A CASE STUDY ON EFFECT OF FOUNDRY SAND AND MINERAL ADMIXTURES ON MECHANICAL PROPERTIES OF CONCRETE

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Abstract - *Foundry sand waste can be utilized for the preparation of concrete as a partial replacement of sand. The strength properties of M25 grade concrete are studied with different percentages of replacement of fine aggregates by foundry sand at 0%, 10%, 20%, 30%, 40%, and 50%. The optimum percentage of foundry sand replacement in the concrete corresponding to maximum strength will be identified. Keeping this optimum percentage of foundry sand replacement as a constant, a cement replacement study with mineral admixtures such as silica fume (5%, 7.5%, 10%) and fly ash (10%, 15%, 20%,) is carried out separately. The maximum increase in strength properties as compared to conventional concrete was achieved at 40% foundry sand replacement. Test results indicated that a 40% replacement of foundry sand with silica fume showed better performance than that of fly ash. The maximum increase in strengths was observed in a mix consisting of 40% foundry sand and 10% silica fume. SEM analysis of the concrete specimens also reveals that a mix with 40% foundry sand and 10% silica fume obtained the highest strength properties compared to all other mixes due to the creation of more C-H-S gel formations and fewer pores.*

Key Words: Foundry sand, Fly ash, Silica fume, Strength properties, SEM analysis

1. INTRODUCTION

Fundamentally, concrete should be economical, strong, and durable. The construction industry recognizes that considerable improvements are essential in productivity, product performance, energy efficiency, and environmental performance. The industry will need to face and overcome a number of institutional competitive and technical challenges. One of the major challenges concerning environmental awareness and scarcity of space for land-filling is waste/by-product repurposing as an alternative to disposal. Consumption of all types of aggregates has been increasing in recent years in most countries at a rate far exceeding that suggested by the growth rate of their economy or construction industries. Artificially manufactured aggregates are more expensive to produce and the available source of natural aggregates may be located at a considerable distance from point of manufacture, in which case the cost of transport is also a disadvantage. The foundry industry produces a large amount of by- product materials during the casting process. Commonly, foundry sand is used for mould-making and consists of a mixture of silica sand (80–95%), bentonite clay (4–10%), a carbonaceous additive (2– 10%), and water (2–5%). Over 70% of the total by-product material is sand, as moulds usually consist of moulding sand, which is easily available, inexpensive, resistant to heat damage, and easily bonded with a binder and other organic materials in the mould. The foundry industry uses high-quality specific size silica sand for their moulding and casting process. Foundries successfully recycle and reuse the sand multiple times, and when it can no longer be reused in the foundry, it is removed from the manufacturing process and is then termed 'foundry sand' (**FS**). It is also known as spent foundry sand (**SFS**) and waste foundry sand (**WFS)**.

2. EXPERIMENTAL STUDY

Ordinary 53 grade Portland cement (Zuari brand) confirming to IS 12269 -1987 norms was used; its properties are given in Table 1. The properties of the fly ash (FS) and silica fume (SF) are given in Table 2. Locally available river sand was used as a fine aggregate. Foundry sand was used as a fine aggregate replacement in this study. Physical properties of the fine aggregate, foundry sand, and coarse aggregate are given in Table 3.

Table 1. Properties of Cement

Characteristics	Values obtained	Standard value per IS code 12269 - 1987
Initialsetting time	42 min	No less than 30 min
Final setting time	310 min	No greater than 600 min

Fineness (%)	4.9	<10
Specific gravity	3.12	-
Compressive strength	56 N/mm^2	No less than 53 N/mm^2

Table 2. Properties of Silica Fume and Fly Ash

Characteristics	Fly ash	Silica Fume
Colour	Grey	White
Specific gravity	2.3	2.1
Size (µm)	5.9	<1
Bulk density (kg/m^3)	994	130-430
Surface area (m^2/kg)	8900	20000

Table 3. Properties of Aggregates

Characteristics	Specific gravity	Fineness modulus	Bulk density (kg/m^3)
Fine Aggregate	2.57	2.64	1753
Foundry Sand	2.2	1.89	2589
Coarse Aggregate (10 mm)	2.704	6.45	1670
Coarse Aggregate (20mm)	2.825	7.68	1630

2.1 PREPARATION AND CASTING OF SPECIMENS

Various concrete specimens - cubes (150mm X 150mm X 150mm) to determine compressive strength, cylinders (150mm in diameter and 300mm in length) to determine split tensile strength, and beams (10mm X 10mm X 50mm) to determine flexural strength - were cast. All specimens were prepared in accordance with Indian Standard Specifications IS 516-1959. Care was taken that no gaps were left in areas where any possibility of slurry leakage could occur. Vibrations were stopped as soon as cement slurry appeared on the top surface of the mould. For each mix, 3 cubes, 3 beams, and 3 cylinders were cast and tested for their respective strengths. The average of 3 measurements for each sample is considered as the final value for their respective strengths.

2.2 EXPERIMENTAL PROCEDURE

An experimental investigation was carried out with reference to a concrete mix of M25 grade concrete. Twelve mixes were prepared. A reference mix (RC) was prepared for M25 grade of concrete per IS: 10262-2009. Five concrete mixes (RC, FS10, FS20, FS30, FS40, FS50) were prepared where the fine aggregate was replaced with 10%, 20%, 30%, 40%, and 50% foundry sand by mass, respectively. It was observed that concrete with 40% FS replacement attains maximum strength properties. Hence, the 40% FS replacement was kept constant, and a cement replacement study was carried out separately; mineral admixtures such as fly ash at 10%, 15%, 20% (FA10+FS40, FA15+FS40, FA20+FS40) and silica fume at 5%, 7.5%, 10% (SF5+FS40+SF7.5+FS40,SF10+FS40) were added in. A number of trial mixes were prepared for the available materials such as cement, coarse aggregate, and fine aggregate, starting with a water-cement ratio of 0.5. Finally, we arrived at the target strength of M25 grade mix at a water-cement ratio of 0.47. Hence, a water-cement ratio of 0.47 was used throughout the study. Component proportions of all mixes are shown in Table 4.

3. RESULTS AND DISCUSSIONS

3.1 FRESH CONCRETE PROPERTIES

Table 4. Different Mixes Cast

Mix No.	RC	FS10	FS20	FS30	FS40	FS50	FA10+ FS40	FA15+ FS40	FA20+ FS40	SF5+ FS40	SF7.5+ FS40	SF10+ FS40
Cement (kg/m^3)	419.14	419.14	419.14	419.14	419.14	419.14	377.23	356.27	335.32	398.19	387.79	377.23
Sand (kg)	643.12	578.81	514.5	450.18	385.87	321.56	385.87	385.87	385.87	385.87	385.87	385.87
Foundry sand (%)	0	10	20	30	40	50	40	40	40	40	40	40
Foundry sand(kg)	0	64.31	128.62	192.93	257.25	321.56	257.25	257.25	257.25	257.25	257.25	257.25
C.A 20mm (kg)	806.28	806.28	806.28	806.28	806.28	806.28	806.28	806.28	806.28	806.28	806.28	806.28
C.A 10mm (kg)	230.37	230.37	230.37	230.37	230.37	230.37	230.37	230.37	230.37	230.37	230.37	230.37
Water (kg/m^3)	197	197	197	197	197	197	197	197	197	197	197	197
Water/cement	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Fly ash (%)	0	0	0	0	0	0	10	15	20	0	0	0
Fly ash (kg)	0	0	0	0	0	0	41.91	62.87	83.82	0	0	0
Silica fume (%)	0	0	0	0	0	0	0	0	0	5	7.5	10
Silica fume (kg)	0	0	0	0	0	0	0	0	0	20.95	31.35	41.91
Compaction factor	0.959	0.942	0.931	0.914	0.87	0.83	0.951	0.948	0.942	0.961	0.958	0.952

3.2 COMPRESSIVE STRENGTH OF CONCRETE PROPERTIES

Table 5. Strength Properties of Concrete

Mix No.	Compressi ve strength in N/mm^2	% Improvement in compressive strength	Split tensile strength in N/mm^2	% Improvement of split tensile strength	Flexural strength in N/mm^2	% Improvement of split tensile strength
RC	33.03	----	2.75	-----	2.57	----
FS10	34.98	5.9	2.83	2.9	2.67	3.9
FS20	36.60	10.8	2.98	8.4	2.90	12.8
FS30	37.88	14.7	3.12	13.5	3.20	24.5
FS40	38.70	17.1	3.40	23.6	3.34	30
FS50	36.13	9.4	3.12	13.5	3.01	17.1
FA10+FS40	35.11	5.2	3.04	10.6	2.90	12.8
FA15+FS40	33.85	1.4	2.97	8.0	2.87	11.7
FA20+FS40	31.29	-6.2	2.91	5.8	2.71	5.4
SF5+FS40	39.82	19.3	3.61	31.3	3.42	33.1
SF7.5+FS40	40.71	22	3.67	33.5	3.47	35.0
SF 10+FS40	42.96	28.7	3.74	36.0	3.52	37

3.3 SPLIT TENSILE STRENGTH OF CONCRETE

The split tensile strengths of the reference mix (RC) and all the other mixes prepared using foundry sand, fly ash, and silica fume are shown in Table 5. It was observed that an increase in split tensile strength was observed gradually up to 40% fine aggregate replacement, and then the strength values decreased. A maximum split tensile strength of 3.40 N/mm^2 was obtained at 40% foundry sand replacement. The maximum split tensile strength obtained with the FS40 mix (40% foundry sand) was 23.6% more than the reference mix. Variations of the split tensile strengths are shown in Figure 3. The split tensile strengths were studied with a combination of 40% foundry sand and 10%, 15%, and 20% fly ash replaced with cement. The mix with 40% foundry sand and 10% fly ash obtained the maximum strength value among all fly ash replacements. It was observed that as the fly ash percentage in concrete increased, its split tensile strength decreased. A mix with 40% foundry sand and 10% fly ash (FA10+FS40) obtained a split tensile strength 3.04N/mm^2, which was 10.5% more than the reference mix (RC), but it was a lower strength value than that of the mix with 40% foundry sand alone (FS40). The split tensile strength of M25 grade concrete was studied with a combination of 40% foundry sand and 5%, 7.5%, 10% silica fume replaced with cement. The mix with 40% foundry sand and 10% silica fume obtained the maximum strength value among all silica fume replacements. It was observed that as the silica fume percentage in concrete increased, its split tensile strength increased as well. The mix with 40% FS replacement and 10% silica fume (SF10+FS40) replacement obtained a split tensile strength of 3.74N/mm^2, which was 36% more than the reference mix. Variations of the split tensile strengths of concrete with 40% foundry sand and different percentages of fly ash and silica fume are as shown in Figure 4.

3.3 SEM ANALYSIS

To study the effects of foundry sand replacement along with mineral admixtures like fly ash and silica fume on concrete specimens, SEM analysis was conducted to identify the changes in the microstructures of the concrete. Specimens were examined at 2 μm and 3 μm microstructural images. Figures 7 and 8 represent SEM images of the specimen produced with the reference mix (RC) and a mix with 40% foundry sand replacement (FS40). Figure 7 represents a 3 μm micrograph of the reference mix specimen which depicts the formation of a uniform the C-S-H gel and evenly distributed pores of longer sizes. Figure 8 represents a 2 μm micrograph of the concrete sample prepared with 40% foundry sand (FS40) which shows a uniform distribution of the C-S-H gel with a lower number of pores of smaller size. In Figures 8 and 9 SEM images of the sample cast with 40% foundry sand and 10% fly ash (FA10+FS40) and 40% foundry sand with 10% silica fume (SF10+FS40) can be seen.

Figure 9 indicates a 3 μm micrograph of the concrete sample with 40% foundry sand and 10% fly ash in cement (FA10+FS40) showing the number of C-H-S gel with large small pores resulting in increased strength as compared to the other mixes.

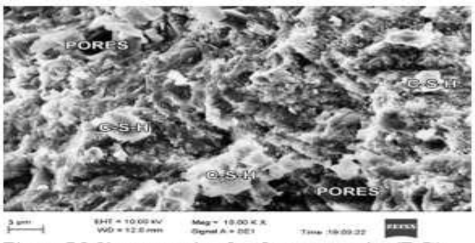

Figure 7 Micrograph of reference mix (RC)

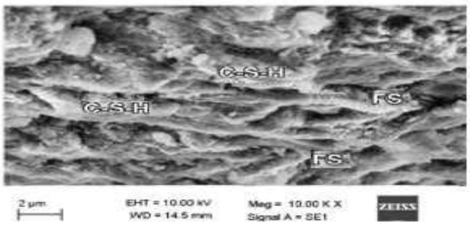

Figure 8 Micrograph of replacement of 40% Foundry sand (FS40)

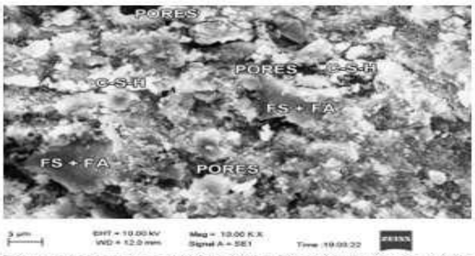

Figure 9 Micrograph of replacement of 40% FS with 10% FA

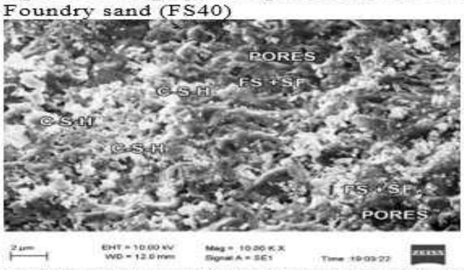

Figure 10 Micrograph of replacement of 40% FS with 10% SF

Figure 10 indicates a 2 μm micrograph of the concrete sample made with 40% foundry sand with 10% silica fume (SF10+FS40) depicting a densely formed C-H-S gel with a lower number of small pores leading to maximum strength among all mixes evaluated in the present study.

4. CONCLUSIONS

Based on the above research, the following observations are made regarding the strength properties of concrete with partial replacement of fine aggregate by foundry sand and of cement by mineral admixtures such as fly ash and silica fume:

- As the percentage of foundry sand increased, its workability decreased. As the percentage of foundry sand increased, strength properties like compressive strength, split tensile strength, and flexural strength all increased up to the 40% replacement ratio, and then decreased.

- Keeping 40% as the optimum percentage of FS replacement in further experiments, mineral admixtures like fly ash (10%, 15%, 20%) and silica fume (5%, 7.5%, 10%) were tested. The concrete mix with 40% foundry sand and 10% silica fume obtained the highest strength properties compared to all other mixes. The concrete mix with 40% foundry sand and 10% fly ash obtained higher strength properties than the reference mix. Based on experimental results it is observed that there is more improvement in the strength properties of concrete when incorporating foundry sand and silica fume than when using a combination of foundry sand and fly ash.

SEM analysis of the concrete samples reveals that the concrete sample with 40% foundry sand replacement and 10 % silica fume replacement obtained the highest strength properties due to the densely formed C-S-H gels and a meagre number of smaller pores.

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