EXPERIMENTAL STUDIES OF BOTTOM ASH AND FIBER OF HIGH STRENGTH MORTAR

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Abstract — The developments of high-strength mortar (HSM) with supplementary cementitious materials(SCM) are in high demand in order to not only enhancing the mechanical properties but also to life span and minimize the maintenance cost of the RC structures. In this experimental investigation, two high strength mortar (HSM) mixes (CM 1:3 and CM 1:2) with w/b ratios of 0.5 and 0.45, respectively as reference mixes with BA replacement (0 - 40%) were selected. Quantity of water for mixes based on flow table test for mortar was assessed. Various mixes incorporating SF varying from 0 - 20 % and GO as additive varying from 0 - 0.2 %, were proportioned. For HSFRM mix (CM 1:3), polypropylene (PP) fibers (Vf = 0- 1%) with SF = 20% were used. The impact energy absorbed by the fibre reinforced mortar slabs were compared with the non-fibrous mortar slabs. It was found that the impact energy at ultimate failure, absorbed by the PP - FRM with Vf = 1% is 80 % more than that of HSM with SF = 20 %, and about 145 % that of HSM with SF = 20 % and GO = 0.15%, which appear to possess relatively a high impact resistance.

Keywords — High-strength mortar; Bottom Ash; Graphene Oxide; Fiber.

I. INTRODUCTION

Cement-based mortar is widely recognized for its cost-effectiveness and versatility in the construction, rehabilitation, and repair of reinforced concrete (RC) structures. Cement mortar maintains good compatibility with the damaged/ distressed concrete surfaces. Despite its widespread use, traditional cement mortar has several limitations, including the presence of micropores, the inevitable formation of microcracks, and low flexural and tensile strengths, as noted by Ankur and Singh (2021); this undesirable characterizes limiting its use in the construction industry. However, the development of high-strength cement mortar is in high demand to enhance compressive strength, extends the mortar's life span, and minimizes the maintenance costs as much as possible. High strength workable mortar generally exhibits increased durability along with high chemical and abrasion resistance, making it suitable for the extensive use in the structural repair applications (Salah, et al., 2023). Khan, et al. (2007) have explored the filler effect of pozzolanic materials on the strength and microstructure development of mortar. Harjinder Singh and Sikha Bansal (2015) have investigated the effect of micro silica fume on the strength of cement mortar.

The production of solid waste is increasing tremendously due to the globalization of thermal power plants, particularly coal by-products like bottom ash and fly ash from coal combustion in power plants is a growing environmental concern

due to their disposal requirements. Bottom ash (BA)/ Fly ash disposal in landfills is a major environmental concern due to land large requirement of land, and poses significant environmental challenges. Utilization of bottom ash (BA) other than land filling is the preferred waste management strategy considering size range of bottom ash closer to sand. Grain size of BA is comparable to sand, and hence, it is not suitable to use as supplementary cementitious materials, and could be utilized as fine aggregate replacement material in cement mortar (Andrade et al., 2009; Ramadoss and Sundararajan, 2013).

2. LITERATURE REVIEW

Ghafoori and Bucholz (1997) investigated 50% and 100% replacement of natural fine aggregates with dry bottom ash to study the properties of high-calcium dry bottom ash concrete with and without a high-range water-reducing admixture. Their findings indicated that bottom ash's porous and angular nature required more water to achieve the desired workability, leading to higher bleeding than reference concretes. While bottom ash did not significantly affect air content or setting times, the increased water demand resulted in lower compressive strength for bottom ash mixtures compared to control samples. Both bottom ash and reference concrete showed similar expansion strains in severe sulphate environments. Bottom ash and natural sand blends exhibited 13% more abrasion resistance than control samples, while mixtures with only bottom ash showed 40% less resistance. The flexural strength of bottom ash mixtures was lower, whereas the split tensile strength was higher than that of reference mixtures, with a lower modulus of elasticity for all bottom ash specimens.

Ghafoori and Cai (1998) explored roller-compacted concretes (RCC) using pulverized coal combustion high-calcium dry bottom ash as fine aggregates. They tested nine mix proportions with varying cement (9-15%) and coarse aggregate (50-60%) contents. After six months of water curing, they found that compressive strength development in RCC with dry bottom ash paralleled that of conventional concrete, achieving 75% of 28-day strength within seven days and surpassing it by 26% after 180 days. Bottom ash produced normal weight RCC ranging from 2254-2407 kg/m³. The inclusion of bottom ash significantly enhanced split tensile resistance more than compressive strength. Young's modulus increased with strength and curing age, and one-year-old drying shrinkage strain in bottom ash RCC was half that of vibratory-placed conventional concrete.

Nisnevich et al. (1999) evaluated the radiological aspects of lightweight concrete with furnace bottom ash from Israeli power stations. Despite the higher porosity and lower bottom ash density than natural sand and crushed stone, the resulting lightweight concrete had densities between 1000-1700 kg/m³ and improved insulating properties. However, the potential exposure to ionizing radiation from radionuclide’s in bottom ash necessitated evaluating and controlling radioactivity. The researchers recommended reducing radioactivity by replacing some bottom ash with non-active aggregates like limestone or natural sand to meet legal requirements in Israel.

Aggarwal P. (2007) evaluated the effect of using bottom ash, which constitutes about 20% of the total ash from coal-fed boilers, as a fine aggregate replacement in concrete. The study examined compressive, flexural, and splitting tensile strengths for various replacement levels (0-50%). Results indicated that the strength development of bottom ash mixes was comparable to normal concrete, showing potential for substituting natural fine aggregates without significant loss of strength. The findings underscore the feasibility of using bottom ash to produce concrete with adequate mechanical properties, which can help reduce the reliance on

natural sand and promote the utilization of industrial by-products.

Ng Hooi Jun et al. (2015) evaluated the effect of bottom ash on the performance of Portland cement mortar. Bottom ash replacement improved the mechanical properties of Portland cement mortar. It provided a solution for disposing of bottom ash waste in a technical, economic, and environmentally friendly manner, demonstrating the potential of bottom ash in sustainable construction.

2.1Replacement of Fine Aggregate by Bottom Ash in Various Materials

Monzo et al. (1996) investigated the use of sewage sludge ash (SSA) in mortars, focusing on its chemical composition, the effect of its size fractions on mortar workability, and the impact of replacing 15% of Portland cement on compressive and flexural strengths. They observed an irregular distribution of chemical compounds like sulphates and SiO_2 among size fractions. Due to the non-spherical shape of SSA particles, workability was negatively affected. However, the compressive strength of mortars containing SSA exceeded that of control mortars at short curing times (3 days) and for longer curing times (14 and 28 days), all SSA-containing mortars surpassed the control, indicating potential pozzolanic reactions in these ashes.

Nicos S. Martys (1997) studied capillary transport in concrete and mortar, finding complex time-dependent water uptake behaviors. Empirical models described capillary suction at short and long times, informing moisture management strategies in construction. This research provides a better understanding of moisture transport in concrete and mortar, aiding in the development of more durable construction materials.

Fahriye Mazlum Kilingkale (1997) analyzed mortars with silica fume replacements. Sulfate exposure increased absorption for 0% silica fume mortars, while higher replacements reduced water absorption and shrinkage, enhancing durability. This study supports using silica fume to improve the durability of mortars exposed to sulfate environments.

Kantiranis N. (2004) investigated the bottom ash Power Plant, focusing on mineralogical composition and organic matter content. Low organic matter bottom ash showed potential for various applications, such as lightweight concrete, raw feed for Portland cement, and other construction uses. This study provides valuable insights into the compositional characteristics of bottom ash and its suitability for different construction applications.

Amir Elsharief (2005) investigated the microstructure and durability of mortars with dry and prewetted lightweight aggregates. Lower sorptivity and electrical conductivity were observed, with better sulphate resistance compared to normal aggregates. The research highlights the benefits of using lightweight aggregates to enhance mortar durability.

3.0 EXPERIMENTAL INVESTIGATION:

3.1 GENERAL

Ccharacteristics of various materials chosen and used, and details of experimental programme to study the optimization of bottom ash as fine aggregate replacement material in HSM, effect of silica fume as SCM and GO as additive, and the effect of volume fractions of polypropylene fibers on mechanical performances, such as compressive strength, flexural strength, stress-strain behavior, modulus of elasticity of HSM/ HSFRM and the durability performance of the mortar composites, are presented. The methodology of research adopted in the experimental study is shown in flow diagram.

3.2 MATERIALS USED

3.2.1 Cement

Ordinary Portland cement (OPC)- 43 grade, having 7-day and 28-day compressive strengths of 34.2 MPa and 45.40 MPa respectively, satisfying the requirements of IS: 12269-2013 was used. Physical properties and chemical composition of ordinary Portland cement are provided in Table 3.1 and 3.2, respectively.

3.2.2 Silica Fume

Silica fume (SF) also called as micro silica (in powder form) supplied by Go green products, Chennai, conforming the requirements of ACI 234R-2012 was used as supplementary cementious materials (SCM). The physical and chemical properties of micro silica are given in Tables 3.1 and 3.2, respectively. Silica fume used in this study is shown in Fig. 3.2. Silica fume particles are too small in size with particles shape of spheroid to be imaged in details by scanning electron microscopic (SEM) analysis is shown in Fig. 3.3. Silica fume has particle diameter of about 0.1 to 0.3 μm, which is in agreement with previously reported dimensions.

Table 3.1 Physical properties of OPC (43 grade) and silica fume (SF)

Parameter	**OPC**	**SF**
Appearance	Grey powder	Light Grey powder
Specific gravity, Sg	3.14	2.65
Pack density, D pack (gm/cc)	1.45	0.77
28-day compressive Strength (MPa)	45.4	-
Standard Consistency, %	28	-
Setting Time (minutes)	Initial: 42; Final: 480	-
B.E.T Fineness (m^2/kg)	260	22500
Soundness by Le-Chatelier expansion	6	-
Greater than 45 micron	-	1.42 percent
Moisture content	-	0.05 percent

Table 3.2 Chemical composition of OPC and Silica fume

Chemical Composition	OPC(% by mass)	SF (% by mass)
Silicon dioxide, SiO2	21.07	94.70
Alumina (Al2O3)	5.54	0.043
Ferric Oxide (Fe2O3)	5.16	0.040
Titanium Oxide(TiO2)	0.00	0.031
Calcium Oxide (Cao)	64.26	0.021
Magnesium Oxide	0.88	0.001
Pottasium Oxide	0.35	0.021
Sodium Oxide	-	0.30
Loss on ignition	1.54	2.00

3.1.1 Graphene oxide

Graphene oxide (GO) supplied by platonic nanotech private limited, India was used as additive to cement. Graphene oxide (GO) having specific gravity of 1, with purity of >99% and lateral dimension: width = 1-5 nm and thickness = 1-5 nm, average number of layers = 4-8 was used. The specific surface area of GO used is 210 m^2/g. Graphene oxide used in this study is shown in Fig. 3.4. GO particles are too small in size to be imaged in details by SEM analysis, is shown in Fig. 3.5. Chemical composition of GO are given in Table 3.3. X-Ray Diffractograms Pattern of graphene oxide is shown in Fig. 3.6.

Table 3.3 Chemical composition of graphene oxide

Elements	Value by mass (%)
Carbon	77.5
Oxygen	16.0
Sulphur	0.4
Hydrogen	1.2
Nitrogen	4.9

4.RESULTS AND DISCUSSION

Comparing the various[1] physical properties[1] of sand and bottom [1]ash, it is observed that the [1]specific gravity is slightly [1]lower, whereas, the water absorption[1] of bottom ash is substantially[1] higher than that [1]of average size of sand. [1]The particle shape (angular) and surface[1] texture (rough) of bottom ash[1] is identical with that of sand. The loose and rodded[1] bulk density of bottom ash are[1] almost equal (i.e., 98%) when compared to that of sand[1]. The sieve analysis results[1] indicate that the predominant particles of bottom[1] ash lie in the range 75 to 300[1] microns i.e., the particle size distribution[1] of the sample of bottom ash[1] lies between the lower range of sand sized particles and[1] the upper range[1] of cement sized particles. [1]Hence, the fineness modulus of bottom[1] ash was very less [1]when compared to sand (FM of BA is 0.982 & FM of sand is 2.56). As the[1] fineness modulus of the bottom[1] ash sample is higher than the sample[1] of sand used in this study, it[1] requires more water[1] during mixing of high[1] strength cement mortar.

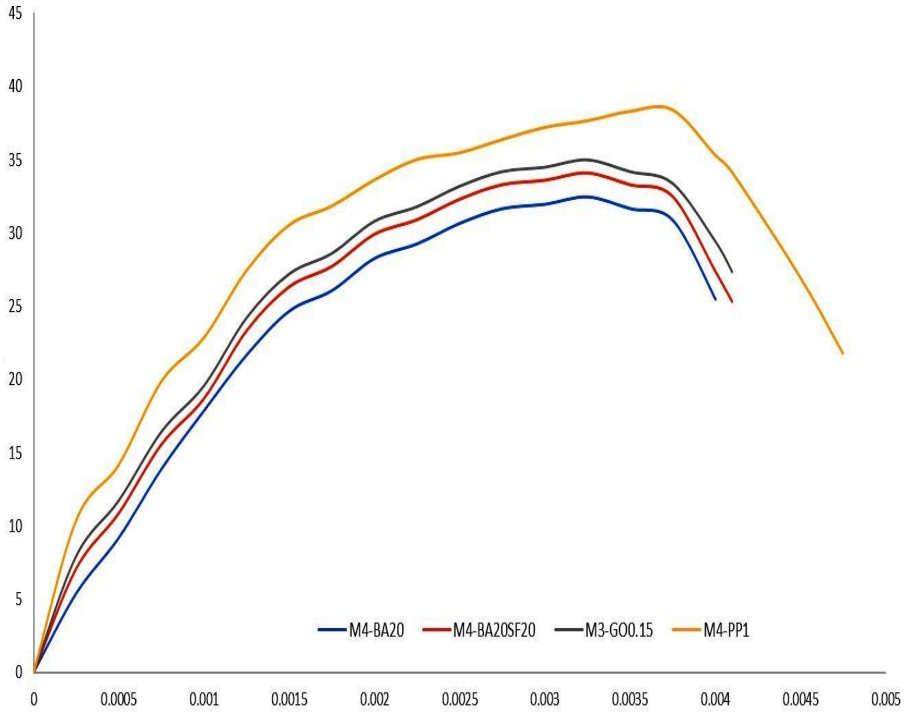
Table 4.1 Compressive Strength of Bottom Ash based High-Strength Mortar-CM 1:3

Mortar designation	BA	Compressive Strength (N/mm^2)		Strength improvement (%)	
	Replacement (%)	7-day	28-day	7 -day	28-day
M1-0	0	18.57	20.91	0	0
M2-10	10	18.79	21.33	1.18	1.76
M3-20	20	19.14	25.88	3.07	4.06
M4-30	30	18.71	25.17	0.75	1.09
M5-40	40	18.32	23.28	-1.35	-2.63

Table 4.2 Compressive Strength of Bottom Ash based High Strength Mortar - CM 1:2

Mortar designation	BA Replacement (%)	Compressive Strength (N/mm^2)		Improvement in strength (%)	
		7 day	28 day	7 day	28 day
M6-0	0	18.94	27.06	0	0
M7-10	10	19.18	25.05	1.27	1.82
M8-20	20	19.52	26.9	3.06	4.72
M9-30	30	18.99	25.99	0.26	0.63
M10-40	40	18.38	22.55	-2.96	-2.31

STRESS-STRAIN BEHAVIOUR IN COMPRESSION



CONCLUSIONS

Based on the experimental[1] investigation carried[1] out on the bottom ash[1] based high-strength mortar (BA-HSM) [1] with SF and GO and on FRHSM containing PP fibers, the following conclusions are drawn.

1. The rheological[1] characteristics of fresh [1]cement mortar are decreased with the increase of[1] bottom ash (BA) replacement in mortar[1] matrix.
2. Beyond 20 % BA replacement, porosity of BA in mortar increases which weakens the transition zone in the mortar.
3. The improvement[1] in compressive resistance of 3.5 % for high-strength mortar was obtained at 20 % bottom ash replacement compared[1] to control mortar mix which is due[1] to fineness of bottom ash filling effect and presence of small quantity of calcium oxide, beyond which there [1]is no improvement in strength.
4. [1]Bottom ash has a high potential to improve the performance of mortar matrix due to its lesser fineness[1] and particle size closer[1] to that of sand, [1]and can be used at 20 % [1]replacement of sand for making[1] good mortar.
5. Bottom ash replacement of[1] fine aggregate in [1]cement mortar has [1]marginally increased the [1]compressive and flexural [1]strengths up to 20% BA replacement[1] level.
6. Compressive strength of bottom ash based high strength mortars (CM 1:3 and CM 1:2) containing SF = 20%, was improved about 10 % and 14%, respectively, compared to control mortar mix.

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