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Rheological properties of self consolidating concrete with various mineral admixtures

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Abstract. This paper reports an experimental study into the rheological behaviour of self consolidating concrete (SCC). The investigation aimed at quantifying the impact of the varying amounts of mineral admixtures on the rheology of SCC containing natural sand. Apart from the ordinary Portland cement (OPC), the cementitious materials such as fly ash (FA), ground granulated blast furnace slag (GGBS) and micro-silica (MS) in conjunction with the mineral admixtures were used in different percentages keeping the mix paste volume and flow of concrete constant at higher atmospheric tempterature (30^{o} to 40^{o}C). The rheological properties of SCC were investigated using an ICAR rheometer with a four-blade vane. The rheological properties of self-consolidating concrete (SCC) containing different mineral admixtures (MA) were investigated using an ICAR rheometer. The mineral admixtures were fly ash (FA), ground granulated blast furnace slag (GGBS), and micro silica (MS). The results obtained using traditional workability results are compared with those obtained using ICAR rheometer. The instrument ICAR (International Center for Aggregate Research) rheometer employed in the present study for evaluating the rhelogical behaviour of the SCC is found to detect systematic changes in workability, cementitious materials, successfully. It can be concluded that the rheology and the slump flow tests can be concurrently used for predicting the flow behaviours of SCC made with different cementitious materials.

Keywords: self compacting concrete (SCC); rheology; workability; ground granulated blast-furnace slag (GGBS); fly ash (FA); microsilica (MS); ICAR rheometer

1. Introduction

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. The rheology is important because of the scope it offers for characterizing fresh cement paste, grout, mortar and concrete; and for understanding as to how they perform in practical applications. Rheology is dominated by the structure that exists in the cement paste, but in mortar and concrete the structure has been partially or fully broken down

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during mixing. As a result, they conform closely to the Bingham model and their behavior during pumping, vibration and in formwork can be explained by reference to that model (Tattersall and Banhill 1983).

2. Review of literature

There have been many research works involving the studies on the rheological behavior of self compacting concrete containing different mineral admixtures. Mineral admixtures (MA) have been used in order to increase the strength and improve durability and flowability of cementitious materials. Ground granulated blast furnace slag (GGBS), fly ash (FA) and microsilica (MS) are some of the typical mineral admixtures for achieving these properties. Nehdi *et al.* (1998) worked on this theme and found that these minerals significantly affect rheology of cementitious materials in the fresh state, which is directly related with developing strength, durability and engineering properties of hardened structures. Generally, ultra-durable cement concrete structures with high strength are closely associated with densified micro-structures which are strongly controlled by the rheological properties in the fresh state of concrete. The rheological behaviors of SCC paste were also researched over these years. It has been observed that the rheology of cement paste can largely dictate the rheology of concrete (Daczko 2003). But the rheological behaviors of SCC mortar were still lack of study. It will be significant to measure the fresh SCC mortar's behaviors with the rheometer and compare the results with SCC.

Much research has been conducted for improving the rheological properties and the mechanical properties using various cementitious materials, and it is reported that the GGBS and FA could contribute to increase the flowability in the fresh state, and densify microstructures and develop higher mechanical properties due to their latent hydraulic properties and pozzolanic reaction, respectively (Nevill 1996, Williams *et al.* 1999, Khayat *et al.* 2012). The use of micro-silica (MS) can improve the workability when used at low replacement rates, but can reduce the workability when added at higher replacement rates. The addition of 2 to 3% micro-silica or silica fume by mass of cement can be used as a pumping aid for concrete (Chidiac and Mahmoodzadeh 2009). Along lines similar to that of fly ash, the spherical shape of silica fume particles is advantageous for workability; however, the small diameter of silica fume particles can significantly increase the surface area that must be wetted.

According to some of the researchers (Tattersall and Banhill 1983, Mork and Gjorv 1996), a threshold value of the silica fume replacement level exists for concrete mixtures, such that below the threshold value, the use of silica fume reduces plastic viscosity but produces little change in yield stress. Above the threshold value, both yield stress and plastic viscosity increase with increasing levels of silica fume replacement. Since cementitious materials have their particular properties, rheological properties of cementitious materials should be controlled by mix design or admixtures. For the high performance concretes these mineral additives have been used for developing special performances, such as self-compacting and leveling concrete, long-time workable concrete, low heat of hydration and high strength development concrete, high durability concrete, etc. (Ferraris 1999, Cry *et al.* 2000).

As the rheology of cementitious material is closely related with developing performance of concrete, the rheology is considered one of the most important factors for the high performance concrete. For predicting concrete flowability many attempts have been carried out measuring rheological properties in the fresh state of cement paste and mortar, from conventional measurements, flow test and slump test, to more quantitative fundamental methodology, rheometer by various researchers, to name a few, Cry *et al.* (2000), Ferraris *et al.* (2001), Nagendra (2013). The quantitative fundamental methodology, which was developed to assess the rheology of fluid state, has been used for analyzing cement paste and mortar. This method introduced rheological parameters, such as yield stress and plastic viscosity, for quantifying the flowability. Recent research indicated that the yield stress of cement paste showed the same trend of slump in concrete, and the plastic viscosity was associated with the stickiness, placeability, pumpability, finishability and segregation in the concrete (Daczko 2003, Park *et al.* 2004).

In addition to the afore-mentioned works, there are several investigations carried out for studying the effect of fine aggregates on rhelogical behavior of self - compacting concrete. Westerholm *et al.* (2008) demonstrated that the large amount of fine materials often found in crushed rock fine aggregate would increase the mortar yield stress whereas the particle shape of the fine aggregate would affect the mortar plastic viscosity. Evidently, the grading and particle shape of the fine aggregate have significant effects on the rheology of the mortar formed. However, they do not directly affect the rheology of the mortar. Instead, they affect the packing density and solid surface area, which then exert influence on the rheology of the mortar. Reddy and Gupta (2008) demonstrated that generally a mortar made of finer sand would need a higher water content for a given workability and explained that this is because of the larger solid surface area arising from the finer sand used. It is now widely recognised that the major parameters governing the rheology of mortar are the water content, packing density and solid surface area.

Further, there are few investigations concerning the effect of super-plasticizers on the self compacting concrete. Polycarboxylates (PCEs) are commonly used as super-plasticizers to disperse cement particles in concretes and mortars. Ramchandran (1992) observed that these super-plasticizers can significantly improve the workability of concrete, reduce the water demand and enhance the strength of cementitious construction materials. Plank *et al.* (2009) indicated that polycarboxylates constitute an essential chemical admixture for the preparation of ultra-high-performance concrete (UHPC).

Although much effort has been devoted to studying the effects of super-plasticizer (SP) on cement paste, mortar and concrete, there have been very few guidelines for their use. In fact, proper use of super-plasticizers is not straightforward. Firstly, demand of the super-plasticizers for a given flow ability requirement is dependent not only on the type of cement, but also on the types and fineness of other cementitious materials; and fillers added to the cement. In general, higher is the fineness of the particles in the cement paste, the higher is the super-plasticizers demand. Secondly, their effectiveness increases with the SP dosage only up to a certain saturation dosage, beyond which further addition of the super-plasticizer gives minimal or even no return (Aydin *et al.* 2009, Jayasree and Gettu 2008). Pursuant to this, Kwan and Ng (2009) pointed out that usage of super-plasticizers beyond saturation dosage is not economical. While the repulsion between particles due to addition of super-plasticizer would improve the flowability of cement paste, mortar and concrete, it would also impair the cohesiveness, thus increasing the risk of bleeding, sedimentation and segregation. This problem of reduced cohesiveness is usually more serious when the effectiveness of the super-plasticizer is high and/or the dosage of the super-plasticizer is high (for instance, when a polycarboxylate-based SP is used at high dosage). ACI (2008) incorporated various parameters affecting rheology of concrete as pointed out in various investigations undertaken by the afore-mentioned researchers.

3. Significance of the present work

Thus, in order to avoid such a problem, it is necessary that the super-plasticizers' dosage should be limited to the optimum one that would not cause bleeding and segregation. The demand of the super-plasticizers, saturation dosage and dosage causing segregation depends not only on the super-plasticizers used, but also on the types and fineness of the powder content (the cementitious materials and fillers) in the cement paste. As the super-plasticizer is a surface reactant adsorbed onto the particle surfaces of the powder content, its effectiveness depends upon the amount of the super-plasticizer per surface area of the powder content. On the backdrop of the above-referred literature and keeping the gaps therein into consideration, this investigation aims at quantifying the impact of the varying amounts of mineral admixtures on the rheological behaviour of self compacting concrete (SCC) containing natural sand.

4. Materials and proportions of mixes

The present work involves the use of International Concrete and Aggregate Research (ICAR) rheometer. A series of SCC mixes covering a range of rheological properties were tested to demonstrate the validity use of the ICAR rheometer.

The cementitious materials used in the present investigation includes ordinary Portland cement (OPC) (53 grade), class- F fly ash (FA), ground granulated blast furnace slag (GGBS) and silica fume (MS). The chemical compositions of these materials are shown in Table 1.

Two aggregate fractions, coarse and natural sand, were used in all the mixes. The particle size distributions of these aggregates are shown in Table 2. The high-range water-reducing admixture (HRWRA), Glenium 8055, a polycarboxylate-based admixture is used in the present study for producing SCC. All the mixes incorporated a water reducing and retarding admixtures in order to achieve constant flow up to 700 ± 10 mm. The sources of different raw materials used in the study are indicated in Table 3 while the physical properties of other materials used in the study are indicated in Table 4.

In the present work, the results obtained using traditional methods in respect of the workability are compared with those obtained using ICAR Rheometer in the present investigation through an experimental study. The study, aiming at studying the rhelogical behavior of SCC, entails the use of ordinary Portland cement (OPC) and other cementitious materials like such as fly ash, ground granulated blast furnace slag, and micro silica. These materials are replaced by various percentages

Table 1 Chemical compositions of the cementitious materials used in the study (wt. %)

Compound	OPC	FA	GGBS	MS
SiO	21.4	68.1	33.79	88.9%
$A1_2O_3$	4.3	25.8	20.73	0.4
Fe_2O_3	2.4	6.9	1.12	0.4
CaO	64.4	8.7	31.06	1.6
MgO	2.1	1.39	11.23	-
SO_3	2.3	0.26	0.10	0.4
Na_2O	0.60	0.18	0.30	0.5

Table 2 Particle size distribution of aggregates used for study

IS Sieve	20 mm	10 mm	Natural sand
Type	Crushed	Crushed	Uncrushed
20mm	93.3	100	100
10mm	4.78	92.23	100
4.75mm	0	1.62	89
2.36mm	0	0	74
1.18mm	0	0	64.1
0.6mm	0	0	41.8
0.3mm	0	0	9.9
0.15mm	0	0	6.6
0.075 mm	0	0	1.0
F. M.	6.02	5.06	3.15
Specific Gravity	2.89	2.86	2.65
Water Absorption	1.60	1.80	2.5
Silt Content (%)	0	0	8
Silt By WT.	0	0	3
Crushing Value	18.54	18.54	---
Impact Value	18.4	18.4	---
Flakiness Index	19.75	22	---
Elongation Index	22.05	22.05	---

Table 3 Source of different raw materials use for study

Material used	Source
Cement	OPC 53 Mumbai region, India.
GGBS	Durocem GGBS,India
Fly Ash	Ash Tech ,Nasik Power plant, India
Micro-silica	Corniche ,China origin
Admixture	BASF India ltd.
Natural sand	Bellari,Karnataka,India
Aggregates	Turbhe, navimumbai, India.

Table 4 Physical properties of the other materials used in the study

Properties of binders	OPC	FA	GGBS	MS
Density (g/cm^3)	3.15	2.25	2.91	2.2
Specific Surface (M^2/kg)	328	3650	5962	620
Properties of admixture				
Aspect	Light brown liquid			
Relative Density	1.05 ± 0.01 at 25°C			
pH	> 6			
Chloride ion content	< 0.2%			

keeping volume of the mix paste and flow of concrete constant. All the measurements were taken at higher temperature (temperature of concrete and atmosphere varying between 33^o to 40^{o}C). The additional details on the mix proportions are provided in Table 5.

Table 5 Mix proportions for laboratory trials

Description	OPC (kg/m³)	FA (kg/m³)	GGBS (kg/m³)	MS (kg/m³)	w/b	Free water (lit/m³)	20 mm (kg/m³)	10 mm (kg/m³)	NS (kg/m³)	150 μ Natural sand (%)	Paste vol. (%)
NS - SCC OP1	650	0	0	0	0.27	176	327	483	822.2	6.0%	41
NS- SCC PF20	504	126	0	0	0.27	170	322	477	810.8	6.0%	41
NS – SCC PF40	366	244	0	0	0.27	165	318	471	800.7	6.0%	41
NS - SCC OP2	650	0	0	0	0.27	176	327	483	822.2	6.0%	41
NS - SCC GGBS40	387	0	258	0	0.27	174	324	479	814.8	6.0%	41
NS - SCC GGBS70	190.5	0	444.5	0	0.27	171	323	478	812.2	6.0%	41
NS - SCC OP3	650	0	0	0	0.27	176	327	483	822.2	6.0%	41
NS - SCC MS5	617.5	0	0	32.5	0.27	176	325	480	816.2	6.0%	41
NS - SCC MS7.5	596.6	0	0	48.4	0.27	174	324	479	815.4	6.0%	41
NS - SCC MS10	576	0	0	64	0.27	173	324	479	814.7	6.0%	41

Fig. 1 ICAR Rheometer testing and set-up

5. Experimental work

The ICAR Rheometer is composed of a container to hold the fresh concrete, a driver head that includes an electric motor and torque meter, a four-blade vane that is held by the chuck on the driver, a frame to attach the driver/vane assembly to the top of the container; and a laptop computer to operate the driver, record the torque during the test and calculate the flow parameters. The container contains a series of vertical rods around the perimeter to prevent slipping of the concrete along the container wall during the test. The set-up of the ICAR rheometer, used for the testing, is shown in Fig. 1.

The concrete was discharged directly from the ribbon mixer into the ICAR rheometer container. Two types of tests were performed. The first one was a stress growth test in which the vane was rotated at a constant slow speed of 0.025 rev/s. The initial increase of torque was

Table 6 Various parameters of the rheology of fresh concrete

Description	Master Glenium 8055 (%)	Pozzolith 55 R (%)	Ambi temp (°C)	Con. temp. (°C)	T_{50} (sec)	Flow (mm)	VSI	L box	V funnel (sec)	Yield stress (Pa)	Viscosity (Pa.s)	Density (kg/m³)
NS - SCC OP1	1.00%	0.20%	39	36.2	5	700	0	0.976	9	185.8	100	2429
NS- SCC PF20	0.95%	0.20%	35.3	34.3	5.6	690	0	0.988	10	173	89	2390
NS - SCC PF40	0.60%	0.20%	40.2	35.6	4	700	0	0.907	17	154.3	106	2380
NS - SCC OP2	1.10%	0.20%	37	36	4	700	0	0.93	10	270.4	100.2	2474
NS - SCC GGBS40	1.00%	0.20%	38.7	34.9	5	690	0	0.932	11.5	172	120.3	2429
NS - SCC GGBS70	0.80%	0.20%	36.1	35.5	6.5	700	0	1	13.3	76.2	82.3	2391
NS - SCC OP3	0.80%	0.20%	33.3	32.7	5	710	0	0.9	14	180.4	87.2	2435
NS - SCC MS5	0.85%	0.20%	33.5	32.9	4.2	700	0	0.92	10	117.9	64.9	2441
NS - SCC MS7.5	1.10%	0.20%	33.5	33	3.8	690	0	0.93	9	85.1	76	2438
NS - SCC MS10	1.25%	0.20%	33.5	33.3	3.2	700	0	0.95	15.6	100.5	93.9	2425

measured as a function of time. The maximum torque measured during the test was used to calculate the static yield stress. The other type of test was a flow- curve test to determine the dynamic yield stress and the plastic viscosity.

In addition, the slump- flow test was performed by filling the concrete into a standard slump cone (ASTM C- 143) that was centered on a level plastic plate. The slump cone was lifted and three measurements were made- the time for the concrete to spread to a horizontal diameter of 500 mm (T(T_{50}), the final horizontal spread diameter; and the visual stability index (VSI). The VSI ratings, which were determined based on the definition as given by Wallevik (2008), were made on a scale of 0 to 3, with 0 exhibiting excellent stability and 3 exhibiting poor stability. Other than flow L-Box, V-funnel test was performed as per EFNARC (2005) standard.

6. Results and discussion

The various parameters obtained in view of the rheology of fresh concrete using various materials such as fly ash, ground granulated blast furnace slag (GGBS) and micro-silica (MS) are shown in Table 6. The effects of the various cementitious materials used in the present investigation such as fly ash, ground granulated blast furnace slag, micro-silica on the rheological behavior of self compacting concrete are discussed below.

6.1 Effect of fly ash

From the various parameters obtained in view of the rheology of fresh concrete using fly ash (PF) as shown in Table 6 and indicated in Fig. 2, it is seen that the addition of increasing levels of fly ash (PF) results in reduction in yield stress in the mixes. With the addition of fly ash, the yield stress is found to decrease from 185.8 Pa in respect of the mix OP-1 to 154.3 Pa for the mix PF-40.

The viscosity is found to reduce from 100 Pa-s to 89 Pa-s, with increasing replacement levels

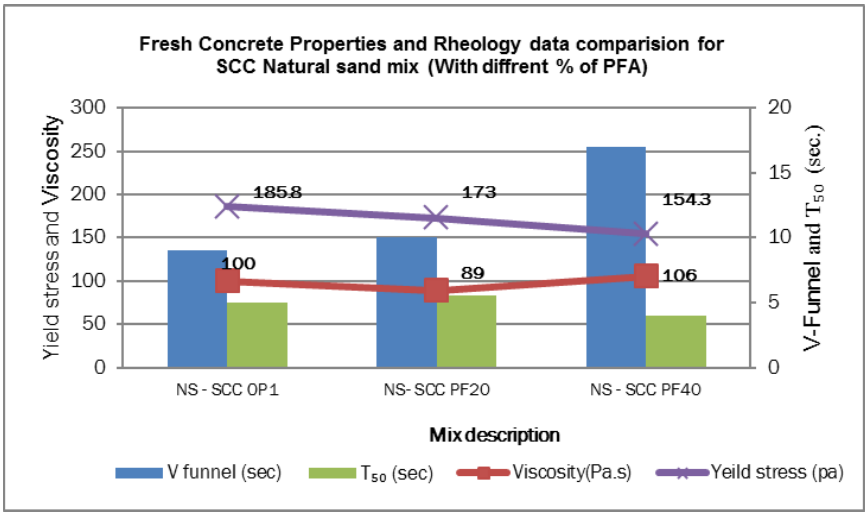

Fig. 2 Influence of fly ash on rheology of fresh concrete

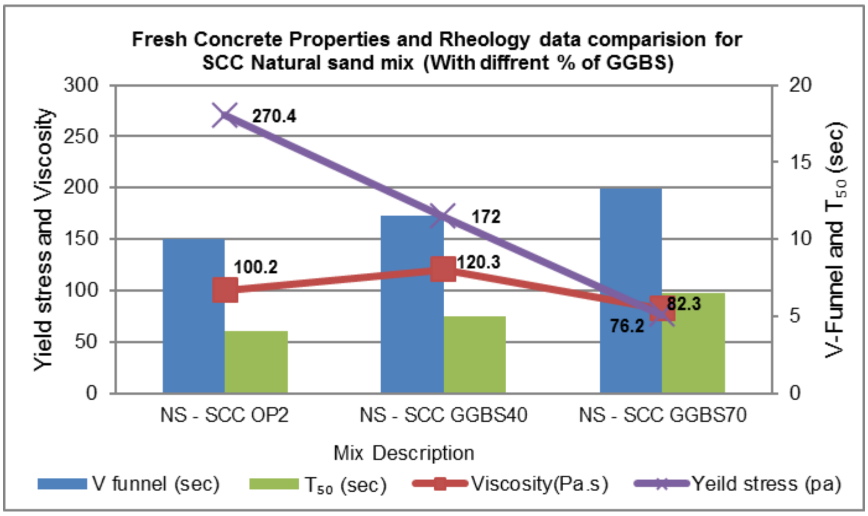

Fig. 3 Influence of GGBS on rheology of fresh concrete

of fly ash up to 20% in NS mix. The effect of fly ash on the plastic viscosity was variable with higher dosage. At 40 % fly ash, the viscosity is found to increase up to 108 Pa-s. The addition of fly ash is found to decrease the admixture dosage for similar flow. With increase in fly ash, the V-funnel value is found to increase from 9 to 17 seconds. For 20% fly ash, the T_{50} value is seen to increase from 5 seconds to 5.6 seconds. However, the corresponding value is found to decrease from 5.6 seconds to 4 seconds with 40 % fly ash.

Therefore, it can be suggested that the fly ash can be used to reduce yield stress without resulting in large decreases in the plastic viscosity without affecting the stability of mixes. The spherical shape of the fly ash particles acts as ball bearings to reduce the friction between particles. The fineness of the fly ash offset this ball bearing effect and could be probably partly responsible for the increase in viscosity.

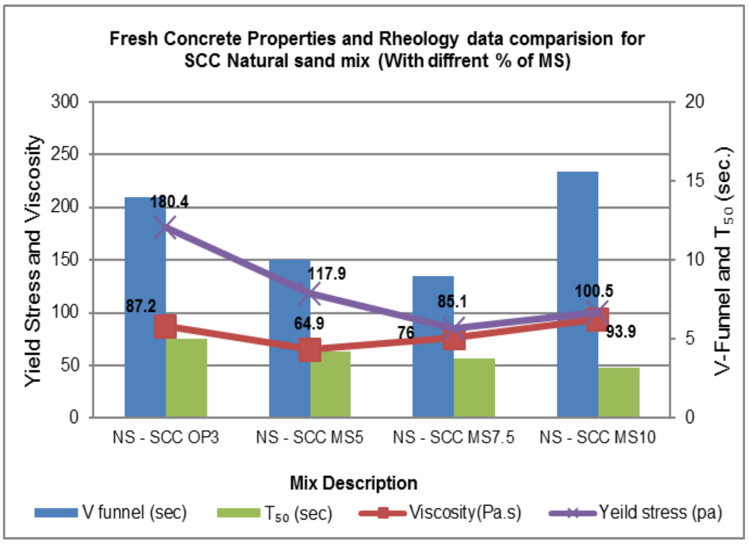

Fig. 4 Influence of micro-silica on rheology of fresh concrete

6.2 Effect of ground granulated blast furnace slag

The various parameters obtained in view of the rheology of fresh concrete comprising ground granulated blast furnace slag (GGBS) are shown in Table 6. They are indicated graphically in Fig. 3. The ground granulated blast furnace slag (GGBS) was used to replace cement on a mass basis at rates of 40% and 70%. It is seen that the addition of increasing levels of GGBS resulted in a reduction in yield stress from 270.4 Pa to 76.2 Pa whereas the plastic viscosity increased slightly corresponding to 40% replacement from 100.2 Pa-s to 120.3 Pa-s. With further replacement of cement by slag up to 70%, the viscosity decreased from 120.3 Pa-s to 82.3 Pa-s. Similarly, with increase in GGBFS, the V-funnel value is found to increase from 10 to 13.3 seconds and T_{5o} value is seen to increase from 4 seconds to 6.5 seconds due to addition of GGBS. Therefore, it can be suggested that the GGBS can be used only up to 70 % in order to reduce yield stress without resulting in large decrease in plastic viscosity.

6.3 Effect of micro-silica

The various parameters obtained in view of the rheology of fresh concrete containing micro-silica (MS) are shown in Table 6. Further, they are indicated graphically in Fig. 4.

Micro-silica (MS) was used as a mass replacement of cement at rates of 5, 7.5 and 10 percent, respectively. From the results tabulated in Table 6, the yield stress and the plastic viscosity were measured as a function of the amount of micro-silica amount in the micro-silica based mixes. The yield stress and the plastic viscosity are found to increase sharply with increasing percentage of micro-silica. The addition of micro-silica (MS) is found to have a tendency towards reduction in the workability of the mixes. It can be attributed to the increased viscosity/cohesiveness of the mix. The higher dosages of super-plasticizer (SP) was needed to keep slump flow of micro-silica based SCC mixes at 700 mm, which suggested the decrease in the slump flow with the increase in the percentage of the micro-silica.

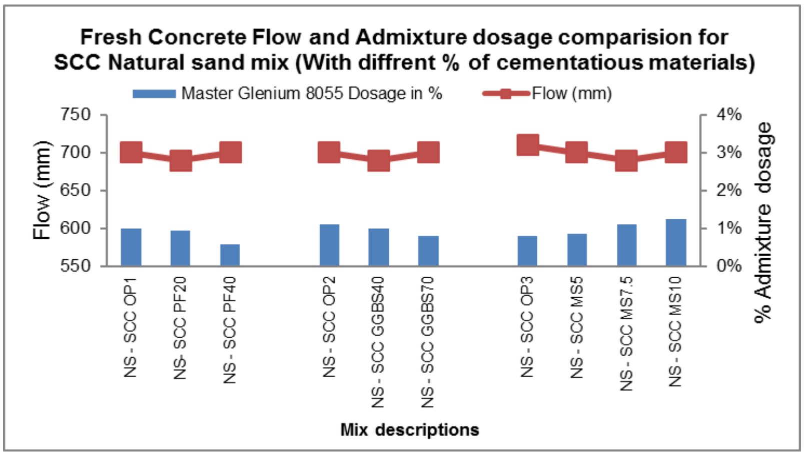

Fig. 5 SCC Flow and admixture dosage comparison

The micro-silica based SCC mixes exhibited good ability to flow through the rebar of the L-box test. Based on the slump flow, L-box and V funnel tests, self-consolidating properties for all the developed micro-silica based SCC mixes were considered satisfactory. Further, the viscosity is observed to decrease from 87.2 Pa-s to 64.9 Pa-s. However, the corresponding value is found to increase from 64.9 Pa-s to 93.9 Pa-s with 10% micro-silica. On the other hand, the yield stress is found to decrease with the increase of contents of super-plasticizer up to 7.5%. The yield stress is found to show a significant increase 85.1 Pa to 100.5 Pa when the percentage of the micro-silica was 10%. The use of micro-silica results in the lower yield stress and higher viscosity for the SCC mixes. The micro-silica also helps to improve the VSI index of mixes thereby indicating the improvement in the stability of the mixes.

6.4 Effect of cementitious material on superplasticiser dosage

In order to study the influence of the cementatious materials on the dosage of superplasticiser, the same water to binder ratio and the same initial worability results are compared in Table 6. They are illustrated further in Fig. 5.

It is seen that the addition of fly ash and ground granulated blast furnace slag in the increasing levels results in reduction in the dosage of super-plasticizer to obtain similar flow. However, the addition of micro-silica is found to increase the dosage of super-plasticizer to obtain similar flow.

6.5 Effect of cementitious materials on the compressive strength

Al though the focus of the study was to study the rheological behaviour of the SCC mixes with various contents of the different cementitious materials, a study was extended to the limited extent so as to include the aspect of the study of compressive strengths of the hardened samples of these mixes. The compressive strength of the various mixes of SCC as considered in the preceding sections corresponding to 3, 7, 28 and 56 days' curing periods and containing different cementitious materials such as fly ash, ground granulated blast furnace slag and micro-silica is also studied. The values of the strengths for various mixes in respect of different curing periods are indicated in Table 7.

Table 7 Values of compressive strengths (N/mm²) for various SCC mixes

Description	3 days	7 days	28 days	56 days
NS - SCC OP1	67	90	105	108
NS- SCC PF20	52	68	97	106
NS - SCC PF40	42	50	77	89
NS - SCC OP2	78	85	92	95
NS - SCC GGBS40	44	49	80	94
NS - SCC GGBS70	36	42	64	80
NS - SCC OP3	54	71	98	101
NS - SCC MS5	56	70	102	107
NS - SCC MS7.5	54	73	105	113
NS - SCC MS10	59	75	112	116

From the values of the compressive strengths tabulated as above, the rate of gain of strength in concrete is found to decrease as compared to the strength gain observed in respect of the mixes containing plain ordinary Portland cement (OPC). However, with the addition of micro-silica is found to improve the rate pf gain of strength as compared to that observed in respect of the mixes prepared with plain OPC, when compared with at the same paste volume and w/b ratio.

7. Conclusions

An experimental study was carried out to study the effect of various cementitious materials on the rheological behaviour of the self consolidating concrete prepared using natural sand. The cementitious materials such as fly ash, ground granulated blast furnace slag and micro-silica in conjunction with the mineral admixture were used in different percentages. A limited study was also carried out on the hardened concrete mixes of the SCC.

Based on the results discussed in the afore-mentioned section, it can be said that the rheology and the slump flow tests can be concurrently used for predicting the flow behaviours of SCC made with different cementitious materials. The instrument ICAR (International Center for Aggregate Research) rheometer employed in the present study for evaluating the rhelogical behaviour of the SCC is found to detect systematic changes in workability, cementitious materials, successfully.

The fly ash can be used to reduce the yield stress without resulting in large decrease in the plastic viscosity and without affecting the problems of the stability of the mixes. However, the ground granulated blast furnace slag can reduce the yield stress without resulting in the large decrease in plastic viscosity only up to 70%. The micro-silica controls the yield stress and plastic viscosity considerably.

The concrete mix containing OPC and cementitious materials like FA, GGBS, MS demonstrates different rheological behavior which will guide the concrete engineers in arriving upon a decision for design of proper pumpable and economical concrete design. ICAR (International Center for Aggregate Research) rheometer used in study generates the rheological information of the concrete mixes other than traditional workability tests and the results can be co-related to establish the relationship between the various parameters. The data generated can be correlated with practical issue like formwork pressure, pump ability and finish ability in order to make suitable changes in mixes according to site requirements.

Due to the wide variation in materials available for concrete production and the infinite number of possible combinations of these materials, the information contained herein applies only to the general cases. However, for specific combinations of materials, trial batches can be tested to confirm trends.

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