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Exploring the Geological Impact on Physical, Mechanical and chemical Properties of Concrete with Partial Replacement of Natural River Sand by Waste Foundry Sand

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This study investigates the feasibility of utilizing waste foundry sand (WFS) as a partial substitute for natural river sand (NRS) in concrete mixtures. By evaluating the physical, mechanical, and durability properties of concrete, the research aims to determine the impact of WFS on compressive and flexural strengths as well as long-term performance. Various concrete samples were prepared with different percentages of WFS (0%, 10%, 20%, 30%, 40%, 50%, and 60%) replacing NRS. The findings reveal that incorporating WFS into concrete not only enhances its compressive and flexural strengths but also improves its durability, making the material more resilient to environmental factors. From a geological perspective, the use of WFS in concrete addresses significant environmental challenges associated with the disposal of this industrial by-product. Foundry sand, typically composed of high-quality silica sand, retains several beneficial properties that can enhance the performance and longevity of concrete. This research highlights the dual benefits of WFS utilization: improving concrete performance and mitigating the environmental impact of waste sand disposal. Additionally, the study examines the geological composition of WFS and its compatibility with concrete matrices. By understanding the mineralogical and chemical characteristics of WFS, the research provides insights into its long-term behavior and stability within concrete structures. The durability aspects, such as resistance to sulfate attack, freeze-thaw cycles, and chloride penetration, are also evaluated, showcasing the potential of WFS to enhance the lifespan of concrete. In conclusion, this study demonstrates that WFS is a viable alternative to NRS in concrete production, offering enhanced mechanical properties, improved durability, and significant environmental benefits. The findings advocate for the integration of WFS in construction materials, paving the way for more sustainable and eco-friendly building practices.

Keywords: Waste foundry sand, Natural river sand, Concrete, Sustainability.

1. Introduction

Concrete is widely recognized as a primary structural material used globally for all types of construction. Communities around the world rely on concrete for its safety, strength, and simplicity as a building material. It is utilized in various construction projects, from residential homes to multi-storey buildings and commercial complexes. Concrete has earned its unique status as a structural material due to its cost-effectiveness and high resistance to fire, wind, water, and earthquakes. Recently, its use has increased significantly, leading to urban environments often referred to as "concrete jungles." The demand for concrete is expected to rise in the future to meet the growing needs for housing, transportation, and amenities driven by population growth.

The civil engineering field must address the challenge of delivering projects that align with sustainable development principles. This means prioritizing cost-effective, high-performance materials that minimize environmental impact. Historically, clay-based materials have been essential in construction, but growing demands for more resilient structures in harsh environments require the development of innovative composites and materials. Additionally, environmental concerns and the drive to repurpose industrial waste have catalyzed advancements in concrete technology, pushing for better performance and longer-lasting solutions in modern construction. Given concrete's crucial role in structural construction, it must possess adequate strength for structural purposes. Concrete comprises aggregates, cement, and water, with aggregates making up about three-quarters of the mix. Aggregates are categorized as fine and coarse. This study focuses on using fine aggregates, specifically waste foundry sand (WFS), in concrete. Before delving further, it is essential to understand the properties and performance of foundry sand.

Concrete

Concrete is an essential building material in the rapidly growing construction sector, which continuously explores new techniques for faster and more efficient construction. The high consumption of natural resources for concrete production is costly and depleting. This situation urges the need to recover natural resources or find alternative solutions. Waste foundry sand (WFS), a by-product of metal casting industries, presents environmental challenges. Utilizing WFS in building materials can alleviate environmental stress.

Waste Foundry Sand (WFS) is a by-product of the metal casting industry, characterized by high-quality silica sand. The properties of WFS vary based on the casting process and industry type. In foundries, molding sand is repeatedly reused until it deteriorates. Research has extensively explored the mechanical and chemical traits of WFS, but less attention has been given to concrete's strength and durability when incorporating WFS. By replacing fine aggregates with WFS, this experimental study aims to create eco-friendly, cost-effective concrete solutions that leverage waste materials for sustainable construction.

Waste Foundry Sand

In the foundry industry, a significant amount of by-product material is produced during the casting process. Metals such as cast iron, steel, aluminium, copper, brass, and bronze are commonly cast in foundries, resulting in by-products primarily consisting of silica and metals. Foundries use high-quality silica sand for molding and casting purposes. This sand must be readily available, highly resistant to heat, and cost-effective. The same sand is used for multiple castings until it loses its original properties, affecting the casting materials' physical and chemical properties. When the sand can no longer be reused for casting, it is termed waste foundry sand (WFS). Disposing of WFS poses significant environmental challenges, such as land pollution. The colour of WFS can vary from black, grey, to brown based on the material cast, the number of uses, and the casting method.

Classifications of Foundry Sand

The classification of foundry sand depends on the bonding characteristics of metals used in the casting process. In ferrous casting, most molds use clay-bonded sand, often referred to as green sand. This mixture typically includes 84–94% high-grade silica sand, 3.5–9.5% clay, and 3–11% additives for enhanced performance. The sand appears black due to carbon content, which helps prevent surface fusion during casting. Foundries favour clay-bonded sand for its exceptional heat resistance and wet binding strength, with chemical traces such as MgO, K2O, and TiO2 contributing to its properties.

Chemically bonded sand is used for high-temperature molds and comprises silica (93–98%) and chemical binders (1–3%). This sand is light brown. In gas-catalyzed systems, a catalyst gas or vapour is used instead of adding a catalyst to the sand mixture. The sand-resin mixture remains uncured until contacting the catalyst agent. The sand mixture hardens almost instantly upon contact with the catalyst. Various gas-catalyzed processes include furan/SO_2, acrylic/SO_2, sodium silicate/CO_2, and phenolic urethane/amine vapour.

Compressive strength can be increased, land pollution can be reduced, and the need for fine aggregate can be reduced by using WFS as a partial substitute for fine aggregates in concrete.

Numerous studies have explored the feasibility of incorporating WFS in concrete. A comprehensive review by Siddique et al. (2009) highlighted the potential benefits of using WFS as a partial replacement for fine aggregates in concrete. The study revealed that WFS could enhance the compressive and tensile strength of concrete while addressing environmental issues related to the disposal of foundry waste.

Mechanical Properties of Concrete with Foundry Sand

Several researchers have focused on the mechanical properties of concrete with WFS. Gey and Kandhal (2005) investigated the compressive strength of concrete mixtures with varying percentages of WFS. Their findings indicated that up to 30% replacement of NRS with WFS resulted in comparable or improved compressive strength compared to conventional concrete. Similarly, Chitlange et al. (2010) reported that the inclusion of WFS improved the flexural strength and durability of concrete.

2. Analytical Studies on Physical Properties

Workability and Density

The workability and density of concrete are critical factors influencing its performance. Studies by Aggarwal et al. (2007) demonstrated that the partial replacement of NRS with WFS affected the workability and density of concrete mixtures. The researchers observed a reduction in workability with increasing WFS content due to its higher water absorption capacity. However, the density of the concrete remained relatively unchanged, suggesting that WFS could be effectively used without compromising the material's overall integrity.

Microstructural Analysis

Microstructural analysis provides insights into the internal composition and bonding of concrete materials. Research by Manjunath and Rajesh (2011) utilized scanning electron microscopy (SEM) to examine the microstructure of concrete containing WFS. Their study revealed that WFS particles contributed to a denser microstructure, enhancing the overall strength and durability of the concrete. The presence of silica in WFS was found to promote better bonding with the cement matrix, resulting in improved mechanical properties.

3. Environmental and Economic Impacts

Sustainability and Waste Management

The use of WFS in concrete aligns with sustainable construction practices by promoting the recycling of industrial waste. Foundry industries generate substantial amounts of sand waste, posing disposal challenges. By incorporating WFS into concrete, researchers have demonstrated a viable solution to mitigate environmental impacts. According to a study by Bhimani et al. (2013), utilizing WFS in concrete not only reduces the demand for natural sand but also addresses the issue of foundry waste disposal, contributing to a more sustainable construction industry.

Cost-Effectiveness

From an economic perspective, the replacement of NRS with WFS can lead to cost savings in concrete production. A study by Khatib et al. (2012) evaluated the cost implications of using WFS as a partial replacement for NRS. The findings indicated that the use of WFS could reduce material costs while maintaining the desired mechanical properties of concrete. This economic advantage, coupled with environmental benefits, makes WFS an attractive alternative for sustainable construction.

4. Challenges and Future Directions

Variability in Foundry Sand Properties

Despite the promising results, the variability in the properties of foundry sand poses a challenge for its widespread adoption. The composition of WFS can vary depending on the casting process and the type of metals used, affecting the consistency of concrete properties. Researchers, such as Kumar and Singh (2014), have emphasized the need for standardized procedures to evaluate and classify WFS to ensure uniformity in concrete performance.

Long-Term Performance and Durability

Long-term performance and durability are critical considerations for concrete structures. While short-term studies have demonstrated the benefits of using WFS, there is a need for comprehensive long-term investigations. Studies by Rajgor et al. (2016) suggested that the long-term effects of WFS on concrete properties, such as resistance to freeze-thaw cycles and chemical attacks, should be thoroughly examined to ensure the reliability and longevity of concrete structures incorporating WFS.

5. Materials Used

Cement

Cement serves as a crucial binding material in concrete mixtures. The raw materials used in cement production include calcareous substances like limestone or chalk and argillaceous materials such as shale or clay.

Aggregate

Aggregates are inert mineral materials used in mortars and concretes. According to Indian Standards (IS: 383-1970), suitable aggregates for concrete construction must be strong, chemically inert, hard, and durable. Aggregates can be natural (sand, gravel, crushed rock) or artificial (furnace clinker, coke breeze, sawdust, foamed slag) and are classified by size into fine and coarse aggregates.

Waste Foundry Sand (WFS)

WFS is a high-quality silica sand compared to ordinary sand, and it is recycled and reused multiple times by foundries. When it can no longer be reused in the foundry, it is termed "waste foundry sand." WFS is an excellent replacement for fine aggregate in concrete due to its high quality. If WFS can replace natural sand in concrete without compromising strength and durability, it offers economic and environmental benefits. Current literature on the effects of WFS on porosity and sulphate attack in concrete is limited. WFS is a significant waste management issue, characterized by its fine particles and blackish colour. The properties of WFS are influenced by the type of metal cast, casting mechanism, furnace type, and finishing procedures.

Table 1: Physical Properties of Waste Foundry Sand

Test Performed	Results
Specific Gravity	2.39-2.55
Fineness Modulus	2.85
Bulking of WFS	24 at 6% moisture content

Chemical Properties of WFS:

- Chemical composition depends on the metal type, binder type, and combustibles used.
- WFS is rich in silica and coated with burnt carbon, residual binder, and dust. Silica sand's hydrophilic nature attracts water to its surface.

Table 2: Chemical Properties of Waste Foundry Sand

Constituents	Value (%)
SiO2	84.04
Al2O3	3.13
Fe2O3	4.06
CaO	1.14
MgO	1.88
SO3	0.16
LOI	2.3

Finally, cement content = 383.16 kg/m^3

CA = 1209.66 kg/m^3

FA = 689.19 kg/m^3

W = 191.58 kg/m^3

W/C = 0.5

Table 3: Material required for M 25 grade concrete per cubic meter quantity of concrete:

Material	Cement	FA	CA	W
Kg/m3	383.16	689.19	1209.66	191.58
Ratio	1	1.79	3.15	0.5

Figure 1: Mixing of concrete in pan mixer

Figure 2: casting of cubes

6. Results and Discussions

Compressive Strength

This study explored the compressive strength of M25 grade concrete by substituting fine aggregate with varying amounts of waste foundry sand (WFS). To assess performance, compressive strength tests were conducted after 7 and 28 days of curing to evaluate the impact of WFS on the concrete mix.

7-Day Compressive Strength Results: The findings show a steady increase in compressive strength as waste foundry sand (WFS) replaced fine aggregate, peaking at 20% replacement with a maximum strength of 24.85 MPa. However, further increases in WFS content led to a decline in strength, with 25% and 30% substitutions resulting in compressive strengths of 22.22 MPa and 21.89 MPa, respectively.

28-Day Compressive Strength Results: After 28 days of curing, the compressive strength showed a similar pattern to the 7-day results. The highest strength was observed with 20% waste foundry sand (WFS) replacement, reaching 36.74 MPa. When the WFS replacement increased to 25% and 30%, the compressive strengths declined to 28.9 MPa and 28.43 MPa, respectively.

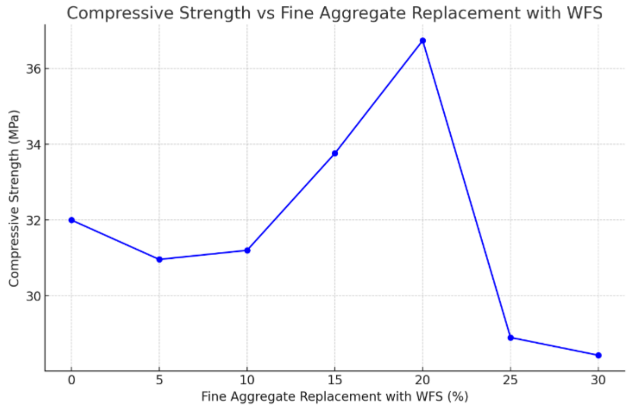


Fig 3 : Compressive Strength of M25 concrete for 7 Days of curing with FA Replacement

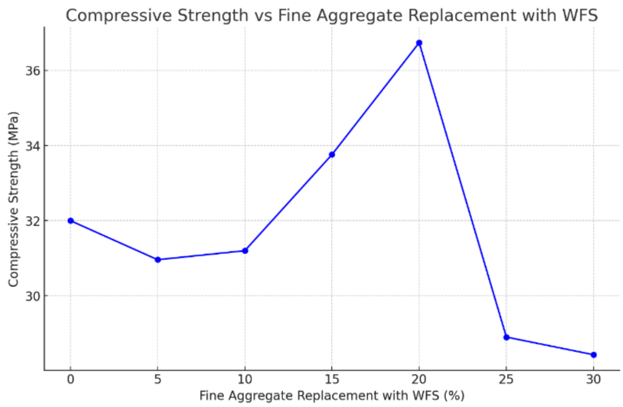


Fig 4: Compressive Strength of M25 concrete for 28 Days of curing with FA Replacement

Discussion The initial increase in compressive strength can be attributed to the filler effect of WFS, which improves the packing density of the concrete mix. However, beyond 20% replacement, the excessive fineness and possible impurities in WFS might have contributed to the reduction in strength. The optimal replacement level of 20% not only enhances the compressive strength but also supports sustainable construction practices by utilizing industrial waste.

Table 4: Compressive Strength Values of M25 Grade Concrete

S. No	Fine Aggregate Replacement with WFS (% MIX)	Compressive Strength (MPa) - 7 Days	Compressive Strength (MPa) - 28 Days
1	0	++++++++	32
2	5	23.96	30.96
3	10	24.10	31.2
4	15	24.59	33.76
5	20	24.85	36.74
6	25	22.22	28.9
7	30	21.89	28.43

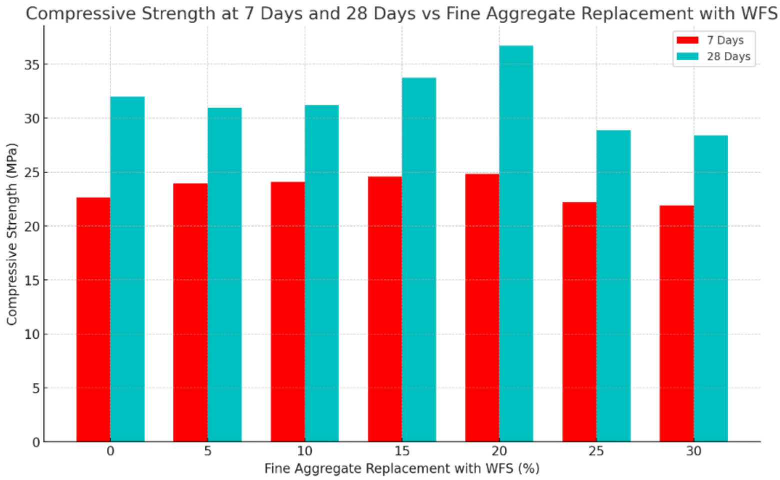


Fig 5: comparison of compressive strength for M25 grade

Flexural Strength

Flexural strength tests were conducted to assess the tensile strength of concrete containing Waste Foundry Sand (WFS) as a partial fine aggregate replacement. Testing was carried out after 7 and 28 days of curing.

7-Day Flexural Strength Results: The strength increased with WFS substitution up to 10%, peaking at 4.93 MPa. Beyond this level, strength declined, with the lowest value of 4.03 MPa recorded at 30% replacement.

28-Day Flexural Strength Results After 28 days, the trend remained similar, with the highest flexural strength of 6.525 MPa recorded at 0% replacement. The strength decreased with higher percentages of WFS, reaching 4.93 MPa at 30% replacement.

Discussion The increase in flexural strength at lower replacement levels can be attributed to the enhanced bonding between WFS and the cement matrix. However, excessive replacement levels likely introduce more voids and reduce the overall matrix integrity, leading to decreased strength.

Table 5: Flexural Strength Values of M25 Grade Concrete

S. No	Fine Aggregate Replacement with WFS (% MIX)	Flexural Strength (MPa) - 7 Days	Flexural Strength (MPa) - 28 Days
1	0	4.35	6.525
2	5	4.53	5.35
3	10	4.93	6.11
4	15	4.79	5.36
5	20	4.77	5.28
6	25	4.57	5.12
7	30	4.03	4.93

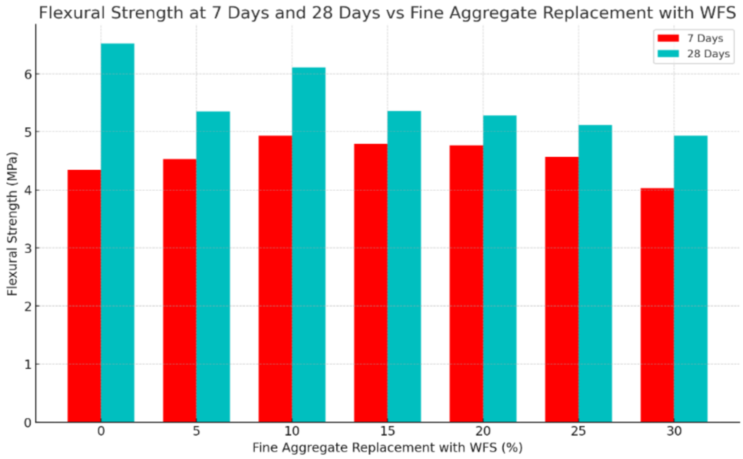


Fig 6: Comparison of flexural Strength Values of M 25 grade concrete

Permeability test:

Concrete permeability plays a critical role in ensuring durability, particularly in water-retaining and substructure applications where watertightness is essential. Structures exposed to harsh environmental conditions also require concrete with low permeability. High permeability can allow aggressive elements to penetrate, leading to the deterioration of reinforced concrete over time, compromising the structure's integrity and longevity.

Fig 7: Permeability test apparatus and arrangement

The test result is the mean of the maximum depth of penetration from the test specimen.

Table 6: depth of penetration

Mix	Depth of penetration (mm)
S1	21.31
S 2	23.01
S 3	23.41
S 4	25.11
S 5	25.91

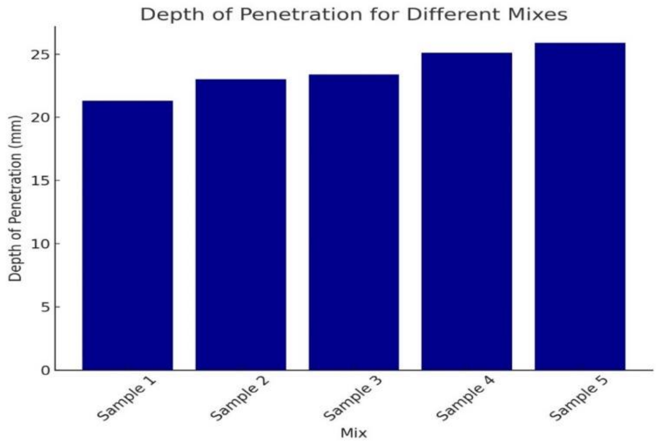
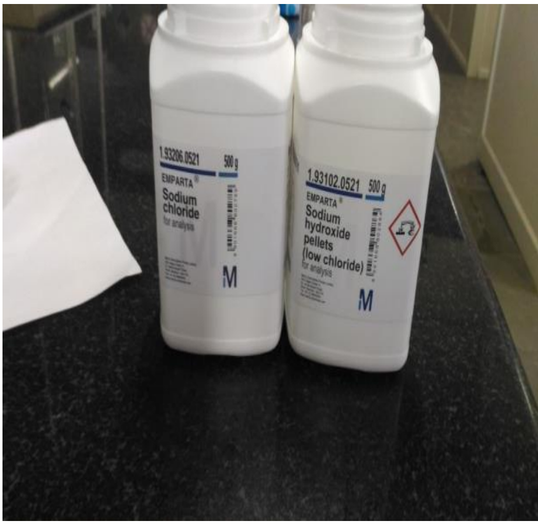


Fig 8: Depth of penetration

RCPT TEST:

The charges recorded in automatic data processing equipment at every 30 minutes for the entire six hours are shown in table 7. The samples are properly connected.

Rcpt apparatus　　　　　　　　　　　　mould along with test cell



NaOH and NaCl

desiccators along with specimen

Fig 9: Rcpt apparatus

Table 7: charges passed through the specimen in mA

Time (min)	Current (mA)				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
00	1022	875	734	590	261
30	1031	883	741	599	267
60	1034	891	747	597	283
120	1051	903	754	603	299
150	1054	911	757	606	305
180	1061	914	760	609	311
210	1073	925	764	613	320
240	1077	933	767	615	329
270	1084	936	769	617	341
300	1091	944	771	619	353
330	1095	956	774	624	361
360	1103	964	780	628	364

7. Conclusion

- Optimal Replacement: The compressive strength of M25 grade concrete increases gradually with the replacement of fine aggregate by waste foundry sand up to 20%. Beyond this point, the strength decreases, making 20% the optimal replacement level for both compressive and flexural strength.

- Environmental Impact: Utilizing waste foundry sand in concrete addresses the disposal issues associated with foundry waste, reducing landfill requirements and promoting environmental sustainability.

- Economic Benefits: The use of waste foundry sand in concrete production can lead to cost savings for the ferrous and non-ferrous metal industries by reducing disposal costs and contributing to the production of greener concrete.
- Flexural Strength: The highest flexural strength was observed at 10% WFS replacement for 7-day curing and 0% for 28-day curing, indicating that lower replacement levels are more beneficial for tensile strength.
- Sustainability: The study supports the use of industrial by-products in concrete, promoting sustainable construction practices and resource conservation.
- Geopolymer concrete is fails in RCPT test because it shows the value more than 4000 according to ASTM C-1202 code
- Geopolymer concrete possess good resistance against the water penetration , depth of penetration is not exceed 25mm
- Fly ash based geopolymer concrete shows better water permeability resistance than that of GGBS based geopolymer concrete

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