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Influence of Fine Aggregate Particle Size and Fly Ash on the Workability Retention of Mortar for SCC

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Abstract

This research paper reports the Study of influence of fine aggregate particle size and fly ash on the workability retention of mortar for Self-Compacting Concrete (SCC). The relative flow area Γ*m and the relative funnel speed Rm of mortar were determined using the results of the mortar spread test and V-funnel flow test respectively. The tests were conducted on mortar mixes with five different cement replacement percentage (CRP) by fly ash and four different particle sizes of fine aggregate at an elapsed time of 60 minutes after mixing. The optimum combination of* Γ*m and Rm were investigated for achieving very good workability retention required for SCC to ensure self-compactability at casting.*

Keywords: Self-compacting concrete (SCC), mortar, spread diameter and V-funnel flow time, workability retention, relative flow area (Γ*m*), relative funnel speed (*Rm*), Ranking of self-compactability.

Introduction

Self-compacting concrete (SCC) is the concrete which flows through dense reinforcement and fill the moulds without segregation and without external compaction. It contains workability which ensures self-compactability under its self weight at casting.

Very good workability retention is required for SCC to ensure self-compactability at casting. For SCC, the problem arising from loss of self-compactability is more serious than in the case of normal concrete since it cannot be 'rescued' by compaction with vibration during placement. Adequate workability retention is therefore essential in case of Self-Compacting concrete, which also depends on the key factors such as dosage of superplasticiser, types of powder and water-powder ratio.

In the present study, the workability retention of mortar mixes to ensure the self-compactability of concrete for casting at 60 minutes after mixing is investigated. The weight of all the contents, namely; fine aggregate, superplasticiser dosage, powder and water-powder ratio were kept constant. Mortar mixes with varying size of fine aggregate particle and cement replacement percentage (CRP) by fly ash is studied.

Hajime Okamura and Masahiro Ouchi[1], proposed mortar spread test and mortar V-funnel test for testing rheological properties of mortar, and the values of deformability index calculated using the expression (1) and the viscosity index calculated using the expression (2) as below-

Relative Flow Area, $\Gamma m = (d_1 \cdot d_2 - d_0^2)/ d_0^2$ (1)

Where: d_1, d_2: measured flow diameter of mortar spread in two perpendicular directions. d_0: bottom diameter of truncated cone used for mortar spread test. A larger Γ*m* indicates higher deformability.

Relative Funnel Speed, $Rm = 10/t$ (2)

Where: t (sec): measured time (sec) for mortar to flow through the V-funnel. A smaller *Rm* indicates higher viscosity.

Okamura H. *et al* [1] recommended the combination of Γ*m* and *Rm* of mortar for ranking of self-compactability of fresh concrete for fixed coarse aggregate content. The values of Γ*m* ranges from 2.5 to 6 and *Rm* ranges from 0.75 to 1.25 for achieving the self-compactability of concrete.

Methodology

Cement: 53 grade Ordinary Portland cement was used and conforms to IS 12269- 1987. Its characteristics are given in table-1.

Table-1
Characteristics of Cement

Characteristics	Values
Normal consistency	28 %
Setting Time-	
Initial set	99 Minutes
Final set	184 Minutes
Compressive strength after	
7 days	51.0 MPa
28days	74.3 MPa
Specific gravity	3.15

Fly ash: Fly ash and its chemical analysis report is obtained from Sanjay Gandhi thermal power station, Birshingpur Pali, M.P., India, the physical characteristics of fly ash are given in the table 2 and the chemical analysis report is given in table-3.

Table-2
Physical characteristics of fly ash

Physical characteristics	
Colour	Grey Blackish
Specific Gravity	2.27

Table-3
Chemical analysis report of fly ash

Elemental Oxides	**Percentage**
Silicon Di-oxide	63.41 %
Aluminium oxide	25.88 %
Calcium Oxide	0.34 %
Magnesium Oxide	1.13 %
Manganese oxide	none detected
Sodium Oxide	1.19 %
Potassium Oxide	1.22 %
Iron Oxide	3.14 %
Phosphorus Pentoxide	1.65 %
Sulphur Trioxide	0.53 %
Titanium Di-oxide	1.51 %

Chemical Admixtures: Conplast SP430 confirms to ASTM-C-494 Type "F" was used as superplasticiser. It is based on Sulphonated Napthalene polymers. The properties of Conplast SP430 are given in table-4.

Table-4
Properties of Conplast SP430

Specific gravity	1.220 to 1.225 at 30^0C
Chloride content	Nil to IS 456
Air entrainment	Approx 1% additional air is entrained

Water: Tap water available in the college laboratory was used.

Fine Aggregate: The sand confirming to IS 650: 1966 was used as fine aggregate. The physical characteristics of sand are given in the table-5. Four fine aggregates, based on particle sizes (PS) were analyzed, viz.

Particle size 1 in between 90 μ to 300 μ, denoted as 90 μ < PS-1< 300 μ.
Particle size 2 in between 300 μ to 500 μ, denoted as 300 μ < PS-2< 500 μ.
Particle size 3 in between 500 μ to 710 μ, denoted as 500 μ < PS-3< 710 μ.
Particle size 4 in between 710 μ to 1 mm, denoted as 710 μ < PS-4< 1 mm

Table-5
Physical characteristics of sand

The physical characteristics of sand	
Colour	Grayish White
Specific Gravity	2.64
Absorption in 24 hours	0.80%
Shape of grains	Sub angular

Experimental procedure for SCC Mortar: Mortar Spread test: The spread tests were conducted by truncated cone as shown in the figure-1.In this test, the truncated cone is placed in the centre of a plate in the same position as indicated in the figure-1. The cone is fully filled with mortar and is then lifted immediately so that the mortar spreads over the plate. The spread diameters are then measured when the mortar flow completely stopped.

The spread tests were conducted by truncated cone, on self-compacting mortar mixes with five different cement replacement percentage (CRP) by fly ash and four different particle sizes of fine aggregate at an elapsed time of 60 minutes after mixing. From this test the mortar spread diameters (mm) d_1 and d_2 is measured in two perpendicular directions at 60 minutes after mixing used for calculating the deformability index denoted as Relative Flow Area, Γm from expression (1).

V-Funnel test: The mortar flow tests were conducted by V-funnel as shown in the figure-2, on self-compacting mortar mixes with five different cement replacement percentage (CRP) by fly ash and four different particle sizes of fine aggregate at an elapsed time of 60 minutes after mixing. From this test the mortar flow time 't' (sec) due to its self weight, measured immediately after placing the mortar in the funnel as the period from releasing the gate until first light enters the opening gap. The values of flow time't' (sec) is used for calculating the viscosity index denoted as Relative Funnel Speed, *Rm* from expression (2).

Mortar Mix Proportions: Table-6 gives the mortars proportion details. The mortar mixtures contains powder which composed of five weight proportions of OPC and fly ash, i.e. 90:10,80:20,70:30,60:40,50:50. The water-powder ratio (w/p) was 0.3 by weight and superplasticiser dosage was 1.5 percent by weight of powder. This w/p ratio and the superplasticiser dosage were decided to achieve a reasonable spread and flow time.

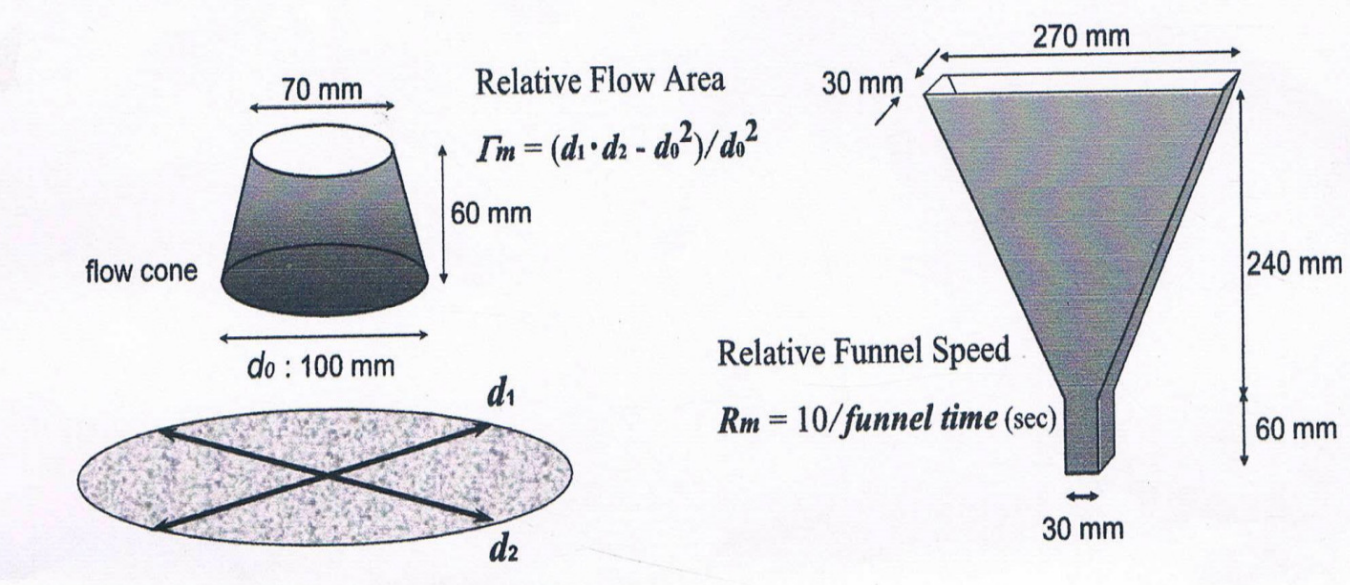

Figure-1
Mortar spread test

Figure-2
Mortar V Funnel test

Table-6
Mortar mix proportions

Mortar Mix Designation	Particle Size of fine aggregate	Powder 'p' (2 kg)			Water 0.3 x p (litre)	admix. (1.5%) (kg)	fine aggregate (3 kg)			
		OPC (kg)	Fly ash (kg)	Ratio			PS-1	PS-2	PS-3	PS-4
PS-1/10	90μ<PS<300μ	1.80	0.20	90:10	0.600	0.030	3 kg			
PS-2/10	300μ<PS<500μ	1.80	0.20	90:10	0.600	0.030		3 kg		
PS-3/10	500μ<PS<710μ	1.80	0.20	90:10	0.600	0.030			3 kg	
PS-4/10	710μ<PS<1mm	1.80	0.20	90:10	0.600	0.030				3 kg
PS-1/20	90μ<PS<300μ	1.60	0.40	80:20	0.600	0.030	3 kg			
PS-2/20	300μ<PS<500μ	1.60	0.40	80:20	0.600	0.030		3 kg		
PS-3/20	500μ<PS<710μ	1.60	0.40	80:20	0.600	0.030			3 kg	
PS-4/20	710μ<PS<1mm	1.60	0.40	80:20	0.600	0.030				3 kg
PS-1/30	90μ<PS<300μ	1.40	0.60	70:30	0.600	0.030	3 kg			
PS-2/30	300μ<PS<500μ	1.40	0.60	70:30	0.600	0.030		3 kg		
PS-3/30	500μ<PS<710μ	1.40	0.60	70:30	0.600	0.030			3 kg	
PS-4/30	710μ<PS<1 mm	1.40	0.60	70:30	0.600	0.030				3 kg
PS-1/40	90μ<PS<300 μ	1.20	0.80	60:40	0.600	0.030	3 kg			
PS-2/40	300μ<PS<500 μ	1.20	0.80	60:40	0.600	0.030		3 kg		
PS-3/40	500μ<PS<710μ	1.20	0.80	60:40	0.600	0.030			3 kg	
PS-4/40	710μ<PS<1mm	1.20	0.80	60:40	0.600	0.030				3 kg
PS-1/50	90μ<PS<300μ	1.00	1.00	50:50	0.600	0.030	3 kg			
PS-2/50	300μ<PS<500μ	1.00	1.00	50:50	0.600	0.030		3 kg		
PS-3/50	500μ<PS<710μ	1.00	1.00	50:50	0.600	0.030			3 kg	
PS-4/50	710μ<PS<1mm	1.00	1.00	50:50	0.600	0.030				3 kg

Mortar mix with sand PS -1 and 10 % cement replacement percentage (CRP) by fly ash designated as PS-1/10
Mortar mix with sand PS -2 and 20 % cement replacement percentage (CRP) by fly ash designated as PS-2/20
Mortar mix with sand PS -3 and 30 % cement replacement percentage (CRP) by fly ash designated as PS-3/30
Mortar mix with sand PS -4 and 40 % cement replacement percentage (CRP) by fly ash designated as PS-4/40
Mortar mix with sand PS -1 and 50 % cement replacement percentage (CRP) by fly ash designated as PS-1/50 and so on

Results and Discussion

The values of Relative Flow Area, Γ*m* and the Relative Funnel Speed, *Rm* at 60 minutes after mixing for self-compacting mortar mixes having four different particle sizes of fine aggregate viz. PS-1,PS-2,PS-3,PS-4 and five cement replacement percentage (CRP) levels by fly ash viz. 10 %, 20 %, 30 %, 40 % and 50 % of weight of powder. The different quantities used for calculating Γ*m* and *Rm*, namely; d_1, d_2, d_0 and t given in table -7 are defined as follows: d_1, d_2: measured flow diameter of mortar spread in two perpendicular directions. d_0: bottom diameter of truncated cone used for mortar spread test = 100 mm. t: flow time (sec), measured immediately after placing the mortar in the V-funnel.

Graphical representations of the workability retention at 60 minutes after mixing and the ranking of self compactability of concrete: The graphical representation showing the workability retention for 60 minutes after mixing to ensure the self- compactability of concrete for fixed coarse aggregate content from the relationship between mortar's relative flow area (deformability) Γ*m* and relative funnel speed (viscosity) *Rm* obtained using the experimental results of mortar spread test by truncated cone and mortar V-funnel flow time test and also the ranking of self-compactability as recommended by Okamura and Ouchi[1] for mortar mixes of table-6 are given in figure-3.

Table-7
Results of Relative Flow Area, Γ*m* and the Relative Funnel Speed, *Rm* at 60 minutes after mixing

Mortar Mix Designation	d_1 (mm)	d_2 (mm)	d_0 (mm)	Γ*m* $= (d_1 \cdot d_2 - d_0^2)/ d_0^2$	t (sec)	*Rm* = 10/t
PS-1/10	120	160	100	**0.92**	14.9	**0.67**
PS-2/10	140	160	100	**1.24**	14.2	**0.70**
PS-3/10	160	190	100	**2.04**	12.9	**0.77**
PS-4/10	170	220	100	**2.74**	11.5	**0.86**
PS-1/20	130	190	100	**1.47**	13.4	**0.75**
PS-2/20	150	200	100	**2.00**	12.5	**0.80**
PS-3/20	190	220	100	**3.18**	11.7	**0.85**
PS-4/20	180	260	100	**3.68**	10.6	**0.94**
PS-1/30	140	190	100	**1.66**	12.3	**0.81**
PS-2/30	160	210	100	**2.36**	11.7	**0.85**
PS-3/30	220	260	100	**4.72**	10.2	**0.98**
PS-4/30	230	270	100	**5.21**	9.5	**1.05**
PS-1/40	150	200	100	**2.00**	10.4	**0.96**
PS-2/40	185	205	100	**2.79**	9.4	**1.06**
PS-3/40	220	270	100	**4.94**	8.4	**1.19**
PS-4/40	240	270	100	**5.48**	7.9	**1.26**
PS-1/50	180	210	100	**2.78**	8.9	**1.12**
PS-2/50	210	270	100	**4.67**	8.3	**1.20**
PS-3/50	250	280	100	**6.00**	7.9	**1.26**
PS-4/50	265	295	100	**6.82**	7.5	**1.33**

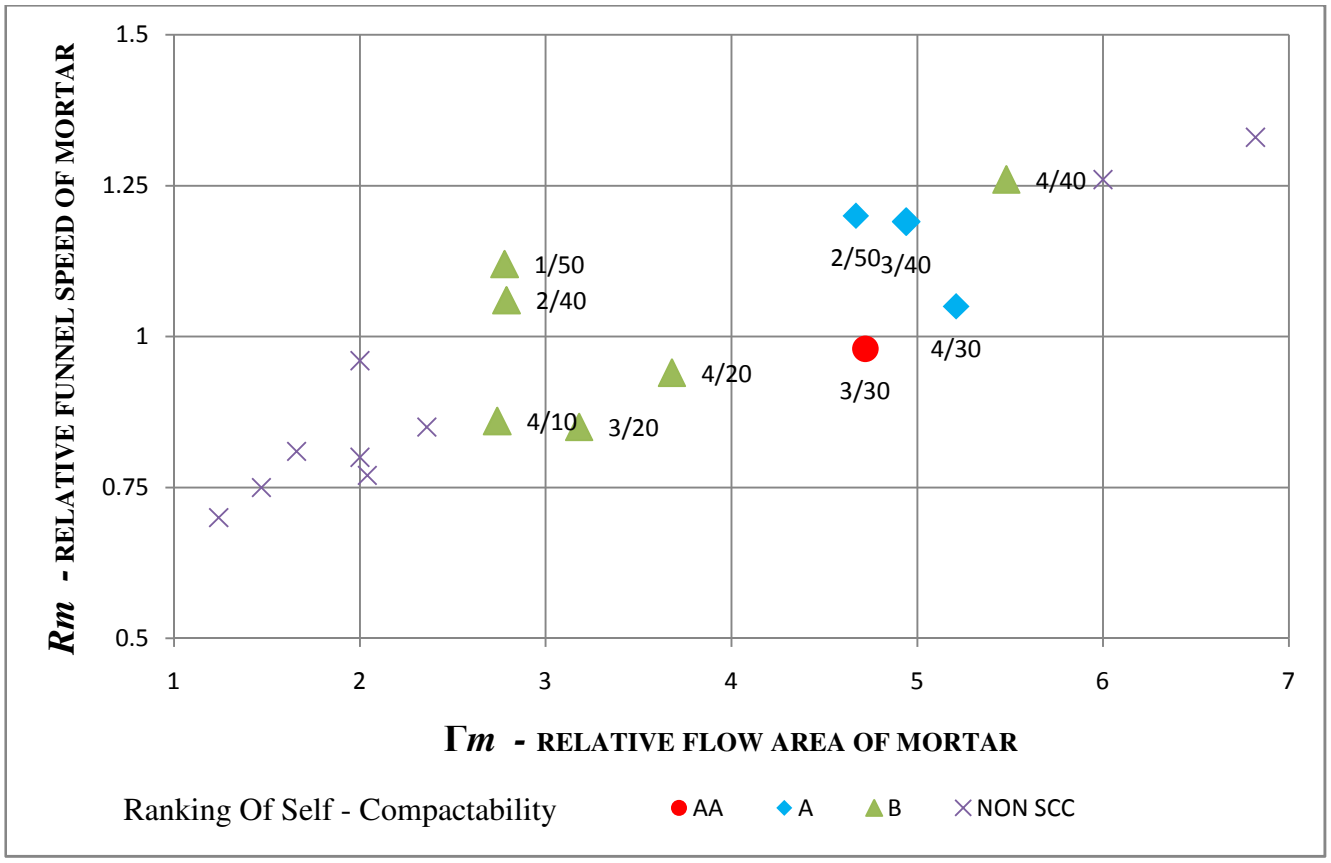

Figure-3
Ranking of Self-Compactability of Concrete

Analysis and Discussion of Results: Very good workability retention is required for self compacting mortar to ensure self-compactability of concrete for casting at 60 minutes after mixing.

Very low viscosity will increase the segregation when concrete passes through the dense reinforcement, on the other hand excessive viscosity will impair the pumping and placing of the concrete. So there is a need for optimum combination of deformability and viscosity to ensure better self-compactability of concrete at casting.

Okamura H. *et al*[1] have proposed the ranking of self-compactability of concrete viz. AA; A and B based on the relationship between the indices for deformability: relative flow area (Γm) and viscosity: relative funnel speed (Rm) by using mortar spread test and mortar V-funnel flow test results. The value of Γm ranges from 2.5 to 6 and Rm from 0.75 to 1.25 for achieving the self-compactibility of fresh concrete. The value of Γm of 5 and Rm of 1 is the optimum combination required to achieve self-compactability ranking AA.

In the present study, the influence of fine aggregate particle size and fly ash on the workability retention of self-compacting mortar mixes to ensure the self-compactibility of concrete at 60 minutes after mixing for 20 mix proportions as given in the table-6 is analysed. The ranking of self-compactability can be depicted from the relationship between Γm and Rm as given in the figure-3 as follows: i. Mortar mix PS-3/30 produced best workability to ensure self-compactibility of ranking AA in the existence of optimum values of relative flow area (Γm) and relative funnel speed (Rm) as the values Γm and Rm approaches to 5 and 1 respectively. ii. Mortar mixes PS-4/30, PS-3/40, PS-2/50 produced good workability to ensure self-compactibility of ranking A in the existence of moderate values of relative flow area (Γm) and relative funnel speed (Rm). iii. Mortar mixes PS-4/10, PS-4/20, PS-3/20, PS-2/40, PS-4/40, PS-1/50 produced poor workability to ensure self-compactibility of ranking B in the existence of a very low values of relative flow area (Γm) as well as relative funnel speed (Rm) and vice versa. iv. Out of 20 mix proportions given in the table-6, 10 mixes except the mixes described above does not exhibit SCC characteristics as their values of Γm and Rm does not fall within the recommended range.

Conclusion

According to recommendations of Hajime Okamura and Masahiro Ouchi[1], the self-compacting mortar mix having fine aggregate particle size in between 500 μ to 710 μ denoted as

500 μ < PS-3< 710 μ and 30 % cement replacement by fly ash designated as PS-3/30 is found to have sufficient workability retention to ensure self-compactability ranking AA for casting at 60 minutes after mixing.

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