EFFECT OF CONTENTS OF MICROFINES IN CRUSHED SAND ON WORKABILITY AND WORKABILITY RETENTION OF PROPERTIES OF HIGH STRENGTH MORTAR

Sunil Bauchkar[1], H S Chore[2]

1. Datta Meghe Collage of Engineering, New Mumbai, India
2. Dr B R Ambedkar National Institute of Technology, Jalandhar, India

ABSTRACT. Now a days, in many developing countries, unwashed crushed sand or quarry dust is popularly getting used as fine aggregates. This often contains higher percentage of dusty, flaky particles and particle sizes are un-controlled. Particles passing 75-micron (0.075 mm) sieve known as microfines in fine aggregates majorly content silt and clay which are not suitable for High strength mortar or concrete. The present investigation is aimed at quantifying the effect of the increase of microfines in unwashed crushed sand on the workability and strength parameters of high strength mortar. Apart from the Ordinary Portland Cement (OPC), the supplementary cementitious materials such as fly ash (FA) are used in binary blend keeping the mix paste volume and flow of mortar constant. Five different contents of microfines particles (fraction <0.075 mm) such as 3, 6, 12, 18 and 24% in the crushed sand were selected. Three tests- flowability, flow retention and strength- were conducted in this investigation. Results indicates that increase in the particles lower than 75 microns has negative effects on PCE admixture dosages, workability retention and strength properties. This emphasizes that higher microfine contents in fine aggregates are not suitable for the construction.

Keywords: Workability, Crushed sand, Microfines, Mortar, Poly carboxylate ether (PCE)

Sunil Bauchkar is a research scholar in Concrete Technology in the Department of Civil Engineering, Datta Meghe Collage of Engineering (University of Mumbai), New Mumbai, India. His research interest includes concrete Rheology, durability with different cementitious materials and aggregates.

Dr. H S Chore is an Associate Professor in the Department of Civil Engineering at Dr. B. R. Ambedkar National Institute of Technology Jalandhar, India. His research interest includes Pavement Engineering, Structural Engineering, Soil-Structure Interaction along with utilization of Pozzolanic and Industrial Wastes in Concrete and Soil with reference to their application in pavement and structures.

INTRODUCTION

Manufactured sand is generally obtained by crushing rocks. It has several synonyms such as crusher sand, crusher dust, stone dust etc. The use of manufactured sand has increased due to the non-availability of river sand, which is regulated and banned from use in most of India. Recently, the North Western states and Delhi went through a similar situation when the court ordered a stay on the use of river sand. As a result, the manufactured is now becoming the only sustainable source of fine aggregates available for use in construction in several states in India.

Hundreds of stone crushing plants in the country generate several thousand tons of crushed sand every day. This crushed sand contains large number of finer particles which contain silt and clay to the considerable extent. If it is possible to use this in making mortar/concrete by replacement of river sand, then it will solve the problem of scarcity of raw materials. Moreover, the usage of unwashed crushed sand containing higher microfines as partial replacement to natural sand further modified by partial replacement of pozzolanic materials like fly ash is receiving more attention these days as their use generally improves the properties of cement mortar /concrete.

During the production of crushed aggregates, fine material such as silt and crusher dust can be generated. The silt is a material between 2 and 60 µm reduced to this size by natural processes and it is found in aggregates won from natural deposits. On the other hand, crusher dust is a fine material formed during the process of comminution of rock into crushed stone. This fine material is present in aggregates in the form of surface coating which interfere with the bond between aggregate and cement paste. The contents of fine material in crushed coarse aggregates is limited 1% and in crushed stone sand to 15% for structural concrete [1]. In a properly laid out processing plant, this dust should be removed from coarse aggregates by washing. Hill *et al.* [2] found this removed quarry dust can amount up to15% of the total aggregate production and poses disposal and environmental problems.

LITERATURE REVIEW

Numbers of significant results have been reported on the use of crushed sand as partial replacement for natural fine aggregate. It has been used for different activities in the construction industry, such as road construction and manufacture of building materials, such as lightweight aggregates, bricks, tiles and autoclave blocks. Considerable research has been conducted in different parts of the world to study the effects of incorporation of unwashed crushed sand into concrete and mortars.

Some of the researchers [3-6] investigated the effect of shape and size of fine aggregate on the strength of cement sand mortars and the possibility of replacing sand by crushed stone dust. The water requirement and the compressive strength are found higher for crushed stone dust as compared to that for conservative sand samples for same grading and mix proportions. Celik and Marar [7] investigated the influence of partial replacement of fine aggregate with crushed stone dust at varying percentages on the properties of fresh and hardened concrete. de Larrard and Belloc [8] studied the influence of aggregate on the compressive strength of normal- and high-strength concrete while Goble and Cohen [9] observed the influence of aggregate surface area on mechanical properties of mortar.

Safiuddin *et al.* [10] investigated the influence of partial replacement of sand with unwashed crushed sand and cement with mineral admixtures on the compressive strength of concrete. Galetakis and Raka [11] mixed limestone dust with Portland cement for producing artificial stone. The results indicate that limestone can be used and give the acceptable compressive strength. Baali *et al.*[12] studied the mechanical response of mortar made with natural and artificial fine aggregates.

Gullerud *et al.* [13] pointed that the silt is always attached to the aggregate surface and is difficult to remove. Conversely, the chemically reactive nature of silt may also affect the properties of the interface between the cement paste and aggregate. On contrary, many researchers [14-20] observed that the stone fines with 10% in crushed sand, having the same grain size as clay (less than 0.075 mm), has no harmful effect on performance of most concrete properties.

In the present investigation, the unwashed crushed sand containing amount of microfine particles (fraction <0.075 mm) in the increasing order from 3,6,12,18 and 24 percent were selected as fine aggregate in high strength mortar mix, evaluated its effect on the fresh and the mechanical characteristics, namely- compressive strength of mortar using fly ash as supplementary cementitious materials.

EXPERIMENTAL PROGRAM

Material Properties

Cement

The Ordinary Portland Cement (53 Grade) was used in the investigation (Fig.1). The various laboratory tests conforming to Indian standard specification (IS: 4031-1996) [21] were carried out and the physical properties are shown in Table 1.

Fly Ash

Class F fly ash samples taken from Nashik Thermal Power Plant (Maharashtra, India) were used in this study. Fly ash (Figure 2) was used as received without processing. The sample satisfied the requirements of IS: 3812 (Part I)-2003 [22]. The physical and chemical properties of PFA as obtained through systematic laboratory investigations carried out at the Research and Development center of Counto Microfine Products Pvt. Ltd.(Goa), are also summarized in Table 1.

Figure 1 OPC cement

Figure 2 Fly ash

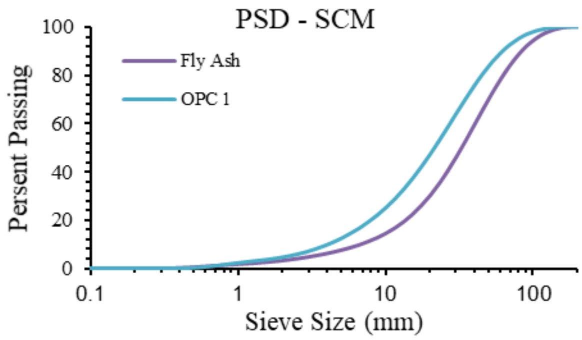


Figure 3 Particle size distribution (PSD) curve of the cementitious materials used in the study

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

MATERIAL	UNIT	PFA	OPC 53
Blaine fineness	(m^2/kg)	345	328
BET Surface Area	(m^2/kg)	-	-
Compressive strength as % of cement	(%)	84.2	100
Lime reactivity	MPa	5.6	-
Autoclave expansion	(%)	0.06	0.059
Sp. gravity	(%)	2.3	3.14
Loss on ignition (LOI)	(%)	1.2	2.81
Silica (SiO_2)	(%)	60.72	20.68
Iron oxide (Fe2O3)	(%)	5.32	4.76
Alumina (Al2O3)	(%)	27.5	5.54
SiO2 + Al2O3 + Fe2O3	(%)	93.54	30.98
Calcium oxide (CaO)	(%)	1.42	61.39
Magnesium oxide (MgO)	(%)	0.48	1.07
Total Sulphur (SO3)	(%)	0.21	2.5
Alkalies (Na_2O + K_2O)	(%)	1.71	0.38
Chloride	(%)	0.36	0.055
Retained on 45 microns	(%)	15	10.66

Crushed sand with varying microfines

The locally obtained quarry dust was used as a partial replacement for fine aggregate in this investigation. The sample of quarry dust (Fig. 4) was analyzed and the results of sieve analysis are presented in Table 2. Figure 4 also presents graphical results of an XRD analysis of a sample of unwashed crushed sand obtained from Mumbai. This sand was found to have a methylene blue index value of 4.5 g/kg. The XRD spectrum indicates the presence of large amounts of Montmorillionite clay. This expandable clay absorbs water and superplasticizer molecules, which in turn, affects the moisture absorption as well as superplasticizer concrete performance such as workability and workability retention. These clays are also known for decreasing the compressive strength. A lot of the detrimental fines also come from cross contamination due to bad mining practices which can also be avoided.

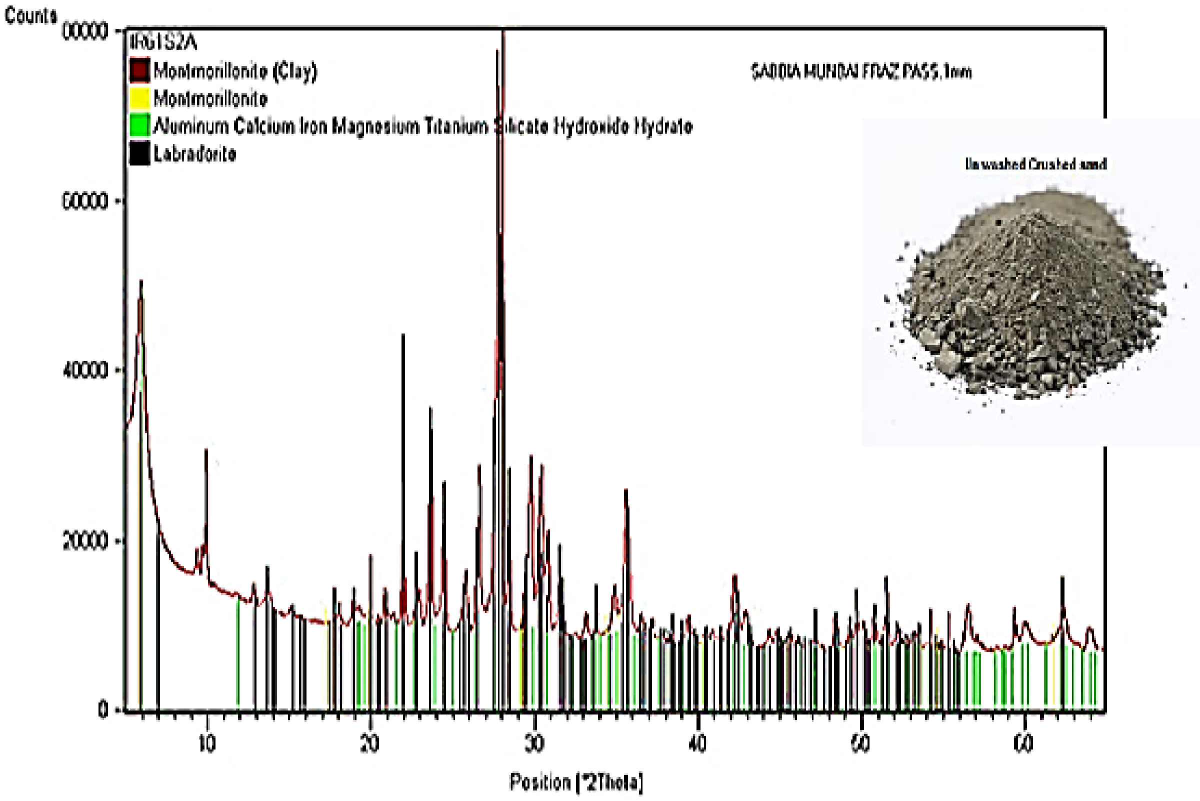


Figure 4 Unwashed crushed sand and its XRD analysis

Table 2 Results of the dry and wet sieve analysis

0.075 mm % Passing	3			6			12			18			24		
Sieve Sizes (mm)	Dry	wet	% variation (Dry /wet)	Dry	wet	% variation (Dry /wet)	Dry	wet	% variation (Dry /wet)	Dry	wet	% variation (Dry /wet)	Dry	wet	% variation (Dry /wet)
	% Passing			% Passing			% Passing			% Passing			% Passing		
10	100	100	0	100	100	0	100	100	0	100	100	0	100	100	0
4.75	97.5	97.9	0	97.3	97.9	1	98.2	98.5	0	98.4	99.14	1	98.52	99.08	1
2.36	69	69.7	1	69.5	70.1	1	70.5	73	3	75	78.18	4	74.56	79	6
1.18	43.7	44.8	2	46.2	47.9	4	48.1	52	8	49	55.61	12	50.5	58	13
0.6.	27.2	28.8	6	29.4	31.5	7	34.2	37.4	9	36.25	40.57	11	37	43	14
0.3	15.7	17.9	12	17.8	20.6	14	20	24	17	23.1	29.63	22	29	35	17
0.15	7.5	10.3	27	6.25	11.2	44	5.91	12	51	12.08	21.29	43	18	28	36
0.075	0.8	3.2	75	1.45	6.1	76	3.1	12.4	75	4.52	17.8	75	6.32	24	74

Table 2 and Figure 5 show the complete dry and wet- sieve analysis of sand used in this study. It is clear from Table 2 that the variation below 0.3 mm dry and wet method of sieve analysis is ranging from 12-75%. The values of wet sieve method are higher than dry sieve method up to 75%.

The water absorption test was performed on all unwashed crushed sand samples in accordance with the guidelines contained in IS 2386 – 1963 (Part III) and the results are reported in Table 3.

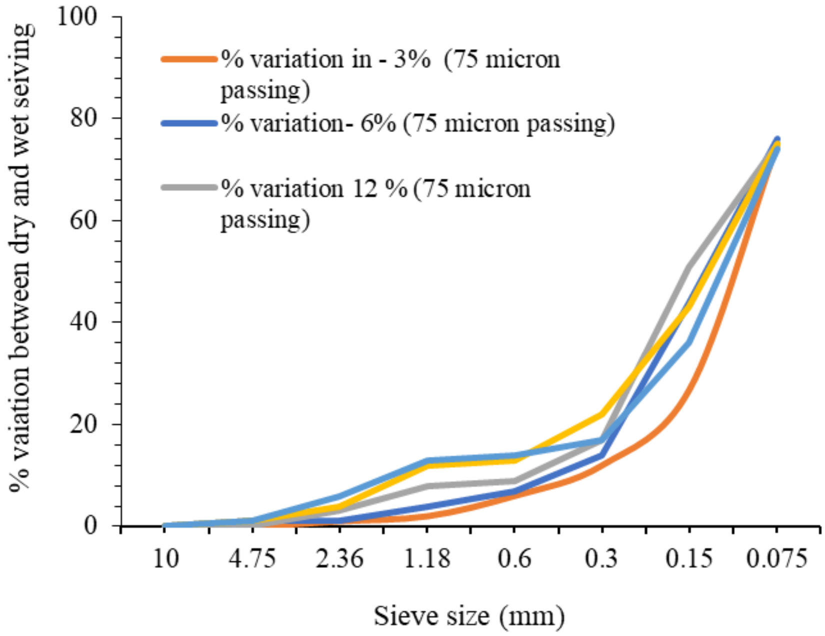
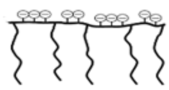
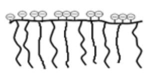


Figure 5 Percentage variation between dry and we sieve analysis results

Table 3 Water absorption of unwashed crushed sand

0.075 mm Passing fines %	0	3	6	9	12	15	18	21	24
Av. WA (%)	2.575	2.79	2.98	3.12	3.295	3.565	3.645	3.92	4.295

Table 4 Physical properties of polycarboxylate ether (PCE)-based superplasticizers

PRODUCT	PCE 3	PCE 4	
Relative Density @ 25˚ C	1.01	1.01	
Dry Material content (%)	25	25	PCE3 (HRWR - SR)
pH	>6	>6	
Chloride-ion content	< 0.2%	< 0.2%	PCE 4 (HRWR- SR)

Admixture

A commercially available Polycarboxilate Ether based superplasticisers PCE 3 and PCE 4 was used in this study. The physical properties of PCE 3 and PCE 4, presented in Table 4 were evaluated using state- of- the- art instrumentation available at the Research and Development centre of BASF India Ltd., Navi Mumbai. The PCE 3 and PCE 4 is the high range water reducer –cum- retaining type of polymers which is specially developed by BASF for high silt sand issues of dispersion and retention of workability.

Preparation and Mixes of High Strength Mortar Mixes

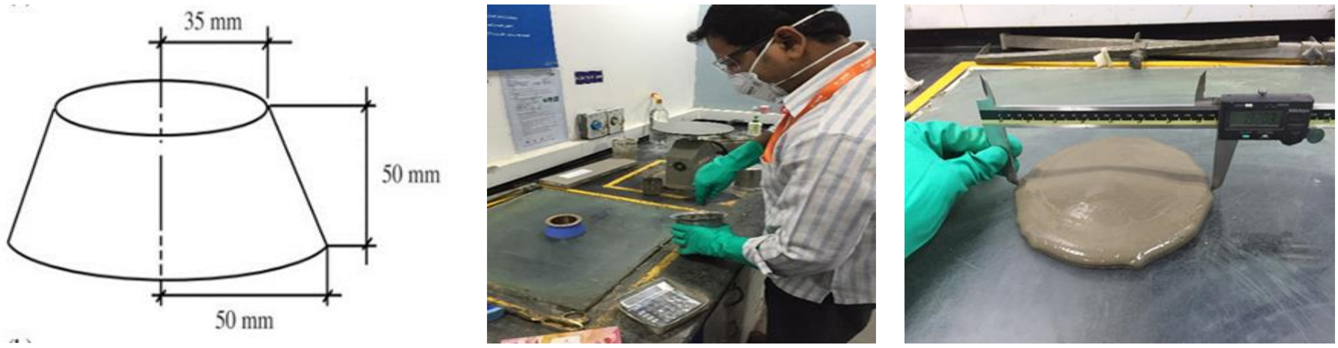
The water-cement ratio (*w/c*) was fixed at 27%. The ratio of OPC to PFA was kept 70:30, 1: 1.26 cement sand mortar mix. The HS-SCM (yes, it is HS-SCM) mortar was prepared with same water- cement ratio and the same fine aggregate - cement ratio. The same fine aggregates having varying fines 0, 6,12,18 and 24% has been used. The mix corresponding to mortar is given in Table 5. The amount of PCE to be added was determined by using flow cone and all the mixes were maintained at the same initial flow.

Table 5 Mix proportions for mortar workability retention with different PCE types

Mix ID	OPC (70%)	PFA (30%)	Free w/b	Total Water	Crushed Sand	Microfines (75 micron Passing)	Admixture and its Dosage
	kg	kg		kg	kg	%	%
MPC1MF00	1.4	0.6	0.27	0.54	2.52	0	PCE 1 (1.5)
MPC1MF06	1.4	0.6	0.27	0.54	2.52	6	PCE 1 (1.7)
MPC1MF12	1.4	0.6	0.27	0.54	2.52	12	PCE 1 (1.8)
MPC1MF18	1.4	0.6	0.27	0.54	2.52	18	PCE 1 (2.0)
MPC1MF24	1.4	0.6	0.27	0.54	2.52	24	PCE 1 (2.3)
MPC2MF00	1.4	0.6	0.27	0.54	2.52	0	PCE 2 (1.2)
MPC2MF06	1.4	0.6	0.27	0.54	2.52	6	PCE 2 (1.3)
MPC2MF12	1.4	0.6	0.27	0.54	2.52	12	PCE 2 (1.5)
MPC2MF18	1.4	0.6	0.27	0.54	2.52	18	PCE 2 (1.8)
MPC2MF24	1.4	0.6	0.27	0.54	2.52	24	PCE 2 (2.0)

Test Method

The flow test was conducted as shown in Figure 6 (a-c) and the workability of all the mixes was adjusted for similar flow level by adjusting the PCE admixture dosages. The flow retention was measured using a flow cone at every 30 minutes interval.



(a) Mini slump mold geometry

(b) Slump mold placed on glass plate

(c) Measuring flow with digitalcaliper

Figure 6 Mortar flow and flow retention test.

RESULTS AND DISCUSSION

The experimental investigations were carried out on the High Strength Self Compacting Mortar for studying its workability and rheological performance with respect to the variation in crushed sand microfines. The Microfines in crushed sand varied from 0, 6,12,18 and 24%. The tests were performed on the mortar, mixed according to procedure described in section 2.3. The crushed sand with varying amount of Microfines was used and the w/c was fixed to 0.27 in all the mixes. All the experiments were performed in a room with controlled temperature (23 +/-2 °C) and relative humidity equal to 65 +/-2 %. All the ten mortar mixes (Table 5) are analyzed for flow cone spread.

The fluidity of mortar compositions is studied to analyze final spread flow diameter under the influence of gravitational force and self-weight of mixes. The mortars were mixed to achieve an initial spread of 220 +/- 25 mm measured on the flow table, by adjusting the amount of superplasticizer to meet the targeted requirement.

The mortar flow cone test is used to assess the flow / spread of mortar. It is one of the most commonly used test method which gives a good assessment of the flowability and its retention over the time for the mortar mixes. The significance of this test is higher the flow value, the better will be the performance of PCE in presence of crushed sand Microfines. The measurements of first flow values were taken at 5 min and consequently, after every 30 minutes up to 210 minutes for crushed sand containing Microfines from 0, 6, 12, 18 and 24 percent with two different types of PCEs. This was done to study the time dependency on final spread flow of pastes. The results of mortar spread test performed on ten mortar mixes are reported in Table 6 and presented in Figure 7 and 8.

Table 6 Laboratory flow retention properties of HS-SCC Mortar with two different types of PCE polymers and varying microfines of crushed sand

Mix ID	Flow (mm)							
	0 min.	30 min.	60 min	90 min	120 min	150 min	180 min	210 min
MPC1MF00	212	238	238	238	230	223	167	125
MPC1MF06	220	247	250	240	190	125		
MPC1MF12	205	218	167	107				
MPC1MF18	195	172	120	100				
MPC1MF24	195	155	105					
MPC2MF00	225	230	230	227	210	160	110	
MPC2MF06	230	250	230	195	120	100		
MPC2MF12	225	240	185	103				
MPC2MF18	235	210	115					
MPC2MF24	230	150	100					

(*MPC1MF00- Mortar with PCE 3 and Crushed sand containing microfines 0%, MPC2MF00- Mortar with PCE 4 and Crushed sand containing microfines 0% etc.*)

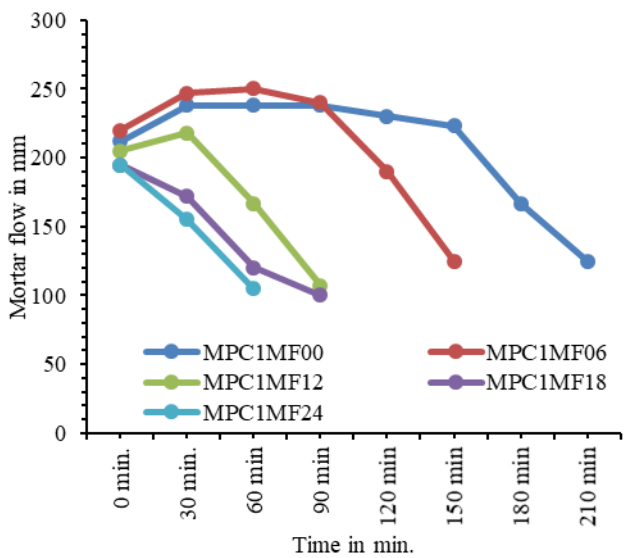


Figure 7 Mortar flow retention with PCE 3 and varying microfines in crushed sand

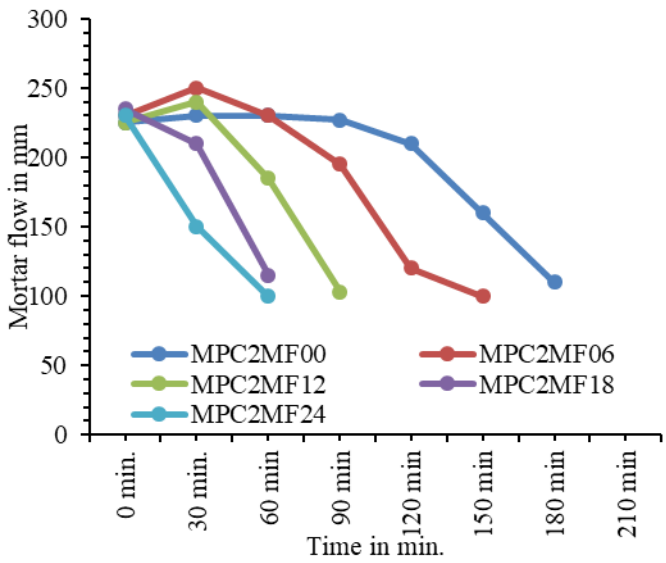


Figure 8 Mortar flow retention with PCE 4 and varying microfines in crushed sand

From the values reported in Table 6 and Figure 7 and 8, it is that observed that admixture dosages increase due to increase in the contents of the Microfines in crushed sand. As per the material properties and gradation report (Table 2), the microfines varies from 0,6,12,18 and 24 %, which results into more cohesive and densely packed mortar mix. Moreover, the washing of sand from 75 micron gives an idea of silt content. The dosages of PCE 3 superplasticizer are found to be higher than PCE 4 based superplasticizers. The PCE 4 superplasticizers are found to show higher efficiency in terms of the water reduction than PCE 3 superplasticizers. The PCE 3 -based products is found to show lower percentage of increase in dosage than PCE4 and low dosages variability between different microfine contents in fine aggregate. It indicates that the PCE 3 possess high cement dispersing ability and good clay tolerance than PCE 4.

The rate of change in flow in respect of the mortars with lesser Microfines is found to be lower than those with higher fines. For the same HS-Mortar flow, an increase in the contents of Microfine in crushed sand causes an increase in the PCE dosage, irrespective of the type of PCE used. This is primarily due to the PCE molecules getting trapped in clay particles thereby affecting performance. Similarly, it reflects on the relative slump flow change or flow loss rate with respect to elapse time.

The micro fine contents and the workability retention are found to be inversely related. Higher the contents of micro fines in crushed sand, lower is the retention of mortar flow. This effect of micro fines on retention time of flow can be reduced either by increasing the PCE dosage or adding a compatible retarder to the mix.

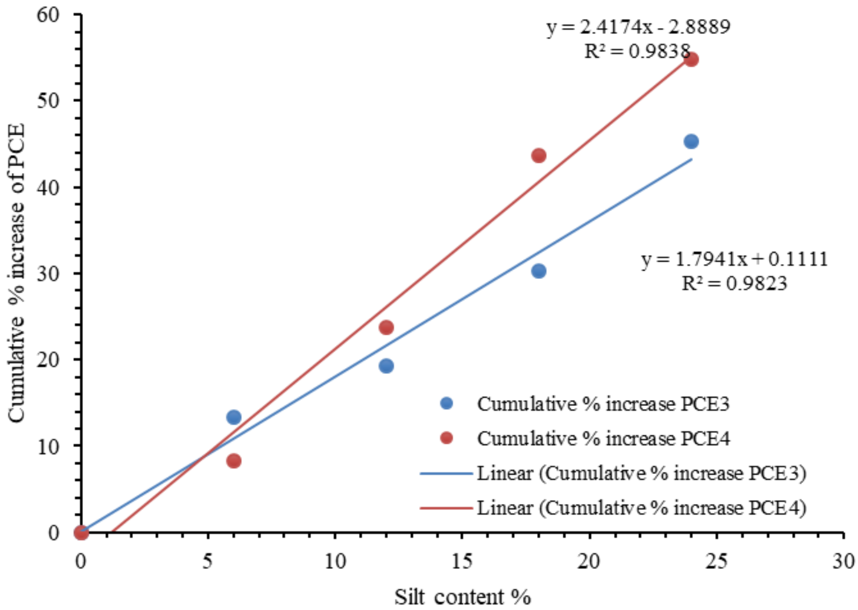


Figure 9 Variation of PCE dosage with contents of Microfines crushed sand

Figure 9 shows statistical analysis of cumulative percentage increase in PCE dosages with respect to the variations in microfine contents in mortar. Generally, lowest slope values are achieved by PCE 3 admixtures for all the Microfine content. The PCE-4 based admixtures show higher slope values in terms of dosage if the different Microfine contents are considered. It can be concluded that PCE 3 gives more robust performance than PCE 4 under varying Microfine contents of crushed sand mortar mix.

CONCLUDING REMARKS

Based on the results discussed in the preceding sections, following broad conclusions can be arrived upon.

- An increase in fines in manufactured sand can reduce both the initial workability and the workability retention performance of a high-range water reducer (HRWR).

- Higher dosages of HRWR than the normal one are required due to the presence of large amounts of ultra-fine particles (less than ~75 μ) to maintain the workability.

- The rate of change in flow in respect of the mortars with lesser Microfines is lower than those with higher fines. The micro fine contents and the workability retention are inversely related.

- PCE 3 gives more robust performance than PCE 4 under varying Microfine contents of crushed sand mortar mix.

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