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An Experimental Study on Rheological behavior of SCC using Concrete Shear Box

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Abstract - Rheology is a study of determination and flow of materials under external forces. Workability of concrete mixture is closely related to the flow of properties of concrete and there is a need to develop methods based on the material science approach. Fluid Rheology is well established, widely used science that can be applied to the propery of fresh concrete. The fresh properties of concrete can be characterized by its flow behavior. Most of the tests which measures the flow of concrete are empirical in nature. The rheology scientific description of flow properties. Traditionally the rheological properties of SCC are described by the Bingham's parameters namely yield stress and pastic viscosity. Rheological test conducted using rheometers such as **BML** Rheometer, **BTRHEOM** Rheometer, **IBB** Rheometer and **TWO POINT** Rheometer attempt to measure yield stress and plastic viscosity. However, there is no concurrence among the test values and hence there is no instrument that is acceptable to all. Further these rheometers are very expensive. To overcome this; concrete shear box fabricated by Dr. S. Girish to determine the fresh properties of SCC is improvised.

In this study an attempt has been made to use a concrete shear box test to obtain yield stress and plastic viscosity of normal concrete shear box test to obtain yield stress and plastic viscosity of normal concrete. In this limit work, three different displacement rates such as 1mm/min, 5mm/min, 15mm/min and normal stresses of $1kg/cm^2$, $2kg/cm^2$ and $3kg/cm^2$ used for SCC. The water content used was 175 lit/m^3 and cement content of 300 to 450 kg/m^3. The results show that concrete shear box test can be used to find the rheological parameters of fresh concrete effectively as a static test. The values obtained in this study are higher as compared to the values obtained by other rheometers. This is due to inter-particle interference. However the trends are very similar to the studies using rheometers.

1. INTRODUCTION

Concrete has become the most widely used construction material in the world. The reason for widespread use of concrete is its adaptability, strength, durability, availability, and economy. Concrete goes through different stages as it develops strength. Soon after mixing and while still workable, it is said to be fresh. When it starts to become solid, but still weak, it is described as being green. Finally, the concrete is said to be in a hardened state. It has two distinct properties-

1) Fresh properties 2) Hardened properties

Fresh properties of concrete, especially workability. The Indian code of practice defines workability as that "property of freshly mixed concrete, which determines the ease and homogeneity with which it can be mixed, transported, placed, compacted and finished". The American standard of testing materials (ASTM:125-93) defines workability as that "property of determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity".

Workability of fresh concrete is very important which can influence many other properties and can affect strength, durability and also appearance and cost. Workability has always been a key characteristic of fresh concrete.

Fresh concrete has significant effect on the quality and cost of concrete construction. They also potentially determine the certain hardened concrete properties, such as uniformity, strength and durability.

For more than 80 years, the workability of fresh concrete has been measured predominantly throughout the world with one simplistic test method-the slump test. In the slump test, a sample of fresh concrete is placed in a 12-inch tall cone mould. The mould is removed and the vertical distance the concrete subsides, or slumps, is recorded as a measure of workability. Whereas workability is a broadly defined term, the slump test measures only one aspect of workability, namely-consistency.

Although the introduction of the slump test as an ASTM standard test method in 1922 represented an important advance in the design and control of concrete mixtures, the slump testis now viewed as incapable of providing an adequate characterization of the workability of today's much more advanced concrete mixtures.

The behavior of fresh concrete is complicated with the addition of different types of materials including marginal materials. Most of the tests developed since the beginning of the twentieth century are empirical, that is, they attempt to simulate a field placement condition and measure a single value such as time or distance, which serves as the index of workability. The method to measure the workability of concrete has not changed significantly since the last century and is still being measured using the empirical test, in particular, the simplistic slump test. But the slump test has numerous deficiencies in properly differentiating a mix and the complexity is further compounded with concrete of today is being transformed itself from basic four ingredient mix to multiple ingredient mix with the addition of mineral and chemical admixtures.

The measurement of workability by using the empirical tests in particularly, slump test has more disadvantages which is described later. For that it needs the study of the concrete with respect to material science approach. For that in 1983 Tattersall and Banfill, observed and point out that workability can be misleading and that they can be interpreted in a number of ways. They divided the workability into three classes namely, qualitative, quantitative empirical and quantitative fundamental science and argued that the empirical tests are single point tests and suggested quantitative fundamental science approach for characterizing the fresh concrete with at least two parameters to describe the behavior in fresh state.

Workability of concrete is measured by rheological properties to overcome the inadequacies of the empirical tests, in particular, the slump test and is based on material science approach.

Rheology deals with deformation and flow of materials under loads and fluid rheology is a well established science. The concept of fluid rheology can be extended to concrete since workability is related to flow properties and concrete can be considered as a fluid with solid particles i.e. aggregates in a viscous liquid- the cement paste. Rheology is an offshoot from the meaning of "Rheo" which is- "everything is in flow". The main goal of rheology is to predict the internal behavior of complex materials under applied forces and the geometrical effects in a fluid. It is being applied in different fields like concrete, ceramics, paint industries, polymer, food technology, pharmacy and other branches. Many fluids posses some minimum stress namely a yield stress-that must be exceeded before flow occurs. Flocculated system such as cement pastes typically are thixotropic and exibhit yield stress. The concept of yield stress is readily seen in concrete slump though it is an empirical test. Even though fresh concrete can be considered as 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 fresh concrete mixture is closely related to the flow properties of concrete and there is need to develop the methods based on 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 be measured as a viscous or visco-elastic fluid and is based on the relationship between shear stress(τ) and shear rate($\dot{\gamma}$) expressed as a flow curve. Most researches 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 versus shear rate. Two parameters provided by the Bingham equation are the yield stress and plastic viscosity. Compare to a Newtonian model, the Bingham model incorporates a yield stress term (τ) and viscosity is often replaced with plastic viscosity (μ). It describes a linear relationship between the stress acting to shear concrete and the rate at which it is sheared with plastic viscosity being the slope in this relationship and the y intercept marks the yield stress(τ_0) and the relation is as follows:

$$\tau=\tau_0+\mu\dot{\gamma}$$

The term yield stress and plastic viscosity provides a more comprehensive description of fresh concrete than the conventional workability tools. The concrete pump ability is controlled by plastic viscosity and stability of fresh concrete placed at an angle is controlled by the yield stress. For advancement to be made in understanding and controlling workability of fresh concrete, testing procedures and standards must move to a more fundamental quantitative basis. Accordingly, workability should be defined in terms of established measurable parameters such as yield stress and plastic viscosity. Today, through the use of Rheometers, concrete Rheology has emerged as a viable technique for characterizing workability of cementitious materials.

OBJECTIVES

The main objective of the study is

- to determine the rheological properties such as yield strength and relative plastic viscosity of SCC concrete by replacing the fine aggregates with demolition waste using direct shear box.
- To determine the rheological reproducibility of aggregate, different W/C ratio & different size of aggregates.

II. LITERATURE REVIEW

Today's modified concrete is with four ingredient mix of cement, water, fine aggregates, and coarse aggregates. Basically the modifications with the addition of new ingredients like filler material, mineral and chemical admixtures were added to improve the quality of concrete. Concrete has two states fresh and hardened state. The workability of fresh concrete is a critical property that has direct impact on the strength, durability, appearance and cost. Workability is defined as the property of freshly mixed concrete which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished.

Still the measuring tool to assess the workability of concrete has not changed significantly in the last century and is measured using the simplistic test method, the slump test, the apparatus of which was developed in the USA around

1910 and it is believed that it was first used by Champman although in many countries the test apparatus is associated with Abram. Later on, other workability tests like the re-mould test, flow table test, compacting factor test, Vee-Bee test, ball penetration test etc were developed since the 1920's are empirical, that is, they attempt to simulate a field placement condition and measure the values such as time or distance, which serves as an index of workability.

In 1986, Tattersall interpreted and divided the workability test in to three classes namely, Qualitative, Quantitative Empirical and Quantitative fundamental science and argued that the empirical tests are single point tests and suggested quantitative fundamental science approach for characterizing the fresh concrete.

***DRAWBACKS OF SLUMP TESTS**

a) **ZERO SLUMP-** basically is the slump test quite incapable of differentiating two concrete of very low workability (Zero slump). The reason two concrete with the same slump may behave differently during placement is that concrete flow cannot be defined by a single parameter.

Concrete with the same slump can exhibit different behavior when tamped with a taming rod. A harsh concrete with less powder or paste will tend to fall apart when tapped and a cohesive concrete with adequate or more powder or paste percent may not fall off apart when tapped and thus suitable for difficult placement condition than the mix with the same slump value.

b) **STATIC TEST-** the slump test is static, not dynamic test; therefore, the results are influenced by concrete thixotropy. The test does not provide an indication of the ease with which concrete can be moved under dynamic loading conditions such as vibrations.

c) **NOT A SCIENTIFIC APPROACH-** slump test is not based on basic material science approach and not a test to be relied for fundamental approach. The test results are subjective assessment which can have disagreements among the persons involved about the exact meaning of workability.

***RHEOLOGY**

Rheology is the science of deformation and flow of matter. The term Rheology was invented in 1920 by Prof.Eugen.C.Bingham at Lafayette College in Indiana. The "Rheo" is from the Greek words "pantarhi", meaning ' everything is in flow', so the Rheology was taken to meanthe theory of deformation and flow of matter. It is well established combination of physics and chemistry branch and applied in different fields like asphalt, ceramics, paint industries, polymer, food technology, pharmacy, lubricants and others. The main objective of Rheology is predicting the fluid flow that would be produced due to applied forces.

Basically fluids are classified as

(a) Newtonian and

(b) Non-Newtonian fluids

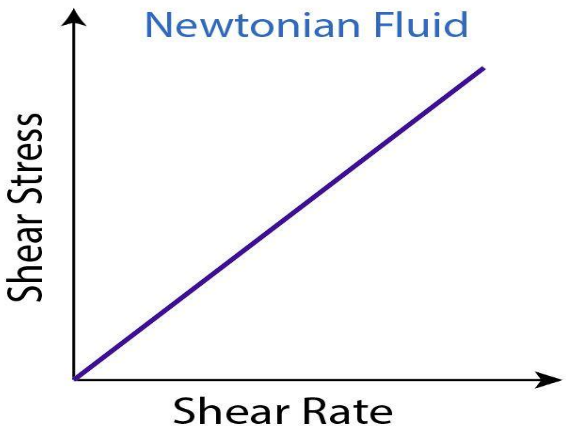
(a) Newtonian fluids

*The Newtonian fluids follow the simple rheological equation known as Newton's law of viscosity (Eq.).

*Generally the rheological behavior shows the linear relationship and passes through the origin.

*Water and mineral oils are common Newtonian liquids.

□= μ□

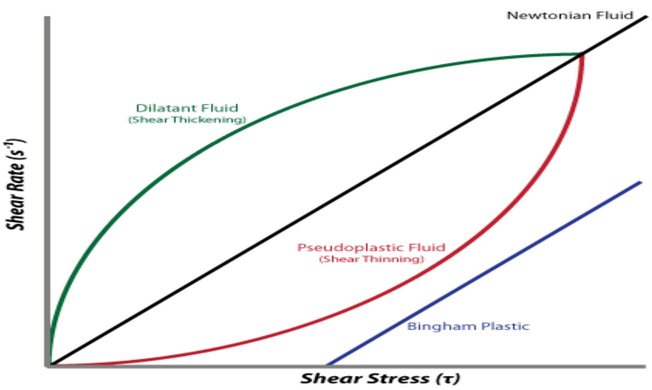


(b) Non-Newtonian fluids

*non- Newtonian fluids do not obey Newton's law of viscosity (Eq.).

*the shear stress is non-linear functions of the shear strain rate.

*non-Newtonian fluids are further divided as time dependent and time independent fluids.



Workability of fresh concrete mixture is closely related to the flow properties of the concrete and the fresh concrete is assumed as a fluid consisting of two phase system; cement paste and aggregate phase and aggregate in turn suspended in cement paste. Fresh concrete can be considered as a concentrated suspension of solid particles in viscous fluid that is, the cement paste, and the cement paste itself is concentrated suspension of cement grains in water, hence concrete is considered as multi-phased fluid.

Yield stress commonly occurs in multi-phase fluids such as concentrated suspensions. The solid particles interact to form a flocculated three dimensional network structure that resists the flow at a sufficiently low stress. Flocculated systems such as cement pastes typically are thixotrophic and exhibit a yield stress. The yield stress is related to the force required to break down this structure and initiate flow. The concept of yield stress is readily seen in concrete slump test.

The fresh concrete can be considered as Bingham fluid and is based on the relationship between shear stress (?) and shear strain rate (∂) expressed as a flow curve. Generally yield stress is related to concrete slump and plastic viscosity is related to the time of concrete slumping

III. METHODOLOGY

The experimental methodology consists of obtaining mixes with different cement contents of ranges from 300 to 450 kg/m^3 and water contents of 175 lit/m^3 were used. The displacement rate ranges from 1mm/min to 15 mm/min .The shear stress developed at such a faster rate is captured using servo-controlled data acquisition system. The loading unit has different normal stresses up to maximum of 3kg/cm^2. The size of the sample was 150 mm cube and can be tested for coarse aggregate of maximum size 25mm. The normal loads are applied on the specimen through a pneumatic actuator and a stress regulator. Electronic data acquisition system is used in acquiring the data and storing it to computer. The important characteristics of this test are the static condition of the test and very low shear rate applied on the specimen during testing which is similar to conditions experienced by the concrete in the field.

1) PROCUREMENT OF MATERIALS

Materials used:

*__CEMENT:__ all types of cement complying with the Indian standards are suitable for making concrete. The choice of the type of cement and content depends on the strength requirement, the exposure class for the durability and the minimum amount of fines required for the mix.

*__FINE AGGREGATE:__ Sand plays a very important role in concrete. It manages to fill the voids between the powders and coarse aggregates. That is why sand must be well grated from a particle size point of view, in order to guarantee the filling between the various aggregates as much as possible, sand can be finer than normal, as the material less than 150 micron may help to increase cohesion, thereby resisting segregation.

*__COARSE AGGREGATE:__ concrete can be made from most normal concreting aggregate. Coarse aggregate differ in nature and shape depending on their extraction and production. SCC has been produced successfully with coarse aggregate up to 40mm. The maximum size depends on the reinforcement layout and formwork dimensions in the same way as traditional vibrated concrete. Natural aggregate requires less water than crushed aggregates in SCC. However, elongated aggregate are not suitable.

*__WATER:__ Potable water as obtained from the bore well will be used for the preparation of the concrete mix and for curing as per Indian standards.

2) TESTS ON MATERIALS

Test on materials used:

*Test on cement

*Test on fine aggregates

*Test on coarse aggregates

a) TEST ON CEMENT:

Standard consistency test:

The consistency at which cement paste will permit penetration of Vicat plunger having 10mm dia.and 50 mm length to a depth of 33-35 mm from the top of the mould is defined as the Standard Consistency of cement.

A standard consistency test of the cement is to find out the water content required to produce a cement paste of standard consistency. Consistency is referred to as the ability by a flow of a freshly mixed concrete paste or mortar. The consistency of cement is also called as a standard consistency or normal consistency.

Apparatus of Standard Consistency test of cement

Vicat Apparatus:

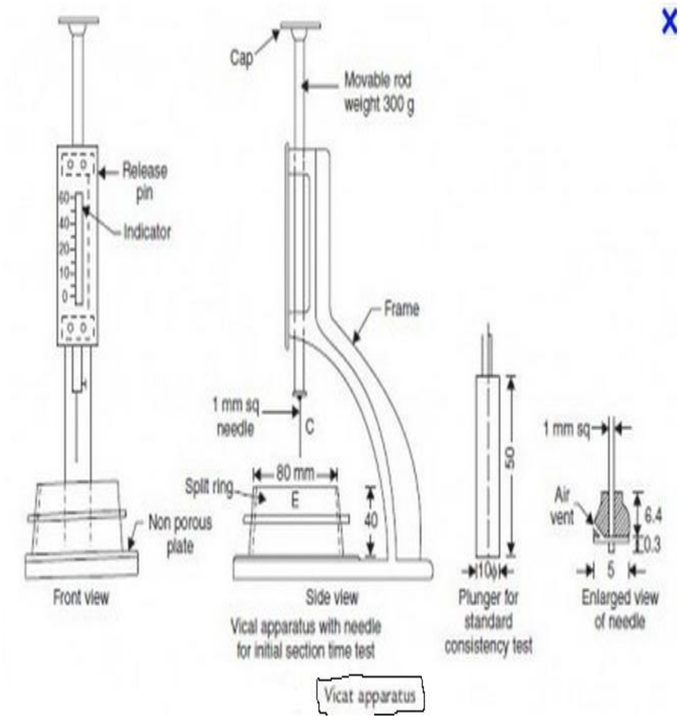
The Vicat apparatus shall consist of:

*a frame is having a movable rod with a platform at one end and the following needle which can be attached at the other end.

*__NEEDLE:__ (a) Needle for determining the final setting time.

(b) Needle for determining the initial setting time.

(c) Plunger for determining the standard consistency.



*GRADUATED SCALE: graduated scale shall be of 40mmin length and the smallest division on the scale is 1mm.

*VICAT MOULD: internal diameter of 70±5 mm at the top, 80±5mm at the bottom and a height of ±0.2 mm.

*GAUGING TROWEL: gauging trowel conforming to IS 10086:1982. The test result should be 33-35mm measurement from the top of the scale in Vicat apparatus. At this penetration, the percentage of water is denoted as a consistency.

OBSERVATION:

Weight of cement 300 grams

Trail no	% of water	Initial reading (mm)	Final reading (mm)	Height not penetrated (mm)
1				
2				
3				
4				

RESULTS: Normal consistency of cement is (P) __

TECHNICAL REFERENCE: IS 4031(Part-4) 1988

b) TEST ON FINE AGGREGATES:

Sieve analysis:

Sieve analysis of aggregate is done to determine its particle size distribution, fineness modulus, effective size and uniformly coefficient.

Observation.

*Weight of fine aggregate 1000 grams.

Trail 01

Sl no	Sieve size	Weight retained	% weight retained	Cumulative % weight retained (F)	% weight passing
01	4.75mm				
02	2.36mm				
03	1.18mm				
04	600 micron				
05	300 micron				
06	150 micron				
07	PAN				

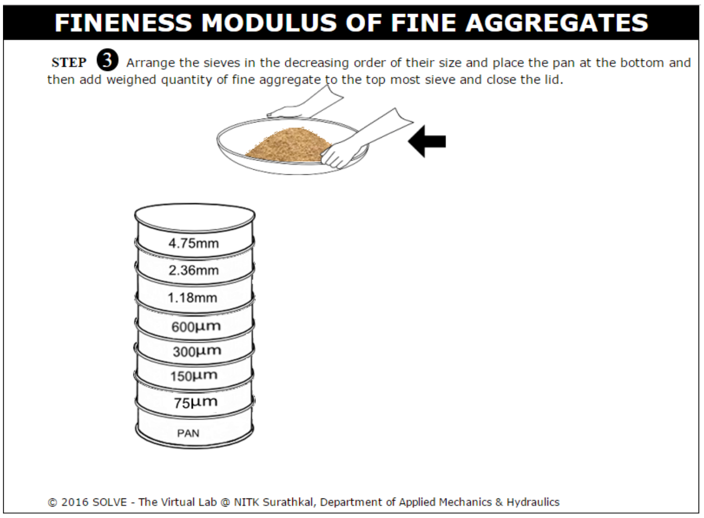
Fineness modulus =ΣF/100

REULTS: The fineness modulus of the fine aggregate is__

Trail 02

Sl no	Sieve size	Wight retained	% weight retained	Cumulative % weight retained(F)	% weight passing
01	4.75 mm				
02	2.36 mm				
03	1.18 mm				
04	600 micron				
05	300 micron				
06	150 micron				
07	PAN				

Fineness modulus=ΣF/100; **REULTS:** The fineness modulus of the fine aggregate is __



c) TEST ON COARSE AGGREGATES:

Specific gravity and water absorption test:

Empty weight of the basket in water (x) =__gm

Aggregates with basket after soaked for a period of 24 hours (y) =__gm

Weight of aggregates saturated (A) = y-x= __gm

Weight of the oven dried aggregates (C) =___gm

Specific gravity of coarse aggregates = C/ (B-A)

Apparent specific aggregates= C/ (C-A)

Water absorption:

Water absorption (percentage by dry weight) = 100(B-C)/C

3) EXPERIMENTAL PROGRAMME

a) Preparing the setup

Before mixing the concrete, Direct Shear Box and the other units should be kept ready as follows

*Turn on the computer and execute the tango software.

*Turn on the data Acquiring Electronic Unit and set it to Zero, and enter the time and date if necessary.

*Place the lower half of the shear box with the base plate and gripper plate inside the housing.

*Place the upper half and insert the shear keys.

*Adjust the housing so that it is in touch with gear box lead screw.

b) Preparing the specimen

*About 8.5 kg of concrete is required to perform one trail of Direct Shear Box test, once the setup is ready as explained above, mix the concrete. Pour about 8.5 kg of concrete in the shear box, so that level of concrete is below 30mm from the top of the shear box.

*Place the gripper plate and loading pad with the steel ball and then place loading yoke above this. Now apply the desired normal stress by adjusting the pressure gauge and enter the desired strain rate in control panel and remove the keys.

c) Performing the test

*Start the data acquiring electronic unit first so that every single value is recorded.

*Use the control panel to shear the specimen.

*Observe the values in display unit (Computer).

*Once load is dropped, stop the data acquiring electronic unit and then stop the shearing unit.

*Terminate the data acquisition and store the data giving the unique file name by using Tango software.

*Stored data can be analysed using direct shear box software (Tango software).

IV. RESULTS

Mix Designation	Cement (kg/m³)	Water (Litre/ m³)	Volume of Paste	Yield stress (Pa)	Plastic viscosity (Pa-s)
M_1					

V. CONCLUSIONS

Rheological Properties of fresh concrete, namely plastic viscosity and yield stress are critical for the concrete industry because they affect placement and workability. The rheological behavior of self compacting concrete is mostly characterized by empirical test methods like the slump flow test, therefore proper characterization of these properties is needed to control the quality of fresh concrete and ensure sustainability of concrete structures.

From the experiments conducted in the present study, though limited in nature, the conclusion can be arrived as follows.

*It is possible to determine the relative yield stress and relative plastic viscosity which are similar to Bingham parameters using direct shear box.

*The rheological parameters are named as relative yield stress and relative plastic viscosity because the values obtained in this study are higher than that reported in the literature using rheometers.

*As the cement content increases higher yield stress and higher plastic viscosity can be achieved when the water content is kept constant.

*Concrete shear box can be alternative in place of expensive rheometers for obtaining Bingham parameters.

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