Rheology of Self Compacting concrete with Marble Powder mixes in comparison to Fly ash and Sand Based Mixes

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Abstract

Marble powder is available in various parts of the world abundantly as there is a great demand of marble stones. The particle size of these material are marginally courser compared to cement and fly ash. Detailed experimental study has shown that with proper water correction, strength is not compromised. In this study, results of an experimental study to show the possibility of use of marble powder in self-compacting concrete (SCC), in comparison to Fly Ash based and Sand Based SCC Mixes. Here, flow, T500, V funnel time and Viscosity by BT2 Rheometer have been presented. It clearly shows that Marble powder can be used in SCC.

Key words: Rheology, workability, particle size, compressive strength

1. Introduction

Self-Compacting Concrete (SCC) is a concrete that can be placed and compacted under its own weight, without requiring any consolidation, and which assures complete filling of formwork. In order to achieve this performance, the fresh concrete must have both high fluidity and stable homogeneity [1]. The stability of SCC can be improved by incorporating fine inert material which may be either pozzolanic materials or inert.

Marble powder is available in various parts of the world abundantly as there is a great demand of marble stones. The particle size of these material are marginally coarser compared to cement and fly ash. Detailed experimental study has shown that with proper water correction, strength is not compromised [2]. In this study, results of an experimental investigation to show the possibility of use of marble powder in self-compacting concrete (SCC), in comparison to Fly Ash based and Sand Based SCC Mixes. Here, flow, T500, V funnel time and Viscosity by BT2 Rheometer have been presented. It clearly shows that Marble powder can be used in SCC.

2. Literature Review

2.1 SCC and marble powder

As per the EFNARC [1], a self-compacting concrete is qualified only when all the three parameters namely flowing ability, passing ability and segregation resistance are qualified. It has also been reported that in highly workable concrete by increasing fines, segregation can controlled and also enhanced cohesiveness and viscosity [3]. Topcu[4] reported that replacing cement and fly ash with marble dust improves the rheological properties of self-compacting concrete ignoring strength. It has also been reported that particles with an irregular shape of marble powder cause a shear thickening behaviour and, therefore, an increase of the viscosity [5, 6]. Similar results were reported by Beladi[7] and Alyamac [8]. In most of these work, comparison is rarely done keeping strength constant.

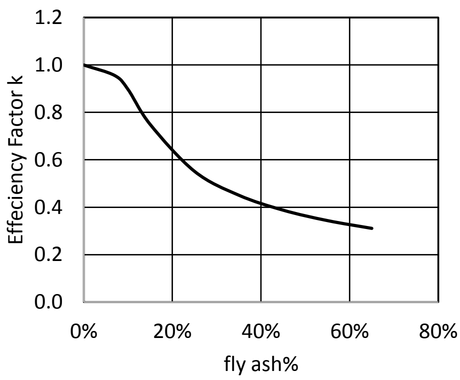

Fig. 1: Efficiency Factor of Fly ash[9] [10]

2.2 Strength prediction for fly ash concrete

Compressive strength prediction of concrete incorporating fly ash can be predicted using an efficiency factor $k = f\left(\frac{f}{c+f}\right)$ as function of fly ash percentage (Fig. 1) [9] [10] as in Eq. 1 for OPC 53 grade. Anuj had shown that marble powder can be used in concrete in significant quantity till without compromising in the strength provided water correction is done appropriately [2]. This is possible till total powder content is about 600 kg/m3 for cement, fly ash and marble powder combination. Micro silica increases cohesivity. c, w, f are Cement, Water and Fly ash in Kg/m^3

$$\text{Strength} = f\left(\frac{w}{c+kf}\right) = 13.5 * \left(\frac{w}{c+kf}\right)^{-1.35} \tag{1}$$

3. Materials

For the purposes of the current study, fly ash and marble powder was used. The chemical analysis as well as the physical properties of fly ash and marble powder are shown in Table 1. 53 Grade OPC cement (c) was used for the production of all SCC mixtures. It is noticeable that fly ash and marble powder present similar grading, which are similar to cement. The particle size distribution curve of all the fine are shown in Fig. 2. Fig. 32 shows the magnified SEM picture of Marble Powder. It is irregular in shape. Potable water (w) and polycarboxylic ether superplasticizer (PCE) were used in all mixtures.

Table 1. Chemical analysis (% m/m) and Physical properties of fly ash and marble powder

Material	Chemical Analysis						Physical Properties		
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	L.O.I	Specific gravity	Specific Surface area (m^2/kg)	moisture content %
Fly ash	42.89	34.7	1.01	0.43	11.76	2.62	2.2	370	0.16
Marble Powder	-	-	41.83	12.07	3.04	42.34	2.54	300	7.91

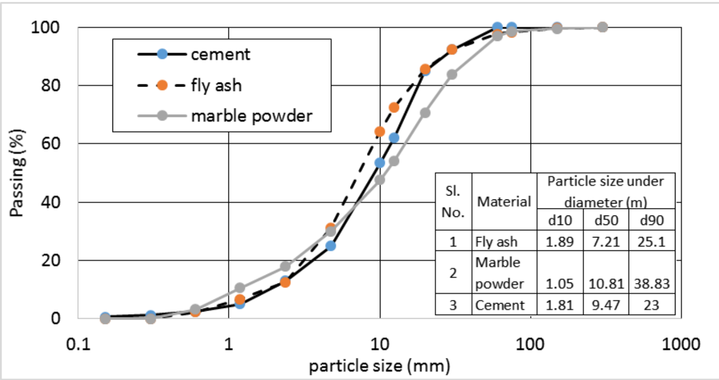

Fig 2: Particle size distribution of fine materials

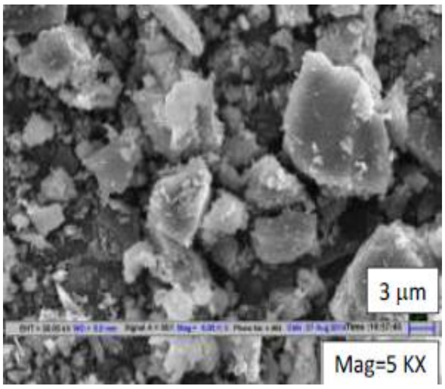

Fig. 3: SEM Picture of Marble Powder.

4. Mixes, Results and Discussion

In order to investigate the rheology properties of Self compacting concrete, nine SCC mixtures were adopted. Three of higher content of coarse aggregate mixes (i.e. G1-S, G3-S and G4-S) and three of higher fly ash mixes (i.e. G1-F, G3-F, G4-F) and three of marble powder mixes (i.e. G1-M, G3-M, G4-M) were casted and tested. In all mixes fly ash was used. Suitable dosages of polycarboxylic ether superplasticizer, were used to all mixtures, in order to reach the required fluidity. Self-compacting mixes were designed incorporating marble and granite powders ensuring a maximum usage of the same especially as powder material for different w/b ratios varying from 0.52 to 0.33. Marble powder is put in water to make soft paste (Fig. 3a). Water correction for both sand and marble powder is done. For the production of the concrete mixtures a fixed-pan type mixer with rotating blades was used and the same mixing procedure was carefully followed for all mixtures. At first, the aggregates were dry-mixed. Then, the fly and cement was added and all ingredients were further dry-mixed. Marble powder paste was add in mixes containing marble powder. Then, 80% of the total water content was added, followed by the rest 20% of the water, in addition

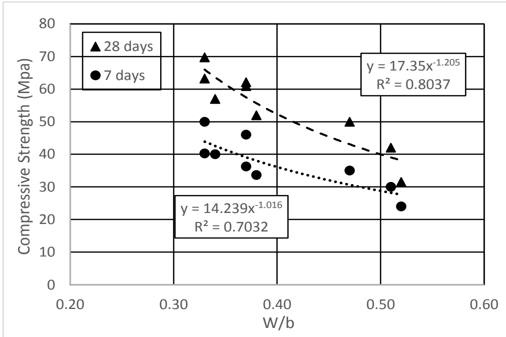

Fig. 4: compressive strength vs w/b

Table 3: Mix proportions Kg/m^3

Mix No	f%	k value	w/b	Water	Cement	Fly Ash	Marble Powder	sand	Coarse Aggregate		Compressive Strength (Mpa)	
									10 mm	20mm	7 Days	28 Days
G1-S	41%	0.27	0.51	175	290	205	0	997	450	250	30.0	42.0
G3-S	29%	0.42	0.37	175	400	165	0	952	450	250	36.3	60.9
G4-S	25%	0.50	0.33	175	450	150	0	930	450	250	40.3	63.2
G1-F	58%	0.20	0.47	175	290	405	0	759	450	250	35.0	50.0
G3-F	45%	0.24	0.37	175	400	332	0	755	450	250	46.0	62.1
G4-F	40%	0.28	0.33	175	450	300	0	751	450	250	50.0	69.7
G1-M	17%	0.74	0.52	178	296	61	357	774	459	255	24.0	31.5
G3-M	16%	0.79	0.38	178	406	76	264	766	457	254	33.7	52.0
G4-M	15%	0.81	0.34	177	455	81	228	760	455	253	40.0	57.0

(a) marble powder paste

(b) SSC at flow of 690mm

(c) V-funnel test

(d) BT-2 Rheometer test

Figure 5. Rheology test set up

with the super plasticizer. Slump-flow, T500, V Funnel and Viscosity by BT2 Rheometer is measured. The mixtures were rheologically classified according to the provisions of the European Guidelines EFNARC for SCC [1].

In order to understand the rheological behaviour of the concrete, admixture was added in increasing quantum in each of the mixes to reflect at least three to four points of different *flow* values. For each *flow* value in each of the mixes, T_{500}, and V_{ft} were measured. Critical yield stress and coefficient of viscosity values obtained by using BT2 rheometer were recorded and the results are reproduced in Table 4.

The EFNARC [1] guidelines for SCC provide consistence classification of self-compacting concrete in terms of *flow*, viscosity, passing ability and segregation resistance of the mix shown in Table 5(b). It mentions three *flow* classes namely SF1 (550 mm – 650 mm), SF2 (660 mm – 750 mm) and SF3 (760 mm – 850 mm) ,depending on the type of structure and congestion of reinforcement. Viscosity of the mix can be assessed by either T_{500} or the V_{ft}. The mix should have optimum balance of *flow* and viscosity. Table 5(b) shows that most of mixes fall under the VS2/VF1 or VS2/VF2 category of EFNARC. It is obvious that mixing of marble powder provides better SCC mixes. To gain maximum efficiency it is acceptable if we use minimum10-15% fly ash and use marble powder to get extra powder content. The consistence parameters like *flow*, T_{500}, V_{ft}, viscosity for different mixes were analysed. The relationship between T_{500}, V_{ft} and viscosity in Fig. 6 were found to be linear.

Table 4: Rheological properties of marble powder, fly ash and higher sand concrete

Mix No	f%	k value	w/b	%age of Admixture		Actual Weight of Admixture (Kg/m^3)	Flow (mm)	T_{500} (s)	V_{ft} (s)	BT2 Rheometer Reading	
				Cementitious Material (c+f+ms)	All fines (C+F+MS+MP)					Yield Stress	Relative Viscosity (10^3)
G1-M	17%	0.74	0.52	1.10%	0.55%	3.85	650.0	1.66	7.26	228.00	2.58
				1.25%	0.63%	4.38	750.0	1.59	5.83	124.00	2.16
				1.35%	0.68%	4.73	790.0	1.21	3.85	271.00	1.98
G3-M	16%	0.79	0.38	0.90%	0.58%	4.28	690.0	3.66	11.33	154.00	7.33
				0.95%	0.61%	4.51	720.0	2.98	10.39	133.00	4.33
				1.00%	0.65%	4.75	740.0	2.50	9.60	125.00	4.29
				1.05%	0.68%	4.99	790.0	2.18	8.66	118.00	4.10
				1.25%	0.81%	5.94	830.0	2.05	8.00	227.00	3.97
G4-M	25%	0.5	0.34	0.70%	0.49%	3.71	640.0	5.07	18.62	62.00	11.28
				0.80%	0.56%	4.24	700.0	4.30	17.63	129.00	6.92
				0.85%	0.65%	4.51	720.0	3.79	12.10	85.00	6.30
				0.90%	0.63%	4.77	750.0	3.22	10.73	52.00	6.11
G1-F	58%	0.20	0.47	0.60%	0.60%	4.17	670.0	3.73	11.50	98.00	5.31
				0.68%	0.68%	4.69	750.0	3.17	7.71	81.00	3.21
				0.78%	0.78%	5.39	815.0	2.65	6.20	27.00	3.19
G3-F	45%	0.24	0.37	0.53%	0.53%	3.88	605.0	4.00	19.11	215.00	8.10
				0.60%	0.60%	4.39	650.0	3.89	18.85	150.00	5.00
				0.70%	0.70%	5.12	700.0	3.38	9.39	94.00	3.37
				0.85%	0.85%	6.22	770.0	2.60	7.50	70.00	2.80
				1.00%	1.00%	7.32	785.0	2.72	7.37	38.00	2.21
G4-F	40%	0.28	0.33	0.50%	0.50%	3.75	550.0	4.31	25.88	204.00	9.03
				0.58%	0.58%	4.35	630.0	4.01	23.70	165.00	4.14
				0.63%	0.63%	4.69	760.0	3.61	13.70	163.00	4.20
				0.73%	0.73%	5.48	800.0	3.31	11.25	159.00	5.29
G1-S	41%	0.27	0.51	0.70%	0.70%	3.47	630.0	2.77	8.12	242.00	2.65
				0.80%	0.80%	3.96	645.0	2.56	7.72	206.00	2.57
				0.90%	0.90%	4.46	710.0	2.32	6.63	171.00	2.17
G3-S	29%	0.42	0.37	0.70%	0.70%	3.96	670.0	4.01	11.00	250.00	5.42
				0.80%	0.80%	4.52	690.0	3.17	10.70	169.00	4.79
				0.90%	0.90%	5.09	740.0	2.80	8.40	192.00	3.20
				1.00%	1.00%	5.65	780.0	2.50	7.18	84.00	4.00
G4-S	15%	0.81	0.29	0.75%	0.75%	4.50	610.0	8.30	24.19	240.00	8.27
				0.80%	0.80%	4.80	650.0	5.27	21.50	180.00	7.00
				0.88%	0.88%	5.25	745.0	4.01	14.70	121.00	5.89
				0.98%	0.98%	5.85	790.0	3.00	11.30	376.00	7.10

Conclusion

This paper presented a study of rheological properties of self-compacting concrete using fly ash based, sand based and marble powder based design. The following conclusion can be drawn:

- Marble powder has particle size in similar range of cement and fly ash. It is slightly coarser and irregular in shape.
- The relationship between T_{500}, V_{ft} and viscosity by BT2 rheometer are linear.
- Marble powder usage provided better mix complying with EFNARC specifications better.

Table 5(a). EFNARC limits for three groups of SCC

	VS1 and VF1				VS2 and VF1				VS2 and VF2			
Mix Name	Flow	T500	V_{ft}	Adm	Flow	T500	V_{ft}	Adm	Flow	T500	V_{ft}	Adm
G1-M	650	1.66	7.26	3.85	Not necessary				Not necessary			
G3-M	Not Possible				790	2.18	8.66	4.99	690	3.66	11.3	4.28
G4-M	Not Possible				Not Possible				640	5.07	18.6	3.71
G1-F	Not Possible				750	3.17	7.71	4.69	670	3.73	11.5	4.17
G3-F	Not Possible				770.0	2.60	7.50	6.22	605	4	19.1	3.88
G4-F	Not Possible				Not Possible				630	4.01	23.7	4.35
G1-S	Not Possible				630	2.77	8.12	3.47	Not necessary			
G3-S	Not Possible				740	2.8	8.4	5.09	670	4.01	11	3.96
G4-S	Not Possible											

Table 5(b). EFNARC [1] for SCC

Class	Slump *flow* (mm)
SF1	550 to 650
SF2	660 to 750
SF3	760 to 850

(b) Viscosity classes

Class	T_{500} (s)	V_{ft} (s)
VS1/VF1	≤ 2	≤ 8
VS2/VF2	> 2	9 to 25

(c) Passing ability classes (L-box)

Class	Passing ability
PA1	$\geq$ 0.80 with 2 rebars
PA2	$\geq$ 0.80 with 3 rebars

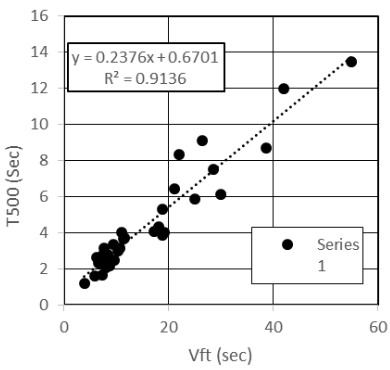

Figure 3: T_{500} vs. V_{ft} for SCC mixes

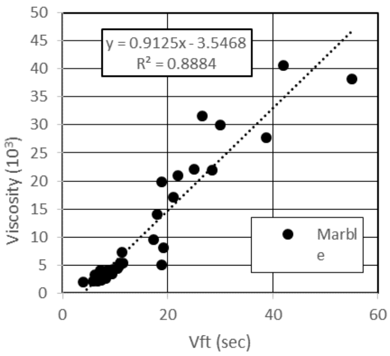

Fig. 6: Viscosity vs. V_{ft} for SCC mixes

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