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ORIGINAL RESEARCH PAPER

Properties of self-compacting concrete modified with m-sand and spent foundry slag

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ABSTRACT

Due to significant industrialization, many countries have adopted the practice of industrial symbiosis, which involves utilizing the waste produced by one industry as a resource for another industry. The utilization of spent foundry sand (SFS), which is derived from the metal casting industry, poses a significant risk to both the environment and living organisms as a result of the existence of inorganic and organic substances. Nevertheless, this waste material can serve as a valuable resource for the construction sector. The utilization of SFS is significantly restricted due to insufficient comprehension of its concrete performance, despite its extensive range of applications. It is imperative to comprehend the behavior of spent foundry sand in concrete, particularly in relation to achieving a structure that is both strength-efficient and durable. The current study explores the usability of M-sand and spent foundry sand in self-compacting concrete. Reference concrete was produced by replacing river sand with 100% M-sand. M-sand was substituted with spent foundry sand in ratios ranging from 0 to 30%. Compared to the reference mix, SCC's mechanical and durability properties with 20% SFS were better. In comparison to the reference mix, SCC containing 20% SFS had higher mechanical and durability characteristics at 3, 7, 28 days, and 28 days, respectively. With 20% SFS, replacement showed better mechanical properties at all curing ages and better durability performance at 28 days of the curing period.

KEYWORDS

spent foundry slag, M-sand, sustainable concrete, sorptivity test

1. INTRODUCTION

The phenomenon of economic globalization can be attributed to the substantial expansion of industrialization, which has concurrently led to a notable surge in the requirement for raw materials. Despite the considerable efforts of researchers and scientists involved in the development of sustainable science strategies, there is still a significant distance to cover towards achieving a more equitable and harmonious world with nature. The notion of sustainability was first introduced in 1987 by the Brundtland Commission, which proposed a strategy to meet the needs of a burgeoning population while preserving resources for future generations. The concept of industrial symbiosis is a recent development that has gained widespread acceptance in many countries. It is believed that this approach can help achieve sustainability goals without compromising economic growth. The proposed approach emphasizes the collaborative utilization of resources among multiple industries. Specifically, the waste generated during the production process of one industry is repurposed as a resource for another industry.

Concrete is the most widely utilized man-made material for building on the planet. Vibrating equipments are normally required to remove the entrapped air in concrete to make it dense and homogeneous. Skilled workers do adequate compaction of concrete, making concrete structures more durable. In the beginning of 1983, Japan's construction companies faced the problem of shortage of skilled workers which in turn lead to the reduction of quality of construction work [1]. This paved the way for the development of SCC. It is a type of

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concrete that can move under its own weight without the need for mechanical vibration. Therefore, SCC is a cohesive concrete that can fill every corner of a congested reinforcement region by flowing under its own weight without any mechanical vibration [2].

When it comes to SCC, the aggregates are responsible for sixty to seventy percent of the entire volume. Fine aggregate used in SCC for centuries is natural sand [3]. On the other hand, due to depletion and increased demand for natural sand, restrictions are being imposed on exploitation of natural sand, making researchers find alternative materials to natural sand [4]. This led to the production of M-sand and SFS as a replacement for natural sand in concrete [5].

Manufactured sand is produced by crushing of stones, screening and washing of sand. Compared to naturally weathered sand, manufactured sand consists of more sharp-cornered and rough surface texture. However, it is possible to produce cubical shape particles with uniform grading by using appropriate crushing technology. Since M-sand contains high fines it increases water demand compared to river sand. On the other hand, these fines present in M-sand contribute to high paste volume, which is essential for any SCC mix [6, 7].

In the United States over 3,000 foundries generate 6 to 10 million tons of SFS per year. Only 10 percent of the 6 to 10 million spent foundry sand is reused. The 'spent foundry sand' from the non-ferrous foundries is generally not reused. In India out of 1.71 million tons of industrial waste, 0.18 million tons of waste are generated from foundry industries per year. Foundry sand is used in engineering usages namely portland cement concrete, embankments, hot mix asphalt and flowable fill. Foundry sand is also used extensively in agriculture as topsoil. Blending spent foundry sand with fine or coarse aggregates can be used as a sub-base or road-base material [8, 9].

Although extensive studies have been accompanied on the mechanical characteristics of regular concrete, very few studies on SCC containing M-sand and spent foundry sand are now available. The current research studied the effect of spent foundry sand and M-sand on workability and strength characteristics. In addition, the quality of spent foundry sand and M-sand incorporated SCC was checked for the transport properties such as sorptivity and water absorption.

2. MATERIALS

OPC of 53 grade conforming to BIS: 12269-1987 [10] with specific gravity, consistency, initial and final setting time of 3.13, 32%, 110 and 280 min, respectively, is used in this research. Fly ash is obtained from a local thermal power plant (i.e., RTPP, YSR district) conforming to IS:3812-2003 [11]. River sand is used as a fine aggregate with specific gravity, bulk density, fineness modulus and maximum size of 2.6, 1810 kg m^{-3}, 3.15 and 4.75 mm, respectively. Coarse aggregate having an angular shape with bulk density, fineness modulus, maximum size and specific gravity of 1940 kg m^{-3}, 6.5, 2.6 and 10 mm, respectively, is used [12]. Manufactured sand is purchased from local industry in Hyderabad and is utilized as a fine aggregate conforming to IS:2386-1963 [13]. Spent foundry sand acquired from local industry in Hyderabad is utilized as a fine aggregate conforming to IS:1918-1966 [14]. GLENIUM (i.e., brand name-BASF) is utilized as a superplasticizer (i.e., polycarboxylate ether).

3. SCC MIX DESIGN

The primary goal of this research is to examine the fresh and strength properties of M-sand concrete without and with spent foundry sand. The mix proportions were determined by testing numerous mixes developed according to IS10262-2009 [15] recommendations for grades M30 with a water-to-cement ratio of 0.45, as shown in Table 1. In all SCC mixes, the quantities of fly ash and alccofine were kept constant at 30% and 20% by weight of whole powder content, respectively. SCC1 mix was prepared by replacing 100% of fine aggregate with manufactured sand without any addition of spent foundry sand. Further mixes SCC2 to SCC4, manufactured sand was replaced with SFS in proportions of 10%, 20% and 30%, respectively. Further mixes SCC2 to SCC4 were prepared by keeping fly ash and alccofine as 30% and 20% of cement as in SCC0 and SCC1 with varying quantities of spent foundry sand (i.e., 10%, 20% and 30%) by weight of manufactured sand. In all mixes, the W/B ratio is kept at 0.45.

4. METHODS

4.1. Fresh properties

Workability characteristics were assessed using European guidelines. Filling ability was assessed using slump flow and U-box, L-box and V-funnel tests were used to determine passing abilities.

Table 1. SCC mix proportions per cubic meter of concrete

Mixes	Cement	Fly ash	Alccofine	Fine aggregate	M-sand	Spent foundry sand	Gravel
SCC0	374.25	124.75	49.9	863.36	0	0	721.60
SCC1	374.25	124.75	49.9	0	863.36	0	721.60
SCC2	374.25	124.75	49.9	0	777.02	86.34	721.60
SCC3	374.25	124.75	49.9	0	690.68	172.68	721.60
SCC4	374.25	124.75	49.9	0	604.34	259.02	721.60

4.2. Hardened properties

The compressive strength was examined using cube specimen of 150 mm [16]. Splitting tensile strength was measured using cylinders (150 × 300 mm) [17]. The flexural strength was measured using prism specimens with measurements of 500 × 100 × 100 mm [18].

4.3. Durability property

The sorptivity of a specimen is calculated at age 28 days based on ASTM C1585-13 [19]. The rate of water penetration into the pores of the concrete by capillary suction is measured by sorptivity. The specimens having a size of 50 mm thick slice of 100 mm diameter cylinders, painted on all sides except at the bottom surface. All the other sides are protected with a rubber membrane. The concrete slice is placed in a pan and exposed to liquid on the bottom surface, as shown in Fig. 3. The liquid level is kept constant at 5 mm. At the regular interval, the mass of slice is weighed and the sorptivity (I) is calculated by using the below Equation.

$$\text{Sorptivity } (I) = \frac{m_t}{a * d}$$

5. RESULTS AND DISCUSSION

5.1. Flow properties

Table 2 shows the fresh properties of SCC mixes without and with 100% replacement of manufactured sand. Figure 2 illustrates the workability test results obtained by employing slump, L-box, U-box, and V-funnel with 100% percent substitution of natural sand by manufactured sand (i.e., SCC1 mix). The surface texture and shape of the M-sand have a major impact on the water demand of the mix. The smooth texture and round shape of the river sand lower interparticle friction in the fine aggregate, resulting in great workability. The rough surface and angular shape of M-sand promote internal friction in the mix, reducing the workability of concrete. The value of workability for SCC2 to SCC4 mixes are the lowest, indicating the low workability at various replacements of spend foundry sand (i.e., 10%, 20% and 30%). Since spent foundry sand is much finer than M-sand, it increases the water demand for workable mix.

5.2. Compressive strength

Figure 1 shows the compressive strengths of SCC mixes at the curing period of 3, 7 and 28 days. It is observed that a slight enhancement in compressive strength is accomplished with a 100% percentage substitution of natural sand by manufactured (i.e., SCC1 mix) sand at all curing days as shown in Fig. 1. The compressive strength of SCC 2 and SCC3 mixes containing 10% and 20% SFS is enhanced by 5.4%, 5.9%, 3.87% and 11.48%, 7.9%, 5.8%, for the curing age of 3, 7 and 28 days, respectively, in compression to the SCC1 mix. However, the compressive strength is enhanced in the range of 1.9%–2.7% with the addition of 30% SFS. With the addition of SFS, the compressive strength is greatly increased, which can be attributed to the densification of the concrete matrix caused by the filling of pores by SFS particles. Possible causes of a loss in strength include disruption of aggregate particle packing or an increase in finer material at high replacement levels. Additionally, the inclusion of fine binder particles in SFS might result in a loss in strength. The binder type and contaminants present in SFS can also substantially impact its strength.

Table 2. Fresh properties of SCC mixes

Mixes	Slump	V-funnel	L-box	U-box
SCC0	680	8.75	0.85	0.8
SCC1	691	8.5	0.87	0.7
SCC2	686	8.52	0.88	1.2
SCC3	682	8.55	0.91	1.5
SCC4	670	8.6	0.86	2.2

5.3. Split tensile strength

Figure 2 illustrates the SPT of SCC mixes measured at the curing period of 7 and 28 days. The outcomes exhibited that the SCC1 mix (i.e., 100% M-sand) had somewhat higher tensile strength values than the SCC0 mix (i.e., Conventional SCC mix). At 7 days, SPT of SCC2, SCC3 and SCC4 mixes improved by 6.25%, 12.5% and 3.125%, respectively,

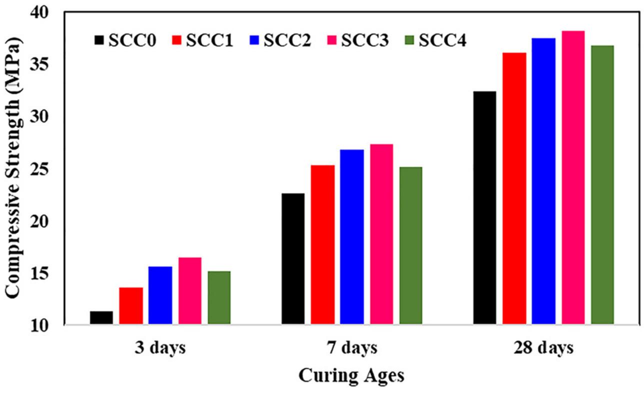

Fig. 1. CS of SCC mixes at curing period of 3, 7 and 28 days

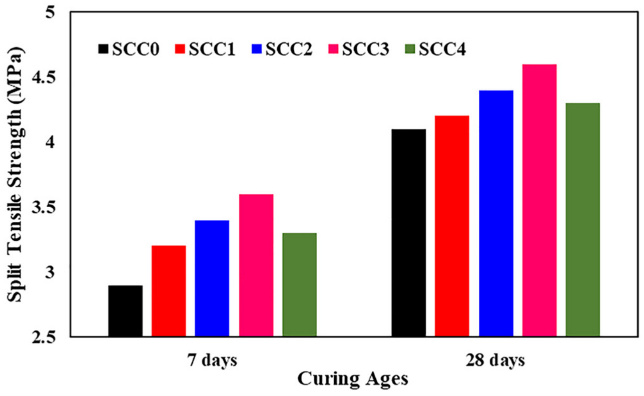

Fig. 2. STS of SCC mixes at curing period of 7 and 28 days

compared to the SCC1 mix. The SPT of concrete at 28th age for mixes SCC2, SCC3 and SCC4 also increased by 4.76%, 11.9% and 2.38%, compared to SCC1 mix. Because of its greater surface area and chemical composition, SFS improves the STS of concrete by reducing the binder paste aggregate transition zone. Because SFS is a very fine substance, it reduced the porosity of concrete, which in turn increased the density and resulted in the achievement of a greater split tensile strength.

Table 3 illustrates the predicted equations for the STS of SCC mixes from CEB-FIP (1990) and ACI 363R (ACI, 1992). The obtained split tensile strength of SCC mixes after curing period of 7 and 28 days was compared with the CEB-FIP (1990) and ACI 363R (ACI, 1992) predicted equations and is displayed in Table 4.

5.4. Modulus of rupture

Figure 3 depicts the modulus of rupture with and without M-sand and spent foundry sand for SCC mixtures at 7 and 28 days after curing. It is observed that a slight enhancement in MOR is accomplished with a 100% percentage substitution of natural sand by manufactured (i.e., SCC1 mix) sand at all curing days as shown in Fig. 3. At 7 days of curing, the MOR for SCC mixes was improved by 6.12%, 12.24% and 8.16% compared to the SCC1 mix. The MOR of SCC at 28th curing age was also enhanced by 3.12%, 7.81% and 4.68% compared to the SCC1 mix. The same pattern was observed in STS and CS at early and later ages. Because of its greater surface area and chemical composition, SFS improves the modulus of rupture of concrete by reducing the binder paste aggregate transition zone. Because SFS is a very fine substance, it reduced the porosity of concrete, which in turn increased the density and resulted in the achievement of a greater modulus of rupture.

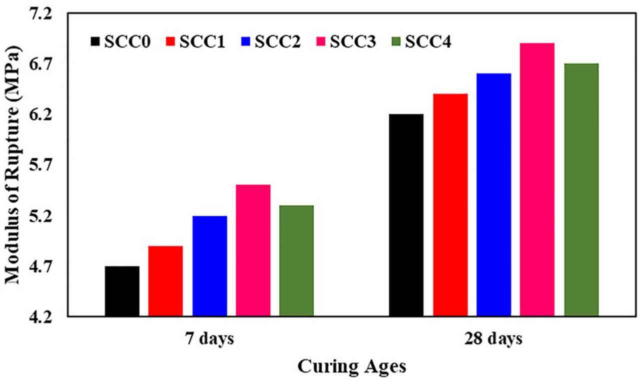

Fig. 3. MOR of SCC mixes at 7 and 28 days of curing

The estimated equations for the concrete's modulus of rupture from ACI 318R and ACI 363R are shown in Table 5. Table 6 compares the measured modulus of rupture of SCC mixes after curing period of 7 and 28 days with the ACI 318R and ACI 363R predicted equations.

5.5. Sorptivity test

The sorptivity of SCC mixes was tested according to the ASTM C1585-13. It could be observed that the maximum absorption (I) is obtained in the SCC0 mix about 1.9 mm and the minimum absorption (I) is obtained in the SCC3 mix about 1.65 mm, comparatively from the other mixes. The result reveals that the inclusion of SFS particles has decreased in capillary suction and improved the resistance against the ingress water into the cement matrix, thus making the concrete highly impermeable.

Table 3. Split tensile strength equations as per codes

Code	Expression for STS (MPa)	Range of compressive strength
CEB-FIP	$1.56\left[\frac{f_c'-8}{10}\right]^{2/3}$	$f_c' < 80$ MPa
ACI 363R	$0.59\,(f_c')^{1/2}$	21 MPa $< f_c' <$ 83 MPa

Table 4. Measured and expected STS of SCC mixes

Mixes	Curing ages	Split tensile strength		
		Experimental	ACI 363R	CEB-FIP
SCC0	7 days	2.9	2.8	2.0
SCC1		3.2	2.97	2.25
SCC2		3.4	3.05	2.38
SCC3		3.6	3.08	2.42
SCC4		3.3	3	2.30
SCC0	28 days	4.1	3.35	2.8
SCC1		4.2	3.54	3.10
SCC2		4.4	3.61	3.21
SCC3		4.7	3.65	3.26
SCC4		4.3	3.58	3.16

Table 5. Expressions for modulus of rupture

Code	Expression for STS (MPa)	Range of compressive strength
ACI 363R	$0.94\,(f_c')^{1/2}$	Not Specified
ACI 318R	$0.62\,(f_c')^{1/2}$	Not specified

Table 6. Measured and predicted modulus of rupture of SCC mixes

Mixes	Curing ages	Modulus of rupture		
		Experimental	ACI 363R	CEB-FIP
SCC0	7 days	4.7	4.47	2.95
SCC1		4.9	4.73	3.12
SCC2		5.2	4.87	3.21
SCC3		5.5	4.91	3.24
SCC4		5.3	4.78	3.16
SCC0	28 days	6.2	5.35	3.53
SCC1		6.4	5.65	3.73
SCC2		6.6	5.76	3.80
SCC3		6.9	5.81	3.83
SCC4		6.7	5.70	3.76

6. CONCLUSION

The following are the key findings of this study:

- It was observed that while replacing M-sand with spent foundry slag reduced the flow of concrete, it significantly improved its cohesiveness.
- A number of tests were conducted to see what effect spent foundry slag had on strength and durability. All concrete mixtures reached their target compressive strength in 3, 7 and 28 days, and most importantly, reference concrete and 20 SFS concrete reached their goals in 3 and 7 days. Up to 20% of M-sand being replaced with SFS, no loss of strength was seen. The SFS concrete demonstrated acceptable flexural and tensile strength results, with the latter displaying a comparable proclivity to compressive strength.
- The sorptivity test showed better results with adding SFS into the concrete; maximum and minimum absorption values were observed for the SCC0 mix and SCC3 mix, respectively.

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