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Effect of Packing Density of Aggregate on Rheological Properties of Self Compacting Mortar

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Abstract**: The workability of self-compacting concrete (SCC) is strongly dependent of its mortar phase rheological behavior. Normally, the SCC mixtures present a high amount of mortar in their composition. Thus, the SCC mortar phase has a very important influence on the SCC rheological behavior. Generally, the rheological properties of fresh concrete are described by Bingham parameters in terms of two physical quantities, namely yield stress and plastic viscosity. Rheometers are used to find the two rheological parameters, but, there is no concurrence in the measurement of rheological values by various rheometers. In this experimental study, the Bingham parameters of mortar for different mixes which is prepared by packing density method were found out using a direct shear box. The advantage of this test is the low shear rate applied on the specimen during testing which is similar to the condition the fresh concrete experiences in the field. The procedure is unique in that, after finding the peak shear stress, shear stress at zero normal stress and at zero displacement was found and finally finding the Bingham parameters i.e. yield stress and plastic viscosity. Different displacement rates (5 and 9 mm/min) and normal stresses (0.049 and 0.098 N/mm2) were used. The results show that the direct shear box can be used as a new tool to measure the relative values of yield stress and plastic viscosity with low shear rate.

Keywords— Rheology, Self-compacting mortar, Yield Stress, Plastic Viscosity, Direct Shear Box.

I. INTRODUCTION

Rheology is the science of the deformation and flow of matter, and is concerned with the relationships between stress, strain, rate of strain, and time. SCC states three main requirements for rheological properties of the mixture: high fluidity, its ability to pass the reinforcement and the resistance to segregation both during the transport and laying. High fluidity of the mixture determines the possibility of automatic removal of the air accidentally caught in during the production and transport from the mixture. Rheological properties of the SCC mixture are characterized by the parameters of Bingham material model – the yield value and plastic viscosity. Their value depends mostly on constituent's properties and mixture composition, time passed from the moment of mixing the constituents, and temperature. Once the stress passes the yield value, the mixture flow occurs with velocity proportional to plastic viscosity. The lower yield value and plastic viscosity the easier mixture will flow and de-aerate, but at the same time, the more vulnerable to segregation. While designing the SCC mixture, one usually aims for relatively low yield value and at the same time optimizes the plastic viscosity of the mixture, making it high enough to prevent segregation, and low enough to enable self-de-aeration. The issues of self – compacting mixture rheology were presented in detail in [1]. Measurements of the rheological parameters of the self-compacting mixture are best carried out with rheometer [2] However, it is relatively expensive, it requires highly qualified staff and moreover it can be used only in laboratory conditions. For these reasons, in technological practice special tests are used which simulate particular conditions occurring during laying the SCC mix.

Rheology is a well-established study of deformation and flow of materials under loads and fluid rheology is a widely used science. Many fluids possess some minimum stress-namely a yield stress-that must be exceeded before flow occurs. The concept of yield stress is readily seen in concrete slump test though it is an empirical test. Even though fresh concrete can be considered a fluid, the characterization of its rheology is complicated by the fact that concrete is a complex heterogeneous material with time-dependent properties. However, workability of a fresh concrete mixture is closely related to the flow properties of the concrete and there is a need to develop methods based on a material science approach especially with the advent of special concretes and finding rheological properties of fresh concrete will always remain the focus of the concrete industry. Various models or constitutive equations have been developed to characterize the flow of concrete. Freshly mixed concrete can be considered as a concentrated suspension of aggregates in cement paste and can be measured as a viscous or viscoelastic fluid and is based on the relationship between shear stress and shear rate expressed as a flow curve. Most researchers agree that the flow of concrete can be described reasonably well using a Bingham equation. This equation is a linear function of the shear stress (the concrete response) versus shear rate. Two parameters provided by the Bingham equation are the yield stress and the plastic viscosity. It describes a linear relationship between the stress acting to shear concrete (shear stress) and the rate at which it is sheared (shear rate) with plastic viscosity being the slope in this relationship and the y intercept marks the yield stress (Fig 4).

The term yield stress and plastic viscosity provides a more comprehensive description of fresh concrete than the conventional workability tools. Bingham flow model commonly assumes that if lower shear rates could be measured the flow curves would continue back and intercept shear stress axis [3]. Accurate data at low shear rates are needed to confirm that flow curves can truly be extrapolated to a zero-shear rate. The advent of modern controlled stress rheometers has allowed measurements to be made at significantly lower shear rates than previously possible. These rheometers show that at low shear rates, plastic viscosity is very high. Ngugen and Boger [4] state that yield stress is a model parameter but not a true material property. If it is assumed that yield stress is a relevant parameter to be measured, the actual measured value can vary significantly depending upon the test method used. Rheology is now seriously considered by users, rather than being seen as an inconvenient and rather specialized branch of cement science [5]. By providing a scientific description of the fundamental flow properties of cement paste, mortar and concrete, rheology represents a useful method of characterizing concrete workability. This study initially outlines the measurement of flow properties of fresh mortar using Bingham equation and then describes a unique new procedure for the determination of rheological properties of mortar from an extensive study of the experimental data obtained using direct shear box. The uniqueness of the procedure is that after finding the peak shear stress, shear stress at zero normal stress and zero displacement were found, and finally finding the Bingham parameters. This complete procedure is attempted previously for concrete [6]. The importance of the test is very much significant in that mortar specimen is subjected to a low shear rate during testing which is similar to that experienced by the concrete in the field. For the experiments, workable mortar mixtures for varying w/c ratios, different normal stresses and displacement rates were considered.

II. MATERIAL SPECIFICATION

Following are the materials used for the experimental work.

A. Cement

The cement used in this experimental work is 53 grades Ordinary Portland Cement. All properties of cement are checked by referring IS 12269 - 1987 Specification for 53 Grade Ordinary Portland cement. The specific gravity of the cement is 3.15. The initial and final setting times were found as 108 minutes and 222 minutes respectively. Standard consistency of cement was 32%.

B. Water

Potable water used for the experimentation.

C. Fine aggregate

Locally available sand passed through 4.75 mm IS sieve is used. The specific gravity of 2.85 and fineness modulus of 3.87 are used as fine aggregate. The water absorption is of 1.60%.

D. Fly-ash

Fly ash is a by- product obtained during the combustion of coal in thermal power plants, Typical physical properties: - Colour: grey, Specific gravity: 2.1. The advantage of Fly ash when used with Portland cement ensures higher durability of concrete avoids thermal cracking and improves workability. Slag has a pozzolanic reaction which allows the increase of concrete strength.

E. Super-plasticizer.

The super plasticizer used in concrete mix makes it highly workable for more time with much lesser water quantity. It is observed that with the use of large quantities of finer material, the concrete is much stiff and requires more water for required workability. Hence in the present investigation samples of super plasticizer are used for better results. Also, to check the compatibility of super plasticizer with concrete Master Glenium sky 8276 is used.

BASF's Master Glenium sky 8276 super plasticizer having specific gravity of 1.12 is used

III.METHODOLOGY

In this study, six mixes of mortar with three different cement contents of 390, 415 and 420 kg/m3 with w/c ratio of 0.37, 0.35 and 0.33 were used. The mortar mixes were proportioned based on packing density concept [7]. Total of 24 trials consisting of two different strain rates of 5, 9 mm/min, in combinations with two different normal stresses of 0.049, 0.098N/mm2, were used. After through mixing of the fresh mortar in a pan the sample was tested for measuring the rheological properties such as yield stress and plastic viscosity.

IV. DIRECT SHEAR BOX

The shear box test is the oldest and simplest form of shear test arrangement. Basically, the testing procedure is very straight forward. The test has been used for measuring the immediate or short-term shear strength in terms of total stresses. In principle, the shear box is an angle of friction test, in which one portion of specimen is made to slide along another by the action of steadily increasing horizontal shearing force while a constant load is applied normal to the plane of relative movement. As reported by Newman [8], Herschel and Pisapia and later L"Hermite and his coworkers used direct shearing apparatus of the kind used for testing the strength of soils to study the resistance of freshly mixed concrete in terms of shear stress. They considered shearing stress in a freshly mixed concrete to be due to internal friction analogous to the friction between a solid body and a plane solid surface when that body is resting on the surface. When they plotted the graphs between shear stress verses shear strain for various normal stresses, keeping the displacement rate constant, interestingly they found that shear stress increases linearly with the degree of distortion up to a maximum value, then decreases and finally leveling off. So, in a direct shear test apparatus (Fig. 1), the shearing stress is created by imposing a movement of the lower half of the shear box while applying a static load to the load plunger and can be used to assess the cohesive strength of a fresh mortar mixture under the influence of normal stress and displacement.

V. PROCEDURE FR DETERMINATION OF RHEOLOGICAL PROPERTIES

The freshly mixed mortar was placed in the direct shear box and a particular displacement rate and a normal stress was applied on the sample. The test was stopped when the shear load started to decrease (point of dilatancy) or when it became almost constant. The tests were repeated for different displacement rates keeping the normal stress constant. For the displacement rates chosen further tests were conducted for different normal stresses. One such plot for the mix (C) (Table I) is shown in Fig. 2. The plot of shear stress verses shear strain for displacement rate of 5 mm/min for normal stress of 0.049 N/mm^2 is shown in Fig. 2(a). From this relation, the maximum shear stress for the normal stress 0.049 N/mm^2 was found. For the same normal stress, similar procedure was followed for the mix for finding the maximum shear stress with the displacement rates of 9 mm/min and the plots are shown in Fig. 2 (c). Similar plots of shear stress verses shear strain for the displacement rates of 5, 9 mm/min were obtained for other normal stress of 0.098 N/mm^2.

Fig. 1: Direct Shear Box

These plots are shown in Fig.s 2 (b) and 2 (d) and maximum shear stresses were obtained. Further, with the values of maximum shear stress for each displacement rate and the different normal stresses, graphs are plotted and straight-line fits were made (Fig. 3a-

3b). The line intersecting the y-axis (shear stress axis) gives the peak shear stress of mortar at zero normal stress for a particular displacement rate, as the shear box test cannot be carried out at a zero-normal stress (Fig. 3a-3b). Similar straight-line fits were made for all displacement rates and peak shear stress at zero normal stresses were obtained. This peak shear stress can be considered as yield stress at zero normal stress. Further, graph was plotted between displacement rates and the yield stress at zero normal stress obtained for different displacement rates (Fig. 4). The intercept of the line on the y-axis (yield stress axis) can be regarded as the relative yield stress and the slope of this line as the relative plastic viscosity similar to Bingham parameters [9].

The uniqueness of this test method is that, the shear stress at zero normal stress and zero displacement was found, before finally finding both the relative yield stress and the relative plastic viscosity. Other important characteristics of this test are the very low shear rate applied on the specimen during testing which is similar to the condition experienced by the concrete in the field.

VI. RESULT AND DISCUSSIONS

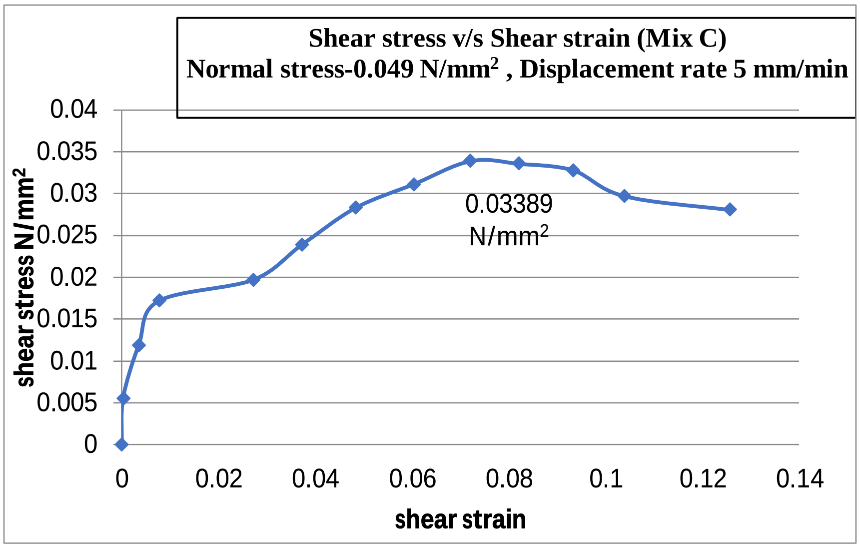

Fig. 2(a): Shear Stress Vs Shear Strain (Disp. Rate-5mm/min)

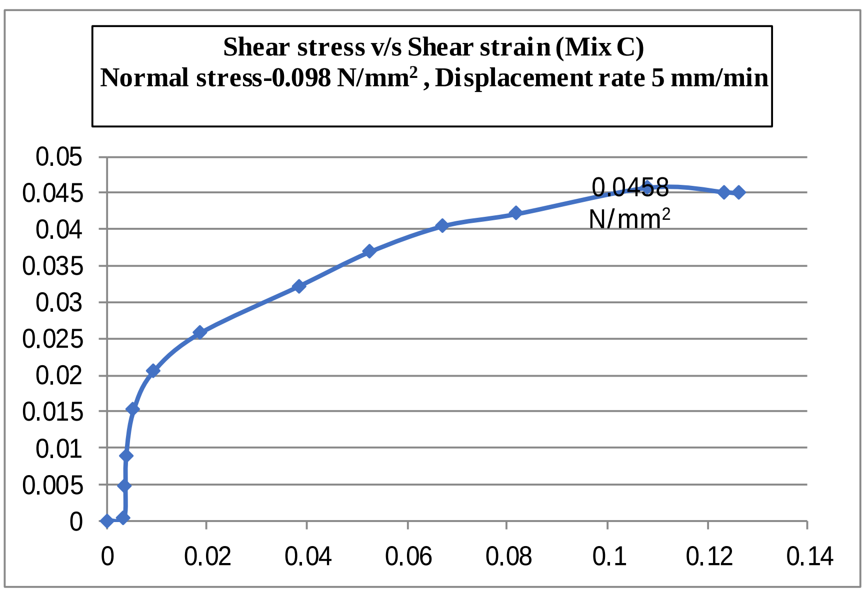

Fig. 2(b): Shear Stress Vs Shear Strain (Disp. Rate-5mm/min)

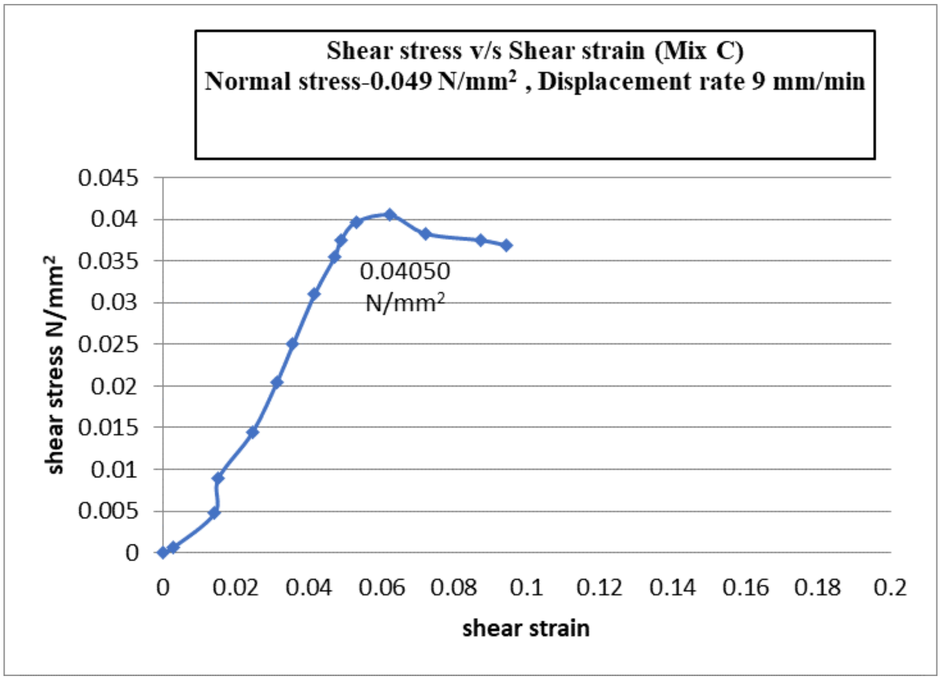

Fig. 2(c): Shear Stress Vs Shear Strain (Disp. Rate-9 mm/min)

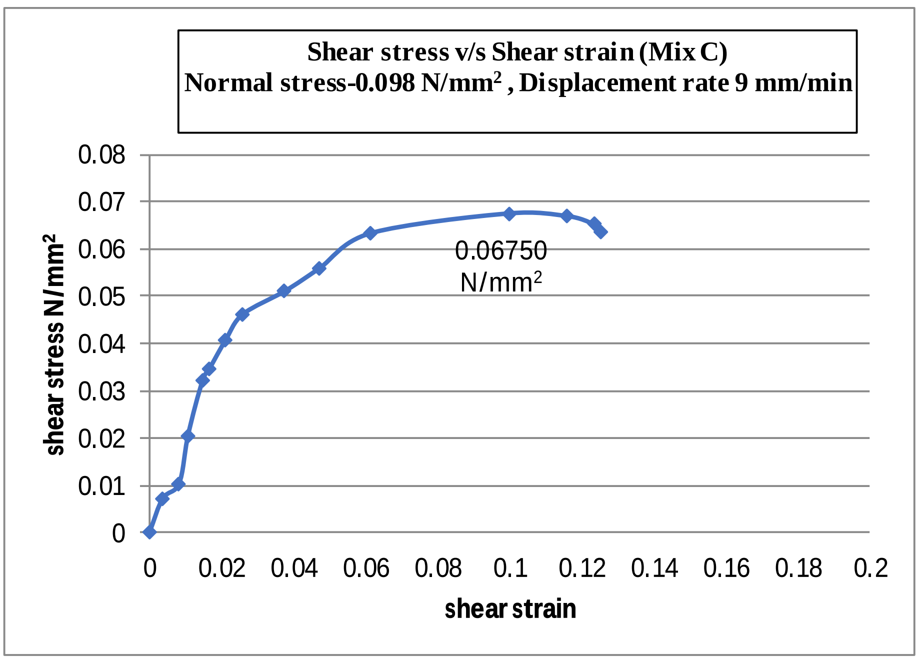

Fig. 2(d): Shear Stress Vs Shear Strain (Disp. Rate-9 mm/min)

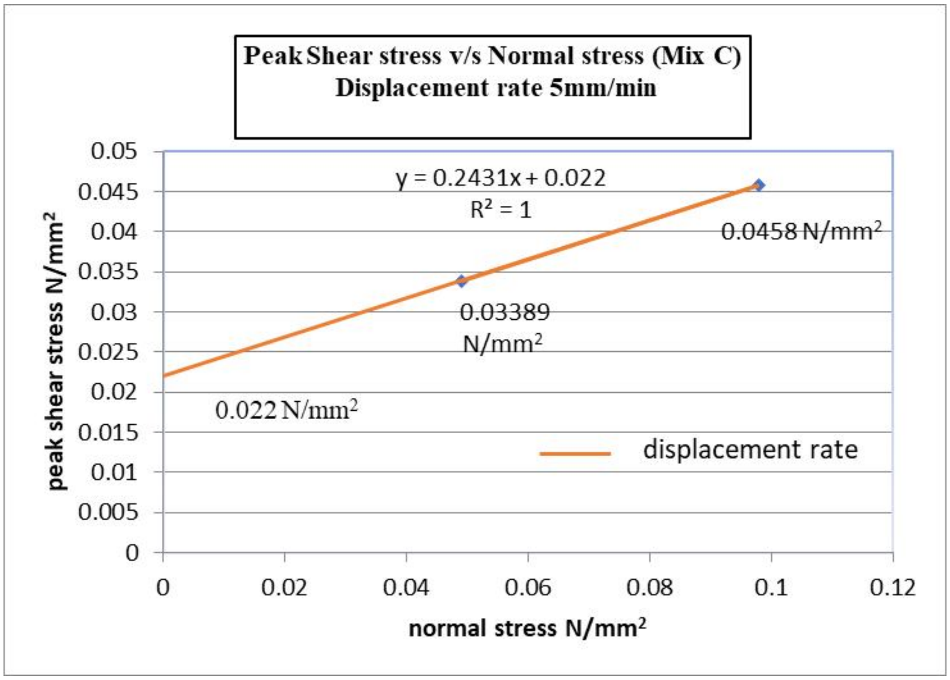

Fig. 3(a): Peak Shear Stress Vs Normal Stress

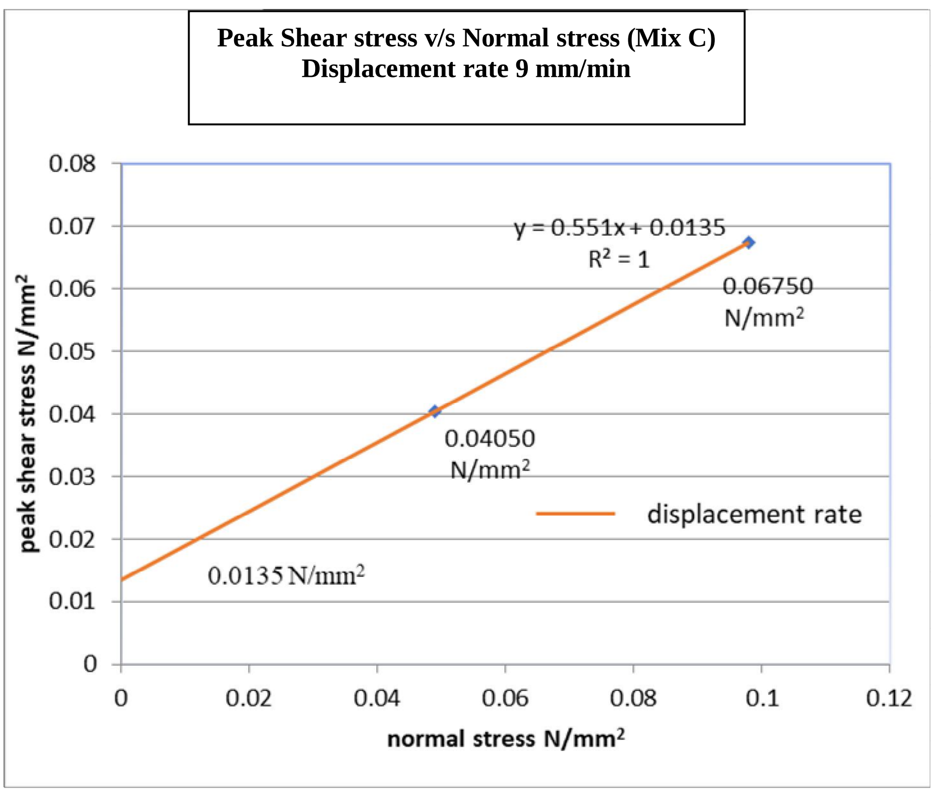

Fig. 3(b): Peak Shear Stress Vs Normal Stress.

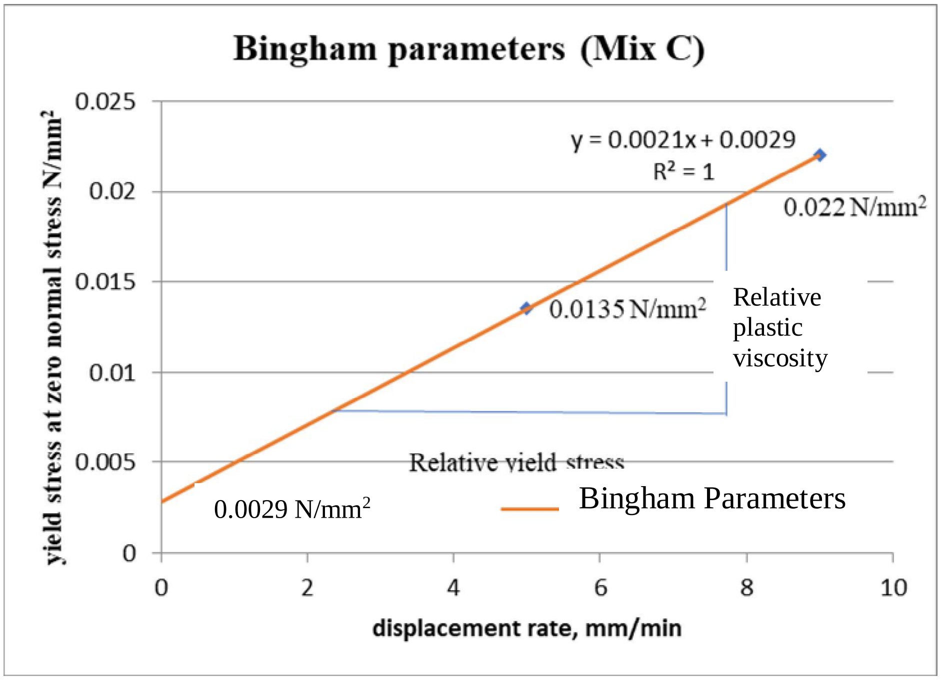

Fig. 4: Yield Stress at Zero Normal Stress Vs Displacement Rate

Normal Stress N/mm^2	Disp. Rate mm/min	Peak shear stress (N/mm^2)					
		M 40-1(A)	M 40-2 (B)	M 50-1(C)	M 50-2(D)	M 60-1(E)	M 60-2(F)
0.049	5	0.0317	0.0328	0.03389	0.0350	0.0383	0.04722
	9	0.0361	0.0478	0.04050	0.0578	0.04250	0.06528
0.098	5	0.0522	0.0489	0.04580	0.0389	0.0544	0.0650
	9	0.0536	0.0672	0.06750	0.0614	0.06979	0.08167

Table I
Peak Shear Stress for Different Normal Stresses and Displacement Rates.

Table II
Relative Yield Stress and Relative Plastic Viscosity

Mix	Cement (Kg/m^3)	Water (L/m^3)	Fine aggregate (Kg/m^3)	Relative yield stress (N/mm^2)	Relative plastic viscosity (N/mm^2-s)
A	390	178.0	1100	0.0022	0.00185
B		187.5	1115	0.0021	0.002925
C	415	179.5	1065	0.0029	0.002125
D		182.77	1077	0.0022	0.005775
E	420	170.71	1010	0.0067	0.001725
F		179.15	1130	0.0050	0.04875

Table I shows the peak shear stress values for all the mixes for different normal stresses and displacement rates. It can be observed from the results that as the normal stress increased for the same mix with a particular displacement rate, the peak shear stress also increased. This could be because as the normal stress is increased the particle gets closer to each other thereby causing the interlocking of the aggregates leading to higher resistance resulting in higher peak values. This is true for all the mixes and displacement rates. Also, for a particular normal stress generally the peak shear stress increased as the displacement rate increased. This could be due to the reason that when the displacement rate is lower there is more time available for the effect of particle re-orientation in the test resulting in lower peak values. It is likely that the displacement rates influence the Bingham parameters and can be one of the factors influencing the results.

Table II shows the relative yield stress and relative plastic viscosity for different mixes. In this study, the yield stress and the plastic viscosity values were called as relative yield stress and relative plastic viscosity because the values are not absolute. From Table II it can be observed that in a given mix for the same cement content as the water content increased the relative yield stress of concrete decreased. This phenomenon is attributed to higher paste content (cement + water). As the water content is increased for the same cement content it results in higher volume of paste and better lubrication of the aggregate particles thereby reducing the inter-particle friction and also probably due to better coating of the paste on the aggregates. Also, higher paste content means lower aggregate content and lower volume fraction of aggregates result in increased spacing between aggregates and thus lesser resistance to flow. This is also true when the water content is increased for the same cement content. As such at lower paste content the inter particle friction dominates resulting in higher relative yield stress which is clearly brought out by the concrete shear box test.

VII. CONCLUSION

This experimental study has shown that the direct shear box can be used to find the Bingham parameters of fresh mortar. The test is unique in the sense that the results are consistent and the values arrived at, are by considering both the normal stress and displacement rate at zero values and the stimulus provided to the mortar is similar to the field practice. The Bingham parameters are named as relative yield stress and relative plastic viscosity partly because the values so obtained are higher than those reported in literature as determined by high shear rate rheometers. For the same mix, as water content increased there is a significant reduction in relative yield stress or in general as the paste content increased there is also significant decrease in the relative yield stress of mortar or increase in relative plastic viscosity. This aspect may be useful in identifying the essential changes in the mixes for the volume of paste or changes in the grading of aggregate for a given paste content. The Direct shear box can be used as a tool to determine Bingham parameters effectively as a static test by following the unique procedure developed in place of rheometers which use high shear rate.

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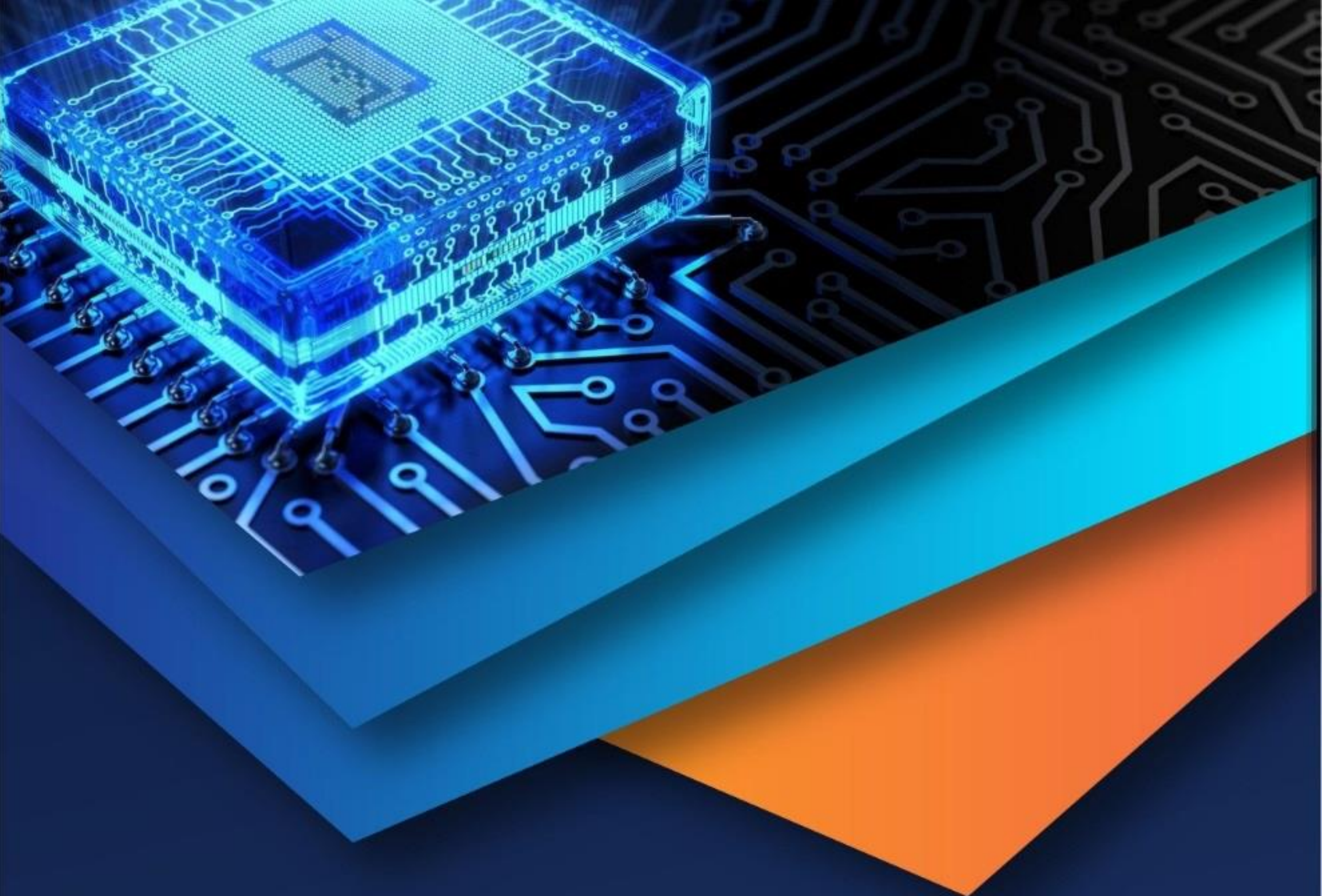

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