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Cementing Sustainability: Utilizing Waste Foundry Sand to Enhance Concrete Performance and Reduce Environmental Impact

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Abstract

The incorporation of waste foundry sand into concrete production represents an environmentally conscious and cost-effective approach. This method involves substituting discarded foundry sand for a portion of traditional fine aggregates in concrete mixtures. The primary objective is to address environmental concerns associated with waste disposal while simultaneously achieving cost efficiency in construction materials. By integrating waste foundry sand into concrete, this practice promotes sustainability by reducing landfill waste and conserving natural resources. Through meticulous engineering and mix design, the resulting cost-effective concrete maintains the requisite structural and durability characteristics, contributing to a more eco-friendly construction sector. In an experimental investigation, concrete mixes were prepared with varying proportions of waste foundry sand, ranging from 0% to 60% by weight, for M-30 grade concrete (Portland pozzolana cement). These mixtures were carefully manufactured, subjected to comprehensive testing, and compared to conventional concrete in terms of workability and strength. The standard cube specimens, measuring 150 mm × 150 mm × 150 mm, were utilized for testing, with curing periods of 7 and 28 days to assess the mechanical properties of the concrete. Based on the experimental findings, it was evident that an increase in the partial replacement of waste foundry sand resulted in higher compressive strength, signifying its potential to enhance the durability and strength properties of concrete. On the other hand, there was a decline in the split tensile strength as the percentage of waste foundry sand increased. These results underscore the safe and beneficial utilization of foundry sand in concrete, showcasing its potential to improve concrete's overall performance and sustainability.

Keywords: Concrete mixtures, foundry, eco-friendly construction, tensile strength

INTRODUCTION

Foundry sand is a type of high-quality silica sand characterized by its consistent physical properties. It acts as a valuable secondary product generated by both ferrous and non-ferrous metal casting sectors. This sand, recognized for its excellent thermal conductivity, has been a staple material in molding for centuries. The specific physical and chemical attributes of foundry sand vary depending on the casting process and the particular sector of the industry it originates from.

In contemporary foundry practices, there is a strong emphasis on reclaiming and reusing sand through multiple production cycles. Industry

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estimates suggest that approximately 100 million tons of sand are utilized annually for casting purposes, with 6 to 10 million tons discarded each year and available for reclamation into other products and industries [1–6].

Notably, the automotive sector and related industries are the primary generators of foundry sand demand. Foundries typically procure high-quality, size-specific silica sand tailored to their molding and casting needs.

The recycling of waste foundry sand (WFS) for use in construction materials, such as concrete, represents an innovative approach with significant environmental and economic benefits. This approach not only reduces waste but also has the potential to enhance the properties of construction materials while lowering production costs [7–14].

The integration of WFS into concrete mixtures is a dynamic field of research and development, aiming to tap into its potential as a functional and sustainable ingredient in the construction industry.

WASTE FOUNDRY SAND

Physical Properties

The typical physical characteristics of spent foundry sand derived from green sand systems are detailed in Table 1. Foundry sand exhibits a remarkably consistent grain size distribution, with a significant portion, approximately 85% to 95%, Within the spectrum of 0.6 mm to 0.15 mm, aligning with sieve sizes No. 30 and No. 100, respectively. Additionally, it can be expected that a minor fraction, about 5% to 12%, will have particle sizes smaller than 0.075 mm (No. 200 sieve) [15–17].

Concerning particle morphology, foundry sand commonly exhibits a sub-angular to rounded shape. It is worth noting that the gradation of WFS is often finer than required to meet specific criteria for fine aggregates in certain applications.

Chemical Composition

The chemical composition of foundry sand is intricately linked to the type of metal casting process conducted at the foundry. This composition is a critical factor influencing the choice of binders and auxiliary materials used in the casting process. It is important to note that there can be some degree of variation in the chemical composition of foundry sand between different foundries. Additionally, foundry sands produced by a single foundry typically exhibit relative stability over time. Moreover, collaborative efforts among multiple foundries often result in the production of consistent and compatible sand blends.

The chemical composition of foundry sand plays a crucial role in determining its performance across diverse applications. In essence, spent foundry sand primarily comprises silica sand. This silica sand is typically coated with a thin layer of burnt carbon, remnants of binders such as bentonite, sea coal, resins, as well as minute dust particles. This composite composition plays a vital role in determining the suitability and behavior of spent foundry sand in different usage scenarios (Table 2).

Table 1. Typical physical properties of spent green foundry sand.

Property	Results	Test Methods
Specific gravity	2.34	ASTM D854
Fineness modulus	1.8	ASTM C136
Absorption, %	0.45	ASTM C128
Moisture content, %	0.1–10.1	ASTM D2216
Plastic limit/Plastic index	Non-plastic	AASTHO T90/ASTM D4318

Table 2. Chemical composition of foundry sand.

Constituent	Value (%)
SiO_2	83.93
Al_2O_3	0.02
Fe_2O_3	0.950
CaO	1.03
MgO	1.77
SO_3	0.057
Loss on ignition (LOI)	2.19

Mechanical Properties

The typical mechanical properties of spent foundry sand are detailed in Table 3. Spent foundry sand exhibits favorable consistency characteristics, as demonstrated by its low micro-Deval abrasion and magnesium sulfate soundness loss test results. The micro-Deval abrasion test involves subjecting a sample of fine aggregate to a rotational process within a specialized drum containing water and abrasive components, spinning at 100 rpm for 15 minutes. The percentage of material loss in this test has been found to be closely related to magnesium sulfate soundness and various other physical properties.

Recent research studies have reported relatively high levels of soundness loss in some instances. It is important to note that this loss is typically attributed to the removal of loosely bound sand particles within the sample, rather than a breakdown of individual sand grains. Moreover, the angle of shearing resistance, commonly known as the angle of internal friction, for foundry sand, has been reported to range between 33° and 40°. This range is comparable to that observed in conventional sands, highlighting the similarity in shear behavior between the two materials.

FOUNDRY SAND ENGINEERING CHARACTERISTICS

Given that foundry sand possesses nearly all the characteristics of natural or quarried sand, it finds versatile applications in various construction contexts. These include:

- *Sand Backfill:* Foundry sand can be effectively utilized as a sand fill material, offering stability and support in construction projects.
- *Dike Filling:* It serves as an ideal direct filler material for dikes, enhancing their structural integrity and preventing erosion.
- *Hot Mix Asphalt:* In the production of hot mix asphalt, foundry sand can function as a sand replacement, contributing to improved asphalt mixtures.
- *Flowable Fill:* Foundry sand can be incorporated into flowable fill formulations, providing a self-leveling and easily pourable material for backfilling or trench filling.
- *Portland Cement Concrete:* Foundry sand is compatible with Portland cement concrete mixtures, offering a sustainable alternative as a fine aggregate.
- *Road Base and Sub-Base:* Blending foundry sand with coarse or fine aggregates allows for its utilization as a reliable road base or sub-base material, contributing to road construction and maintenance.

Table 3. Typical mechanical properties of waste foundry sand.

Property	Results	Test Methods
Micro-Deval abrasion loss, %	<2	—
Magnesium sulfate soundness loss, %	5–15 6–47	ASTM C88
Friction angle (deg)	33–40	—
California bearing ratio, %	4–20	ASTM D1883

LITERATURE REVIEW

In 2013, Salokhe and Desai [2] conducted experimental investigations to assess the comparative properties of fresh and hardened concrete when ferrous and nonferrous foundry waste sand replaced fine aggregates. They examined four replacement percentages: 0%, 10%, 20%, and 30% by weight of fine aggregate for M-20 grade concrete, curing the samples for both 7 and 28 days. Their findings indicated that at a 30% addition of ferrous foundry waste sand, the compressive strength at 28 days increased noticeably.

Similarly, in 2013, Bhimani and colleagues [3] conducted an experimental study on concrete strength, investigating the optimal percentage of partial replacement of fine aggregate. They tested replacement percentages of 0%, 10%, 30%, and 40% by weight for M-20 grade concrete. Their results revealed that the compressive strength increased significantly, especially with a 40% addition of used foundry sand, surpassing the strength of traditional concrete.

The properties of concrete incorporating WFS and bottom ash as replacements for fine aggregate in varying percentages (ranging from 0% to 60%) over curing periods of 28, 90, and 365 days. Their research demonstrated that the most significant improvements in compressive, tensile, and flexural strengths, compared to conventional concrete, were achieved when substituting 30% of natural fine aggregates with industrial by-product aggregates. This improvement in strength remained consistent, except for a 60% replacement, suggesting that the inclusion of WFS and bottom ash did not adversely affect the concrete's strength properties.

Findings from experimental investigation on the durability of concrete made with foundry sand revealed that the shrinkage ratio of WFS mixes was initially higher but eventually leveled out with other concrete types after 28 days. The modulus of elasticity of concretes containing WFS was found to be similar to the compressive strength results. Up to a 30% WFS replacement level, improvements in modulus of elasticity were reported. Additionally, the addition of fine WFS led to an enhancement in abrasion resistance, attributed to the denser matrix. WFS positively influenced the sulfate resistance of concrete at replacement ratios of up to 30%. However, higher substitution levels resulted in reduced resistance, possibly due to traces of SO_3 in WFS. Furthermore, beyond a 30% substitution rate, an increase in carbonation depth was observed in concrete with WFS, likely associated with poor workability and compaction issues.

MIX PROPORTION AND PREPARATION OF SPECIMENS

The concrete admixture was formulated following the procedure outlined in the Indian Standard [6] with the goal of achieving a 28-day compressive strength of 30 MPa. The concrete mix design ratio was set at 12.0:3.2:6.6 (cement:sand:aggregate), and for experimentation purposes, five different scenarios were considered, incorporating 60% foundry sand into the trial mixtures. To maintain consistency, the water-to-cement ratio was held constant at 0.40 across all mixtures. A plasticizer was introduced into the mix to lower the water-to-cement ratio while ensuring workability. Comprehensive details of the mixture composition and the unit weights of the various ingredients can be found in Table 4.

Table 4. Proportion of M-30 grade concrete.

Mix	Cement (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Foundry Sand (kg/m^3)	Water (kg/m^3)	Plasticizer (kg/m^3)	Plasticizer (%)
M-1	394	799.17	1111.86	0	157.60	1.97	0.5
M-2	394	639.34	1111.86	159.83	157.60	1.97	0.5
M-3	394	559.42	1111.86	239.75	157.60	3.94	1
M-4	394	479.50	1111.86	319.67	157.60	7.88	2
M-5	394	399.58	1111.86	399.58	157.60	7.88	2
M-6	394	319.67	1111.86	479.50	157.60	7.88	2

MATERIAL SPECIFICATION

Cement

We utilized IS mark 53 grade cement, specifically Ambuja cement brand, for all concrete mix formulations. The cement employed was in a fresh and lump-free state. Testing procedures for the cement were carried out following the guidelines outlined in IS: 8112-1989. A comprehensive summary of the test results conducted on the cement can be found in Table 5.

Coarse Aggregate

In this study, we employed locally sourced coarse aggregates with a maximum size of 10 mm and 20 mm. To assess the quality of these coarse aggregates, we conducted tests in accordance with the IS: 383-1970 standards. For the 10 mm aggregates, an initial sieving process involved passing them through a 10 mm sieve, followed by a subsequent pass through a 4.75 mm sieve. Similarly, for the 20 mm aggregates, an initial sieving process through a 20 mm sieve was performed. Subsequently, the aggregates underwent a thorough washing procedure to eliminate any dust and impurities, after which they were dried to achieve a surface-dry condition. Detailed results from various tests conducted on the coarse aggregates are presented in Table 6.

Fine Aggregate

The sand utilized in this experimental program was sourced locally and adhered to grading zone II standards in accordance with IS: 383-1970 guidelines [11]. Prior to its use, the sand underwent a meticulous preparation process. Initially, it was sieved through a 4.75 mm sieve to eliminate any particles exceeding 4.75 mm in size. Subsequently, a thorough washing procedure was employed to eliminate dust and impurities from the sand. Comprehensive details regarding the properties of the fine aggregate utilized in this experimental study can be found in Table 7.

Foundry Sand

The research focused on waste foundry sand sourced from Aurangabad Foundries, located in Chikalthana, Aurangabad, Maharashtra. Detailed information regarding the physical properties of the foundry sand under investigation is presented in Table 8, while the chemical properties are outlined in Table 9.

Table 5. Properties of cement.

S. No.	Characteristics	Values Obtained
1.	Normal consistency	34%
2.	Initial setting time (minutes)	30
3.	Final setting time (minutes)	600
4.	Fineness (%)	3.5%
5.	Specific gravity	3.15

Table 6. Properties of coarse aggregates.

S. No.	Characteristics	Value
1.	Type	Crushed
2.	Specific gravity	2.7
3.	Water absorption (%)	1.14
4.	Moisture content (%)	0.33
5.	Fineness modulus	6.35

Table 7. Properties of fine aggregates.

S. No.	Characteristics	Value
1.	Type	Natural
2.	Specific gravity	2.68
3.	Water absorption (%)	1.2
4.	Moisture content (%)	0.16
5.	Fineness modulus	3.2

Table 8. Physical properties of foundry sand.

Property	Results	Test Methods
Specific gravity	2.34	ASTM D854
Fineness modulus	1.8	ASTM C136
Absorption, %	0.45	ASTM C128
Moisture content, %	0.1–10.1	ASTM D2216
Plastic limit/Plastic index	Non-plastic	AASTHO T90/ASTM D4318

Table 9. Foundry sand sample chemical oxide composition.

Constituent	Value (%)
SiO_2	83.93
Al_2O_3	0.02
Fe_2O_3	0.950
CaO	1.03
MgO	1.77
SO_3	0.057
Loss on ignition (LOI)	2.19

Water

Water plays a pivotal role in concrete by engaging in chemical reactions with cement, facilitating the creation of the cement gel that imparts strength. Hence, meticulous attention must be paid to both the quantity and quality of water employed in the concrete mix. In this study, potable tap water was employed for both the concrete mixing and the curing of specimens.

To enhance the workability of the concrete mixtures, a superplasticizer was incorporated. Specifically, a sulfonated naphthalene formaldehyde polymer based superplasticizer was used, complying with the specifications outlined in IS 9103 – 1999. The superplasticizer utilized in this study was sourced from Sika India Pvt. Ltd. and goes by the product name Sikament–610. The dosage of the superplasticizer varied within the range of 0.5% to 2% by weight of cement for both plain concrete and concrete incorporating foundry sand. For additional technical details regarding the superplasticizer, please refer to Table 10.

Specimen Preparation and Casting

For the assessment of compressive strength, we casted concrete cubes with dimensions measuring 150 mm × 150 mm × 150 mm, as detailed by Manoharan et al. [7]. Additionally, to evaluate splitting tensile strength and modulus of elasticity, we prepared cylindrical specimens measuring 150 mm in diameter and 300 mm in height, following the procedures outlined in the Indian Standards [5, 6].

After the initial casting, the specimens were carefully demolded after a curing period of 24 hours. Subsequently, they were transferred to a water-curing chamber, where they remained until the scheduled testing procedures were carried out.

Table 10. Technical data of superplasticizer.

S. No.	Characteristics	Details
1.	Color	Dark brown liquid
2.	Chemical base	Modified naphthalene formaldehyde sulfonate
3.	Relative density	1.20 kg/L at 30°C
4.	pH value	Min 6
5.	Chloride content	0.2% max.
6.	Air entrainment	Nil
7.	Nitration content	Nil

EXPERIMENTAL AND TESTING

- Slump test
- Compressive strength test
- Split tensile test

Slump Test

To assess the workability of the fresh concrete, a slump test was conducted in accordance with ASTM standards. The procedure involved pouring the freshly mixed concrete into a standard cone in three distinct layers. Each layer was meticulously compacted using 25 blows from a tamping rod, and the resulting drop in height was duly recorded. Notably, it was observed that the slump value exhibited a decreasing trend as the percentage of natural sand replacement with WFS increased, all while maintaining a consistent water-to-cement (w/c) ratio.

Compressive Strength Test

Compressive strength testing was conducted using a compression testing machine. For each concrete mix, a total of six cubes were subjected to the testing procedure. These tests were conducted at both the 7-day and 28-day curing intervals. To determine the compressive strength of a particular mix, the average strength from three cubes was taken into consideration for accurate assessment and analysis.

Split Tensile Strength Test

For assessing the splitting tensile strength, cylinder specimens were employed, and the testing protocol followed the guidelines outlined in IS: 5816-1970(10). Throughout the test, compressive line loads were methodically administered along a vertical symmetrical plane, resulting in the splitting of the specimen.

Similar to the compressive strength tests, splitting tensile strength tests were conducted at both the 7-day and 28-day curing periods. The tensile strength for each specific mix was determined by calculating the average strength derived from three separate specimens, ensuring robust and reliable results.

RESULTS AND DISCUSSION

In this investigation, the compressive strength values for various replacement levels of foundry sand content (ranging from 0% to 60%) at different curing durations (7 days and 28 days) are detailed in Table 11.

The incorporation and escalation of waste foundry sand up to 60% resulted in a substantial enhancement in concrete's compressive strength. Notably, the highest compressive strength was achieved with a 50% replacement of fine aggregate with WFS.

Split Tensile Strength

Regarding split tensile strength, the concrete's performance incorporating foundry sand, with replacement levels ranging from 0% to 60% for fine aggregate and a water-cement ratio of 0.4, exhibited a discernible dependence on the proportion of foundry sand utilized. The detailed variations in split tensile strength can be found in Table 12.

Table 11. Compressive strength (MPa) of concrete with foundry sand for M30 grade.

Foundry Sand Content, %	Designation	Compressive Strength, MPa
0	M-1	32.50
20	M-2	37.25
30	M-3	37.33
40	M-4	37.91
50	M-5	36.83
60	M-6	29.50

Table 12. Split tensile strength (MPa) of concrete with foundry sand for M30 grade.

Foundry Sand Content, %	Designation	Split Tensile Strength, MPa 28 days
0	M-1	4.38
20	M-2	4.77
30	M-3	5.01
40	M-4	5.81
50	M-5	5.74
60	M-6	4.50

A marked improvement in the split tensile strength of concrete was noted with the incorporation and progressive escalation of WFS, reaching a replacement level of 60%. The peak strength was achieved when 40% of the fine aggregate was substituted with WFS.

CONCLUSIONS

Based on the findings of this study, the following conclusions can be drawn. The fresh concrete data indicates that the addition of WFS results in a lower slump, primarily attributed to the presence of very fine binders. Hence, the incorporation of superplasticizers becomes imperative to uphold sufficient workability.

The compressive strength of concrete showcased an augmentation with higher levels of sand replacement, employing varying percentages of foundry sand. Furthermore, at each replacement level of fine aggregate with foundry sand, a consistent enhancement in strength was observed as the concrete aged.

The maximum compressive strength was attained when 50% of the fine aggregate was replaced with WFS. Although a marginal decline in strength was evident at a 60% replacement level, it remained superior to that of conventional concrete.

Similarly, split tensile strength demonstrated an increasing tendency with rising replacement levels of foundry sand in lieu of fine aggregate. Additionally, split tensile strength improved with longer curing periods. In summary, the results suggest that replacing sand with WFS up to 60% is a viable option for construction projects, offering potential benefits in terms of both strength and sustainability.

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