An Investigation of the Effects of Incorporation of Supplementary Cementitious Materials on Fresh State Properties of Grouts for Grouted Aggregate Concrete

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Abstract

Grout flowabiity is the key parameter in the production of grouted aggregate concrete (GAC). High flowability due to high water to binder ratio (w/b) of GAC grout in its fresh state invites bleeding and segregation whereas, low flowability due to low w/b in fresh state greatly influences setting times, loss in flowability and the grout handling process. It is difficult and crucial to have a grout that will exhibit adequate flowability in its fresh state maintaining appropriate w/b ratio. Scanty research is available in this regard and needs investigation. Therefore, an experimental study was proposed to develop the grout for GAC, investigating the effects of supplementary cementitious materials (SCMs) incorporation in place of ordinary Portland cement (OPC), for repairing or retrofitting of the reinforced cement concrete (R.C.C) piles subjected to damage or deterioration. Binary and ternary binder grout compositions, at water/binder = 0.45 and sand-to-binder ratio 1:1, using optimized poly-corboxylic ether (PCE) based high range water reducer (HRWR) adhering to the efflux time of 35-40 ± 2s according to American concrete institute (ACI) 304.1-2005, were studied to investigate the effect incorporation of SCMs, viz., fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS) and metakaolin (MK), on fresh state properties of GAC grouts. Utilization of supplementary cementitious materials (SCMs) in grouts will serve them green and will lead to ecological and economical benefits with true sustainable development. Therefore, an attempt was made to investigate the effects of SCMs on GAC grout fresh state properties for their suitability in repairs and retrofitting of R.C.C piles based on setting times, bleeding, flowability, and its loss employing flow cone method. Results have shown that grouts produced incorporating SCMs partially replacing OPC can result in many synergic effects and can offer significant benefits in view of their fresh state properties to suit with the pile repair and retrofitting methodology. Moreover, it was observed that ternary grout compositions offer significant benefits over binary grout compositions when binary grout system performing well is combined to form ternary grout system.

Keywords : Bleeding, flowability, fresh state, GAC, grout, SCM

I. INTRODUCTION

A special type of concrete produced by placing coarse aggregates first in the form work and then filling the inter-particle gaps introducing special type of grout mixture by way of gravity fill or pumping [1]. According to Manal F. Najjar [2], GAC grout normally consists of pure cement or cement blended with SCMs, well graded sand, chemical admixtures, and water. In his research work on two stage concrete (TSC) grouts, he observed that partial substitution of OPC by fly ash (FA) improves the flowability and increases the bleeding whereas, partial replacement of OPC with 10% silica fume (SF) or 10% metakaolin (MK) reduces the flowability and bleeding. It was also observed that ternary grouts composed of FA and SF or MK exhibited acceptable flowabilty and adequate bleeding resistance. Abdul Awal [3] carried out an experimental work to manufacture and

Manuscript received June 17, 2019; revised October 5, 2019; accepted October 10, 2019. Date of publication November 5, 2019.
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DOI : 10.17010/ijce/2019/v2i2/149069

study the strength and deformation behavior of pre-packed concrete comparing the same with normal concrete. He had an objective to study the manufacture of suitable grouts using different admixtures to improve grout workability and strength of pre-packed concrete. He recommended that to obtain required flowability, use of admixtures is indispensable. Malhotra [4], concluded that use of SCMs in GAC grouts provides several benefits in their fresh and hardened states and reported that SF incorporation in place of OPC reduces flowability whereas, it accelerates the conversion of hydration by-product, portlandite, into calcium-silicate-hydrate (C-S-H) gel and improves strength properties. Abdelgader [5] studied the effect of using fly ash in grouts replacing OPC and observed several benefits such as, improved grout flowability, extended grout's handling time, reduced water demand and bleeding in its fresh state. O'Malley and Abdelgader [6] reported in their investigation on grouts using silica fume (SF) that SF has adverse effect on grout flowability and can only be used by optimization, incorporating HRWR to obtain adequate flowability and acceptable strength. American Concrete Institute (ACI) 304.1-2005 [7] suggests that use of preplaced coarse aggregates in GAC eliminates the challenges viz., ingredient mixing, segregation, volume change and energy loss in mixing and pumping etc. that constitute traditional concrete. It also suggests that the flowability of grout is of vital importance in production of GAC and set efflux time recommendations of 35-40 ± 2s for high strength GAC. Abdelgader [8] concluded in his experimental work on grout for TSC that quantity of fine aggregate (sand) used in grout greatly affect fluidity and sedimentation. Grout penetration through the aggregate skeleton voids and around the aggregate particles can be achieved by use of PCE based HRWR which on later ages improves the strength parameters [4]. To evaluate and achieve the recommended grout flowability, flow cone method technique was imparted [1,7]. Fine aggregate grading controls grout flowability [7]. Use of well graded fine aggregate in grouts increases grout stability and reduces segregation [6], whereas, fine aggregate of high fineness modulus increases the water demand. Therefore, King [9] recommends that the fineness of fine aggregate should range from 1.2 to 2. Folagbade [10] reported that cement substitution by FA increases setting time, whereas, cement replacement by SF reduces setting time. Abdelhamed I. Ganaw [11] reported that grout rheology gets affected by its cement paste rheology and sand properties and also stated that the use of fly ash in a pulverized form, replacing OPC partially, reduced the water demand. This is lower than the water demand of grout mix made with OPC alone. GAC grout mixture proportions were selected in accordance with the American Society for Testing and Materials (ASTM) C938-2010 and flowability in grouts was maintained in accordance with the provisions of ASTM C939-2010.

Beside the green effects of using SCMs in grouts, their use for concrete repairs and under water constructions are their testimony and their use in mass concrete is gaining popularity. The use of grout and corresponding GAC in repairs or retrofitting of R.C.C. piles is less. Therefore, an attempt was made to investigate the consequences of SCM replacement rates in place of OPC on fresh state properties, viz., setting times, stability (bleeding), efflux time, and loss in flowability of grouts, at w/b = 0.45, incorporating HRWR dosage to their optimum targeting the recommended efflux time of 35-40 ± 2s. Moreover, flowability and its loss during 0 to 90 minutes were explored as unavoidable circumstances. This may halt the grouting process or result in delay of work. Therefore, the loss in grout flowability was investigated to ascertain the extended grout handling time for various grout compositions.

II. EXPERIMENTAL MATERIALS AND GROUT COMPOSITIONS

A. Cement

In this research study, ordinary Portland cement (OPC), manufactured by associated cement companies (ACC), was used. The cement satisfied the requirements of IS: 8112-1989.

B. Fine Aggregates

Fine aggregates used confirmed the grading as per ACI 304.1, 2005. River sand with a fineness modulus of 1.49 and a saturated surface dry specific gravity of 2.64 was used as a fine aggregate with sand to binder ratio 1:1.

C. Fly Ash

The fly ash used in the present research study was obtained from Tata Thermal Power Station (TTPS), Chembur, Mumbai, India. The values in the table indicate that the fly ash samples confirm the requirements of IS 3812:2013. Chemical characterization shows that fly ash contains 85.86% of SiO_2+Al_2O_3+Fe_2O_3 and thus, it is classified as 'Siliceous Pulverized Fuel Ash', according to IS 3812:2013, and 'Class F' fly ash as per ASTM C 618.

D. Silica Fume

Silica fume of grade 920D was obtained from Elkem India Private Limited, Navi Mumbai, India.

E. Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS) was obtained from JSW cement limited (JSW, a steel making company), Pen, Raigad, Maharashtra. Since there is no specification for GGBS in the Indian Standard, ASTM C989-14 is referred. The values are also compared with IS 12089-1987-'Indian standard specification for granulated slag for the manufacture of Portland slag cement'.

F. Metakaolin

Metakaolin admixture was obtained from Parshwa Enterprise, Mumbai (Maharashtra), India.

G. Properties of Cement, FA, SF, GGBS, and MK

The chemical composition and physical properties of OPC, FA, SF, GGBS, and MK are presented in Table I.

H. Superplasticizer

The superplasticizer (SP) used for the present research work was CAC Hyperfluid R100 manufactured by CAC Concrete Additives Pvt. Ltd. It is a Polycorboxylic Ether Polymer liquid admixture and complies with IS: 9103. Properties of superplasticizer provided by the manufacturer are given in table II.

TABLE I.

CHEMICAL ANALYSIS AND PHYSICAL PROPERTIES OF OPC, FA, SF, GGBS AND MK

Minerals	OPC	FA	SF	GGBS	MK
SiO_2 (%)		85.86	96.88	34.71	52.68
Al_2O_3 (%)			00.6	15.75	36.34
Fe_2O_3 (%)	90		1.0	0.64	2.14
CaO (%)		3.15%- Class-F	00.49	36.56	0.78
SO_3 (%)		1.09	00.24	0.25	0.05
Na_2O (%)		0.1	00.73	--	0.25
Loss on ignition (%)	1.90	0.49	1.52	0.36	0.95
Specific gravity	3.11	2.54	2.40	2.84	2.63
Surface area (m^2/kg)	301	670	19500	337	14000
OPC	Norm as per IS 8112-1989				
Initial setting time (IST)	175 min.	> 30 min.			
Final setting time (FST)	235 min.	< 600 min			
Compressive strength					
3days	29.0 N/mm^2	>27 N/mm^2			
7days	40.3 N/mm^2	>37 N/mm^2			
28days	62.4 N/mm^2	>53 N/mm^2			

TABLE II.

PROPERTIES OF SP (POLYCORBOXYLIC ETHER POLYMER)

Properties	Results	Permissible limits
Specific gravity	1.129	
pH	7.03	> 6
Solid content	42.85	43 ± 2.15
Chloride ion content	NIL	< 0.2%
Color	Light brown free flowing liquid form	

III. EXPERIMENTAL METHOD

A. Grout Mixture

To produce grouts, ordinary Portland cement, OPC, of grade 53 was used as the main binder. SCMs such as FA, SF, GGBS, and MK were used to replace OPC partially. Water cement ratio of 0.45 and sand to binder ratio of 1:1 were employed. Well graded river sand was used. Potable water was used throughout the experimental work. All grout mixtures were prepared as per the guidelines of ASTM C938-2010. Table III reports optimization of HRWR dosage based on grout flowability to satisfy recommended efflux time of 35-40 ± 2s according to ACI304.1-2005, whereas, table IV lists optimized HRWR dosage. Fig.1. depicts the optimum HRWR dosage for different grout mixtures.

B. Setting Time

The setting times were determined using the vicat apparatus described in ASTM C191 and C 953-1987 (fig. 2).

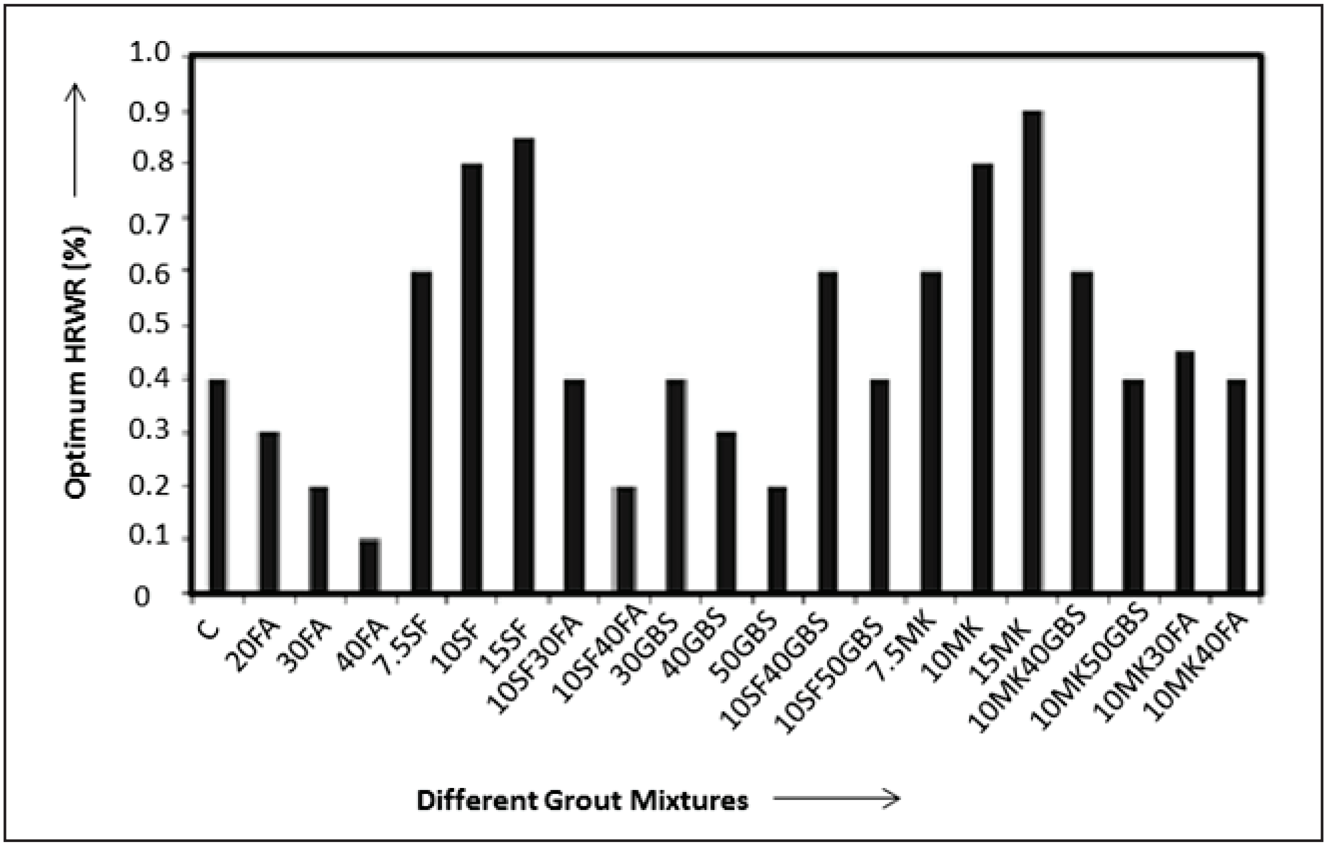

Fig. 1. Optimum HRWR for Different Grout Mixtures

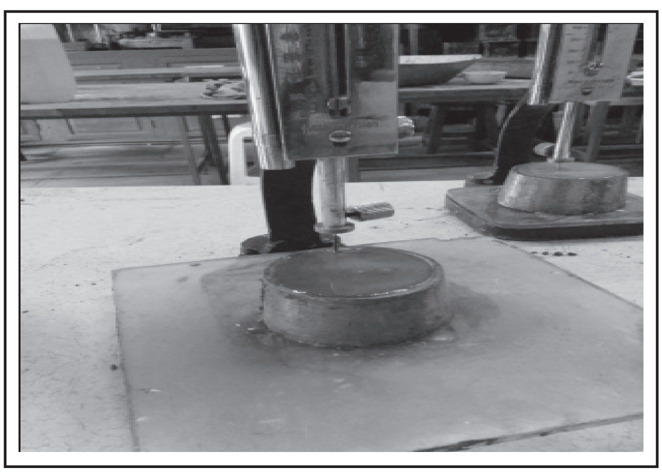

Fig. 2. Setting Time Test on Grouts

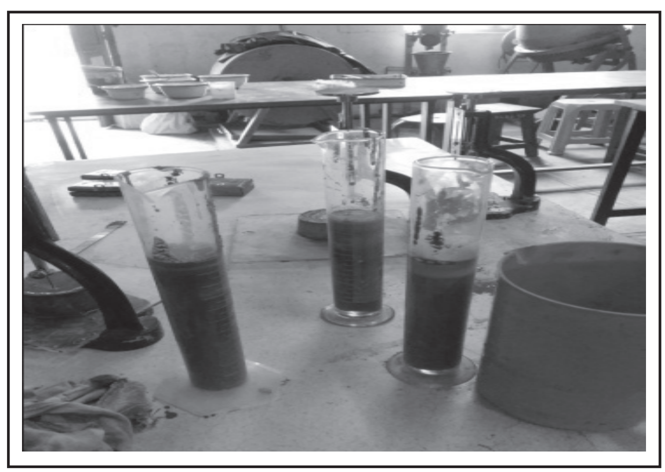

Fig. 3. Bleeding Test on Grouts

C. Bleeding

Bleeding test was conducted in accordance with ASTM C 940 (2010). An 800 ml quantity of freshly mixed grout with introduction of SCMs was poured into a 1000 ml glass graduated cylinder (fig. 3). Four readings of free water height at equal time intervals were taken for the first testing hour and two readings per hour at equal time intervals were taken in the remaining two hours of testing.

After 3 hours, % grout bleeding was obtained as per equation (Eq. 1) [12, 2]

$$\text{\% Grout bleeding} = V_w / V_1 \times 100 \qquad (1)$$

where,

V_w is the volume of decanted bleed water *(ml)* and *V1* is the volume of grout at the beginning of test (*ml*).

D. Flowability

In the present study, the flow of grouts was measured using the Marsh flow cone test. The test is conducted in accordance with ASTM C939. Initially, water flow efflux time of 8s to pass 1725 ml of water was measured as calibration of flow cone and was continued often to check the performance of apparatus. A grout of 1725 ml was allowed to flow freely through a flow cone discharge tube of diameter 12.7mm and time of efflux was measured and recorded (Table III).

E. Loss in Flowability

In order to examine the loss in grout flowability, the efflux time for each grout mixture was measured at 0, 30, 60, and 90 minutes from the end of the mixing stage. Test on loss of grout flowability is shown in fig. 4.

IV. OBSERVATIONS AND DISCUSSION ON TEST RESULTS

Effects of incorporation of SCMs on fresh state properties of grouts such as, initial setting time (s), final setting time (s), bleeding (%), and efflux time (s), and its extension within 90 minutes were investigated and discussed. Table 5 reports the results of different fresh state properties of grouts.

TABLE III.

OPTIMIZATION OF GROUT COMPOSITIONS BASED ON FLOWABILITY BY HRWR DOSAGE

Grout mixture ID Group B	Grout efflux time (s) HRWR dosage (%)			W/C = 0.45		
	0.0	**0.2**	**0.4**	**0.6**	**0.8**	**0.9**
C	210.0	105.0	39.0	32.0	--	
20FA	87.0	43.0	35.0	28.0	--	
30FA	70.0	34.0	26.0	23.0		
40FA	39.0	23.0	20.0	16.0	--	
7.5SF	234	163	69	37	32	
10SF	275	198.0	91.0	55.0	40.0	32
15SF	>300	210	108	90	47	31
10SF30FA	125	88	39	23	-	
10SF40FA	90.0	39.0	29.0	21.0	--	
30GBS	90	73	39	32	26	
40GBS	83	61	31	26	24	
50GBS	73	41	31	23		
10SF40GBS	127	105	76	38	31	23
10SF50GBS	110	78	34	30	24.0	
7.5MK	215	129	51	33	33	
10MK	251	148	81	51	41	
15MK	>300	160	97	80	49	32
10MK40GBS	130	110	80	41	29	24
10MK50GBS	118	80.0	39	30	24	22
10MK30FA	116	94	44	34	-	-
10MK40FA	95	59.0	38.0	25.0	--	-

A. Setting Time

From Table V and fig. 5, it can be seen that IST and FST are greatly influenced by type and percentage incorporation of SCMs in grout mixes. Highest initial setting time of 7 hours was observed in binary grout mix 40FA while lowest of 5.0 hrs was in 15SF, respectively. They were more by 33.33% and shorter by 4.76% than control grout mixture, respectively.

In the context of FA, for their % increase, i.e. 20FA, 30FA, and 40FA, increase in both, IST and FST, was observed. IST was found to be more by 19.04%, 23.8%, 33.33%, and FST was more by 0%, 11.9%, and 16.66% than control grout mixture, respectively. This can be ascribed to the fact that the substitution of OPC by FA with their percentage increase reduces pore water alkalinity and makes it low reactive, and causes retardation in setting times. Also, increased percentage of FA can cause dilution effect of OPC and results in

TABLE IV.

OPTIMIZED GROUT COMPOSITIONS SATISFYING RECOMMENDED EFFLUX TIME BY HRWR DOSAGE

Grout mixture ID	w/b ratio	Optimum HRWRA dosage (%)	Efflux time (s)
C	0.45	0.40	39
20FA	0.45	0.40	35
30FA	0.45	0.20	34
40FA	0.45	0.10	39
7.5SF	0.45	0.60	37
10SF	0.45	0.80	40
15SF	0.45	0.85	41
10SF30FA	0.45	0.40	39
10SF40FA	0.45	0.20	39
30GBS	0.45	0.40	39
40GBS	0.45	0.30	40
50GBS	0.45	0.20	41
10SF40GBS	0.45	0.60	38
10SF50GBS	0.45	0.40	34
7.5MK	0.45	0.60	33
10MK	0.45	0.80	41
15MK	0.45	0.90	42
10MK40GBS	0.45	0.60	41
10MK50GBS	0.45	0.40	39
10MK30FA	0.45	0.45	34
10MK40FA	0.45	0.40	38

retarded or slower hydration reaction. This could be the reason of prolonged IST and FST [10,4]. In general, percentage FA increase in place of OPC increases both IST and FST more than control grout mixture.

In case of GGBS, for their percentage increase i.e. 30GBS, 40GBS and 50GBS, increase in both, IST and FST, was observed. IST was found more by 4.76%, 14.28%, and 19.04%, and FST was higher by 0%, 2.38% and 9.52% than control grout mixture, respectively. This can be associated with the fact that increase in percentage GGBS in place of OPC might have delayed early hydration reaction and causes low heat of hydration resulting in increase in setting times [13,14]. In general, percentage GGBS increase in place of OPC increases both IST and FST more than control grout mixture.

Grouts incorporated with 10SF and 10MK both have exhibited same or little short IST and FST than control grout mixture. This could be ascribed to the higher finer particles of SF and MK with higher specific surface area. Finer particles of SF or MK adsorb on cement particles

Fig. 4. Loss in Grout Flowability

and provide more nucleating sites giving way to flow water through water channels. This has caused accelerated hydration reaction with high heat of hydration and consequently, reduced the initial setting time [10].

In case of MK, as % replacement increases, IST increases up to certain limit and later on it decreases. As can be seen in case of 7.5MK, initial setting time was 5.10 hrs, which was increased for 10MK to 5.20 hrs and then reduced to 5.0 hrs for 15MK in place of OPC. The reason associated with this may be delayed hydration reaction

TABLE V.

FRESH STATE PROPERTIES OF GROUTS

Grout mixture ID	Bleeding %	Initial setting time (h)	Final setting time (h)	Grout efflux time (s) 0 min.	30 min.	60 min.	90 min.
C	0.31	5.25	10.50	39	47	52	60
20FA	0.45	6.25	10.50	35	40	44	48
30FA	1.15	6.50	11.75	34	38	42	46
40FA	1.25	7.0	12.25	39	43	47	50
7.5SF	0.19	6.0	10.5	37	46	50	54
10SF	0.22	5.25	10.5	40	47	52	59
15SF	0.25	5.0	10.0	41	49	54	61
10SF30FA	0.85	5.75	12.0	39	45	49	55
10SF40FA	1.15	5.75	10.50	39	43	48	54
30GBS	1.37	5.50	10.50	39	44	47	56
40GBS	1.25	6.00	10.75	40	45	48	54
50GBS	1.16	6.25	11.50	41	47	49	53
10SF40GBS	0.75	5.45	10.75	38	47	52	55
10SF50GBS	0.65	6.0	11.0	34	40	46	49
7.5MK	0.20	5.10	10.0	33	39	46	48
10MK	0.25	5.20	10.5	41	47	51	60
15MK	0.27	5.00	11.0	42	50	53	62

10MK40GBS	0.91	5.5	12.0	41	47	49	57
10MK50GBS	0.87	5.45	11.5	39	45	48	54
10MK30FA	0.93	5.75	11.5	34	41	45	49
10MK40FA	1.22	6.5	11.50	38	45	48	54

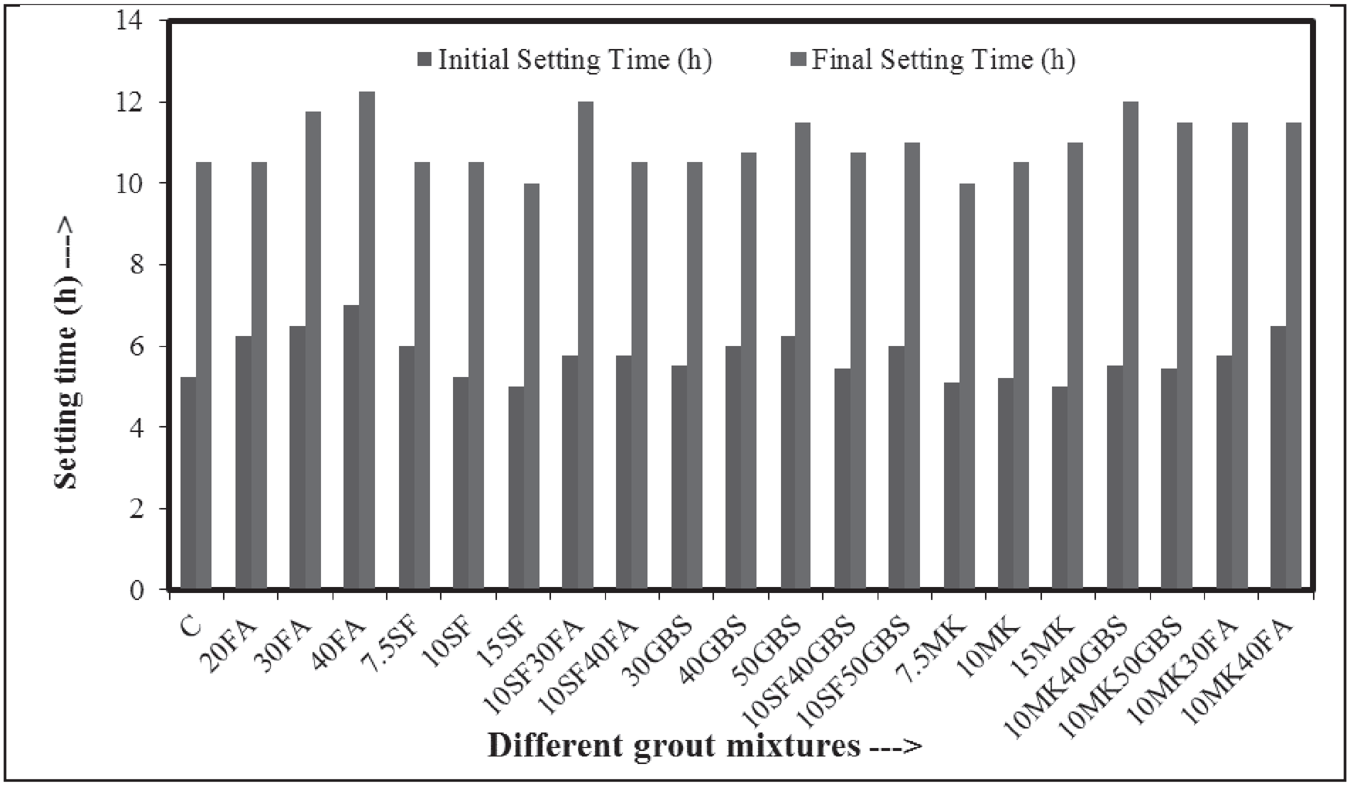

Fig. 5. Setting Times of Various Grout Mixtures

due to the greater water demand for higher percentage MK and hence, lesser amount of $Ca(OH)_2$ release in pore water resulting increase in initial setting time. Replacement of 15MK could have developed a denser binder phase of high chemical reactivity and consequently, have accelerated the initial setting time [15]. Higher metakaolin content than its optimum (10%) results in delayed final setting times [15].

In case of ternary grout mixtures with FA and MK, it was observed that the retardation in setting time of binary mix with FA greatly neutralized or diminished by the combined use of MK and FA. High initial setting retardation is observed in FA than MK. If they are combined in a proper proportion, a remarkable reduction in setting time can be obtained in grout mixtures in comparison to the grout mixtures with FA alone [15]. For instance, 30FA has its initial setting time 6.5 hrs. Its incorporation with 10MK shows initial setting time 5.75 hrs. It was found to be shorter by 11.54% than initial setting time of 30FA. Similar trend as FA and MK was observed in ternary grout mixture compositions of FA+SF, GGBS+SF, and GGBS+MK also. This infers that ternary compositions offer significant benefits over binary compositions in consideration of setting times [10]. Nearly, all grouts have shown prolonged final setting time than control grout mixtures due to partial replacement of SCMs in place of OPC.

B. Bleeding

Bleeding occurs due to the settlement of heavier solid particles suspended in water under their own weight [16]. Generally, incorporation of FA in place of OPC in grout mixtures reduces water demand. Therefore, there should be reduction in bleeding. However, addition of class F fly ash without reduction of water content is the exception to this condition [17]. Therefore, in this research study, high bleeding that happened due to addition of fly ash associated with free water content on account of the constant w/b = 0.45. Same water content and higher percentage of FA causes excess water retention in grout mixture, which causes loss in shear strength of binder particles. Consequently, it reduces their yield stress and viscosity, separating the grout ingredients making the grout composition unstable [18]. For instance, with increase in FA contents, i.e. 20FA to 40FA, there was increase in bleeding by 0.45% to 1.25%, respectively. Generally, fly ash reduces the amount of bleeding due to the reduction in water demand, but addition of class F fly ash at same water content increases bleeding [19].

Highest bleeding of 1.37% was observed in 30% replacement of GGBS than its 40% or 50% replacement. It was 4.41 times that of control grout mixture. The reason associated with this could be the incorporation of GGBS in place of OPC reduces bleeding. At constant w/b of 0.45, percentage increase in GGBS results in increase in solid surface area because it is finer than OPC, which utilizes free water to cover it and thus, reduces bleeding [13]. In general, as percentage GGBS in place of OPC increases, amount of bleeding decreases.

It can be seen from Table V and fig. 6 that grout mixtures with SF and MK exhibited lower bleeding than all grouts produced. The fact can be ascribed to their fineness. As fineness increases, surface area increases, which utilizes more water, and in turn lowers the bleeding in grout mixtures. Because of higher fineness, SF and MK act as filler materials and block the pores between binder particles leading to reduction in bleeding [20]. In the present study, SF was finer than MK and other binders too. Therefore, SF incorporation resulted in lower bleeding than other grout mixtures.

In case of ternary grout mixtures, it is observed that bleeding of 10SF30FA (0.85%) and 10SF (0.22%) was 73.91% and 19.13% of 30FA (1.15%), respectively. Thus, it can be said that 10SF offsets the bleeding rate of 30FA or 30FA compensates for water demand of 10SF. Similar is the case for other ternary grout mixtures also.

In ternary blended grout mixture, highest bleeding of 3.93 times the control grout mixture was seen in 10MK40FA, while lowest bleeding of 2.09 times the control mixture was observed in 10SF50GBS. All the ternary grout mixtures, both in binary and ternary phases, were satisfying requirements of ASTM C 937 – 2002 to have lower values of bleeding than maximum bleeding limit of 2%.

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C. Loss in Grout Flowability

Experimental results based on efflux time for grout mixtures are reported in tables V and VI. Efflux times were measured at 0, 30, 60, and 90 minutes from the end of the mixing stage (fig.7). It was found that HRWR dosage and type of binder significantly influences the grout flowability and flowability loss as well. From

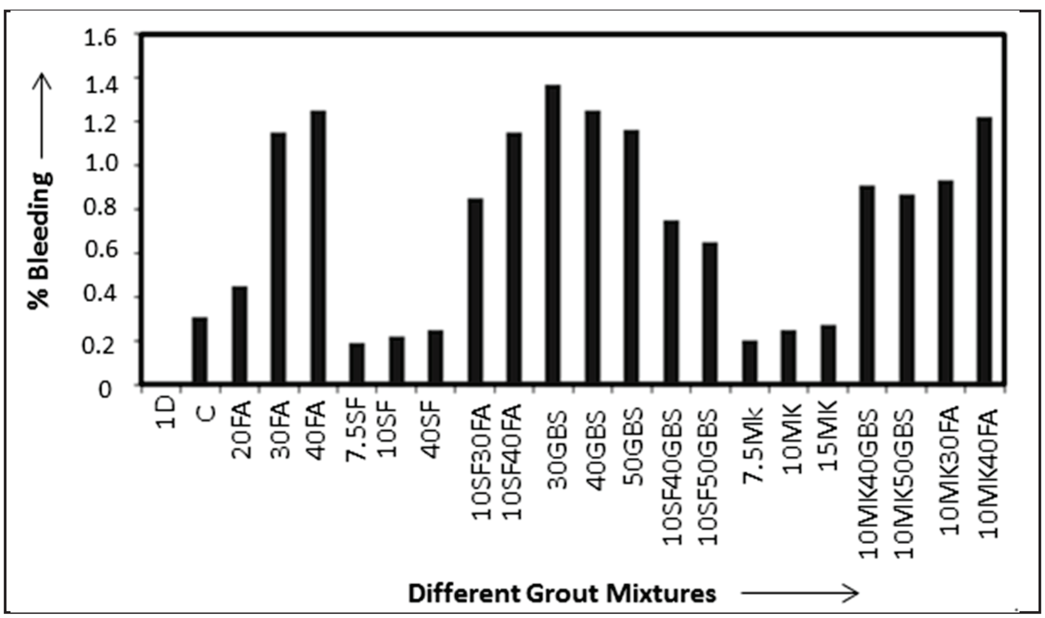

Fig. 6. Bleeding of Various Grout Mixtures

TABLE VI.

LOSS OF GROUT FLOWABILITY

Grout mixture ID	Grout efflux time (s)			% loss of grout flowability w.r.t. OPC	decrease in grout flowability % loss than OPC
	0 min.	90 min.	% more than 0 min.		
C	39	60	53.84	100	0
20FA	35	48	37.14	68.98	31.01
30FA	34	46	35.29	65.55	34.45
40FA	39	50	28.20	52.38	47.61
7.5SF	37	54	45.94	85.33	14.66
10SF	40	59	47.50	88.22	11.77
15SF	41	61	48.78	90.60	9.39
10SF30FA	39	55	41.02	76.20	23.81
10SF40FA	39	54	38.46	71.43	28.56
30GBS	39	56	43.58	80.90	19.03
40GBS	40	54	35.00	65.00	35.00
50GBS	41	53	29.26	54.36	45.63
10SF40GBS	38	55	44.73	83.09	16.90
10SF50GBS	34	49	44.11	81.94	18.05
7.5MK	33	48	45.45	84.42	15.57
10MK	41	60	46.34	86.07	13.92
15MK	42	62	47.61	88.44	11.55
10MK40GBS	41	57	39.02	72.48	27.51
10MK50GBS	39	54	38.46	71.43	28.56
10MK30FA	34	49	44.11	81.94	18.05
10MK40FA	38	54	42.10	78.20	21.79

fig. 8, it is clearly evident that the loss of flowability reduces with addition of SCMs like FA or GGBS, whereas it increases on addition of SCMs like SF or MK (fig. 8). After 90 minutes from its start, the loss of grout flowability can be measured for equal percentage of HRWR dosage and compared with the control grout mix. Actually, increase in flow time indicates loss of fluidity [21]. For instance, after 90 minutes and at 0.4% HRWR dosage (table VI), percentage decrease in loss of grout flowability observed for grout mixtures 50GBS, 10SF30FA, 10MK40FA, and 10SF50GBS were 45.63%, 23.81%, 21.79%, 18.05%, that is, more than that of control mixture C. In the context of 10SF30FA and 10MK40FA, it can be seen that the addition of FA decreases the flowability loss in comparison with SF and MK, respectively (fig. 8). This might be due to the lubrication effect caused by fly ash [10]. Moreover,

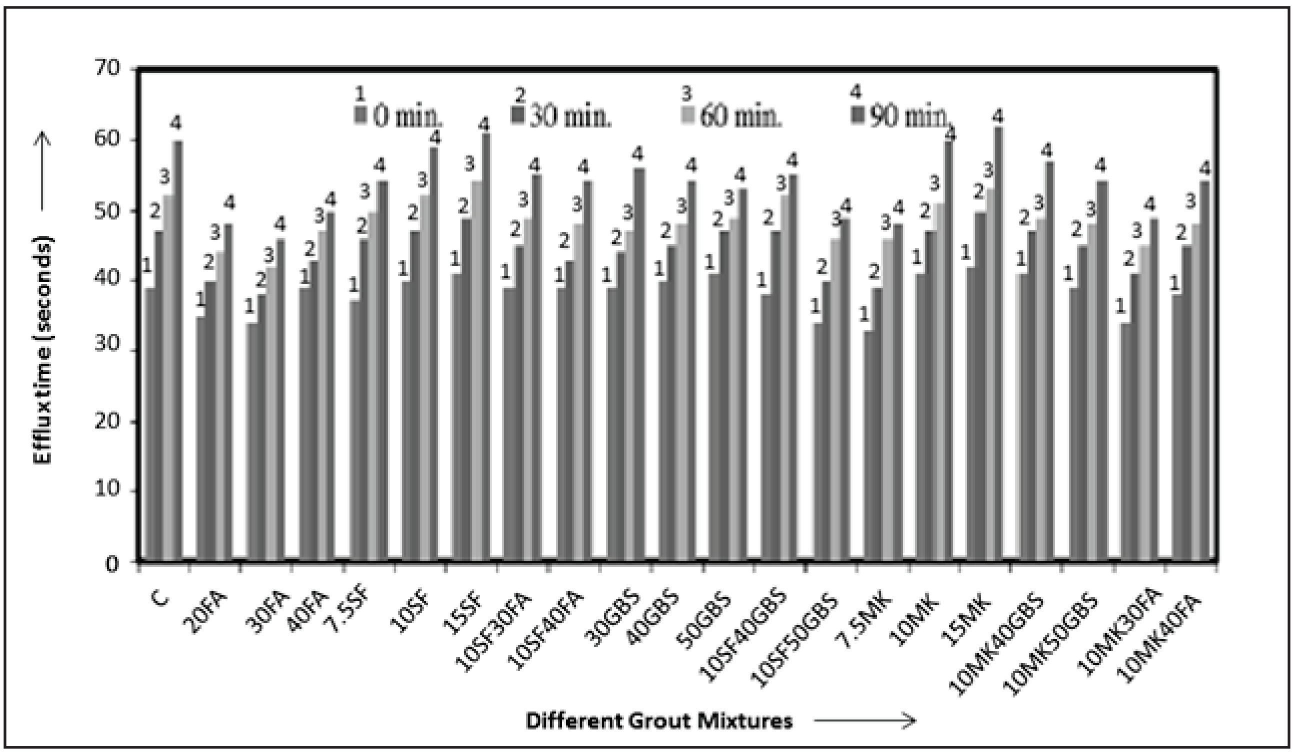

Fig. 7. Efflux Time for Various Grout Mixtures

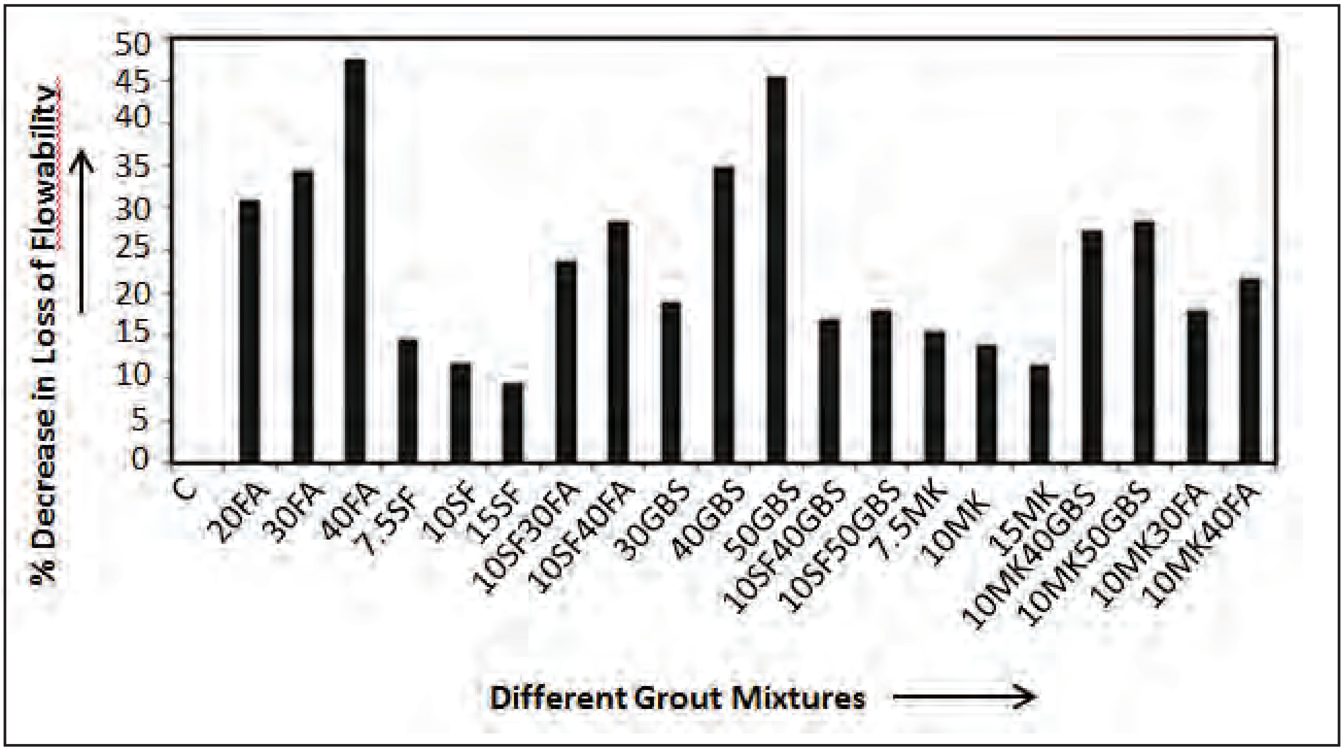

Fig. 8. Percentage Decrease in Grout Flowability Loss as Compared to OPC

addition of FA prolonged the initial setting time lowering loss of flowability with time [15]. For example, the percentage decrease in grout flowability loss for 20FA, 30FA, and 40FA was 31.01%, 34.45%, and 47.61% more than OPC, respectively (table VI). Impact of percent increment addition of FA in the form of increased flowability can clearly be seen in binary grouts of FA.

Similarly, in case of GGBS it can be observed that loss of flowability reduced on account of its addition, both in binary and ternary grout mixtures. Its effect was observed more predominantly in ternary grout phase of GGBS with MK than SF, that is, percentage loss of flowability observed was lower in case of GGBS+MK than GGBS+SF (fig. 8). This can be ascribed to the glassy nature of GGBS particles which reduces water demand and prolongs initial setting time with delayed hydration reaction evolving lower amount of heat leading to lowering in grout flowability loss [13]. Also, MK has lower fineness as compared to SF, requires lower water to cover the particle surface area. Consequently, it allows more water to render reduced grout flowability loss [2, 10].

On the contrary, decrease in flowability loss (that is, increase in flowability) was observed slightly less in 10SF (11.77%) than grout mixture of 10MK (13.92%) with application of similar HRWR dosage of 0.8%. The reason ascribed to this is higher fineness of SF than MK. OPC replacement by SF and MK, both having high specific area and fineness, increased water demand and reduced flowability [2, 10].

V. CONCLUSION

In this research study, the following concluding remarks may be made :

- The partial replacement of ordinary Portland cement with fly ash (FA) or ground granulated aggregate blast furnace slag (GGBS) improved the GAC grout's flowability but increased its bleeding.
- Partial substitution of ordinary Portland cement by silica fume (SF) or metakaolin (MK) improved the bleeding resistance of GAC grout.
- Ternary binders incorporating OPC+FA+SF or MK and OPC+GGBS+SF\or MK produced grouts that exhibited acceptable flowability and adequate bleeding resistance, and can render them suitable in pile retrofitting or their repairs.
- Loss of flowability can greatly be controlled by incorporating FA or GGBS in grout mixtures of SF or MK

and vice versa and thus, can advantageously be used in pile retrofitting or repairs on account of availability of large extended grout handling time.

- Ternary grout compositions can result in many synergic effects and can offer significant benefits over binary compositions in view of setting times, bleeding, and loss in flowability, and can provide suitability to use in pile retrofitting and their repairs.
- Judicious utilization of SCMs would be worship to the cement concrete industry and would not be a curse to the environment and industries producing them will acquire status of small scale cement producing industries, rather than blaming them for producing environmental health hazardous by-products.

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