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Investigations on the cementitious grouts containing supplementary cementitious materials

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Abstract

Concrete structures often exhibit distress during their service life due to one or more of the following causes: faulty design, use of substandard materials, poor construction, misuse or overloading. Of these, poor construction practices result in porous concrete which necessitates remedial and strengthening measures, if a structure is to meet the strength, serviceability and durability requirements, for which it has been originally designed. However, before strengthening the structure, the integrity of the concrete should be restored, which is often carried out through grouting using cement slurry, followed by grouting with epoxy or low viscous monomer. Grouting using cement slurry to fill up the voids in porous matrix of the concrete is the most simple and economical method, requiring less capital investment and skills. However, there are problems associated with cement grouting, such as shrinkage, stability of the grouts, etc. These problems associated with cement grouting can be solved by using cementitious grouts, i.e., grouts containing supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBS) and silica fume (SF) as admixtures in cement grout. This paper gives the results of the investigation undertaken to evaluate the flow, strength and durability characteristics of the cementitious grouts.

Keywords: Cementitious grout; Supplementary cementitious materials; Durability; Grouting; Flow characteristics of cementitious grout

1. Introduction

Concrete structures often undergo distress during their service life due to various reasons. Of these, lack of quality control during construction (such as poor compaction) results in porous concrete, which necessitates remedial and strengthening measures to satisfy the strength, serviceability and durability requirements as envisaged in the design. Presence of voids in the concrete becomes a source of weakness, leading to deterioration of reinforced concrete (RC) due to environmental factors, and during the earlier part of the service life itself, the integrity of the concrete would get affected requiring strengthening/retrofitting measures. However, before strengthening the RC structures, the integrity of the concrete should be restored, which is often carried out through grouting using only neat cement slurry or cement slurry followed by grouting with epoxy or low viscous monomer. Grouting using cement slurry to fill up the voids in a porous matrix of the concrete is the most simple and economical method, requiring less capital investment and skills. Earlier, at the Structural Engineering Research Centre (SERC), Chennai, India, investigations were carried out on the behaviour of porous RC beams under static and fatigue loading, both in their original (porous) condition and after improving their strength with neat cement slurry injection [1,2]. It was concluded that the cement slurry grouting improved the behaviour of porous beams in achieving strength equal to that of normal concrete beams under static and fatigue loading.

However, the problems, which are normally associated when grouting using neat cement (i.e., ordinary Portland cement [OPC]) slurry are as follows [3,4]:

- Formation of shrinkage cracks, especially when higher cement content is used
- Stability of the grout

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Table 1
Details of SCMs used in the study

SCMs used	Cement replacement levels adopted (percentage by weight of binder)
Fly ash (Class C)	20, 30, 40
GGBS	20, 30, 40
SF	5, 10

- Existence of an open/continuous pore structure of the cement matrix favouring the penetration of aggressive chemicals
- Possibility of leaching of lime present in the hydrated cement grout.

Most of the above problems associated with cement grouting may possibly be overcome by using supplementary cementitious materials (SCMs), such as fly ash, ground granulated blast furnace slag (GGBS) or silica fume (SF), as partial replacement of OPC. When SCMs are introduced in the cement grouting, the fluidity/flowability of grout is affected, particularly, at lower water–cementitious materials (w/cm) ratios. However, lower w/cm ratio is preferred from the strength point of view. Addition of a superplasticiser (SP) would overcome the fluidity problem when SCMs are used in the cement grout. However, not much information on the properties and behaviour of concrete structural elements, grouted with cementitious grout, is available. The integrity of the grouted structural elements using cementitious grouts containing SCMs has to be verified and their performance has to be assessed and compared with those of the elements grouted with normal Portland cement alone. The development of strength of these cementitious grouts, along with the improvement imparted by such grouts in the durability characteristics of concrete, needs to be studied in detail. Hence, experimental studies were undertaken to evaluate the strength and durability characteristics of the cementitious grouts containing SCMs. This paper presents the details and results of an investigation carried out at SERC, Chennai, India.

2. Scope of the investigation

The objective of the present investigation was to determine the efficacy of the use of industrial byproducts, such as fly ash, GGBS, and SF to partially replace the quantity of cement normally used for grouting applications, and to evaluate the flow, strength, and durability characteristics of such cementitious grouts. The following investigations were carried out:

- Studies on the flow characteristics of the cementitious grouts
- Evaluation of the efficacy of the cementitious grouts by obtaining the properties of core samples extracted from the concrete blocks, cast using no-fines concrete and later grouted with the cementitious grouts containing SCMs.

3. Investigation on the flow characteristics of the cementitious grouts

Towards studying the flow characteristics of the cementitious grouts, the optimum dosage of SP (OSD), which would impart maximum fluidity to the cementitious grout, was obtained for different SCMs at various cement replacement levels and for different w/cm ratios.

3.1. Parameters investigated

The following parameters were varied in this investigation:

- Cement replacement levels using the SCMs such as fly ash, GGBS, and SF
- w/cm adopted: 0.25, 0.30, 0.35, and 0.40.
- Dosage of SP
- Three different brands of cement of the same grade

3.2. Materials

3.2.1. Cement

In the present investigation, three different brands of normal (ordinary) Portland cement 53 grade, identified as OPC-1, OPC-2, and OPC-3, were used.

3.2.2. Mineral admixtures

The details of mineral admixtures, which were used as SCMs, are given in Table 1. The properties of SCMs, viz., fly ash, GGBS, and SF are given in Table 2.

3.2.3. Water

Potable water was used.

Table 2
Characteristics of fly ash, GGBS, and SF

Chemical composition	Fly ash	GGBS	SF
SiO_2 (%)	35.8–42.83	32.6	93
Al_2O_3 (%)	18.0–26.9	12.8	0.6
Fe_2O_3 (%)	6.5–8.2	1.3	1.0
MgO (%)	3.5–4.1	7.2	1.2
Na_2O, K_2O	–	2.60	1.10
SO_3 (%)	2.2–3.5	0.03	0.30
CaO (%)	18.8–19.8	41.0	0.2
Specific gravity	2.15	2.95	2.4
Moisture (H_2O) (%)	0.2–1.9	–	–
LOI (%)	2–2.4	0.2	0.5
Fineness (cm^2/g)	2900	4000	200,000

3.2.4. Chemical admixtures

Sulphonated naphthalene formaldehyde condensate SP in the form of aqueous solution was used.

3.3. Mixing of the cementitious grout

The mixing of the cementitious grout was done in an electrically operated paddle-type mixer machine.

3.4. Test for flow characteristics of the cementitious grout

The use of chemical and mineral admixtures such as SP and SCMs in concrete mixture depends on the following:

- compatibility of the chemical admixture with the cement
- influence of the mineral admixture on the workability
- w/cm ratio

Marsh cone apparatus was used to study the flow characteristics of the grout [5–8]. The required grout material was loaded into the drum of the mixer and the calculated quantity of water was added to the grout material and mixed in the paddle-type mixer machine for 2–3 min. An initial dosage of the SP was added to obtain fluidity of the grout. The Marsh cone was placed on a stand and a measuring jar was placed underneath the Marsh cone apparatus. The bottom end of the Marsh cone was closed with a finger and the mixed grout was then poured into the cone up to its brim level. After the cone was filled to the required level, the bottom end of the cone was opened and the grout was allowed to flow through the narrow bottom end and was collected in the measuring jar. Time required to collect 200 ml of the grout was recorded. Then the grout mix collected was transferred again into the mixer machine and mixed further after adding an additional dosage of SP. Then the mixture was poured into the Marsh cone again and the time required for collecting 200 ml of the grout was again recorded. This procedure was continued till an optimum SP content was obtained. The optimum SP content value for imparting maximum fluidity to the grout was that beyond which further addition of SP did not bring about any appreciable reduction in the time for collection of 200 ml of the grout. The same procedure was repeated for all the grout mixes to obtain the optimum SP content for the various w/cm ratios and for the different combinations of cement with SCMs at different cement replacement levels. In general, it was noted that the initial dosage of SP to obtain the fluidity of

Table 3
Results of Marsh cone test for cement sample OPC-1 with and without SCM

		No SCM		20% Fly ash		30% Fly ash		40% Fly ash		20% GGBS		30% GGBS		40% GGBS		5% SF		10% SF	
Sl. no.	w/cm	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)	SP (%)	FT_{200} (s)
1	0.25	1.00	28	1.50	11	1.80	48	2.20	17	1.20	18	1.40	24	2.40	32	1.10	60	1.70	22
		1.20	10	1.55	9	1.90	27	2.30	14	1.40	9	1.60	10	2.50	24	1.20	26	1.80	18
		1.30	5	**1.60**	8	2.00	20	2.50	12	1.60	7	1.80	7	2.60	17	1.30	18	1.90	11
		1.40	5	1.65	8	2.10	20	**2.60**	9	1.80	6	**2.00**	5	2.70	11	1.40	11	2.00	8
						2.30	14	2.70	9	**2.00**	5	2.20	5	**2.80**	7	1.60	9	2.10	7
						2.40	10	2.90	9	2.20	5			2.90	7	**1.70**	7	**2.20**	6
						2.50	10									1.80	7	2.30	6
						2.70	10												
2	0.30	0.50	20	0.70	16	0.80	13	1.00	9	0.50	7	0.70	18	1.10	15	0.60	9	0.90	17
		0.60	12	0.80	8	0.85	7	1.10	8	0.60	6	0.80	11	1.20	8	0.70	7	1.00	11
		0.65	4	**0.85**	5	**0.90**	6	1.30	6	0.80	5	0.90	8	**1.30**	4	0.80	5	1.10	8
		0.70	4	0.90	5	1.00	6	1.40	5	0.90	4	1.00	6	1.40	4	**0.90**	4	1.20	5
								1.50	5	**1.00**	3	**1.10**	4			1.00	4	**1.30**	4
								1.60	4	1.20	3	1.20	4					1.40	4
								1.70	4										
3	0.35	0.10	8	0.25	13	0.30	10	0.50	15	0.20	6	0.50	9	0.30	20	0.20	17	0.20	8
		0.15	3	0.30	7	0.35	7	0.60	8	0.30	4	0.60	6	0.40	11	0.30	6	**0.30**	4
		0.20	3	0.35	5	0.40	5	0.70	5	0.40	3	0.70	4	0.50	6	**0.40**	3	0.40	4
				0.40	4	**0.50**	3	0.90	4	**0.50**	2	0.90	3	**0.60**	2	0.50	3		
				0.45	4	0.60	3	**1.10**	3	0.70	2	**1.10**	2	0.70	2				
								1.20	3			1.20	2						
4	0.40	**0.00**	2	0.05	7	0.00	15	0.20	11	**0.00**	2	0.00	6	0.00	8	**0.00**	2	0.00	8
				0.10	4	0.10	6	0.30	6			**0.10**	2	0.10	4			**0.10**	2
				0.15	3	0.15	4	**0.40**	3			0.20	2	**0.20**	2			0.20	2
				0.20	3	**0.20**	3	0.50	3					0.30	2				
						0.30	3												

SP (%)—superplasticiser in an aqueous form (% by weight of cementitious material); FT_{200}—flow time for 200 ml.
Bold values indicate the OSD.

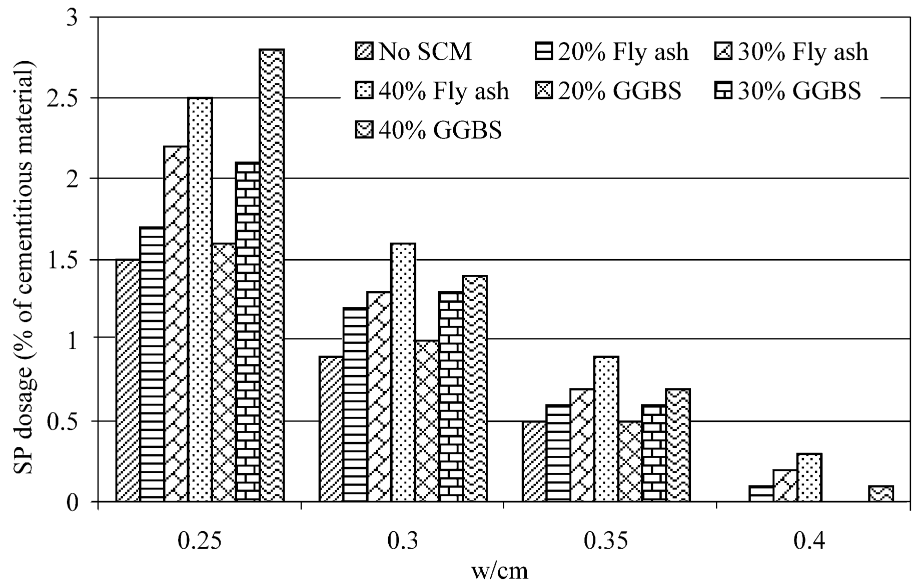

Fig. 1. Variation of OSD with w/cm for cement sample OPC-2 with and without SCM (fly ash or GGBS).

the grout varied depending on the w/cm and the type of SCM and its cement replacement level.

3.5. Discussion of the test results

The results of the Marsh cone test for cement sample OPC-1 with and without SCMs for different w/cm ratios and SP dosages in the form of aqueous solution (% by weight of binder) are given in Table 3. The variation in the OSD for different w/cm for the cement samples OPC-2 and OPC-3 with and without SCMs is shown in Figs. 1 and 2, respectively. The variation in the OSD for the three cement samples (OPC-1, OPC-2, and OPC-3) without SCM and for different w/cm is shown in Fig. 3. It is seen that for a given w/cm, the flow time for all the cementitious grouts reduced with an increase in the SP dosage and further, with the increase in the w/cm, the requirement of SP dosage decreased. The OSD for the cement samples (without any SCM) for a w/cm of 0.25 is found to be in the range of 1.3–1.7%. However, when the cement is partially replaced with SCMs, the flow time of the cementitious grouts for the OSD for a given w/cm is found to increase with an increase in

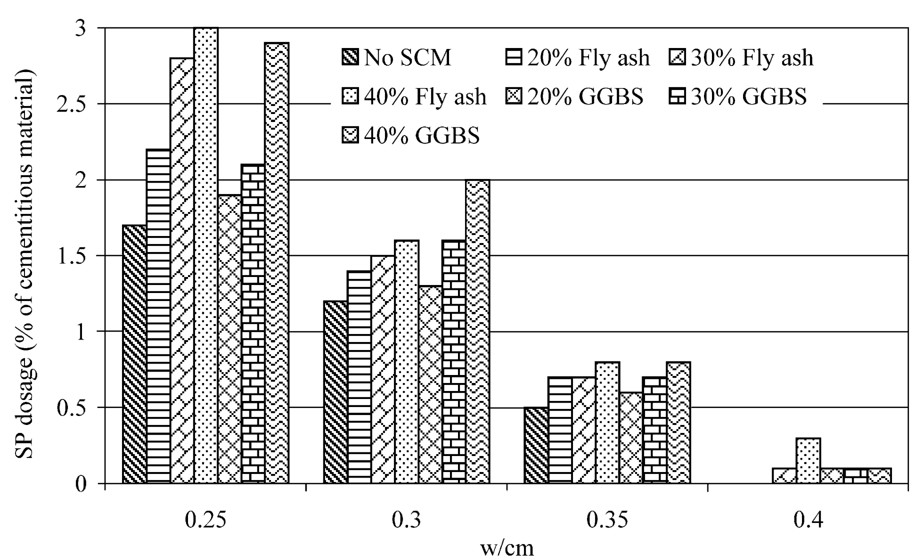

Fig. 2. Variation of OSD with w/cm for cement sample OPC-3 with and without SCM (fly ash or GGBS).

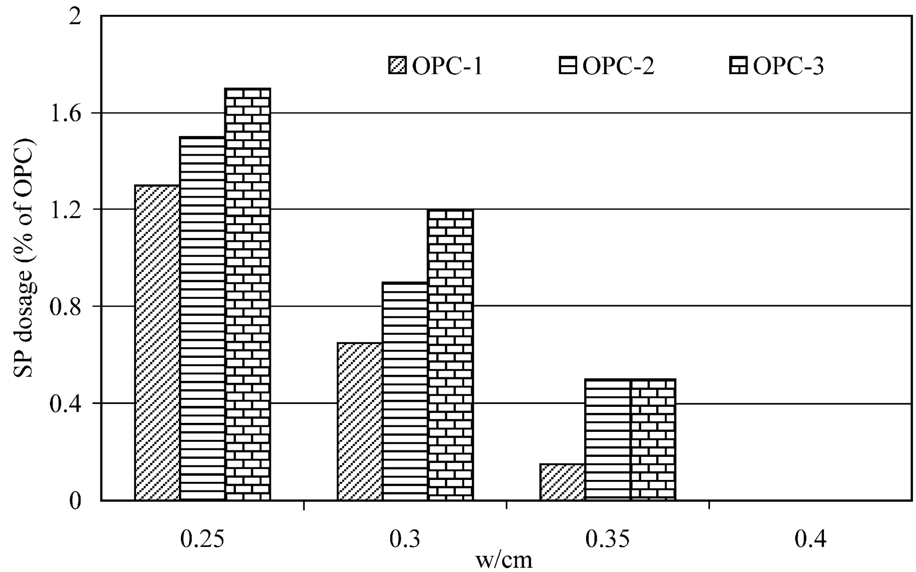

Fig. 3. Variation of OSD with w/cm for the three cement samples (without SCMs).

cement replacement levels. This trend was noticed for all the w/cm adopted in this study. As w/cm increased, the requirement of SP dosage dropped drastically and a reduction in the range of 60–75% was observed for a w/cm of 0.35 when compared with a w/cm of 0.25 for cementitious grouts having fly ash or GGBS as SCMs. The flow time for OSD of the cementitious grouts was found to vary for the three different brands of cements used.

4. Investigation on the strength and durability characteristics of the cementitious grouts

A high-performance grout intended for use to improve the integrity of concrete must meet important performance criteria, such as fluidity, stability, impermeability, and strength. Porous concrete blocks were cast with no-fines concrete and were grouted with cementitious grouts containing SCMs, such as fly ash, GGBS, and SF. Concrete core samples were taken from the grouted blocks at the end of 28, 56, and 90 days and were tested for assessment of strength and water absorption characteristics to explore the possible applications of such grouts in rehabilitation of distressed concrete structures.

4.1. Preparation of no-fines concrete blocks

In order to study the effectiveness of the cementitious grouts in improving the integrity of porous concrete, it was decided to cast concrete blocks having maximum porosity, so that they could be subsequently grouted with the cementitious grouts. ‘No-fines’ concrete was used for casting these porous concrete blocks. The following materials were used in the preparation of the no-fines concrete blocks of size $900 \times 600 \times 400$ mm.

Normal Portland cement: 43 Grade
Coarse aggregate: size between 9 and 19 mm
Water–cement ratio: 0.4
Mix proportion by weight: 1:6 (cement/aggregate)

4.2. Casting of no-fines concrete blocks

The casting of concrete blocks was carried out using steel moulds. The ingredient materials required for concrete were mixed in a titling-type mixer machine. The concrete mixture was transferred to the mould and placed in layers. Each layer was compacted using steel rods. The shuttering was removed after 24 h and the curing of the specimens was started immediately. After curing for 28 days, all the sides of the concrete block were plastered with cement mortar (1:3, cement/sand) to facilitate the grouting (Fig. 4). The integrity of the concrete blocks was tested by measuring the ultrasonic pulse velocity (UPV) using an Ultrasonic tester (PUNDIT), before and after

Fig. 4. No-fines concrete blocks before and after plastering.

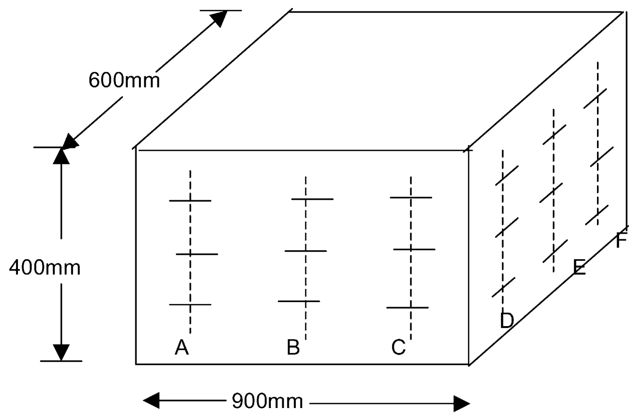

Fig. 5. Grid line location for UPV measurements for concrete block.

grouting. Fig. 5 shows the locations of the UPV grid lines (A, B,. . .F) on the concrete block. For each grid line, three UPV readings were taken and the average value was computed.

4.3. Grouting of 'no-fines' concrete blocks using cementitious materials

The number of grout entry points was obtained from the size and volume of the specimen and from the point of view of obtaining uniform and effective flow of the grout material into the concrete block. The grout entry holes were drilled in the block using a masonry drilling machine, and the location of these holes was distributed on the top surface and four side surfaces except the bottom surface of the block (Fig. 6). Aluminum pipes of 10 mm diameter were inserted into the drilled holes to a depth of 50 mm in the block and were fixed using a quick setting cement. These pipes formed the grout pipes for injecting the cementitious grout into the block.

The grouting equipment consisted of a grout container, air compressor, and hoses fitted with the nozzles. The capacity of the grout container was 5 l. Sufficient quantity of the grout material was weighed and mixed in a paddle-type mixer. Shrinkage compensating chemical admixture was added, as per the manufacturer's specification, only to the grout mixture, which was prepared using normal Portland cement (without any SCM). The w/cm was kept constant at 0.35 for all the grout mixes. The required quantity of SP dosage, obtained from the investigations on the flow characteristics, was added to obtain the maximum fluidity. Then the grout mixture was transferred to the grout container and the grout was injected under 0.5–0.6 N/mm^2 pressure. The grouting was started at the first grout pipe of the bottom row of one of the side faces of the block and continued till the grout material flowed out through the adjacent grout pipes. The grouting was continued through the grout pipes, which were not blocked during the grouting operation. In a block, there were a total number of 35 grout pipes. It took more than 1 h to complete the grouting operation in a block at a stretch (i.e., without any stoppage).

It was noticed during the grouting operation that the dosage of SP had to be adjusted to a marginally higher dosage than the OSD, which had been determined based on the investigations on the flow characteristics of the cementitious grouts. For example, the SP dosage required for a w/cm of 0.35 in the case of the fly ash-based grouts at 30% SCM level was 0.6%, whereas during the actual grouting operation, the SP dosage had to be adjusted to 1% to enable the grout to flow smoothly through the grout pipe. In the case of the slag and SF-based grouts also, the SP dosage required was found to be higher than the OSD level.

In order to compare the performance of neat cement grout and grouts containing SCMs, the first block was grouted using OPC only, and the remaining blocks were grouted using cementitious grouts containing SCMs. The details of the grouts injected in different concrete blocks are given in Table 4. After the grouting of each block was completed, the block was cured with water for 28 days.

4.4. UPV measurement

To check the performance of the different grouts in improving the integrity of the concrete blocks, UPV read-

Fig. 6. Location of the grout ports fixed using aluminium pipes.

Table 4
Details of the blocks grouted with cementitious materials

Sl. no.	Block designation	Grouting mixture	w/cm	SP dosage (%)
1	G1	OPC + shrinkage compensating admixture	0.35	0.40
2	G2	OPC + 25% fly ash	0.35	1.0
3	G3	OPC + 40% GGBS	0.35	1.0
4	G4	OPC + 7.5% SF	0.35	0.4

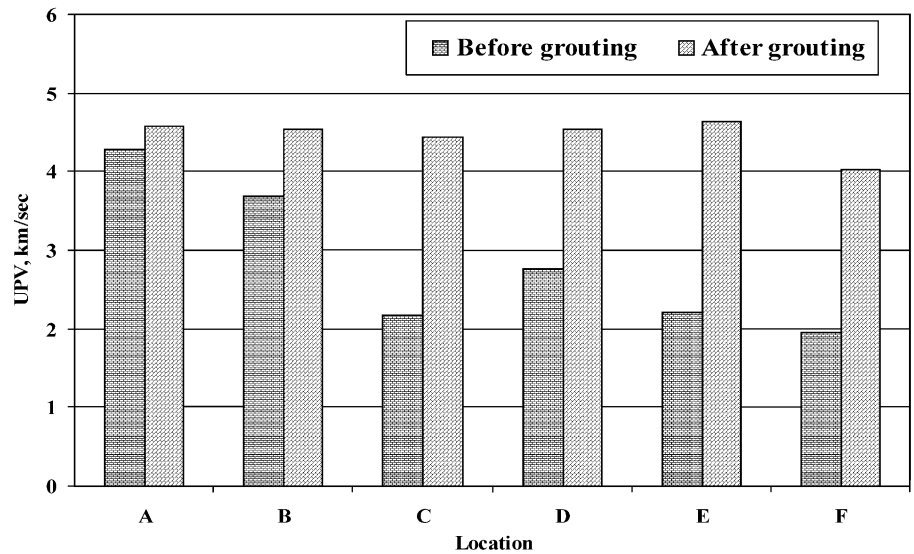

Fig. 7. UPV readings for concrete block G1.

ings were taken on the blocks before and after grouting at the same locations. These measurements also helped in assessing the uniformity of grouting. The UPV readings were taken after 28 days of curing period after grouting. Figs. 7–10 show the comparison of the UPV values before and after grouting for the blocks G1 to G4.

4.5. Concrete core drilling

To evaluate the strength and water absorption characteristics of the grouted blocks, concrete core samples were extracted from the grouted concrete blocks by using a portable core drilling equipment. Eight to ten cylindrical cores of size 93ϕ (diameter) × 400 mm (length) were taken from each block. The cores were then dressed to the required size using a concrete cutting machine to obtain the test specimens and were then tested to obtain compressive and split tensile strengths, and water absorption characteristics of the concrete. The sizes of the test specimens are as follows:

For compressive strength test = 93ϕ × 186 mm length
For split tensile strength test = 93ϕ × 50 mm length
For water absorption test = 93ϕ × 50 mm length.

4.6. Testing of the concrete core samples

4.6.1. Strength tests

The test for compressive strength of the cylindrical concrete specimens was carried out at the end of 28, 90,

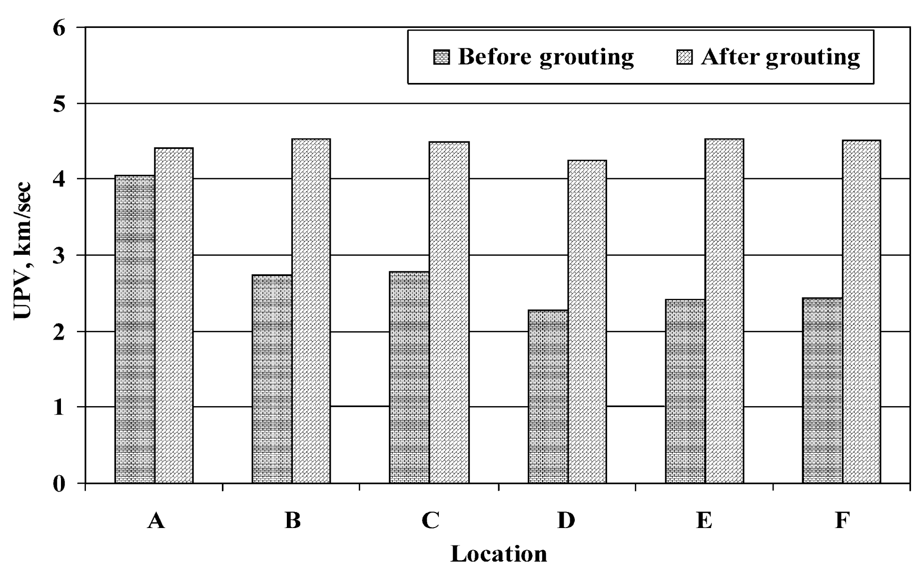

Fig. 8. UPV readings for concrete block G2.

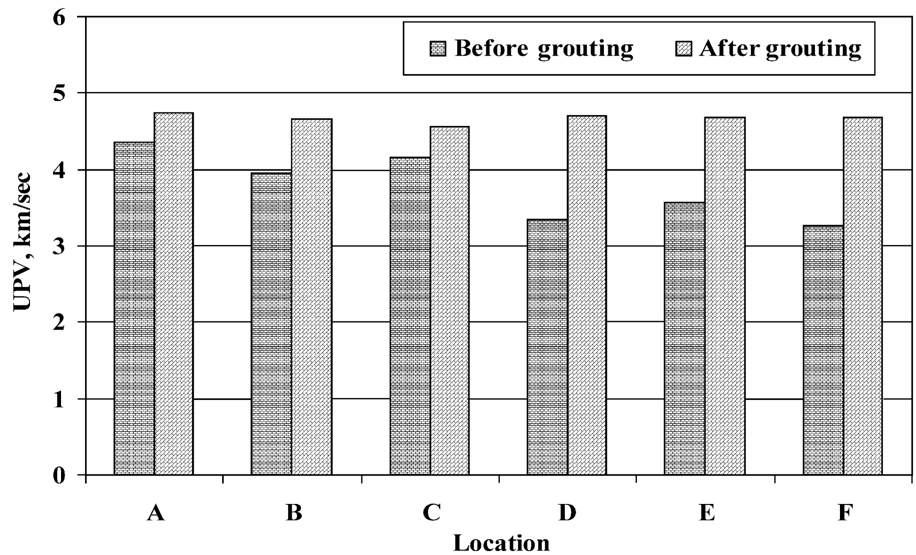

Fig. 9. UPV readings for concrete block G3.

and 180 days after grouting the respective blocks, G1 to G4. The split tension test was carried out at the end of 28 days only after grouting the blocks. The results of the test for compressive strength and split tensile strength are given in Table 5 and Fig. 11.

4.6.2. Water absorption test

Water absorption test was carried out at the end of 28, 90, and 180 days after grouting the blocks G1 to G4. The concrete specimens were first oven dried at a temperature of 100 °C for 72 h. After 72 h, the specimens were removed from the oven and were allowed to cool to room temperature. They were then weighed (W_1), immersed in water, and removed at periodical intervals for taking wet weight for a period up to 24 h (W_2). The water absorption (WA) of concrete at any stage is given by

$$\mathrm{WA} = [(W_2 - W_1)/W_1]^*100.$$

The results of test for water absorption are presented in Table 5 and Fig. 12.

4.7. Discussion of the results of tests on the concrete core samples

It can be seen from Figs. 7–10 that the integrity of the concrete blocks, G2 to G4, improved very much after grouting with the cementitious grouts and such improvement, as reflected in their UPV values, was almost the

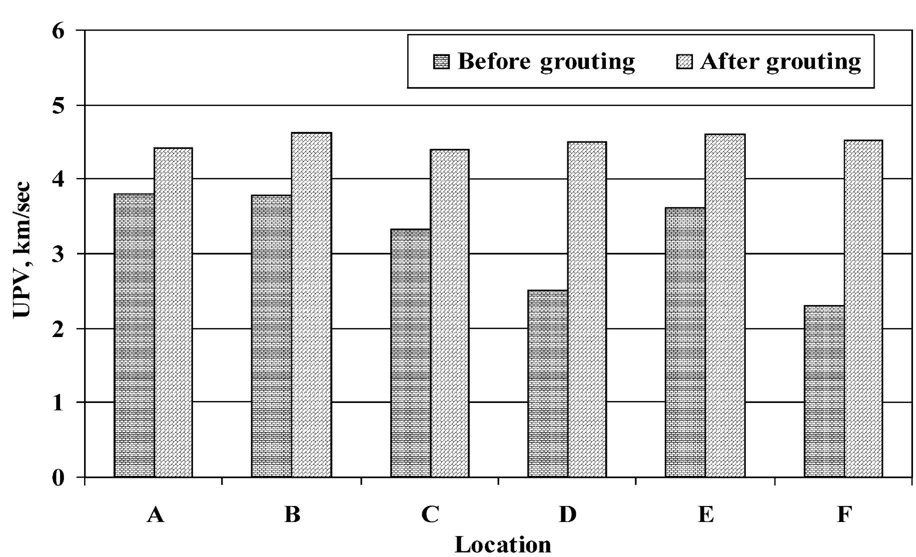

Fig. 10. UPV readings for concrete block G4.

Table 5
Results of the tests on core samples extracted from the grouted concrete blocks

		Compressive strength (N/mm^2)			Water absorption (%)			Split tensile strength (N/mm^2)
Sl. no.	Block ID	28 days	90 days	180 days	28 days	90 days	180 days	28 days
1	G1	14.95	15.40	18.00	4.00	3.75	3.60	3.88
2	G2	17.09	18.70	19.74	3.25	3.25	3.10	3.02
3	G3	15.29	16.06	19.80	4.18	3.25	3.15	3.71
4	G4	17.49	18.78	21.10	3.66	3.50	3.35	4.82

Compressive strength of 'no-fines concrete' block at the age of 28 days = 6.5 MPa.

same as that obtained for the reference concrete block G1, which was grouted with only OPC. The UPV values, which were between 2 and 4 km/s in the case of the concrete blocks prior to grouting, did get enhanced to values above 4 km/s after grouting with cementitious grouts incorporating SCMs.

The compressive strength of the 'no-fines' concrete was only of the order of 6.5 MPa. However, the core specimen

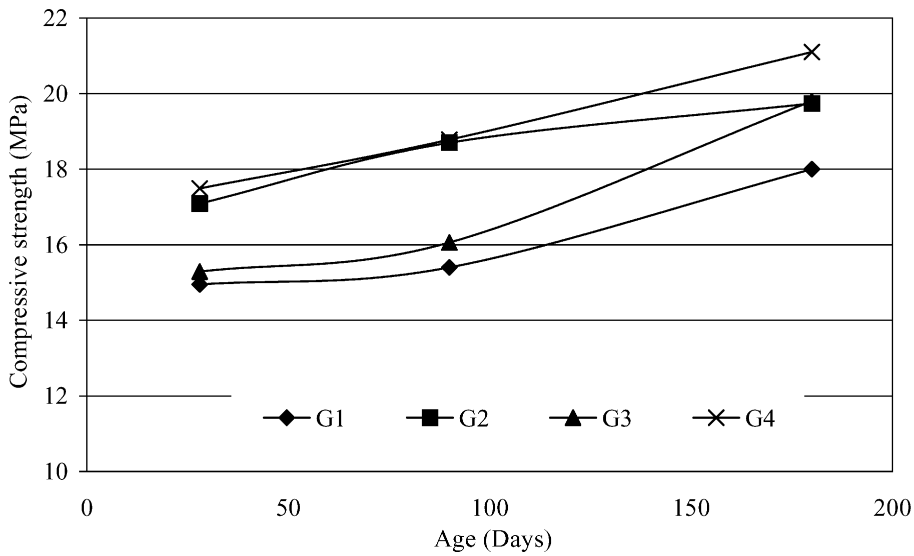

Fig. 11. Variation of compressive strength with age for core samples taken from grouted concrete blocks.

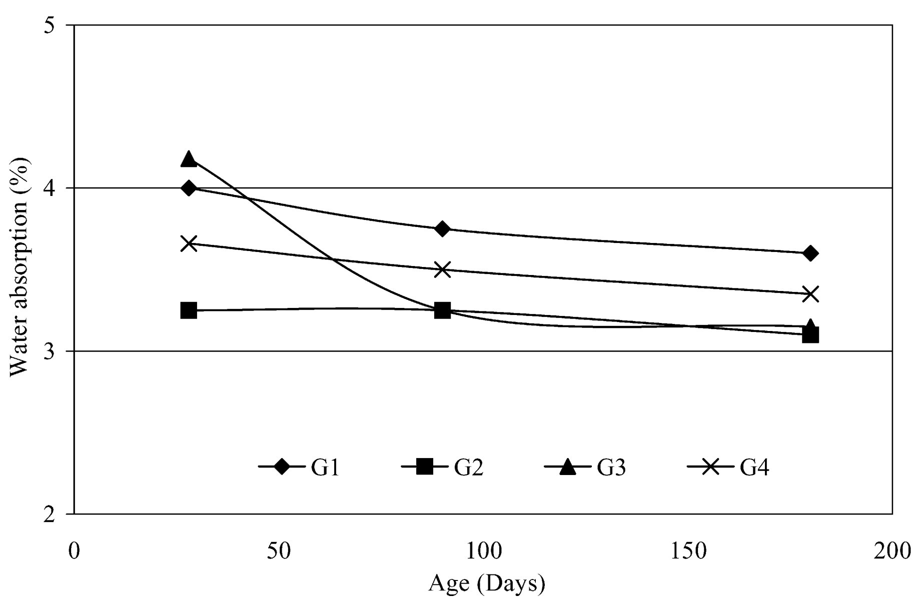

Fig. 12. Variation of water absorption with age for core samples taken from grouted concrete blocks.

taken from the blocks after grouting had a compressive strength of 15–17.5 MPa at the end of 28 days and 18–21 MPa at the end of 180 days. The core specimens from blocks G2 to G4, i.e., blocks grouted with cementitious grouts containing SCMs, showed an increase in their compressive strength up to nearly 15% over the core specimens obtained from the block G1 which was grouted with neat cement grout. These results, together with the respective UPV values, clearly showed that the integrity of concrete improved with grouting, and the performance of the cementitious grouts containing SCMs was superior when compared with that of the grout containing only normal Portland cement.

The water absorption characteristics of all the core specimens improved with grouting. The core samples from blocks grouted with cementitious grouts containing SCMs had reduced water absorption compared with the samples from the block grouted with neat cement. Among the SCMs, at the age of 28 days, the specimens from the block grouted with grout containing fly ash had water absorption values lower than the specimens for the blocks grouted with grout containing GGBS and SF. However, at the age of 90 days after grouting, specimens from blocks grouted with cementitious grouts containing SCMs, such as fly ash and GGBS had much reduced water absorption than the specimens from the block grouted with neat cement and this trend was maintained at the age of 180 days as well. The water absorption of the specimens from the block grouted with cementitious grout containing SF was also lower at the age of 28 days and onwards than that of specimens from the block grouted with neat cement.

5. Conclusions

The investigations conducted on the flow, strength, and durability characteristics of the cementitious grouts containing SCMs conclusively show that SCMs could be successfully used to partially replace normal Portland cement (OPC) in grouting operation to improve the integrity of concrete structures. Based on the experimental investigations, the following conclusions are drawn:

- The flow time for OSD of grouts was found to vary for the three samples of cements used in the present investigation.
- For the three samples of cements (i.e., without SCMs), the OSD for w/cm 0.25 was found to be in the range of 1.3–1.7% and addition of SP was not required for w/cm of 0.4 and above.
- The SP dosage was found to increase when the cement was partially replaced by SCMs and it increased with an increase in the cement replacement level using SCM.
- For cementitious grouts containing fly ash or GGBS as SCMs, as w/cm increases, the requirement of SP dosage dropped drastically and a reduction between 60% and 75% was observed for w/cm of 0.35, when compared with that for a w/cm of 0.25.
- It is seen from the UPV readings of the concrete blocks, taken after grouting with cementitious grouts, that the integrity of the concrete considerably improved with grouting.
- The compressive strength of the porous concrete before grouting was only of the order of 6.5 MPa. After grouting with cementitious grouts containing SCMs, the compressive strength of the concrete increased to 15–17.5 MPa at the end of 28 days and 18–21 MPa at the end of 180 days.
- The water absorption of the concrete specimens grouted using cementitious grouts containing SCMs was lower than that of the specimens grouted with only neat cement. Thus, the addition of SCMs in cement grouts is found to enhance the durability characteristics of the concrete.
- The results of the investigations have conclusively proved that the use of SCMs in cement grouts as CRMs, besides resulting in a reduction of cement content, does not affect the mechanical properties of concrete when compared to that of the concrete grouted with neat cement grout, and results in the improvement of durability-related characteristics of concrete.

Higher cement replacement levels using SCMs in cement grouts may also be possible, but this would require further investigation. It is observed from the results of the present investigation that w/cm 0.35 to 0.4 may be used in the grouting operation using SCMs as CRMs to ensure enhanced durability without affecting the mechanical and workability-related properties. The specifications of cementitious grouts, i.e., grouting mixture proportions, w/cm, and SP dosage, obtained in the laboratory tests may require marginal modification to suit the site conditions.

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