

Mechanical properties of high strength mortar for repair works

Sunilkumar K. A., Ramadass S. and Job Thomas

Division of Civil Engineering, Cochin University of Science and Technology, Kochi, Kerala, India, PIN 682022

Abstract: - The experimental study was conducted to determine the mechanical properties of high strength mortar. A control mortar mix of high strength grade is prepared using ordinary Portland cement, standard sand of grades 1, 2 and 3 having silica fume, super-plasticizer. The influence of replacement of cement content with fly ash FA is studied. The variables considered in this study are replacement ratio of fly ash and volume fraction of steel fibers. The replacement ratio of 10 percent, 15 percent, 20 percent, and 30 percent by weight of cement) is used. The steel fiber content of 2 percent and 4 percent is used. The mechanical properties such as compressive strength, tensile strength, modulus of elasticity were determined. The experimental results show that the strength of mortar is not affected by addition of fly ash up to 30 percent of the cement content. The addition of steel fibers is found to be beneficial in increasing the tensile strength of the mortar.

Keywords: - fly ash, steel fibres, compressive strength, tensile strength, mortar

I. INTRODUCTION

Mortar is an excellent material for repair of concrete structures. The mortar is a product that maintains good compatibility with the distress concrete surfaces. It is expected that the high strength workable mortar is generally have increased durability. The high chemical and abrasion resistance of the high strength mortar make it amenable for the extensive use in the structural repair applications. The mechanical properties of the high strength cement mortar are described in this paper.

High strength mortar (HSM) is a repair material that can be prepared in the site with conventional and locally available materials. The use of cement can be controlled by addition of fly ash in the mortar. The tensile strength of mortar can be improved by adding steel fibers. The influence of adding fly ash as a replacement material for the cement and also fibers to enhance the structural tensile strength is studied.

Dili and Santhanam [1] developed an optimized particle size packing for high strength mortar matrix, in which also the cement content is much more of the order of about 685 kg/m³. Cwirzen et al. [2] studied that incorporation of steel fibers up to 30 percent increases the flexural strength rather than compressive strength and increased compressive strength can be achieved by mechanical heat-treat curing of the matrix. Yazici et al. [3] tried to reduce the cement content by replacing with ground granite blast furnace slag (GGBFS) and / or fly ash (FA) and concluded that 20 percent replacement of cement by fly ash gives 20 percent increase in flexural strength without any reduction in compressive strength. Also heat treat curing for the matrix can increase compressive strength considerably and may reduce flexural strength. Richard and Cheyrezy [4] studied reactive powder concrete in which cement content is more, about 800 kg/m³, which causes in addition to high cost, excessive shrinkage and micro-cracking of the matrix. Yunsheng et al. [5] studied that addition of UFFA and UF slag are effective to increase the compressive strength and other mechanical properties of the matrix even after 28 days at standard curing and it is economical and also good for environment.

II. NEED FOR THE STUDY

Cement content in the conventional high strength mortar in the range of 800-1100 kg/m³ gives high cost of construction and also excessive shrinkage and micro-cracking of the concrete matrix. If it is possible to utilize industrial waste product such as fly-ash from coal power plants (due to its pozzolanic nature), for partial replacement of cement in HSM without sacrificing the high strength and other micro-structural properties, it will be more economical and also leads to reduce the environmental impact due to these waste products on the surrounding atmosphere and human health. It also conserves the resources of raw material required for cement

industry and thus reducing another environmental impact due to mining of these resources too. Hence it is necessary to arrive an optimum quantity of FA against replacement of cement in HSM. There is no mix design available to produce HSM. As such, the main aim of this study is to produce a control mix of HSM by experimental trial and also to compare the physical and mechanical properties of FA based HSM with the control mix. This paper deals with the mechanical properties of high strength mortar used for repair works

III. EXPERIMENTAL PROGRAMME

The experimental study was conducted to arrive a control mix of mortar by trial using standard sand of grades 1, 2 and 3, silica fume, super-plasticizer in varying range with a reduced water /binder ratio of 0.18. Then further study was carried out on the control mix by replacing cement content of the control mix with varying percentage of FA (10, 15, 20, and 30 percent) by weight of cement in the control mix and also adding varying percentage of steel fibers (2 and 4 percent) by volume of the mortar mix. Various properties of the matrices, such as compressive strength (cube and cylinder), tensile strength (splitting and flexure), modulus of elasticity etc. have been found out for specimens prepared with these mixes The results have been compared with the results of the control mix.

The materials used in the casting of specimen are cement, silica fume, standard sand, fly ash, steel fibers water and admixture. The materials were tested as per standard procedures and sophisticated testing instruments to assess their engineering properties. The information provided by the manufacturers was also tabulated. The source and properties of materials have been presented in Table1.

Table 1 Details of constituent Materials

Classification of material	Properties
Cement	Type-OPC – 53 grade RAMCO Specific gravity-2.93 Compressive strength at 28 days-57.0 N/mm ²
Silica fume-	specific gravity- 2.12, SiO ₂ - 69.8 percent, CaO-13.5 percent
Mineral admixtures fly-ash	Type-Class F from Mettoor, Tamil Nadu- Specific gravity-1.9407
Standard sand (IS: 650, 1991)	<i>grade-1</i> (between 2 mm and 1 mm), Specific gravity =2.6 <i>grade -2</i> (between 1 mm and 500 μ) , Specific gravity =2.52 <i>grade-3</i> (between 500 μ and 90 μ) , Specific gravity =2.47
Super-plasticizer	Structuro-402 manufactured by FOSROC,India Limited- Specific gravity- 1.06 , pH value- 6.04, Total solid content- 33.95 percent
Steel fibers	0.32 mm (30 gauge) galvanized iron fibers marketed by M/s Oswal Weld mesh Private Limited, Kochi.Length-6 to 10 mm, aspect ratio - 20 to 30, specific gravity-7.85, tensile strength- 400 MPa

Variables such as replacement ratio of cement with fly ash (by weight of cement) and addition of steel fibers (by volume of concrete mix) have been considered in this study. The control mix was prepared by trial and error by varying the water to powder ratio of about 0.18. The mix is designated with the fly-ash replacement ratio (F) and steel fiber content in the matrix (S). For example, the mix F15S2 represents a mix having 15 percent fly ash replacement by weight of cement in the control mix and 2 percent steel fibers by volume of matrix. Table 2 shows the specimen designation and constituent contents in this study.

Table 2 Specimen designation

Mix designation	w/b ratio	Quantity of constituents per cubic meter of concrete								
		Cement	Silica fume	Standard sand 1	Standard sand 2	Standard sand 3	Water	Super Plasticizer	Fly ash	Steel fibers
		(kg)	(kg)	(kg)	(kg)	(kg)	(l)*	(l)*	(kg)	(kg)
F0S0	0.19	870	261	558	223	90	214	45.2	0	0
F10S0	0.2	740	261	558	223	90	226	45.2	87	0
F20S0	0.19	610	261	558	223	90	214	45.2	174	0
F30S0	0.19	475	261	558	223	90	214	45.2	261	0
F0S2	0.16	870	261	558	223	90	180	45.2	0	157
F15S2	0.16	675	261	558	223	90	180	45.2	131	157
F30S2	0.19	475	261	558	223	90	214	45.2	261	157
F0S4	0.18	870	261	558	223	90	203	45.2	0	314
F15S4	0.17	675	261	558	223	90	192	45.2	131	314
F30S4	0.16	475	261	558	223	90	180	45.2	261	314

* 1 = Liters

Details of specimen and test

The fresh concrete is prepared and workability is measured by slump flow test. The increase diameter of the concrete is measured and reported in this paper. The maximum size of the aggregate in mortar mixes are only 2 mm and correspondingly, specimens of cross section 50 square centimeter as given in IS:4038-Part 8(1988) is prepared to test the compressive strength. The compressive strength and split tensile strength is determined using cylinder of 100 mm diameter and 200 mm height. Modulus of elasticity is determined using 150mm diameter and 300 mm height.

IV. RESULTS AND DISCUSSION

Fresh and hardened properties of different mortar mixes with varying percentage replacement levels of cement by fly ash and incorporating different percentages of micro steel fibers are studied. For fresh property, workability yhas been assessed by finding the slump flow using flow table apparatus. For hardened properties, density, compressive strength (cube and cylinder), tensile strength (split and flexural) and modulus of elasticity have been determined.

Workability

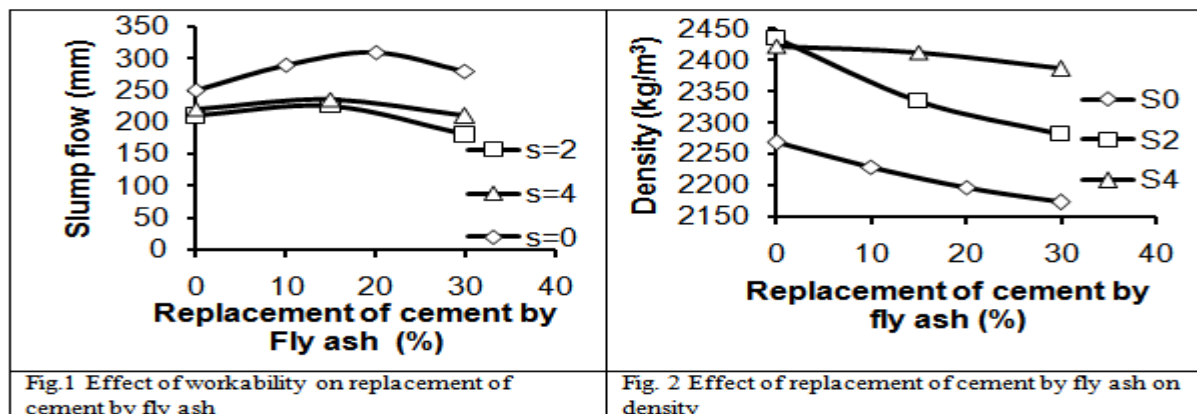
Workability of different mixes with varying percentage of fly-ash and steel fibers were studied by conducting flow table test. Flow value increases with the replaced content of fly ash up to 20 percent and then decreases with further increased content of fly ash. The increase in flow value is due to the finer particle sizes and rheological property of the fly ash content in the mix. The decrease in flow value on further increase in replacement level is due to the increased consistency, due to the increased surface area of fine particles of FA, requiring more water to become a consistent paste. Incorporation of steel fibers were much reduced the flow value, causing increased compaction effort for placing. This reduction in flow value might be due to the increased surface area of fibers causing resistance to flow. The flocculated nature of the fibers may also be a reason for reduction in flow value. The reduction in flow-ability of fibers in the matrix causing non-uniform spreading was seen compensated by the replaced content of fly ash and thus the rheology of the mix has been seen increased without increasing the w/b ratio. Fig. 1 shows the flow ratio of concrete mixes.

Hardened density

The density of different concrete mixes was found out in the hardened state by taking the weight of the specimens while testing. The density of specimens (with 28 days curing period) for various mixes obtained are in the range of 2173 to 2435 kg/m³.The density of mixes are decreased with the increase in replaced content of fly ash in cement. The reduced density corresponding to the increase in FA content for all percentage of steel fibers, is due to the lesser specific gravity of FA compared to cement. Also the reduction in density with the increasing level of FA is almost linear. The reduction in density due to increased FA content alone has been crossed by the addition of steel fibers, due to its higher specific gravity compared to the cement. Fig.2 represents the effect of replacement of cement by fly ash on density for the various mixes studied.

Cube compressive strength

Fig. 3 shows the variation in cube compressive strength of various mixes at 28 days normal curing corresponding to the replacement of cement with fly ash. The result shows that replacement of cement with 10 to 15 percentage of fly ash achieves higher compressive strength. However addition of steel fibers has not shown much improvement in compressive strength, but the brittle failure mode was found to be removed and ductility seen improved.



The increase in compressive strength by the replacement of cement with fly ash might be due to the dense packing of fine particles of fly ash in the matrix and the secondary hydration of $\text{Ca}(\text{OH})_2$, produced during the primary hydration of the cement in the matrix, with the pozzolanic reaction of the partially replaced fly ash to form extra C-S-H gel in the paste and slow down the strength development at early stage, effecting a great reduction in the hydration heat of the exothermic rate and prolonged the arrival time of highest temperature. The reduction in hydrated heat helps in reducing the chance of cracks at early ages in the structure and the forming of extra C-S-H gel in the paste helps to produce more dense micro-structure in the matrix resulting in achievement of higher compressive strength.

The silica fume used had only lesser amount of SiO_2 (<70 percent) compared to Elkem micro silica containing very high amount of SiO_2 (>98 percent) as mentioned in the referred journals and this might have adversely effected in achieving lesser strength

Effect of fly ash replacement on cylinder compressive strength for various mixes is represented in Fig. 4. Without adding steel fibres, the cylinder compressive Strength is seen increased by the replacement of fly ash up to 20 % of cement and then the rate of increment in the strength is reduced on further replacement of cement. An increase of 39 percent and 34 percent of strength were noticed by the replacement of cement with 20 and 30 percent of FA and without any incorporation of steel fibers and is much economical when considering the minimum cost of FA. Also decrease in strength in the range of 6 to 18 percent were seen for mixes with steel fibers, except for mix F30S4, where a marginal increase of 13 percent obtained, But when comparing to the mix without fibers, the gain in strength is greatly less and not economical.

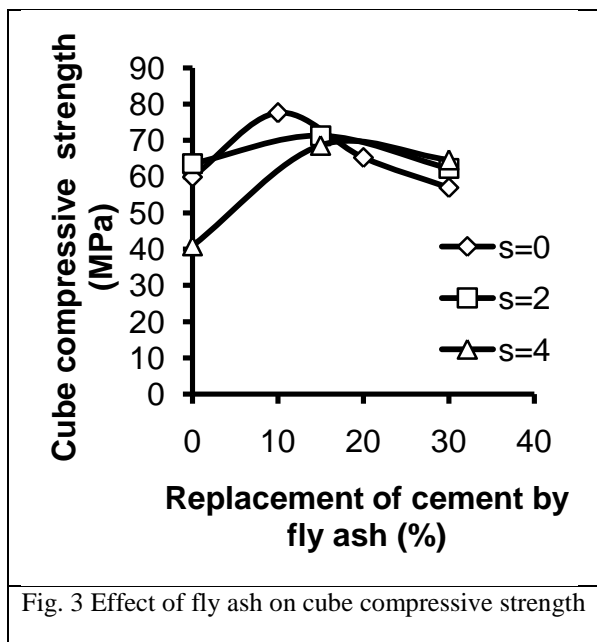


Fig. 3 Effect of fly ash on cube compressive strength

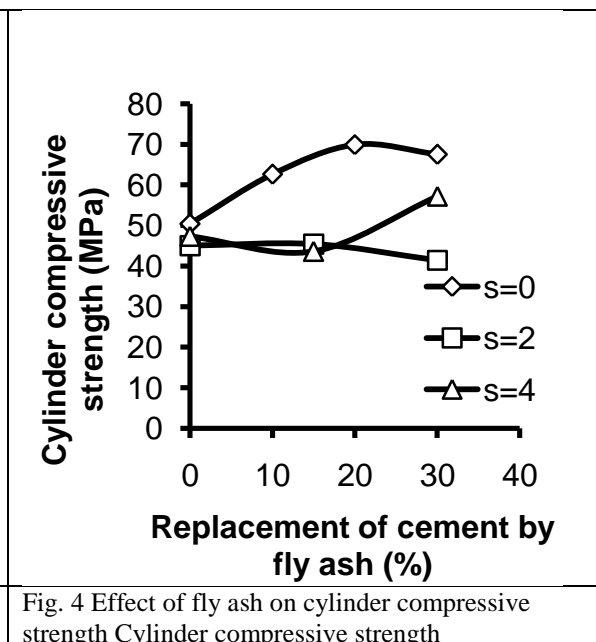


Fig. 4 Effect of fly ash on cylinder compressive strength

The increased cylinder compressive strength resulted in the mix without fibers might be due to the pozzolanic reaction of the fly ash and thereby the formation of dense micro-structure, effecting reduction in the micro voids, when compared to specimen with control mix. The increased cylinder compressive strength also means fly ash with cement in the matrix can also increase tensile strength of concrete, in addition to the compressive strength. The closer packing of fine fly ash particles in the matrix was also a reason for the increased strength. The resistive strength and bond imparted by the bridging effect of steel fibers in the matrix against widening of the crack, as expected, did not resulted in the fibered matrix. This might be due to balling effect also. However the increase in cylinder compressive strength increases the durability of concrete, rather than strength criteria.

Tensile strength

Fig.5 represents the variation of split cylinder tensile strength of the various mixes studied corresponding to the replacement of cement by fly ash in the control mix, F0S0. The results show that on increasing the replacement of cement with FA content, the split tensile strength be decreased. Further, with the increase in percentage of steel fibers in the matrix increases the splitting tensile strength. As a contrary to the above, the reduction in strength for mixes F30S2 and F0S4 shows that balling of steel fibers might have been affected for those mixes. A gain in splitting tensile strength of 42 to 59 was achieved by cement replacement

with 15 to 30 percent FA and adding 2 to 4 percent of steel fibers. The replacement of cement with fly ash up to 30 percent does not worsen the flexural strength and hence economical and environmentally good. The addition of 2 to 4 percent steel fibers with replacement of cement with 15 to 30 percent fly ash shows an additional strength of 25 to 41 percent in flexure also giving increased durability.

The decrease in tensile strength with the increase in percentage replacement level of cement by fly ash might be due to the decrease in bond strength between particles of the replaced fly ash content and the fibers when compared to those specimens with cement particles alone. The behavior of brittle failure, as is not good for any structural members, was almost found to be eliminated in specimens with the fibers.

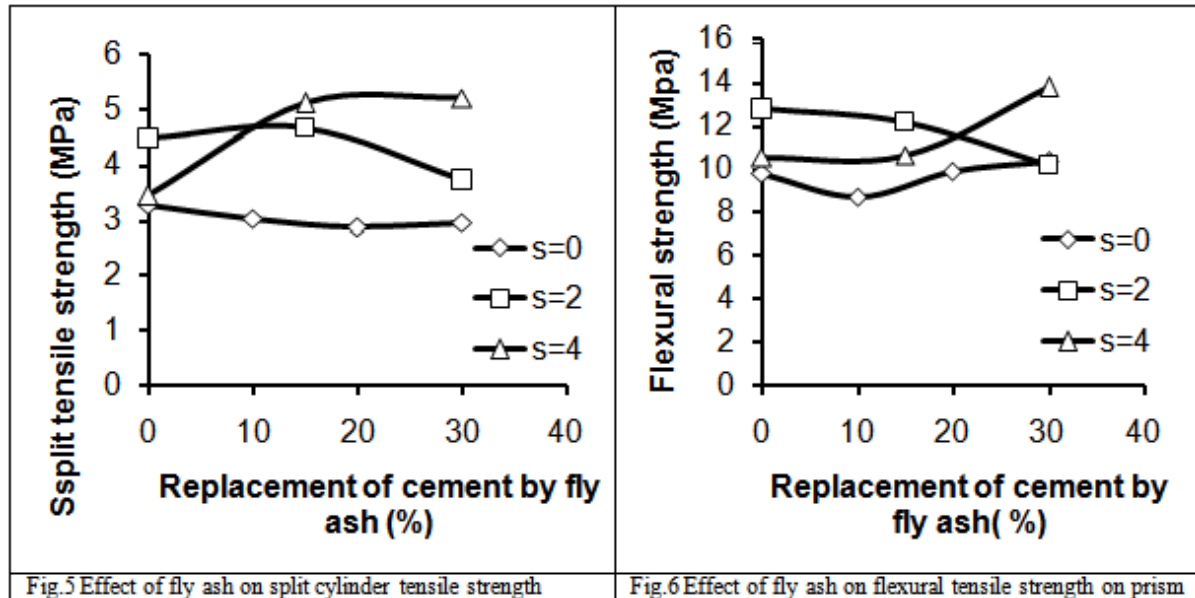


Fig.6. represents the variation of flexural tensile strength (prism) of the various mixes studied corresponding to the replacement of cement by fly ash in the control mix, F0S0. For all mixes the observed values of flexural strength by conducting prism test are higher (40 to 140 percent) than those calculated by the formula, $f_{cr} = 0.7 \cdot f_{ck}$ as per IS:456(2000), based on the corresponding observed values of cube compressive strength. The prism strength obtained for all mixes are 2 to 3.5 times greater than the corresponding split cylinder strength.

Modulus of elasticity

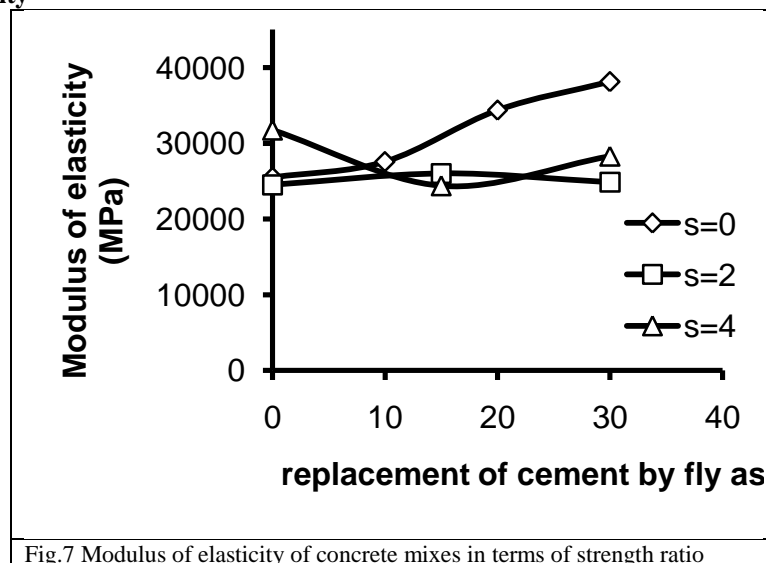


Fig.7. represents the variations in the modulus of elasticity by the replacement of fly ash and addition of steel fibers in the control mix. The increase in fly ash content without any steel fibers improved the value of young's modulus up to 50 percent on replacement level of 30 percent fly ash. The increased strength on

addition of FA without any steel fibers might be due to the reduction of voids space in the micro structure of the mix with the fine particles of fly ash and the secondary hydration with the Ca(OH)_2 formed by the primary hydration of cement paste in the matrix. The reduction in strength in fibered concrete by the replacement of cement by FA might be due to the chance of flocculated arrangement of steel fibers in the matrix having improved flow-ability of the matrix.

V. CONCLUSION

The experimental test data indicated that the addition of fly ash up to 30 percent will not affect the strength properties. Hence greener repair mortar can be prepared by replacing the cement content up to 30 percent. The addition of steel fibers increases the tensile strength. Hence addition of fibers is also recommended for enhanced structural performance of high strength workable concrete.

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