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Repair Mortar for Structural Sustainability

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Abstract

Objectives: Study on the engineering properties of fiber reinforced polymer cement mortar with incremental replacement of cement by silica fume, Granulated Blast Furnace Slag (GGBS) and Metakaoline (MK). **Methods/Statistical Analysis**: Cement is replaced by the additives as 5, 10 and 15 percent by weight. Polymer content (SBR) was varied as 5, 10, 15 and 20 percent by weight of water to be added. The FRP fiber addition is optimized to one percent by weight of cement in all the specimens. The intention was to study the variation in engineering properties of fiber reinforced polymer with additive replacement of binder with the additives and water with polymer. **Findings:** It is concluded from the test results that the compressive and flexural strength of modified mortar were improved markedly with increasing polymer binder ratio and also additive replacement of binder weight by silica fume, GGBS and Metakaoline. The results obtained has given much higher values when compared to individual addition of additives or polymer. The consistency in values of both compressive and flexural strength marks the much higher efficiency of the mortar even in lower percentage of addition of additive or polymer when added individually. Supplementary Cementing Materials (SCM) have growing importance in the construction industry, as it upgrades the economic and engineering efficiency of cement compositions. The replacement of water with polymer reduces the water binder ratio, driving to high strength and durable repair mortars. The polyester fibers addition resulted in the improvement of the mechanical properties of the composition**. Applications/Improvements:** Thus the fiber reinforced mortar combination is a mark in structural sustainability of not only modern but also for structural rehabilitation of historic monuments, where it can replace the ancient lime mortars with high strength and durability hand in hand.

Keywords: Compressive Strength, Flexural Strength, Ground Granulated Blast Furnace Slag (GGBS), Metakaolin (MK), Polyester Fibers (FRP), Silica Fume (SF) Sustainability,

1. Introduction

Polymer cement mortar is produced by mixing polymeric admixture with cement mortar. They are widely used for repair and rehabilitation work. Commonly used polymers are styrene butadiene rubber latex and acrylic emulsion which upgrades the engineering properties like compressive strength, flexural strength of conventional cement mortar. Metakaolin/silica fume/GGBS are reported to be a highly efficient pozzolanas which react rapidly with the excess calcium hydroxide resulting in additional alumina silicate hydrates of calcium of cement[1]. There are numerous studies on study of polymerizing cement mortar to study the compressive strength[2], flexural strength[3], water absorption[4], adhesive strength[5], tensile strength[6], water retention[7] and chloride penetration[8,9]. From the literature, it is understood that the polymer addition improve the major engineering requirements of the cement composition of conventional mix. Similar to polymer, Metakaoline[10–19] is also being used as a successful replacement for the binding component. Metakaolin/silica fume/GGBS being comparatively cheaper when compared to the cost of polymers there is to be a need to find an optimum proportion of the two to achieve the best properties of cement mortar. Silica fume[20–25] is another such additive to improve the engineering efficiency of the mortar specifically imparting very high strength, low permeability and creep in contrast with ordinary cement concrete or mortar. Polymers are also employed to impart ductile, impermeability, tensile and abrasion

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ability to mortar so that they are effective for floorings, paving, water-proofing, decorative coating and repairing materials. Silica fume and polymer can together impart mechanical, compressive strength flexural strength and ductility, impermeability and higher adhesion with steel compared with normal cement mortars. GGBS is obtained as a by-product from blast furnace of iron industries. Use of GGBS in concrete or mortar will improve resistance against chlorine attack and sulphate attack, it will reduce the initial heat liberation in concrete resulting it less cracking. Considering all these advantages of GGBS, in construction around 50 percentage of normal Portland cements are replaced by GGBS. In some case the percentage did go up to 70 percentages. But the higher percentage addition of GGBS will decrease the early strength gain of concrete[26–29]. The mechanical properties can be improved significantly due to addition of polymers and Silica fume, Metakaolin and Ground Granulated Blast Furnace Slag. The reasons are as follows: 1. Water-reducing effect of polymer: The flocculent structure of cement particles are dispersed by the surfactant part of the polymer modifiers. The mixing effect is enhanced by free water molecules. Porosity of the hardened mortar is greatly reduced due to reduction in water cement ratio, 2. Filling effect of polymer: The micro cracks, pores and cracks in transition zone and film in these places of the hardened mortar, improves the density and impermeability, 3. Pozzolanic effect: The silicon dioxide of silica fume oxidises the Hydrates of cement, namely $Ca(OH)_2$. The reduction of water soluble calcium hydroxide reduces the chance of formation of large and continuous cavities in the hardened mortar. The directional distribution of $Ca(OH)_2$ decreases around the aggregates and interfacial, which results in the increase of H_v and 4. Filling effect of fine particle: The specific surface area of SF is 23.2 m^2/g and cement's specific surface is 3560 m^2/g. Such ultra-fine particles of Silica fume fills the cavities of cement particles with good grading; this effect brings down water quantity at standard consistency. The filling of cavities boosts overall density of the hardened cement mortar, brings down the water filling in interspaces of cement particles and raises the flow ability of cement mortar. This paper focused to formulate the optimum composition of cement mortar with polymer replacing water and Metakaoline/silica fume/GGBS replacing cement to achieve their individual success in formidable cost. Thereby to optimize the proportion of the additives and styrene butadiene rubber latex in the cement mortar to have optimum compressive strength and flexural strength.

2. Materials and Methodology

2.1 Materials

2.1.1 Styrene Butadiene Rubber Latex (SBR)

The SBR latex for the experimental compositions with the cement mortar was procured from reputed chemical company in Chennai.

2.1.2 Polyester Fibres

The Recron polyester fibres were procured from a reputed Industry.

2.1.3 Cement

Ordinary Portland cement 53 grade was used in all mixes. The physical and chemical properties of cement are reported in Tables 1(a) and (b).

Table 1(a). Physical properties of cement

Density	Blain's Specific surface Cm^2/g	Setting time,(h-min)		Compressive strength, N/mm^2		
		Initial set	Final set	3-d	7-d	28-d
3.16	3320	2-22	3-32	29.1	43.5	60.8

Table1(b). Oxide composition of cement (%)

Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	R_2O	Cl
1.7	21.1	5.1	2.9	64.4	1.4	2.0	0.30	0.45	0.60	0.005

Sand; River sand (passing through 2.35 mm and retaining in 1.25 mm sieve) with fineness modulus of 2.40 was used for the preparation of cement mortar in all mix compositions. Properties of silica fume are presented in Table 2.

2.2 Methodology

Cement mortar has been prepared using Styrene Butadiene Rubber Latex replacing water; admixtures like Metakaoline/silica fume/GGBS in varying % by replacing cement. The quantity of Recron polyester fibres was kept constant as 1%. For achieving the objective, samples were casted for compressive strength test (ASTM C 109/ C191-81) and Flexural strength (ASTMC 78) for each admixtures (Metakaolin, GGBS and silica fume) and SBR latex combination. The specimens were moisture cured for seven days without demoulding and demoulded specimens were left in room temperature for remaining twenty one days. They were tested at 28 days and the results are reported in Section 3. The details about the replacement of cement with various admixtures are presented in Tables 3 to 5.

Table 2. Engineering properties of fine aggregate

Maximum size, mm	Fineness modulus	Specific gravity	Water absorption percent	Organic impurities
1.2	2.40	2.65	3.00	Nil

Table 3. Details in replacing cement with silica fume

Specimen Number	Water to binder ratio	SBR replacing water(%)	Silica fume replacing to weight of cement (%)	FRP to cement (%)
1	0.4	0	0,5,10,15	1
2	0.33	5	0,5,10,15	1
3	0.31	10	0,5,10,15	1
5	0.29	15	0,5,10,15	1
6	0.27	20	0,5,10,15	1

Table 4. Details of replacing cement with Metakaolin

Specimen Number	Water to binder ratio	SBR replacing water (%)	Metakaolin replacing to weight of cement (%)	FRP to cement (%)
1	0.4	0	0,5,10,15	1
2	0.33	5	0,5,10,15	1
3	0.31	10	0,5,10,15	1
5	0.29	15	0,5,10,15	1
6	0.27	20	0,5,10,15	1

Table 5. Details for replacing cement with GGBS

Specimen Number	Water to binder ratio	SBR replacing water (%)	GGBS replacing to weight of cement (%)	FRP to cement (%)
1	0.4	0	0,5,10,15	1
2	0.33	5	0,5,10,15	1
3	0.31	10	0,5,10,15	1
5	0.29	15	0,5,10,15	1
6	0.27	20	0,5,10,15	1

3. Results and Discussions

3.1 Cement Mortar with Silica Fume

The 28 day compressive strength and fleural strength of polyster fiber reinforced cement mortar with various dosages of SBR and silica fume are presented in Tables 6 and 7. The graphical representation is shown in Figures 1 and 2. It is observed that the increase in silica fume upto 10% resulted in an increase of compressive strength. Similarly addition of SBR up to 10% had shown in significant improvement for compressive strength of the mortar. Flexural strength of mortar increased with SBR dosage up to 10%; silica fume addition upto 10%.

3.2 Cement Mortar with GGBS

The 28 day compressive strength and flexural strength of polyester fiber reinforced cement mortar with various dosages of SBR and GGBS are presented in Tables 8 and 9. The graphical representation is shown in Figures 1 and 2. It is observed that the increase in GGBS upto 15% resulted in an increase of compressive strength. Similarly addition of SBR up to 20% had shown in significant improvement in the compressive strength of the mortar. Flexural strength of mortar increased with SBR dosage up to 15%; GGBS addition upto 15%.

3.3 Cement Mortar with Metakaolin

The 28 day compressive strength and flexural strength of polyester fiber reinforced cement mortar with various dosages of SBR and Metakaolin are presented in Tables 10 and 11. The graphical representaion is shown in Figures 3 and 4. It is observed that the increase in Metakaolin upto 15% resulted in an increase of compressive strength. Similarly addition of SBR up to 15% had shown in significant improvement in the compressive strength of the mortar after which there was no prominent variation in the property. Flexural strength of mortar increased with SBR dosage up to 20%; Metakaolin addition upto 15%.

Table 6. 28 day compressive strength with silica fume (N/mm^2)

Mix	0% Silica Fume	5% Silica Fume	10% Silica Fume	15% Silica Fume
0% SBR	58.55	61.88	63.21	65.75
`5% SBR	59.32	63.97	65.57	66.90
10% SBR	62.97	65.73	68.87	69.31
15% SBR	63.68	68.34	70.11	70.03
20% SBR	64.14	69.03	71.49	71.66

Table 7. 28 day flexural strength of mortar with silica fume (N/mm^2)

MIX	0% SF	5% SF	10% SF	15% SF
0% SBR	8.23	9.08	11.11	12.38
5% SBR	8.98	10.57	12.86	13.59
10% SBR	9.76	11.43	14.66	14.83
15% SBR	10.53	12.88	15.17	15.55
20% SBR	11.86	13.43	16.49	16.36

Table 8. 28 day compressive strength with GGBS (N/mm^2)

FRP (1%)	0% GGBS	5% GGBS	10% GGBS	15% GGBS
0% SBR	35.13	34.32	33.87	32.85
5% SBR	38.08	37.41	37.11	36.42
10% SBR	42.26	41.84	41.43	40.83
15% SBR	44.43	44.10	43.87	43.04
20% SBR	45.11	44.96	44.71	43.98

Table 9. 28 day flexural strength with GGBS (N/mm^2)

Mix	0% GGBS	5% GGBS	10% GGBS	15% GGBS
0% SBR	8.23	9.62	11.92	12.88
5% SBR	8.98	11.21	13.11	13.92
10% SBR	9.76	12.28	14.57	15.43
15% SBR	10.53	13.36	15.85	16.01
20% SBR	11.86	13.89	15.69	16.88

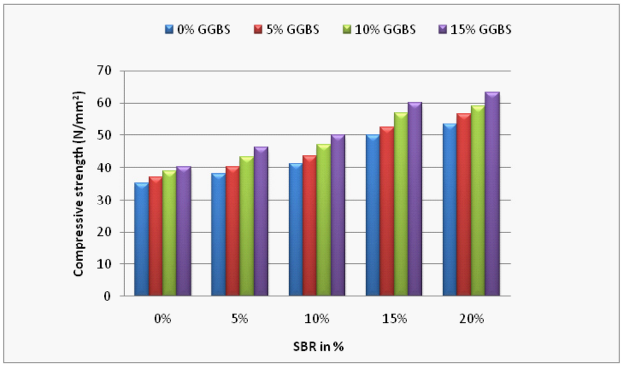

Figure 1. Variation of compressive strength with GGBS.

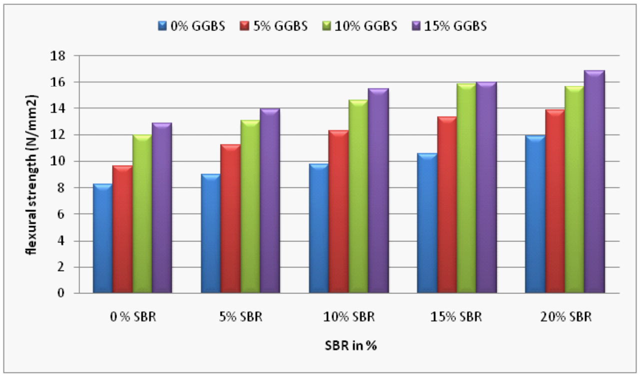

Figure 2. Variation of flexural strength with GGBS.

Table 10. 28 day compressive strength with Metakaolin (N/mm^2)

MIX	0% Metakaolin	5% Metakaolin	10% Metakaolin	15% Metakaolin
0% SBR	54.00	54.50	59.67	75.19
5% SBR	57.75	60.88	62.34	79.94
10% SBR	59.30	64.75	65.78	86.76
15% SBR	67.05	65.76	66.45	90.23
20% SBR	67.90	69.24	69.80	100.21

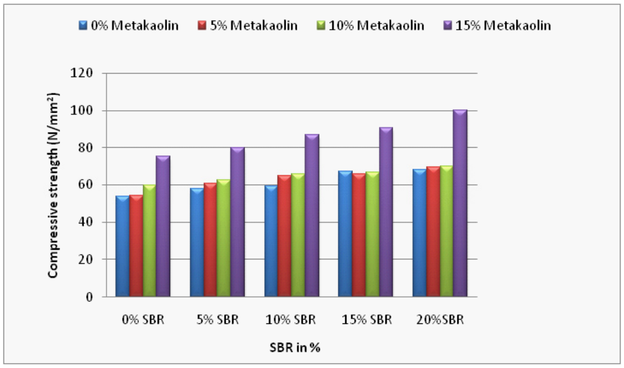

Figure 3. Variation of compressive strength with Metakaolin.

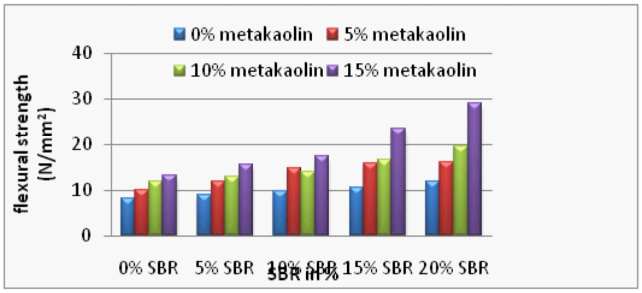

Figure 4. Variation of flexural strength with Metakaolin.

Table 11. 28 day flexural strength with Metakaolin (N/mm^2)

MIX	0% Metakaolin	5% Metakaolin	10% Metakaolin	15% Metakaolin
0% SBR	8.23	10.05	11.87	13.23
5% SBR	8.98	12.04	12.89	15.65
10% SBR	9.76	14.87	13.98	17.45
15% SBR	10.53	15.89	16.78	23.50
20% SBR	11.86	16.23	19.54	28.89

4. Conclusions

Pertaining to the materials used and the tests conducted, the following conclusions are drawn:

- The addition of SBR latex from 0% to 20% has resulted in an increase of compressive and flexural strength of the fibre reinforced cement mortar with mineral admixtures.
- The optimum composition of silica fume as per the experiment, 10% SBR to 10% binder replacement by silica fume to yield maximum variation in compressive strength and flexural strength.
- The optimum composition of GGBS as per the experimental study, 20% SBR to 15% binder replacement by GGBS to yield maximum compressive strength and 15% SBR to 15% binder replacement by GGBS to yield maximum flexural strength.
- The optimum composition of Metakaolin as per the experimental study, 15% SBR to 15% binder replacement by Metakaolin to yield maximum compressive strength and 20% SBR to 15% binder replacement by GGBS to yield maximum flexural strength.

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