Effect of fineness modulus of manufactured sand on fresh properties of self-compacting concrete

D. Pavan Kumar and C. Sashidhar

Self-compacting concrete (SCC) is considered as an innovative construction material in the construction industry due to its excellent fresh and hardened properties. Due to depletion of natural sand deposits and environmental issues, manufactured sand (MSand) is being used as fine aggregate in place of sand. Keeping in view of the required quality of gradation of fine aggregate, this investigation is carried out to examine the effect of different values of fineness modulus (FM) of MSand (2.3, 2.5, 2.7, 2.9 and 3.1) on the fresh properties of SCC. The test methods that were conducted are slump flow, T_{50cm}, V-funnel and L-box. Results showed that SCC with FM value of 2.7 gave better results than other FM values. It is observed that from 2.3 to 2.7 FM values, the increase in FM value increased the SCC fresh properties due to decrease in finer fraction. It is also noted that from 2.7 to 3.1 FM values, the increase in FM value decreased the SCC fresh properties due to increase in coarser fraction. Hence, it is revealed that proper gradation of finer and coarser fractions of MSand has to be maintained to obtain adequate SCC fresh properties.

1. INTRODUCTION

Self-compacting concrete (SCC) is a highly flowable concrete which does not require any external vibration and can spread into place, fill the formwork with heavily congested reinforcement under its self weight [1]. In SCC, the aggregates contribute nearly 60–70% of the total volume. Proper choice of aggregates plays a vital role on the fresh properties of concrete [2]. Aggregate characteristics such as shape, texture and grading influence workability, pumpability, bleeding and segregation of fresh concrete [3]. The effects of shape and texture of fine aggregate are much more important than the effects of coarse aggregate [4]. In general, the demand of natural river sand is quite high in developing countries to satisfy the rapid infrastructure growth, in this situation developing country like India facing shortage in good quality natural sand [5]. Particularly in India, natural sand deposits are being depleted and causing serious threat to environment as well as the society.

This has led to several environmental issues thereby government imposing a ban on the unrestricted use of natural sand. This has resulted in the scarcity and significant rise in the cost of natural sand. Therefore, an alternative to river sand has become the need of the hour. Some alternatives materials viz. fly ash, limestone powder have already been used as a partial replacement of natural sand in concrete mixes. However, scarcity in required quality is the major limitation in some of the above materials. Now a day's, sustainable infrastructural growth demands the alternative material that should satisfy technical requisites of fine aggregate as well as it should be available abundantly. The promotional use of manufactured sand (MSand), which is purpose made fine aggregate produced by crushing and screening, will conserve the natural resources for the sustainable development of the concrete in construction industry. By using appropriate impact crushing technology, it is possible to produce cubical particle shapes with uniform grading, consistently under controlled conditions [6]. Manufactured sands contain high fines content [7..9]. Generally, the fines are composed of rock dust rather than the silts and clays in the case of natural sands. Due to the presence of high fines content, the Msand has a significant influence on the water demand and the workability of the mortar [8..5].

It is pointed out that manufactured sand is anytime better than river sand. The particle shape is cubical, which is almost closer to rounded river sand. Another issue associated with river sand is that of obtaining required grading with a fineness modulus (FM) of 2.4 to 3.1. Generally FM of 2.2 to 2.6, 2.6 to 2.9 and 2.9 to 3.2 indicates that the sand is fine, medium and coarse confirming to grading zones ranging from IV to I (IS383). It has been verified and found, at various locations across south India, that it has become increasingly difficult to get river sand of consistent quality in terms of grading requirements and limited silt / clay content. In case of manufactured sand with well-designed screening system the required grading and fineness modulus (2.4 to 3.1) can be achieved consistently [11671]. It must be noted that properly gradedaggregates can improve both fresh and hardened properties of concrete [eff fp, eff mp, seenu gj] . Owing to the importance of grading of fine aggregates, this investigation is carried out to evaluate the SCC fresh properties using MSand with different values of fineness modulus.

Table 1. Chemical and physical properties of cementitious material

Particulars	Cement	Class F fly ash
Chemical composition		
% Silica(SiO_2)	19.79	**65.6**
% Alumina(Al_2O_3)	5.67	**28.0**
% Iron Oxide(Fe_2O_3)	4.68	**3.0**
% Lime(CaO)	61.81	**1.0**
% Magnesia(MgO)	0.84	**1.0**
% Sulphur Trioxide (SO_3)	2.48	**0.2**
Physical properties		
Specific gravity	**3.15**	**2.13**
Fineness (m^2/kg)	**311.5**	**360**

Table 2. Sieve Analysis of 12.5 mm coarse aggregate

Sieve Size	Cumulative Percent Passing	
	12.5 mm	**IS 383:1970 Limits**
12.5 mm	99.64	85-100
10 mm	43.36	0-45
4.75 mm	6.67	0-10
2.36 mm	1.4	N/A

2. EXPERIMENTAL STUDY

Our objective was to determine the effect of different values of fineness modulus (2.3, 2.5, 2.7, 2.9, 3.1) of MSand on fresh properties of SCC. The test methods that were conducted are slump flow, T_{50cm} slump flow, V-funnel and L-box [16,17].

2.1. Materials

Ordinary Portland cement 53 grade corresponding to IS 12269:1987 [29] and class F fly ash according to ASTM: C 618 [30] were used in this research. The chemical and physical properties of cement and fly ash are presented in Table 1. Crushed granite stones of size 12.5 mm were used as coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate were 2.6 and 0.3% respectively. Manufactured sand (MSand) was used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of MSand were 2.61 and 1% respectively. The gradation of coarse aggregate and fine aggregate were determined by sieve analysis as per IS 383:1970 [31] and presented in the Tables 2 and 3.

Polycarboxylate ether based superplasticizer (SP) was used in SCC. The percentage of dry material in SP was 40%.

Table 3. Sieve analysis of Msand with different fineness modulus

Sieve Size (mm)	Cumulative Percent Passing				
	FM – 2.3	**FM – 2.5**	**FM – 2.7**	**FM – 2.9**	**FM – 3.1**
4.75	96.00	95.00	93.90	91.96	91.50
2.36	91.50	87.00	84.50	82.43	77.50
1.18	82.00	75.00	70.00	64.86	55.00
0.6	75.00	55.00	50.00	41.87	38.00
0.3	15.00	27.00	20.00	19.81	20.00
0.15	12.00	10.00	10.00	7.85	6.00

Table 4. SCC mix proportions

Mix	w/cm	Binder kg/m^3	Cement kg/m^3	Fly ash kg/m^3	Water, l/m^3	12 mm kg/m^3	Msand, kg/m^3	SP, l/m^3
SCC	0.36	497	323	174	179	722	863	4.45

2.2 Mix proportions

SCC mixes were prepared with MSand having different fineness of modulus (2.3, 2.5, 2.7, 2.9, 3.1) to evaluate the SCC fresh properties [opt]. As per EFNARC (2002) [16], minimum coarse aggregate content of 28% was maintained for all the mixes. Keeping in view of the savings in cost and land fill, greenhouse gas emissions, fresh, mechanical and durability properties of SCC, the replacement level of class F fly ash was kept at 35% as per IS 456:2000 [32] for all mixes. Keeping in view of the moderate fines and all SCC properties, water-cementitious ratio (w/cm) by weight was kept at 0.36 for all mixes. SCC mixes have been designated as SCC_FM2.3, SCC_FM2.5, SCC_FM2.7, SCC_FM2.9 and SCC_FM3.1 respectively for various FM values of 2.3, 2.5, 2.7, 2.9 and 3.1. Mix proportions of all SCC mixes are remain same and presented in Table 4.

2.3 Testingof SCC

As per EFNARC [16], test methods such as slump flow [Figure 1], T_{50cm} Slump flow, V-funnel [Figure 2]and L-box [Figure 3] were carried out to assess the fresh properties of SCGC. Slump flow test is conducted to determine the spread of the SCC. $T_{50\ cm}$ is measured to indicate the viscosity of the SCC. V-Funnel time is measured to indicate the viscosity of the SCC and L-Box test is conducted to evaluate the passing ability of SCC.

Figure 1. Slump flow test

Figure 2. V-funnel test

Figure 3. L-box test

Table 5. **Fresh Properties of SCC mixes**

Mix Type	Slump Flow (mm)	T_{50cm} (sec)	V-funnel Time (sec)	L-box Ratio (h_2/ h_1)
SCC_FM2.3	595	5.69	15.23	Blocked
SCC_FM2.5	665	4.24	8.16	0.85
SCC_FM2.7	685	3.12	6.20	1.00
SCC_FM2.9	672	4.18	7.26	0.88
SCC_FM3.1	605	5.76	14.38	Blocked
Acceptance criteria as per EFNARC	650-800	3-5	6-12	0.80-1.00

3. RESULTS AND DISCUSSION

SCC fresh properties i.e., slump flow, $T_{50\ cm}$, V-Funnel time and Lboxratio (h_2/h_1) are presented in the Table 5 for all the mixes.

From the Table 5, it is observed that the mix SCC_FM2.3 got the slump flow spread,$T_{50\ cm}$, V-funnel time values of 595 mm, 5.69 sec and 15.23 sec respectively, this mix got failed in L-box test. This mix can be categorized as a failure mix as the fresh properties of this mix were not meeting SCC acceptance criteria. It is mainly due to increased finer fraction of MSand at the lower fineness modulus (2.3). This finer fraction of MSand haslarger specific area which demands more water and paste. The angular shape of finer particles also increases the plastic viscosity that affect the workability of SCC. It is examined that the fresh properties of the mixes SCC_FM2.5, SCC_FM2.7 and SCC_FM2.9 have met the SCC acceptance criteria and can be categorized as successful SCC mixes. Out of these three successful mixes, the performance of SCC_FM2.7 was observed to be much better than the other two mixes SCC_FM2.5 and SCC_FM2.9. It is also noted that the mix SCC_FM3.1 got the slump flow spread, $T_{50\ cm}$, V-funnel time values of 605 mm, 5.76 sec and 14.38 sec respectively, this mix got failed in L-box test. This mix also can be categorized as a failure mix as the fresh properties of this mix were not meeting SCC acceptance criteria. It is mainly due to increased coarser fraction of MSand at the higher FM (3.1). This coarser fraction contains more angular shape and causes increased the yield stress that affect the workability of SCC.From the results, it is clearly observed that from 2.3 to 2.7 FM values, the increase in FM value increased the SCC fresh properties due to decrease in finer fraction. It is also noted that from 2.7 to 3.1 FM values, the increase in FM value decreased the SCC fresh properties due to increase in coarser fraction. Hence, it is revealed that proper gradation of finer and coarser fractions of MSand has to be maintained to obtain adequate SCC fresh properties.

4. CONCLUSIONS

Based on the results of this experimental investigation, the following conclusions can be drawn:

1. The mix SCC_FM2.3 got failed at fineness modulus of 2.3 as it contains more finer fraction which increases the plastic viscosity.
2. The mix SCC_FM3.1 got failed at fineness modulus of 3.1 as it contains more coarser fraction which increases the yield stress.
3. Three mixes SCC_FM2.5, SCC_FM2.7 and SCC_FM2.9 are categorized as successful SCC mixes as they met SCC acceptance criteria.
4. Out of these three successful mixes, the performance of SCC_FM2.7 was observed to be much better than the other two mixes SCC_FM2.5 and SCC_FM2.9.
5. From the results, it is clearly observed that from 2.3 to 2.7 FM values, the increase in FM value increased the SCC fresh properties due to decrease in finer fraction.
6. It is also noted that from 2.7 to 3.1 FM values, the increase in FM value decreased the SCC fresh properties due to increase in coarser fraction.
7. Hence, it is revealed that proper gradation of finer and coarser fractions of MSand has to be maintained to obtain adequate SCC fresh properties.

References

1. ACI 237 R. Self-consolidating concrete. American Concrete Institute; 2007.
2. AIB005 – 1 – 7/01 "Quality Aggregates and Manufactured Sand for Concrete", Report by Metso Minerals Limited, Matamata, New Zealand.
3. Alexander M, Mindess S. Aggregates in concrete. New York: Taylor and Francis; 2005.
4. AS 1141.11 "Methods for sampling and testing aggregates – Particle size distribution by sieving", 1996.
5. Brameshuber W, Uebachs S. Practical experience with the application of self-compacting concrete in Germany. In: Proc of 2nd Int Symp on self-compacting concrete, Tokyo, Japan, October 2001, COMS Engineering, Japan. p. 687–96.
6. CCAA T 60, Guide to the specification and use of manufactured sand in concrete, Cement concrete aggregate Australia, ISBN 978 – 1 – 877023 – 25 – 5, pp. 1-15.

7. Centing M, Jonsson U, Nilsson H, Tuutti K, Widenbrant K. Site applications of self-compacting and pigmented concrete. Proc Int. Conf. on innovations and developments in concrete materials and construction, Dundee, September. London: Thomas Telford; 2002. p. 465–72.
8. Dilek U, Leming ML. Effects of manufactured sand characteristics on water demand of mortar and concrete. In: Proceedings of Transportation Research Board 85th annual meeting. Washington (DC): Transportation Research Board; 2006.
9. ______*Indian Standard Silica Fume- Specification*, IS 15388:2003, Bureau of Indian Standards, New Delhi.
10. G.C. Cho, J.S. Dodds, J.C. Santamarina, Particle shape effects on packing density, stiffness and strength — natural and crushed sands, ASCE Journal of Geotechnical and Geoenvironmental Engineering 132 (5) (2006) 591–602.
11. Goldsworthy, S.: Manufactured Sands in Portland Cement Concrete – The New Zealand Experience.
12. Gonçalves JP, Tavares LM, Toledo Filho RD, Fairbairn EMR, Cunha ER. Comparison of natural and manufactured fine aggregates in cement mortars. Cem Concr Res 2007; 37(6):924–32.
13. Kubo M, Nakano M, Aoki H, Sugano S, Ouchi M. The quality control method of self-compacting concrete using testing apparatus for self-compactability evaluation. In: Proc of 2nd Int Symp on selfcompacting concrete, Tokyo, Japan, October 2001, COMS Engineering, Japan. p. 555–64.
14. M.F. Kaplan, Flexural and compressive strength of concrete as affected by the properties of coarse aggregates, American Concrete Institute 55 (1959) 1193–1208.
15. Nanthagopalan P, Santhanam M. A new empirical test method for the optimisation of viscosity modifying agent dosage in self-compacting concrete. Mater Struct 2010;43(1–2):203–12.
16. EFNARC. Specification and guidelines for self-compacting concrete. European Federation of Producers and Applicators of Specialist Products for Structures. 2002.
17. EFNARC. The SCC European Project Group. The European guidelines for self-compacting concrete: specification, production and use. 2005.
18. Okamura H, Ozawa K. Mix design for self-compacting concrete. Concr Lib JSCE 1995;25:107–20.
19. P. Quiroga, D. Fowler, The effects of aggregates characteristics on the performance of portland cement concrete, International Center for Aggregates Research 104-1F (2004) 358.
20. Prakash Nanthagopalan, Manu Santhanam Fresh and hardened properties of self-compacting concrete produced with manufactured sand, Cement & Concrete Composites,vol 33., 2011, p.p 353-358
21. Santhanam M, Subramanian S. Current developments in self-compacting concrete. Ind Concr J 2004;78(6):11–22.
22. Sedran T, de Larrard F, Hourst F, Contamines C. Mix design of selfcompacting concrete (SCC). Proc of RILEM Int Conf on production methods and workability of concrete, Paisley, Scotland, June. London: E&FN Spon; 1996. p. 439–50.
23. Shadle R, Somerville S. The benefits of utilizing flay ash in producing self-consolidation concrete (SCC). In: Proc of the 1st North American Conf on the design and use of self-consolidating concrete, Centre for Advanced Cement Based Materials, North Western University, Chicago, November 2002. p. 235–41.
24. Walraven J. Structural applications of self-compacting concrete. In: Wallevik O, Nielsson I, editors. Proceedings of 3rd RILEM international symposium on self-compacting concrete, Reykjavik, Iceland, August. Bagneux, France: RILEM Publications PRO 33; 2003. p. 15–22.
25. Westerholm M, Langerblad B, Silfwerbrand J, Forssberg E. Influence of fine aggregate characteristics on the rheological properties of mortars. Cem Concr Compos 2007;30(4):274–82.
26. Wigum, B. J (2010): Classification and Particle Properties of Fine Aggregates (< 63μ)
27. Wigum, B. J. (2011): Hokksund Quarry. Review of the aggregate production. Optimization of 0/4 mm size fraction. COIN Project report 33 - 2011. 15 pp.
28. Wigum, B.J., Danielsen, S.W., (Editors), Hotvedt, O. & Pedersen, B., (2009): Production and Utilisation of Manufactured Sand. COINProject report 12 – 2009.
29. ______*Specification for 53 grade ordinary Portland cement*, IS 12269:1987, Bureau of Indian Standards, New Delhi.
30. ASTM C 618. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. 2003.
31. ______*Specification for coarse and fine aggregates from natural sources for concrete*, IS 383:1970, Bureau of Indian standards, New Delhi.
32. ______*Plain and reinforced concrete code for practice*, IS 456:2000, Bureau of Indian Standards, New Delhi.

D. Pavan Kumar received his B.Tech in Civil Engineering and M.Tech in Structural engineering from JNTUA, Ananthapur, AP; pursuing his PhD in the Civil Engineering Department under JNTUA, Ananthapur, AP. He is also a lecturer in Civil Engineering Department at JNTUA, Ananthapur, AP, with more than six years of teaching experience. His areas of research interest are self compacting concrete, geo polymer concrete, material sciences.

Dr. C. Sashidhar holds an M.Tech and PhD from J.N.T. University, Hyderabad. He is a Professor in the Department of Civil Engineering, JNTUA, Ananthapur, AP. His research interests include SCC, geopolymer Concrete, FRC, SIFCON, HPC and non-destructive test evaluation. He has more than 18 years of teaching experience and guiding research scholars. He has published papers in more than 50 journals and visited USA, France, Russia, South Africa and New Zealand to attend international conferences and present research papers.