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MICROBIOLOGICAL APPORACH OF SOLID WASTE MANAGEMENT IN FOUNDRY WASTE SAND

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Abstract—**Waste foundry sands represent highest amount of solid wastes generated by foundries. The high cost of land - filling and the potential uses of waste foundry sand in construction purposes have prompted research into their beneficial reuse. For high - performance construction materials microbial (bacteria/fungi) modified concrete has become an important area of research. This study investigates the potential re-use of waste foundry sand (WFS) and reclaimed WFS in high strength concrete production. The natural fine sand replaced with waste foundry sand(5%, 15%, 25%, 35%, 50%).The findings from a series of test program has shown in compressive strength, tensile strength water absorption and porosity of concrete containing waste foundry sand.**

***Keywords*— concrete, waste foundry sand, compressive strength, concrete behaviour.**

1. INTRODUCTION

Concrete is the most widely used construction material in the construction industry, and offers a number of advantages, including good mechanical and durability properties, low cost, and high rigidity. Over the past several decades, the demand for concrete has been increasing rapidly due to growth in infrastructure development. River sand is one of the main ingredients in concrete production, and it is used as a fine aggregate. The heavy demand for concrete has resulted in the over-exploitation of river sand in the river bed, and this has led to a range of harmful consequences, including increased river bed depth, water table lowering and the intrusion of salinity into rivers. The restriction in the extraction of sand from the river increases the price of sand and has severely affected the stability of the construction industry [1]. As such, finding an alternative material to river sand has become imperative. Over the past several decades, an enormous amount of research [1–10] has been carried on the use of industrial waste as a substitute/replacement material for fine aggregate. The research findings revealed that the substitution of an alternative material in concrete could improve both the mechanical and durability properties, and the practice led to the sustainable concrete development. Foundry sand (FS) is a by-product from the metal alloys casting industry with high silica content. Silica sand is bonded with clay or chemicals, and is used for the material casting process. Foundries recycle the sand many times, and when the sand is no longer recyclable, it is disposed of; this is called foundry sand [11]. About 15% of sand used by foundries is ultimately disposed of, amounting to millions of tons. In India, many foundries dump this waste in nearby vacant areas (Fig. 1), which creates an environmental problem. With increased restrictions on disposal in nearby areas, industries are constrained to find alternative ways to reuse waste. Past few decades, FS have been utilized in highway applications [11–13], but the amount of waste re-utilized in this way is still negligible. For this reason, there is a need to utilize FS in other ways become very imperative. Recently, research has been carried out on the utilization of FS in concrete and concrete related products. Siddique et al. [11] evaluated the mechanical properties of concrete containing FS. Fine aggregate was replaced by foundry sand in three different percentages (10%, 20%, and 30%). A marginal increase in the strength properties was observed with the substitution of FS and it was suggested that FS, can be effectively used in concrete making. The findings of Bakis et al. [14] showed that fine aggregate replaced with 10% of FS was suitable for asphalt concrete mixtures. Kraus et al. [15] conducted an investigation to evaluate the feasibility of the use of FS in self consolidating concrete (SCC). It was concluded that it is viable to produce economical SCC by using FS in addition, and further research is needed to determine the optimum FS proportion. Siddique et al. [16] made an attempt to study the mechanical, durability and micro-structural properties of concrete made with FS. The results showed that concrete mixtures with foundry sand showed good resistance to carbonation and rapid chloride penetration. The mechanical properties of the concrete improved with the substitution of FS, and it was recommended that FS be used in concrete production without affecting the mechanical and durability properties. In another study, Singh and Siddique [17] studied the abrasion resistance and strength properties of concrete containing waste foundry sand (WFS). The feasibility of the re-use of FS in ready-mixed concrete (RMC) production was examined by Basar and Nuran Deveci Aksoy [18]. The test results indicated that partial replacement of FS decreased the strength of the concrete and increased the water demand of the concrete mixture. While a great deal of research has been carried out on the re-use of FS in civil engineering applications, there has been limited research on the use of FS in concrete production, and more research is needed to determine the optimum replacement of FS in concrete production. In addition, environmental pollution created by dumping of FS, in the surrounding of Coimbatore, in Tamilnadu, India should be minimized. In order to resolve the both issues, experimental investigation was carried out on the re-utilization of FS obtained from an aluminium casting industry, Coimbatore, in Tamilnadu, India, as a replacement for fine aggregate in concrete production, at different substitution rates. Based on the test results obtained, the optimum proportion of FS in concrete production was established. Furthermore, the obtained test results were verified using the expressions recommended in design standards.

2. EXPERIMENTAL PROGRAM

2.1. Materials

Portland pozzolana cement which conformed to BIS: 1489-Part-1 [6] was used. Properties of the cement are given in Table 1.The natural river sand passing through 4.75 mm was used as fine aggregate. Locally available blue metal jelly having a size of 20 mm was used as coarse aggregate. Blue metal jelly is the blue-gray hard stone, bluish in color, which is widely used as a coarse aggregate in concrete production in South India. The specific gravity [20] of the sand and the coarse aggregate was about 2.48 and 2.67. Sieve analysis was carried out on both fine and coarse aggregate, according to IS 2386(1):1963 [21]. Foundry sand (FS) obtained from an aluminium casting industry, Coimbatore, in Tamilnadu, India was used in this study. The physical and chemical properties of the FS were tested according to Indian standards. The specific gravity and density [20] of the FS were about 2.24 and 1576 kg/m3, respectively. The water absorption [22] of the FS was about 1.13%, which is higher than that of normal sand due to the presence of ashes and wood particles. Sieve analysis was carried out to understand the grain size distribution of the FS and it was observed that 8% of FS were less than 75 lm, which shows that the FS is fine material. The sieve analysis results of FS and river sand is presented in Table 1. The chemical properties of the FS were tested according to IS 4032:1985 [23], and the results showed that FS contains about 87.48% silica (SiO_2) and 4.93% alumina (Al_2O_3). The results of a chemical analysis indicated that the FS is a very suitable material for concrete production.

2.2. Concrete

According to IS 10262 [24], the concrete mix proportions were designed to achieve the strength of M_{20}. The concrete mix proportion was 1:1.5:3. A constant water cement ratio (W/C) was followed for all mixtures and the value was about 0.44. Among the six mixtures, five mixtures were prepared by replacing 5%, 15%, 25%, 35% and 50% of natural sand with FS, and the one remaining mixture was a control mixture (CM) without FS. The detailed formulations of the proportions of six mixtures are given in Table 2.

Table 1
Physical properties of Portland pozzolana cement.

Properties	Results	Requirement BIS: 1489(part 1):1991
Fineness (retained on 90 lm sieve)	5.3	10 max
Fineness: specific surface (air permeability test) (m2/kg)	310	225 min
Normal consistency	35%	–
Vicat time of setting(min)		
Initial	92	30 min
Final	248	600 max
Compressive strength (MPa)		
3 days, 7 days, 28 days	18.0, 36.0, 47.8	16.0 min, 22.0 min, 33.0 min
Specific gravity	3.07	–

Table 2
Sieve analysis of river sand foundry sand aggregates.

Foundry sand(FS)		Natural sand	
Sieve size	% of Passing	Sieve size	% of Passing
4.75 mm	100	4.75 mm	100
2.36 mm	100	2.36 mm	91.42
1.18 mm	94.12	1.18 mm	52.64
600 µm	83.63	600 µm	24.18
300 µm	36.24	300 µm	9.84
150 µm	16.12	150 µm	6.18
75 µm	11.86	75 µm	3.24

Table 1: Mix Proportion (M20)

Unit of Batch	Water (Liters)	Cement (Kg)	F.A (Kg)	C.A (Kg)
Cubic meter content	44.1	88.2	132.54	265.08
Ratio of ingredients	0.5	1	1.50	3.0

Table 2: Mix Proportions of Concrete (WFS)

WFS type	**Untreated WFS**				
WFS%	5	15	25	35	50
Cement (kg/m^3)	44.1	44.1	44.1	44.1	44.1
Fine Aggregate (kg/m^3)	12.59	11.26	9.94	8.61	6.63
Coarse Aggregate (kg/m^3)	132.54	132.54	132.5	132.54	132.54
Water (kg/m^3)	22.05	22.05	22.05	22.05	22.05
WFS(kg/m^3)	0.66	1.98	3.32	4.64	6.63

Table 3: Mix Proportions of Concrete (reclaimed WFS)

WFS type	Reclaimed WFS				
WFS%	5	15	25	35	50
Cement (kg/m^3)	44.1	44.1	44.1	44.1	44.1
Fine Aggregate (kg/m^3)	12.59	11.26	9.94	8.61	6.63
Coarse Aggregate (kg/m^3)	132.54	132.54	132.5	132.54	132.54
Water (kg/m^3)	22.05	22.05	22.05	22.05	22.05
reclaimed WFS(kg/m^3)	0.66	1.98	3.32	4.64	6.63

Laboratory studies

Isolation of fungus for biosolubilization of waste foundry soil

Sample processing and serial dilution

About 1g of each sand sample (North, South, East and West) was added into 100ml of distilled water and serially diluted. A series of tubes containing 4.5ml of sterile distilled water was taken. About 0.5ml of the sample was serially diluted using sterile pipettes and the serially diluted samples were inoculated on the surface of Potato dextrose agar by using spread plate method. The plates were kept for 7 days incubation at 28˚C. Fungal cultures were selected based on their morphology and subcultured and stored for further studies.

Screening of fungi on to selective media for organic acid production

The screening method given by Abin *et al.* (2002) was used for the estimation of acid activity. The acidity was estimated on a medium containing

Bromocresol purple. Isolated fungal cultures were inoculated to the broth having following composition in g/L:

Glucose – 20

Peptone – 1

Yeast Extract – 5

$CaCO_3$ - 5g

Bromocresol purple - 0.030

pH - 6.0

Test tubes were then incubated at 28^0C for 5-6 days. After 6 days the test tubes were observed for the appearance of yellow colour as a result of acid production.

Screening for fungi on to selective media for calcium oxalate production

Fungal culture was inoculated in flask containing potato dextrose broth (PDB) along with urea-$Cacl_2$ and incubated for 20 days at 28°C. After 20 days the fungal mycelium was extracted from the broth and washed twice with sterilized distilled water. The fungal mycelium was crushed to form powder and was analyzed by using X- ray diffraction (XRD) technique for identification of phase of mineral formed.

2.3. Specimen preparation

The concrete mixtures were prepared with and without FS substitution. The FS substitution rate ranged between 5% and 50%, in increments of 10%. The FS used in this study was washed by fresh water more than four times to remove ash and clay particles. The FS was then dried in sunlight for two days and then used in concrete mixtures. For all mixtures, aggregates such as cement, natural sand, coarse aggregate and FS were weighed in a dry condition and were then mixed together in a laboratory batch mixer, in order to avoid aggregate and water loss. Fresh concrete properties such as workability of the concrete were measured using the slump cone test. In addition, the unit weight of the concrete was also examined. To determine the compressive strength and tensile strength of the concrete, cubes and cylinders having a size of 150 x 150 x 150 mm was prepared. All specimens such as cubes were filled with concrete in three layers, and each layer of the concrete was effectively compacted using a table vibrator. After casting of all specimens, the specimens were covered with a plastic sheet in order to avoid moisture loss. After that, specimenswere kept at room temperature for 24 h, and thereafter were demoulded and transferred to the curing tank until their testing dates. After the required curing days, the cubes were tested in a compression testing machine (CTM) having a capacity of 2000 kN at the ages of 7, 28 days. All specimens were tested according to the Indian standards [25]. To simplify the discussion of the mixtures, names were given to the mixtures, such as CM, FS 5%, FS 15%, FS 25%, FS 35% and FS 50%. For example, the name FS 20% indicated that the concrete mixture contained 20% of foundry sand.

Fig. 1. Foundry industry dumping solid waste along Madurai to Coimbatore highway in Tamilnadu, India.

3. RESULT AND DISCUSSION

3.1. Workability

The slump cone test was used to measure the workability of the concrete with the time ranging from 0 min, 30 min and 60 min. The influence of the FS on the workability is presented in Fig. 2. From Fig. 2, it can be understood that the substitution of FS in concrete decreases the workability of the concrete; furthermore, an increase in the substitution rate affects the workability of the concrete further. However, the effect of FS on workability is not significant with the substitution rate up to 5%, and the slump value of the mixtures was relatively equal to the CM.

However, beyond the 5% substitution rate a loss in the workability of the concrete was observed. We know that the workability of concrete is directly proportional to the fineness of the material used in concrete. Compared to natural sand, FS has 8% of particles less than 75 µm. The fineness of the FS increases the water demand of the concrete by water absorption, which has the result of decreasing the workability of the concrete. The other possible factor is the high water absorption properties of the FS due the presence of ash and clay particles. The workability of all mixtures was decreased by elapsed time. Normally, slump loss occurs when the water from the concrete is removed by the hydration process. However, a significant loss in slump was observed for the mixtures having more FS when compared to the CM. This is a result of the fact that the higher fineness of the FS increases the surface of hydration products, leading to more water absorption. From this observation, it was concluded that the modification of water content should be applied to the mixtures based on the fineness of the substitution material.

3.2. Compressive strength

The compressive strength of all mixtures at the ages of 7, 28, days are given in Table 3 and are presented in Fig. 3. The aim of this investigation is to reuse the FS in concrete production without affecting the limitations described in the concrete standards. The test results revealed that FS can be effectively used as a substitute material for fine aggregate in concrete production. Even though no marginal improvement in strength was observed, the compressive strength of the concrete mixtures containing FS up to 15% was relatively close to the strength of the CM. Compared to mixtures FS 15% and FS 25%, the mixtures CM showed a increased compressive strength of only 1.6% and 5.7%, respectively, at the age of 28 days, which is not significantly different from the strength value of CM. However, mixtures FS 35% and FS 50% showed lower strength when compared to the CM, and the mixtures showed a decrease in compressive strength of 11.04% and 23.95% compared to CM at the age of 28 days. In all ages (28 days) the increase in the substitution rate of FS decreases the strength of the concrete, and the effect was significant, at a substitution rate beyond 15%. It was expected that the presence of more silica in the FS would increase the hydration process and significantly increase the formation of C_3S. Nevertheless, the fineness of the FS decreases the workability of the concrete, and decreases the compressive strength of the concrete as a result. The fineness of the FS creates water demand in the concrete, causing poor workability, and this water demand is directly proportional to the FS substitution rate. The relation between the compressive strength 28 days and the workability of concrete observed at immediate mixing of concrete is presented in Fig. 4 using linear regression analysis. From the correlation (Fig. 4) it can be understood that the compressive strength of the concrete is mainly depends the workability of concrete. The poor workability of the concrete decreases the compaction of the concrete and increases the porosity of the concrete. The increase in porosity decreases the density of the concrete (see Fig. 5) and leads to a reduction in compressive strength [5]. The other possible factor is the presence of clay, sawdust and wood flour. In general, the density of the concrete is related to the physical properties of the materials used in concrete. Many foundries still are using clay, sawdust and wood flour as a binding material to form the moulds. The presence of those particles reduces the specific density of the material, and also decreases the density of the concrete by creating air voids in the concrete. The relation between the compressive strength and hardened density of the concrete for all ages is shown in Fig. 6. From Fig. 6, it can be understood that the substitution of FS decreases the density of the concrete, and also that the decrease in the strength of the concrete is directly proportional to the density of the concrete. ACI 209 (ASTM Type 1) [26], recommended the following equation to evaluate the compressive strength of concrete with time.

$$f_{cm}(t) = f_{c28}\,(t/(4+0.85t))$$

where, fcm(t) is the mean compressive strength at the age of t days, f_{c28} is mean compressive strength at 28 days and t is the age of the concrete in days. The calculated compressive strength values of the concrete are listed in Table 3. The relation between the measured and computed compressive strength is shown in Fig. 7. The linear regression line was used to represent the relationship. Fig. 7 clearly shows that the measured compressive strength of the concrete, fairly agreed with the computed strength, and that the correlation between the measured and computed strength was quite strong (R^2 = 0.9735).

Table 3
Measured compressive strength

Mixtures designation	Measured compressive strength	
	7 days	28 days
CM	21.54	33.14
FS 5%	21.16	33.24
FS 15%	21.17	32.58
FS 25%	20.30	31.24
FS 35%	19.41	29.48
FS 50%	16.38	25.23

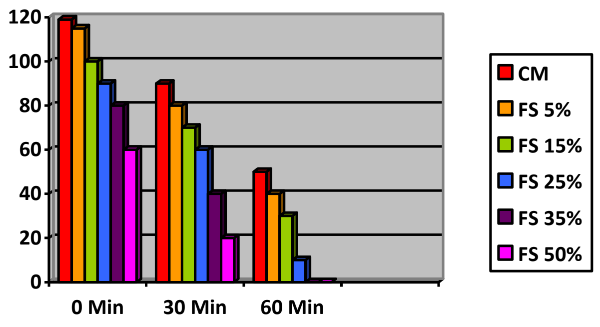

Fig.2 Workability of all mixtures – comparison.

X – Axis: Duration
Y – Axis: slump loss (mm**)**

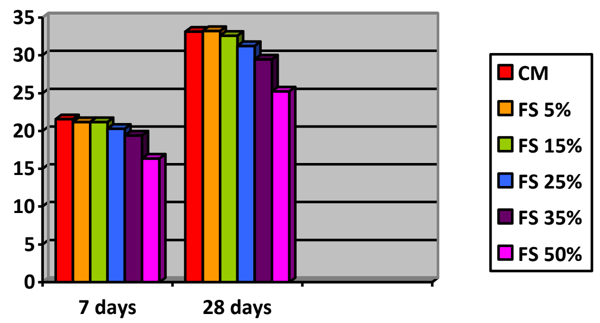

Fig. 3. Compressive strength of all mixtures at various ages – comparison.

X – Axis: Curing (Days)
Y – Axis: Compressive Strength (N/mm^2)

4. CONCLUSION

Based on the test carried out on the five mixtures the following Conclusion has been made:

- The fineness and high water absorption properties of the FS Reduce the workability of the concrete, and the workability of The concrete also decreases with an increase in the FS substitution Rate.
- In all ages of concrete, the strength properties of the concrete Mixtures containing FS up to 25% was relatively close to the Strength value of the CM.
- The concrete mixtures FS 25% and FS 35% showed a decrease in Compressive strength of only 1.6% and 5.7%, respectively, at the Age of 28 days when compared to the CM. Beyond the substitution rate of 25% the concrete mixtures Showed inferior behavior when compared to the CM due to fineness
- Of FS and the presence of clay, sawdust and wood flour in The FS.
- From the results obtained it is suggested that FS with a substitution Rate up to 20% can be used effectively as a fine aggregate In good concrete production without affecting the concrete Standards.

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