 550 instrument was used to directly measure the yield stress of fresh pastes by applying the shear rates. Using the Herschel-Bulkley model (Refer Equation 4) yield stress was obtained.

$$\tau=\tau_0+k\gamma^n \quad (4)$$

Where τ_0=dynamic yield stress
k and n=fitting constants
n=1(Bingham model is a special case of the Herschel-Bulkley model)

It was summarized that at higher yield stress i.e. values greater than 10Pa, the yield stress determination by mini-slump test appeared less reliable. It can be said that relatively a degree of scatter is observed in the values for yield stresses above 10Pa. It was concluded that the correlation between the two methods for low yield stress values is good, but shows the deviation at higher yield stresses. The results also discuss the influence of mixing methods on the tests stating that the shape obtained by hand mixing was found to be less circular than the paste mixed by the high shear mixer.

In 2017, authors named as Dimitri Feys, Rolands Cepuritis, Stefan Jacobsen, Karel Lesage, Egor Secrieru, Ammar Yahia informed about the appropriate procedures that can be used to assess the rheological properties of a cement paste. The authors carried out the research work on “Measuring rheological properties of cement pastes: most common techniques, procedures, and challenges.” The study explained the significance of rheological tests over the standard workability test. The prior test allows better fundamental investigation, more accurate description of flow properties and serves as a support for numerical simulations.

The authors mentioned the advantages and disadvantages of the most frequently employed geometries i.e. Concentric cylinders geometry and Parallel plate geometry that are used by cement paste rheologists. The study lists down the concerns and choices that one can keep into account while performing cement paste rheological tests. It also states the challenges during measurement and actions to counter the same.

III. CONCLUSION

By synopsizing the above research work regarding the workability of cement paste and admixtures, the following were outcomes: The Mini-slump cone test performs practically good for determining the yield stress of the material. A numerical approach can be used to provide the validity of the yield stress values by comparison with experimental data. The suitable dosages of admixtures significantly affect the viscosity and yield stress of paste. For yield stress values more than 10Pa, Mini-slump cone test turns out to be less reliable. A controllable high shear mixer is greatly preferred over the hand mixing method. Therefore, mixing protocols play a major role in influencing the cement paste characteristics. Cement and admixtures are chemically active, the chemical composition of admixtures have an adverse effect on the workability of cement pastes. Various guidelines and procedures to measure the rheology of cement paste should be followed to rectify the errors while measuring the fresh properties of cement paste.

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