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Experimental studies on rheological properties of smart dynamic concrete

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Abstract. This paper reports an experimental study into the rheological behaviour of Smart Dynamic Concrete (SDC). The investigation is aimed at quantifying the effect of the varying amount of mineral admixtures on the rheology, setting time and compressive strength of SDC containing natural sand and crushed sand. Ordinary Portland cement (OPC) in conjunction with the mineral admixtures was used in different replacement ratio keeping the mix paste volume (35%) and water binder ratio (0.4) constant at controlled laboratory atmospheric temperature (33°C to 35°C). The results show that the properties and amount of fine aggregate have a strong influence on the admixture demand for similar initial workability, i.e., flow. The large amounts of fines and lower value of fineness modulus (FM) of natural sand primarily increases the yield stress of the SDC. The mineral admixtures at various replacement ratios strongly contribute to the yield stress and plastic viscosity of SDC due to inter particle friction and cohesion.

Keywords: smart dynamic concrete (SDC); rheology; workability; ground granulated blast-furnace slag (GGBS); fly ash (FA); microsilica (MS); ICAR rheometer

1. Introduction

Concrete rheology exhibits a complex behaviour, both in fresh and hardened state. The flow of concrete is so complicated because it is a complex suspension of particles. Particles of coarse aggregates are dispersed in mortar and within the mortar, particles of fine aggregates are dispersed in cement paste and further within cement paste, cement particles are dispersed in water. Owing to this, the rheological behavior of fresh concrete cannot be described using Newtonian viscosity function, which is the simplest equation for describing the flow behavior of liquids. The Bingham model, which is the simplest form of non-Newtonian model, is frequently used for describing the flow behavior of ordinary concrete. However, some other types of concrete, especially the self-compacting concrete (SCC) exhibit different kinds of behavior and hence, need different non-Newtonian models to describe their behavior (Feys *et al.* 2008). Despite this, for simplicity, most of researchers follow Bingham model only. The smart dynamic concrete is classified as low fines self compacting concrete using special viscosity modifying admixtures (VMA) similar to the

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Table 1 Chemical compositions of the cementitious materials used in the study

Material	UoM	FA	GGBS	MS	OPC 53
Blaine fineness	(m^2/kg)	345	390		328
BET Surface Area	(m^2/kg)			22000	
Compressive strength as % of cement	(%)	84.2	92	156	100
Lime reactivity	MPa.	5.6		8.5	-
Autoclave expansion	(%)	0.06		NA	0.059
Sp. gravity	(%)	2.3	2.86	2.2	3.14
Loss on ignition (LOI)	(%)	1.2	0.37	2.6	2.81
Silica (SiO2)	(%)	60.72	33.72	92.3	20.68
Iron oxide (Fe2O3)	(%)	5.32	0.64	0.06	4.76
Alumina (Al2O3)	(%)	27.5	18.22	0.62	5.54
SiO2+Al2O3+Fe2O3	(%)	93.54	52.58	93.88	30.98
Calcium oxide (CaO)	(%)	1.42	34.51	0.3	61.39
Magnesium oxide (MgO)	(%)	0.48	11.22	0.3	1.07
Total sulphur (SO3)	(%)	0.21	0.22	0.05	2.5
Alkalies (Na2O+K2O)	(%)	1.71	0.53	0.6	0.38
Chloride	(%)	0.36	0.001	0.001	0.055
Retained on 45 microns	(%)	15	1.55	0.2	10.66

3. Significance of the present work

With increased urbanization, mass housing is one of the great challenges that the developing country like India is facing when rapid construction is necessary for a burgeoning population, building material that is strong and suitable for fast construction is the need of the hour. Smart Dynamic Concrete (SDC) is one such. It flows under its own weight, allowing it to be easily and is quickly worked into different structures which are as strong as a regular concrete. It is durable, helps in saving the construction resources and time and reduces the need for maintenance, thus reducing overall carbon footprint. Its use is becoming more popular lately, especially in mass housing projects.

This concrete is designed to upgrade low grade high slump concrete (150-200 mm) to become self-compacting and robust concrete for day-to-day use at minimum extra cost. The centerpiece of this concept is Master Matrix, a high performance viscosity modifying agent (VMA), which allows for a quantum leap in concrete robustness. This concrete combines the advantages of both-traditionally vibrated concrete and self-compacting concrete. This concept makes unique mix-design optimization (by reducing fines) possible. Smart Dynamic Concrete adds economical, ecological and ergonomic values to concrete and has the potential to move the market up to the next level of advanced construction practice (Corradi *et al.* 2007, Brayan *et al.* 2011, Seow *et al.* 2011, and Bruce *et al.* 2012).

Plenty of studies have explored the effect of mineral and chemical admixtures along with the different types of aggregates on the rheological behavior of SCC. However, the studies with respect to the smart dynamic concrete (SDC) has not been yet reported. On this backdrop, the study on rheological properties of smart dynamic concrete is presented here. The main objective of

Table 3 Physical properties of MasterGlenium Sky 8632

Aspect	Light brown liquid
Relative Density	1.04 ± 0.01 at 25℃
pH	>6
Chloride ion content	< 0.2%

Table 4 Mix proportions for laboratory trials and results of fresh properties

Mix Code	OPC	FA	GGBS	MS	MG 8632 Admixture	Flow	T_{500}	Yield stress	V funnel	Viscosity
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	(%)	(mm)	(sec)	(Pa)	(sec)	(Pa-s.)
NS OP 1	450	0	0	0	0.52	650	3.27	56.6	7.56	25.2
NS PFA 1	405	45	0	0	0.50	640	3.29	57	9.06	32
NS PFA 2	360	90	0	0	0.47	640	3.3	57.6	10	39
NS PFA 3	315	135	0	0	0.44	640	3.33	61	11	46.7
NS PFA 4	270	180	0	0	0.41	650	3.35	64.3	12	54.5
NS GGBS 2	360	0	90	0	0.48	640	3.36	66.7	11.96	56
NS GGBS 3	315	0	135	0	0.48	650	3.5	77	17	61
NS GGBS 4	270	0	180	0	0.45	640	3.69	86.9	21.5	66.4
NS GGBS 5	225	0	225	0	0.38	640	4.2	80	24	80
NS GGBS 7	135	0	315	0	0.35	650	5	93.9	28	92.1
NSMS2.5	438.8	0	0	11.25	0.60	650	3.3	65	8.7	29.3
NS MS 5	427.5	0	0	22.5	0.70	650	3.45	73	9.81	33.3
NS MS 7.5	416.3	0	0	33.75	0.80	630	3.35	75.2	10.06	25.5
NS MS 10	405	0	0	45	0.90	640	4.5	99.1	11.47	27.9
CS OP 1	450	0	0	0	0.60	640	2.43	61.8	10	17.2
CS PFA 1	405	45	0	0	0.55	640	2.9	60	12.5	23
CS PFA 2	360	90	0	0	0.51	640	3.3	56.6	15.12	27.7
CS PFA 3	315	135	0	0	0.50	650	3.4	63	20	32
CS PFA 4	270	180	0	0	0.47	650	3.45	68.8	24.6	38.8
CS GGBS 2	360	0	90	0	0.48	640	3.59	62.2	16.16	25.1
CS GGBS 3	315	0	135	0	0.48	650	3.62	72	19	27.9
CS GGBS 4	270	0	180	0	0.47	640	3.68	83.2	21.5	29.5
CS GGBS 5	225	0	225	0	0.43	650	3.85	71.5	23	35.8
CS GGBS 7	135	0	315	0	0.37	650	4	60.1	25	41
CS MS 2.5	438.8	0	0	11.25	0.65	650	2.6	36	12	19.4
CS MS 5	427.5	0	0	22.5	0.70	630	3	52.2	13.38	21.5
CS MS 7.5	416.3	0	0	33.75	0.85	640	3.4	69.7	15.36	17.8
CS MS 10	405	0	0	45	0.96	640	4.8	111	16.31	24.2

(OP1-100% OPC, PFA 1-10% PFA, PFA 2-20% PFA, PFA 3-30% PFA, PFA 4-40 % PFA, GGBS 2-20% GGBS, GGBS 3-30% GGBS, GGBS 4-40% GGBS, GGBS 5-50% GGBS, GGBS 7-70% GGBS, MS2-2.5% Micro silica, MS5-5% Micro silica, MS 7-7.5% Microsilica, MS10-10% Micro silica, NS-Natural sand, CS-Crushed sand.)

(a) Slump Flow (b)V-Funnel

Fig. 3 V-funnel, flow table, ICAR Rheometer used for the testing

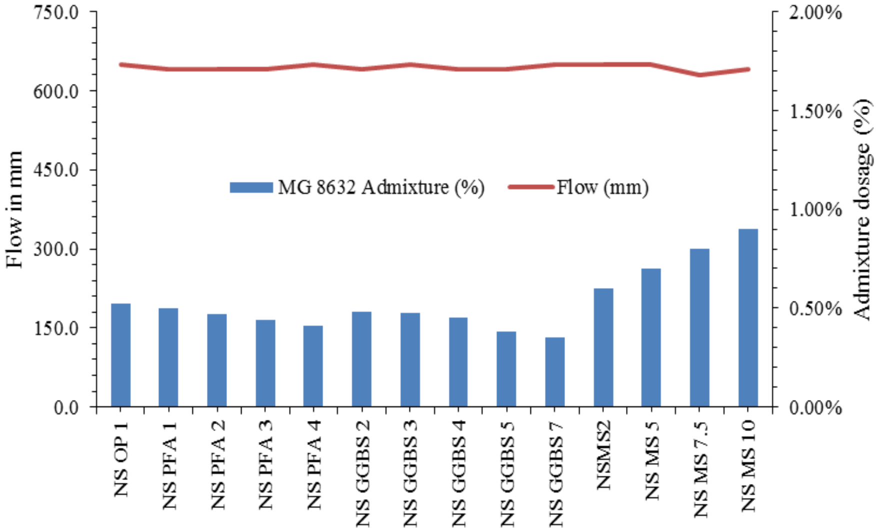

Fig. 4 The influence of natural sand and cementitious materials on admixture dosage for similar workability in SDC mixes

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 (Fig. 3(a)). 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_{500}), 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

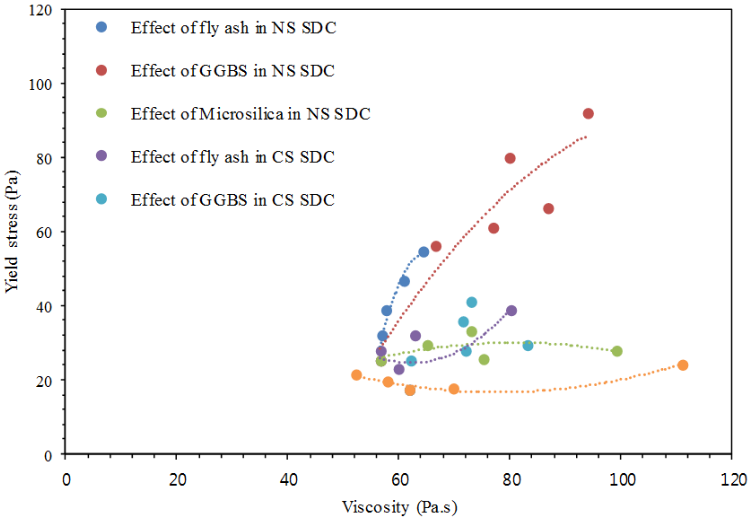

Fig. 6 Effect of replacement of fly ash, GGBS, Microsilica on rheology of SDC

6.1 Effect of cementitious materials on admixture dosage for similar flow

Though the paste volume of SDC mixes is constant, physical properties of fine aggregates (sand) influence the rheology of concrete. As per material properties and gradation report (Table 2), the natural sand (0-3 mm) is finer than crushed sand (0-4.75 mm) which, results in to more cohesive and densely packed concrete mix. The fineness of natural sand silt content is 3.5%, water absorption is 0.5% while for crushed sand silt content, the corresponding values are 12.5% and 4%, respectively. Hence, for similar initial flow, the SDC mixes with crushed sand are found to required higher dosage of Admixture (MasterGlenium Sky 8632) than that in the mix with natural sand. The mixes with crushed sand is found to require approximately 8-10% higher dosage of admixture than that in the mixes with natural sand, for similar flow value in SDC.

The fineness of fly ash and GGBS is lesser than that of Microsilica. The addition of fly ash and GGBS decreases the demand of admixture while that of micro silica, increases the demand for similar workability in both the mixes, i.e., the mixes with natural and crushed sand (Figs. 4 and 5).

An increase in fines in sand can reduce both-the initial workability and the workability retention performance of a high-range water reducer (HRWR). The higher dosages of HRWR than the normal dosage are required due to the presence of large amounts of ultra-fine particles (less than ~150 μ). At the construction site this can be interpreted as an addition of water to the concrete mixture so as to maintain the workability which can result in the higher dosage of admixture for maintaining *w/b* value and achieving the desired workability and workability retention. From this it can be inferred that, the proper control of aggregate source and an understanding of the variance in fines is necessary to ensure good quality control of SDC concrete at the site.

6.2 Effect of contents of mineral admixtures on rheological properties

The effect of replacement of fly ash, GGBS, Microsilica in the different proportion on the rheological properties of SDC is illustrated in Fig. 6.

It is evident from Fig. 6 that, the addition in the replacement contents of fly ash, GGBS, Micro

Table 5 Effect of crushed sand on yield stress and viscosity of SDC mixes

Mix	NS Yield stress (Pa)	CS Yield stress (Pa)	Change in Yield stress (Pa.)	Change in Yield Stress (%)	NS Viscosity (Pa.s.)	CS Viscosity (Pa.s.)	Change In Viscosity (Pa.s)	Change in Viscosity (%)
100% OPC	56.6	61.8	-5.2	-9	25.2	17.2	8	32
10% FA	57	60	-3	-5	32	23	9	28
20% FA	57.6	56.6	1	2	39	27.7	11.3	29
30% FA	61	63	-2	-3	46.7	32	14.7	31
40% FA	64.3	80.2	-15.9	-25	54.5	38.8	15.7	29
20% GGBS	66.7	62.2	4.5	7	56	25.1	30.9	55
30% GGBS	77	72	5	6	61	27.9	33.1	54
40% GGBS	86.9	83.2	3.7	4	66.4	29.5	36.9	56
50% GGBS	80	71.5	8.5	11	80	35.8	44.2	55
70% GGBS	93.9	60.1	33.8	36	92.1	41	51.1	55
2.5% MS	65	58	7	11	29.3	19.4	9.9	34
5% MS	73	52.2	20.8	28	33.3	21.5	11.8	35
7.5% MS	75.2	69.7	5.5	7	25.5	17.8	7.7	30
10% MS	99.1	111	-11.9	-12	27.9	24.2	3.7	13

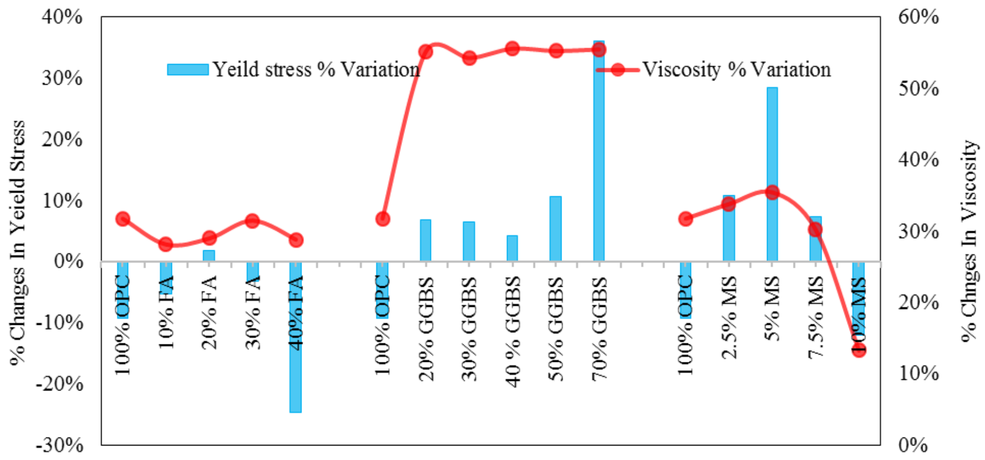

Fig. 9 Effect of crushed sand on the yield stress and viscosity w.r.t. natural sand

crushed sand mixes. The fly ash is a lighter material with spherical shape and high fines than OPC and this, contributes to the increase in the viscosity.

Ground granulated blast furnace slag (GGBS) was used to replace OPC on a mass basis at rates of 20, 30, 40, 50 and 70% (various percentages of GGBS which satisfies the IS 456-2000 code allowed limit). From Figs. 7 and 8, and Table 4, it is seen that the addition of GGBS in the increasing levels of GGBS increases the yield stress and viscosity. This may be attributed to the flaky particles. The change in the rheology of SDC mixes made with natural and crushed sand seems to be similar when the GGBS is used. The GGBS have sharp edges and angles; and stick shape with a bit smaller. The GGBS particles when compared with the particles of ordinary

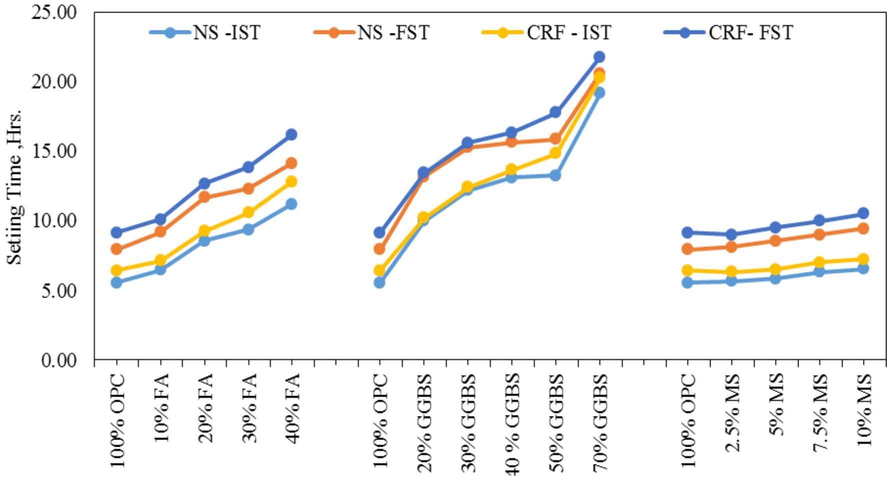

Fig. 12 Effect of cementitious materials on setting time

the dosage of MS up to 5% is found to improve the viscosity and at 7.5% and 10% dosage, however, significant decrease in the viscosity is observed. Some of the researchers reported the optimum content of MS to the tune of 7.5% for strength and durability of concrete. This observation also may also be considered valid for the rheology of concrete. The MS to some extent helps the SDC mixes made using crushed sand in order to achieve better cohesiveness, robustness and rheology.

6.3 Effect of crushed sand on rheology of SDC concrete

The effect of addition of various cementitious materials on the SDC mixes made with natural sand and crushed sand is also examined from the results obtained using the experimental data. The change in the yield stress and viscosity with respect to the use of either type of sand is obtained and is shown in Table 5 and also indicated in Fig. 9.

The effect of addition of the various mineral admixtures such as fly ash, GGBS and micro silica on rheology is not observed to be similar for the SDC mixes with crushed sand when compared with those with natural sand. In the mixes with similar contents of the cementitious materials, the crushed sand based SDC mixes is observed to show an increase in the viscosity (min. 13% and max 55%). It is clear that due to the use of crushed sand, viscosity and stickiness gets increased. The results also indicate that the yield stress increases in respect the mixes made with GGBS and Microsilica whereas in those with fly ash, the yield stress decreases. It is also noted from Table 5 that the percentage increase or decrease in the yield stress in crushed sand based SDC mixes is complex in nature; one can use similar fineness modulus sands to differentiate further. It is reported in the literature that the yield stress depends on the workability (flow/slump) of concrete. This may be the reason that all mixes in the present study are showing similar workability, which may affect the proper yield stress correlation in crushed and natural sand SDC mixes.

6.4 Significance of the relationship between traditional test method and rheology data

The establishment of the relationship between the fresh characteristics of the respective SDC

the setting time. Similar effect of fly ash on setting time is also reported in the literature (Webster *et al*. 2015). The micro silica does not have significant impact on the delay in setting time. The setting time of microsilica based crushed sand mixes shows delay in setting when compared with the natural sand mixes. This is mainly due to the addition of higher superplasticizer dosage.

6.6 Effect of natural and crushed sand on the development of strength

The compressive strength of the SDC mixes made using natural and crushed sand for 7 days, 28 days and 90 days' curing period for various proportions of admixtures was obtained and indicated in Fig. 13.

It is observed from Fig. 13 that the natural sand based mixes shows slightly better strength as compared to that in crushed sand mixes. It may be noted that the silt contents in the crushed sand affects the strength to some extent. The mixes with replacement of OPC by fly ash mix show decrease in strength whereas that by GGBS and Micro silica, enhancement in the strength. It is also seen that the replacement by GGBS up to 40% helps in maintaining the strength. However, the replacement above 40% replacement affects the strength. This could be due to the slow reaction of cementitious materials with OPC with the increasing contents of such materials.

7. **Conclusions**

From the experimental investigations carried out to study the effect of cementitious materials such as fly ash, GGBSMS and their influence on the rheology of smart dynamic concrete (SDC), following broad conclusions can be deduced:

- Flow properties of low fine SDC concrete are largely affected by the use of crushed sand when compared with the natural (river) sand.
- Crushed sand mixes shows low viscosity as compared to that natural sand mixes. This is mainly due to higher fineness modulus of crushed sand (3.41) than that of natural sand (2.32). Further, the natural sand is seen to have passed 100% through 2.36 mm sieve, which contributes in dense packing of the aggregates and thus, increases the yield stress and the viscosity.
- Viscosity values of crushed sand mixes is very low (average 27 Pa.s). The low viscosity affects stability of mix and create problems for pumping. When compared with the rheology of SCC reported in the past by the authors (Bauchkar and Chore 2014), the viscosity of SDC mixes is very low. Hence, more care is required for the design and execution of SDC. Low viscosity may lead to segregation of concrete and pump blockage if variation in moisture, w/b ratio or cementitious materials is not controlled at site.
- The rheological properties of SDC are highly dependent on the type of cementitious materials used in mixes and the contents thereof.
- The GGBS considerably increases the yield stress and the viscosity of concrete, i.e., beyond optimum limit as a result of which it may create pumping issues or high pump pressure.
- Crushed sand slightly helps in improving the lateral compressive strength of SDC due to better particle packing of aggregates.
- Higher admixture dosages in crushed sand based SDC mixes cause delay in setting and reduction in early strength, i.e., strength of even one day.

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

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References

American Concrete Institute (2008), *Report on Measurements of Workability and Rheology of Fresh Concrete*, Report No. 238.1 R-08.

Aydin, S., Hilmi, A.A. and Ramyar, K. (2009), “Effects of fineness of cement on polynaphthalene sulfonate based superplasticizer-cement interaction”, *Constr. Build. Mater.*, **23**(6), 2402-2408.

Bauchkar, S.D. and Chore, H.S. (2014), “Rheological properties of self-consolidating concrete with various mineral admixtures”, *Struct. Eng. Mech.*, **51**(1), 1-13.

Bruce, J.C. and Huebsch, C. (2012), “Solutions to support more sustainable construction practices”, *Spec. Publ.*, **289**, 1-12.

Bryan, B, Roncero, J., Magarattom, R., Mara, S. and Khurana, R. (2011), “Friendly self-compacting concrete”, *Concrete Plant Int.*, **21**, 60-66.

Chidiac, S.E. and Mahmoodzadeh, F. (2009), “Plastic viscosity of fresh concrete-a critical review of predictions methods”, *Cement Concrete Compos.*, **31**(8), 535-544.

Corradi, M., Kluegge, J., Kar, N., Christensen, B. and Yang, J. (2007), “A new viscosity modifying agent (VMA) for low fines self-consolidating concrete”, *Proceedings of the 5th International RILEM Symposium on Self-Compacting Concrete*, **2**, 875-880.

Cry, M., Legrand, C. and Mouret, M. (2000), “Study of the shear thickening effect of superplasticizers on the rheological behaviour of cement pastes containing or not mineral additives”, *Cement Concrete Res.*, **30**(9), 1477-1483.

Daczko, J.A. (2003), “Stability of self-consolidating concrete-assumed or ensured?”, *Proceedings of the 1st North American Conference on the Design and Use of Self-Consolidating Concrete*, Chicago, U.S.A., November.

EFNARC (2005), *The European Guideline for Self-Compacting Concrete (SCC): Specification for Production and Use*, 68.

Ferraris, C.F. (1999), “Measurement of the rheological properties of high performance concrete-state of the art report”, *J. Res. NIST*, **104**(5), 461-478.

Ferraris, C.F., Obla, K.H. and Hill, R. (2001), “The influence of mineral admixtures on the rheology of cement paste and concrete”, *Cement Concrete Res.*, **31**(2), 245-255.

Feys, D., Verhoeven, R. and De Schutter, G. (2008), “Why is fresh self-compacting concrete shear thickening?”, *Cement Concrete Res.*, **39**(6), 510-523.

IS: 383 (1970), *Specification for Coarse and Fine Aggregates from Natural Sources for Concrete*, Bureau of Indian Standards, New Delhi, India.

Jayashree, C. and Gettu, R. (2008), “Experimental study of the flow behavior of super-plasticized cement paste”, *Mater. Struct.*, **41**(9), 1581-1593.

Khayat, K.H., Omran, A.F., Naji, S., Billberg, P. and Yahia, A. (2012), “Field-oriented test methods to evaluate structural build-up at rest of flowable mortar and concrete”, *Mater. Struct.*, **45**(10), 1547-1564.

Kwan, A.K.H. and Ng, I.Y.T. (2009), "Optimum super plasticizer dosage and aggregate proportions for SCC", *Mag. Concrete Res.*, **61**(4), 281-292.

Mork, J.H. and Gjorv, O.E. (1996), "Effect of Gypsum hemihydrates ratio in cement on rheological properties of fresh concrete", *ACI Mater. J.*, **94**(2), 142-146.

Nagendra, R., Bharti, G.S.H. and Suresh, M.R. (2013), "Rheology of SCC with pond ash as partial replacement to fine aggregate", *Proceedings of the International Conference on Innovation in Concrete*, Hyderabad, India, October.

Nehdi, M., Mindess, S. and Artcin, P.C. (1998), "Rheology of high-performance concrete: Effect of ultrafine particles", *Cement Concrete Res.*, **28**(5), 687-697.

Neubauer, C.M., Yang, M. and Jennings, H.M. (1998), "Interparticle potential and sedimentation behaviour of cement suspensions: Effects of admixtures", *Adv. Cement Base Mater.*, **8**, 17-27.

Neville, A.M. (1996), *Properties of Concrete*, Wiley Publication, New York, U.S.A.

Park, C.K., Noh, M.H. and Park, T.H. (2004), "Rheological properties of cementitious materials containing mineral admixtures", *Cement Concrete Res.*, **35**(5), 842-849.

Pilegis, M., Gardner, D. and Lark, R. (2016), "An investigation into the use of manufactured sand as a 100% replacement for fine aggregate in concrete", *MDPI J.*, **9**(6), 1-19.

Plank, J., Vlad, D., Brandl, A. and Chatziagorastou, P. (2009), "Colloidal chemistry examination of the steric effect of polycarboxylate superplasticizers", *Cement Int.*, **3**(2), 100-110.

Ramachandran, V.S. (1992), *Super-Plasticizers Progress in Cement and Concrete*, ABI Books (Part II), New Delhi, India, 345-375.

Reddy, B.V.V. and Gupta, A. (2008), "Influence of sand grading on the characteristics of mortars and soil-cement block masonry", *Constr. Build. Mater.*, **22**(8), 1614-1623.

Seow, K.H., Kar, N. and Qiuling, F. (2011), "The use of low fines self consolidating concrete (SCC) in everyday applications to improve productivity", *SCI Concretus Mag.*, **3**(1) 4-6.

Tattersall, G.H. and Banfill, P.F.G. (1983), *The Rheology of Fresh Concrete*, Pitman Publishing, Marshfield, Massachusetts, U.S.A.

Wallevik, J.E. (2008), "Rheological properties of cement paste: Thixotropic behavior and structural breakdown", *Cement Concrete Res.*, **39**(1), 14-29.

Wallevik, J.E. (2009), *The Bingham-Model: Retrieving the Bingham Parameters When Using the Coaxial Cylinders Viscometer*, Lecture Notes for the ICI Rheocenter, Rheology Course, Innovation Center Iceland, Reykjavik, Iceland.

Westerholm, M., Lagerblad, B., Silfwerbrand, J. and Forssberg, E. (2008), "Influence of fine aggregate characteristics on the rheological properties of mortars", *Cement Concrete Compos.*, **30**(4), 274-282.

Williams, D.A., Saak, A.W. and Jennings, H.M. (1999), "The influence of mixing on the rheology of fresh cement paste", *Cement Concrete Res.*, **29**(9), 491-1496.

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