

Eco-friendly Concrete using Waste Foundry Sand

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Abstract - The present research work investigates the feasibility of utilizing waste foundry sand as partial replacement of natural fine aggregate in M20 grade concrete. Natural sand was replaced by waste foundry sand in proportions of 0%, 10%, 20%, 30% and 100%. Laboratory characterization such as sieve analysis, specific gravity and water absorption was conducted, followed by slump cone test, compressive strength test and split tensile strength test at 7- and 28-days curing. The results indicated that moderate incorporation of waste foundry sand improved particle packing and matrix densification, while excessive replacement reduced workability and mechanical performance due to finer gradation and higher water absorption. The maximum compressive and split tensile strengths were obtained at 20% replacement level, indicating this proportion as the optimum dosage for structural applications. The study confirms that controlled utilization of waste foundry sand can produce economical, sustainable and eco-friendly concrete while reducing environmental burden associated with industrial waste disposal.

Key words: Foundry Sand, Concrete, Compressive Strength, Split Tensile Strength, eco-friendly construction.

INTRODUCTION

Concrete remains the most indispensable construction material in modern infrastructure development because of its adaptability, durability, moldability, and relatively low production cost. The unprecedented expansion of urban settlements, transportation networks, industrial facilities, and public utilities has substantially increased the global consumption of concrete over the past few decades. Such large-scale utilization has simultaneously intensified the demand for conventional raw materials, particularly natural river sand, which serves as the principal fine aggregate in concrete production. Since fine aggregate contributes significantly to the workability, cohesiveness, density, and mechanical integrity of concrete, the continuous extraction of natural sand has become an unavoidable consequence of infrastructure growth [1], [2].

However, excessive mining of river sand has emerged as a serious environmental concern worldwide. Unregulated removal of sand from river beds has resulted in channel instability, degradation of aquatic ecosystems, reduction in groundwater recharge, erosion of river banks, and long-term depletion of naturally available granular resources. In many developing regions, the scarcity of quality fine aggregate has also led to substantial escalation in construction cost. These concerns have shifted the attention of researchers and construction professionals toward the identification of alternative fine aggregate materials capable of reducing dependence on natural sand while maintaining the structural performance of concrete [3].

Parallel to this resource scarcity issue, modern industrial activity is generating enormous quantities of solid waste materials whose disposal has become increasingly problematic. One such industrial by-product is waste foundry sand (WFS), generated from ferrous and non-ferrous metal casting industries during moulding and core making operations. Foundry sand is primarily a uniformly graded high silica sand specifically selected for its refractory stability and binding compatibility. During repeated use under elevated casting temperatures, the sand particles become coated with residual binders, carbonaceous matter, metallic oxides, and clay impurities, eventually rendering the material unsuitable for further foundry applications. Consequently, substantial quantities of this spent foundry sand are discarded annually as industrial waste [4], [5].

The disposal of waste foundry sand presents both environmental and economic burdens. Conventional disposal practices such as open dumping and landfilling not only consume valuable land resources but may also contribute to localized contamination of soil and surrounding areas. At the same time, the material itself possesses several engineering characteristics that make it potentially suitable for reuse in cementitious composites. Waste foundry sand is predominantly silica based, exhibits granular morphology, and in many cases contains a substantial fraction of fine particles capable of occupying micro-voids within concrete. Such characteristics suggest that, when judiciously incorporated, WFS can function not merely as an inert replacement material but also as a micro-filler capable of improving particle packing density and matrix compactness [6].

In recent years, the concept of utilizing industrial by-products in concrete has gained increasing importance under the broader framework of sustainable and circular construction. The incorporation of waste foundry sand into concrete directly addresses two pressing engineering concerns: conservation of rapidly depleting natural fine aggregate resources and productive utilization of

industrial waste that would otherwise require disposal. Therefore, WFS offers a dual environmental advantage by reducing landfill burden on one hand and minimizing river sand extraction on the other. In addition, if the material can be employed without compromising structural properties, it also offers the possibility of lowering the overall cost of concrete production [7].

Despite these apparent benefits, the performance of waste foundry sand concrete is highly dependent on the replacement percentage adopted. The finer gradation and higher water absorption of WFS may significantly alter the rheological characteristics of fresh concrete and influence hydration efficiency, internal porosity, and bond development in the hardened state. While limited quantities may enhance the density of the concrete matrix through filler action, excessive replacement may lead to reduced workability, incomplete compaction, and subsequent loss of strength.

In this context, the present study investigates the feasibility of using waste foundry sand as a partial replacement of natural fine aggregate in M20 grade concrete. Concrete mixes were prepared with varying levels of WFS incorporation and experimentally evaluated through physical characterization of materials, slump test, compressive strength test, and split tensile strength test. The study aims to determine an optimum replacement level at which the environmental advantages of waste utilization can be achieved simultaneously with acceptable or improved mechanical performance, thereby contributing toward the development of sustainable green concrete for practical construction applications.

LITERATURE REVIEW

The increasing demand for sustainable construction materials has led researchers to explore the utilization of industrial by-products in concrete production. Among various alternatives, waste foundry sand (WFS) has attracted considerable attention due to its widespread availability and silica-rich composition. Foundry sand is primarily composed of high-quality silica that is repeatedly used in metal casting processes. After several reuse cycles, it becomes unsuitable for further casting operations and is discarded as waste. The disposal of this material poses significant environmental challenges, thereby encouraging its reuse in construction applications [4], [5].

Several researchers have investigated the feasibility of using waste foundry sand as a partial replacement for natural fine aggregate in concrete. Early studies reported that WFS possesses physical characteristics similar to natural sand, although it is generally finer in gradation. This finer particle size distribution enables WFS to act as a micro-filler within the concrete matrix, improving particle packing and reducing internal voids at lower replacement levels. As a result, concrete mixes containing limited amounts of WFS have shown improved mechanical performance compared to conventional concrete [6], [7].

S. M. Kacha, J. Pitroda, and J. J. Bhavsar conducted a comprehensive investigation on the use of waste foundry sand in concrete and concluded that partial replacement of fine aggregate with WFS can produce satisfactory strength and durability properties. Their findings indicated that replacement levels around 20–25% often result in improved compressive strength due to better particle packing and densification of the cement matrix. However, they also reported that excessive replacement may adversely affect strength due to the higher proportion of fine particles and increased water demand [8].

Similarly, D. R. Bhimani, J. Pitroda, and J. J. Bhavsar carried out experimental investigations on eco-friendly concrete incorporating used foundry sand. Their study demonstrated that concrete mixes containing up to 30% WFS replacement exhibited acceptable workability and strength characteristics. The researchers emphasized that the use of WFS not only improves certain mechanical properties but also contributes to reducing the overall cost of concrete by partially replacing natural sand [9].

Further research by T. C. Nwofor and C. Ukpaka focused on the fresh and hardened properties of concrete containing foundry waste. Their results indicated that while lower replacement levels maintained or slightly improved strength, higher percentages led to a reduction in compressive strength due to poor workability and inadequate compaction. They highlighted that the high water absorption and finer nature of WFS reduce the availability of free water in the mix, which negatively impacts hydration and strength development [10].

In addition to these studies, several other researchers have reported that the performance of WFS concrete is largely governed by the balance between its beneficial filler effect and its negative influence on workability. At lower replacement levels, the fine particles fill the micro-voids within the concrete, enhancing density and improving the interfacial transition zone between cement paste and aggregates. This leads to improved compressive as well as tensile strength. However, as the percentage of WFS increases, the excessive fines content results in higher water demand, reduced workability, and increased likelihood of void formation, ultimately reducing strength [11], [12].

From an environmental perspective, the utilization of waste foundry sand in concrete offers significant advantages. It reduces the burden on landfill sites, minimizes environmental pollution caused by industrial waste disposal, and decreases the dependence on natural river sand, the extraction of which leads to ecological imbalance. Thus, the use of WFS aligns with the principles of sustainable construction and circular economy [13].

Based on the review of previous studies, it can be concluded that waste foundry sand has strong potential as a partial replacement for fine aggregate in concrete. Most researchers have identified an optimum replacement range between 10% and 30%, within which concrete exhibits improved or comparable performance to conventional mixes. However, the exact optimum percentage depends on the physical properties of the foundry sand and local material conditions. Therefore, further experimental investigation is necessary to establish suitable replacement levels for specific materials and applications, which forms the basis of the present study.

MATERIALS AND METHODOLOGY

Constituent Materials

The experimental program was designed to evaluate the feasibility of utilizing waste foundry sand as a partial replacement of natural fine aggregate in M20 grade concrete. For this purpose, Ordinary Portland Cement, natural river sand, crushed coarse aggregate, waste foundry sand, and potable water were used as the principal constituent materials. All materials were collected from local sources and tested prior to concrete preparation to ensure their suitability for structural concrete applications.

Ordinary Portland Cement of 53 grade conforming to IS 8112 specifications was employed as the binding material throughout the investigation. Natural river sand passing through 4.75 mm IS sieve was used as the conventional fine aggregate in the control concrete mix. Crushed angular coarse aggregate of nominal maximum size 20 mm was adopted for all batches to provide the required load-bearing skeleton. Waste foundry sand was procured from a nearby ferrous metal casting industry after repeated use in moulding operations and subsequent disposal as industrial by-product waste. The collected material was dark grey in color, silica rich, and visually much finer than natural river sand. Potable water free from harmful salts and organic impurities was used for both mixing and curing of concrete specimens.



(a) Coarse aggregate



(b) Fine aggregate



(c) Green foundry sand

Fig. 1. Waste Foundry Sand and Conventional Aggregates Used in the Experimental Investigation.

Physical Characterization of Fine Aggregate Materials

Since the engineering behavior of concrete is significantly influenced by the physical characteristics of fine aggregate, both natural river sand and waste foundry sand were subjected to preliminary laboratory characterization. The tests included sieve analysis, specific gravity determination, and water absorption measurement in accordance with relevant Indian Standard procedures [14], [15]. The comparative physical properties obtained from laboratory testing are presented in **Table 1**.

Table 1. Comparative Physical Properties of Natural Sand and Waste Foundry Sand

Property	Natural Sand	Waste Foundry Sand
Fineness Modulus	2.43	1.653
Specific Gravity	2.74	1.973
Water Absorption (%)	4.68	8.30
Particle Texture	Medium Graded	Very Fine Granular
Color	Yellowish Brown	Dark Grey

The observed values indicate that waste foundry sand possesses substantially finer particles and significantly higher water absorption than natural river sand. Such characteristics suggest that the material may contribute to improved micro-void filling at lower replacement levels while simultaneously increasing the moisture demand of fresh concrete mixes.

Gradation Analysis

To assess the particle size distribution of the fine aggregate materials, sieve analysis was carried out in accordance with IS 2386 (Part I) [14]. The percentage retained on each standard sieve was calculated and used to determine the gradation characteristics.

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Table 2. Comparative Sieve Analysis of Natural Sand and Waste Foundry Sand

IS Sieve Size	Percentage Passing of Natural Sand (%)	Percentage Passing of Waste Foundry Sand (%)
4.75 mm	88.43	100.00
2.35 mm	79.66	100.00
1.60 mm	67.91	99.58
600 μ	54.71	97.26
300 μ	17.50	35.14
150 μ	4.52	64.76
75 μ	0.00	0.62
Pan	0.00	0.00

The gradation results clearly reveal that waste foundry sand contains a much larger proportion of finer particles compared to natural river sand. This confirms its potential role as a micro-filler material within the concrete matrix.

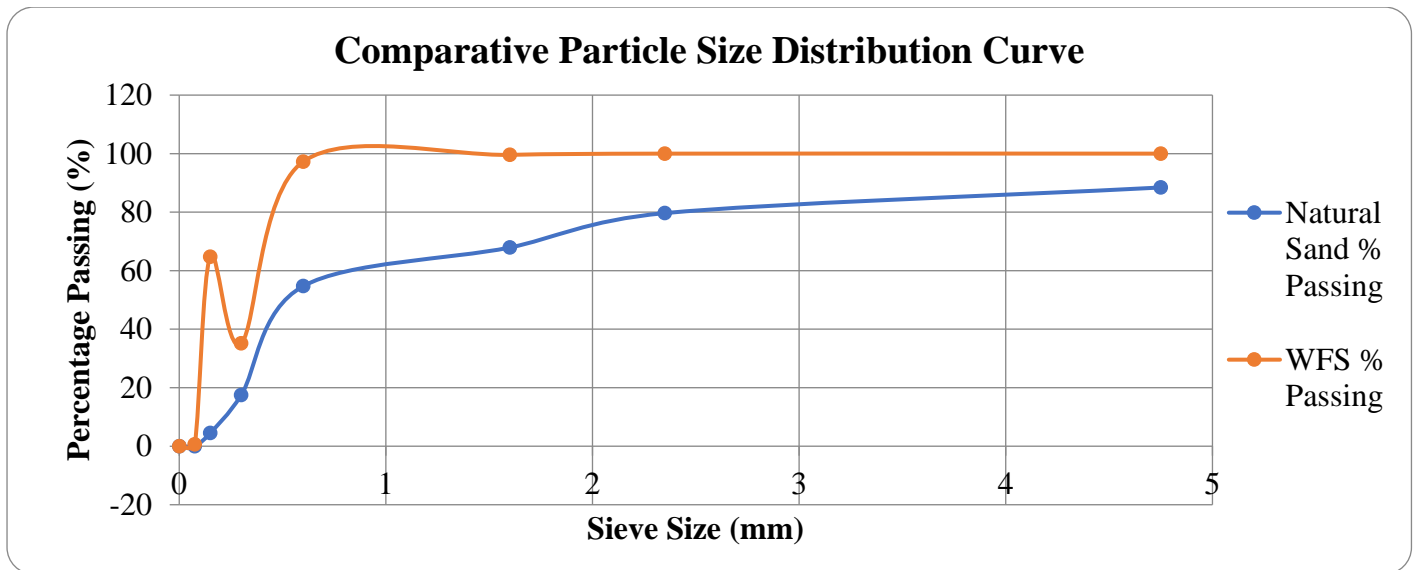


Fig. 2. Comparative Gradation Curve of Natural River Sand and Waste Foundry Sand.

Specific Gravity and Water Absorption

Specific gravity and water absorption tests were conducted in accordance with IS 2386 (Part III) [15] to determine the density-related and moisture-related characteristics of the aggregate materials. The obtained results are summarized in **Table 3**.

Table 3. Specific Gravity and Water Absorption Values of Aggregate Materials

Material	Specific Gravity	Water Absorption (%)
Natural Sand	2.74	4.68
Waste Foundry Sand	1.973	8.30
Coarse Aggregate	2.61	1.64

The lower specific gravity and higher absorption capacity of waste foundry sand indicate that the material contains lighter and finer particles with greater tendency to absorb mixing water, which is expected to influence the rheological properties of concrete.

Concrete Mix Proportioning

M20 grade concrete mix was designed in accordance with IS 10262:2009 [16] while maintaining a constant water-cement ratio of 0.50 for all concrete batches. Waste foundry sand was introduced as a partial replacement of natural fine aggregate at five different levels, namely 0%, 10%, 20%, 30%, and 100%, in order to systematically evaluate its influence on concrete behavior.

Table 4. Mix Proportions for Different Replacement Levels

Mix ID	WFS Replacement (%)	Cement (kg/m ³)	Water (L/m ³)	Natural Sand (kg/m ³)	WFS (kg/m ³)	Coarse Aggregate (kg/m ³)
NS	0	340	197	724.67	0	1126
R10	10	340	197	652.20	65.06	1126
R20	20	340	197	579.74	130.12	1126
R30	30	340	197	507.27	195.18	1126
R100	100	340	197	0	724.67	1126

Preparation, Casting and Curing of Specimens

For each concrete batch, the constituent materials were weighed accurately according to the designed proportions. Dry mixing of cement, natural sand, waste foundry sand, and coarse aggregate was first carried out thoroughly to ensure uniform distribution of materials. The measured quantity of water was then added gradually and machine mixing was continued until a homogeneous concrete mass was obtained.

Fresh concrete from each batch was initially subjected to slump cone test. Thereafter, the concrete was placed into moulds in three equal layers and compacted adequately using a tamping rod to minimize entrapped air voids. Cube specimens of size 150 mm × 150 mm × 150 mm were prepared for compressive strength determination, while cylindrical specimens of 150 mm diameter and 300 mm height were cast for split tensile strength evaluation. A total of thirty cube specimens and thirty cylindrical specimens were prepared considering all replacement levels and curing ages.

After 24 hours of casting, all specimens were demoulded and immersed in a water curing tank until the designated testing ages.



(a) Preparation & Casting

(b) Curing

(c) Testing of Concrete Specimen

Fig. 3. Preparation, Casting, Curing and Testing of Concrete Specimens.

Experimental Testing Program

The testing program adopted in the present study included evaluation of both fresh and hardened concrete properties. Fresh concrete workability was determined using slump cone test in accordance with IS 1199 [17]. Hardened cube specimens were tested for

compressive strength as per IS 516 [18], while cylindrical specimens were tested for split tensile strength in accordance with IS 5816 [19]. All specimens were tested after 7 days and 28 days of curing, and the average values obtained from the tested samples were used for final comparison.

Table 5. Experimental Testing Schedule

Test Conducted	Standard Followed	Specimen Type	Testing Age
Slump Test	IS 1199	Fresh Concrete	Immediate
Compressive Strength Test	IS 516	Cube (150 mm)	7 Days and 28 Days
Split Tensile Strength Test	IS 5816	Cylinder (150 × 300 mm)	7 Days and 28 Days

RESULTS AND DISCUSSION

Workability Behavior

The workability of fresh concrete containing different percentages of waste foundry sand was evaluated using slump cone test. The measured slump values for all concrete mixes are presented in **Table 6**.

Table 6. Slump Values of Concrete Mixes

Mix ID	Waste Foundry Sand Replacement (%)	Slump Value (mm)
NS	0	98
R10	10	92
R20	20	86
R30	30	79
R100	100	61

A continuous reduction in slump value was observed with increase in the percentage of waste foundry sand. The control mix exhibited the highest slump of 98 mm, whereas the concrete containing complete replacement of natural sand with waste foundry sand recorded the minimum slump of 61 mm. The mixes containing 10%, 20%, and 30% replacement showed slump values of 92 mm, 86 mm, and 79 mm respectively. This clearly indicates that the incorporation of waste foundry sand reduced the workability of fresh concrete in a progressive manner.

The reduction in slump can be primarily attributed to the finer particle size and higher water absorption capacity of waste foundry sand. Due to the increased specific surface area of finer particles, additional water is required to maintain lubrication and ease of flow within the concrete matrix. Simultaneously, the absorptive nature of WFS reduces the amount of free water available for mobility, resulting in comparatively stiffer and harsher mixes at higher replacement percentages [11], [20].

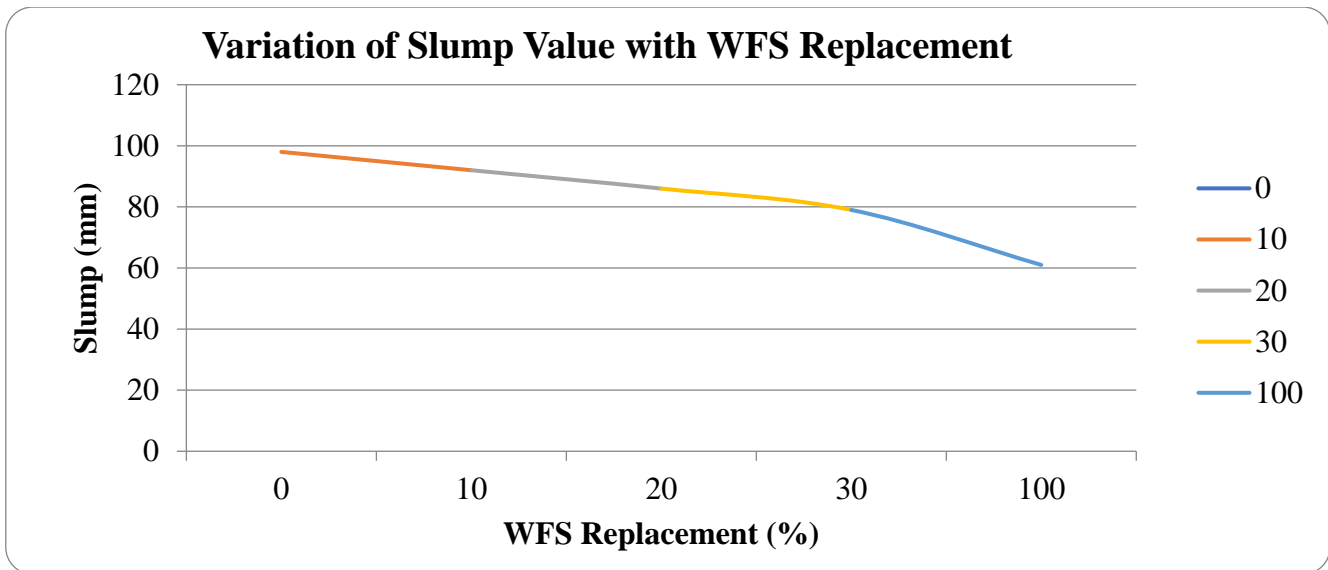


Fig. 4. Variation of Slump Value with Waste Foundry Sand Replacement.

Compressive Strength Characteristics

The compressive strength of cube specimens was determined after 7 days and 28 days of water curing. The average strength values obtained for each replacement level are summarized in **Table 7**.

Table 7. Average Compressive Strength of Concrete Cubes

Mix ID	Waste Foundry Sand Replacement (%)	7 Days Strength (N/mm ²)	28 Days Strength (N/mm ²)
NS	0	15.634	26.86
R10	10	15.334	23.20
R20	20	15.933	28.36
R30	30	14.867	25.90
R100	100	14.867	23.16

At 7 days curing, the control mix developed an average compressive strength of 15.634 N/mm². The mixes containing 10% and 20% waste foundry sand recorded strengths of 15.334 N/mm² and 15.933 N/mm² respectively, whereas the 30% and 100% replacement mixes showed comparatively lower values of 14.867 N/mm².

At 28 days curing, a more pronounced variation in compressive strength was observed. The control mix attained a compressive strength of 26.86 N/mm². The 10% replacement mix showed a lower value of 23.20 N/mm², while the 20% replacement mix exhibited the maximum compressive strength of 28.36 N/mm² among all trial batches. Further increase in waste foundry sand content caused a reduction in strength, with the 30% and 100% replacement mixes recording 25.90 N/mm² and 23.16 N/mm² respectively.

These results indicate that partial incorporation of waste foundry sand improves the compressive resistance of concrete up to an optimum replacement level of 20%. The increase in strength at this level can be associated with the micro-filler action of finer foundry particles, which occupy internal capillary voids and improve the compactness of the cementitious matrix. However, excessive incorporation of foundry fines increases water demand, reduces workability, hinders proper compaction, and consequently lowers the final compressive strength of concrete [8], [9].

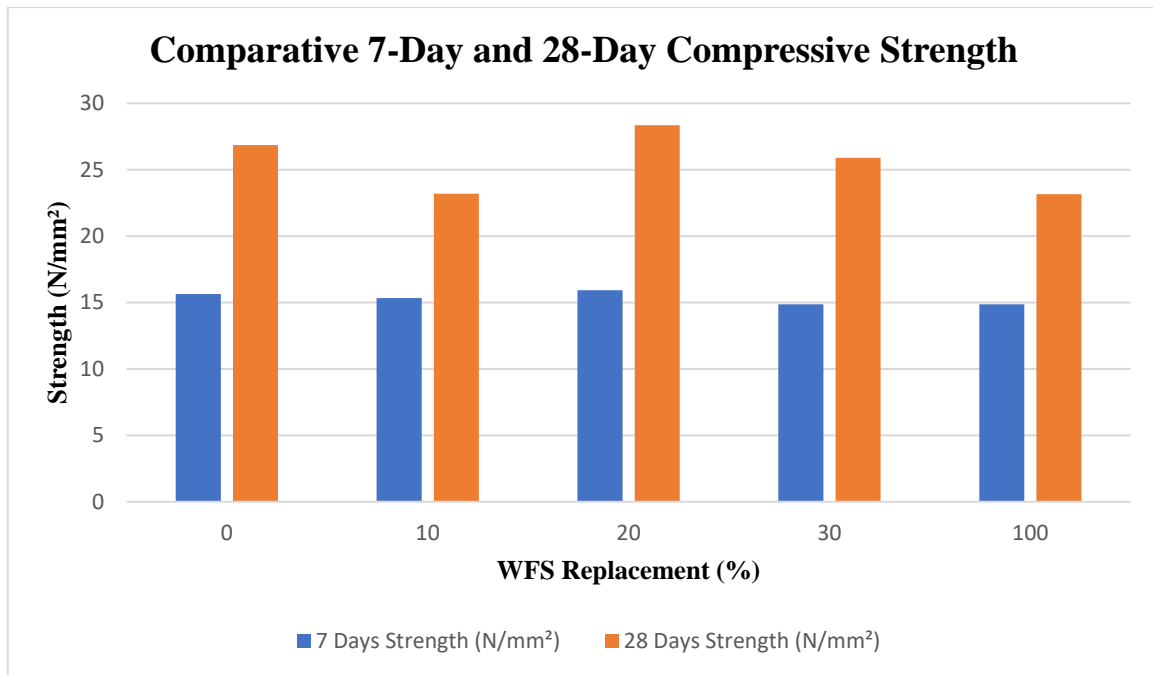


Fig. 5. Comparative 7-Day and 28-Day Compressive Strength of Concrete Mixes.

Split Tensile Strength Characteristics

The tensile resistance of concrete was assessed by split tensile strength test on cylindrical specimens after 7 days and 28 days curing. The average values obtained are given in **Table 8**.

Table 8. Average Split Tensile Strength of Concrete Cylinders

Mix ID	Waste Foundry Sand Replacement (%)	7 Days Strength (N/mm ²)	28 Days Strength (N/mm ²)
NS	0	1.68	2.46
R10	10	1.54	2.18
R20	20	1.79	2.61
R30	30	1.63	2.37
R100	100	1.49	2.11

At 7 days curing, the control concrete developed an average split tensile strength of 1.68 N/mm². The mixes containing 10%, 20%, 30%, and 100% waste foundry sand recorded values of 1.54 N/mm², 1.79 N/mm², 1.63 N/mm², and 1.49 N/mm² respectively. Among these, the highest early-age tensile resistance was observed for the R20 mix.

A similar trend was observed after 28 days curing. The control mix attained a split tensile strength of 2.46 N/mm², while the mixes R10, R20, R30, and R100 recorded values of 2.18 N/mm², 2.61 N/mm², 2.37 N/mm², and 2.11 N/mm² respectively. The maximum tensile strength was therefore achieved at 20% replacement of natural fine aggregate with waste foundry sand.

The improvement in split tensile strength at moderate replacement levels may be attributed to the improved internal cohesion and stronger interfacial bond developed due to the fine granular nature of waste foundry sand. The finer particles fill the micro-voids around aggregate surfaces, thereby increasing resistance against crack initiation and propagation. However, beyond the optimum replacement limit, the adverse effect of reduced workability and improper compaction becomes dominant, resulting in lower tensile resistance [10], [12].

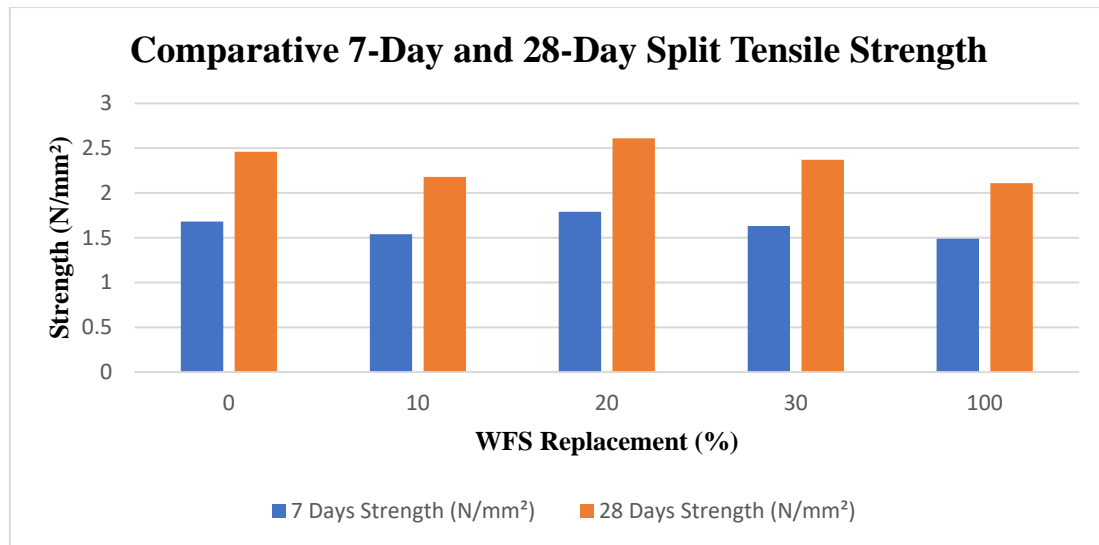


Fig. 6. Comparative 7-Day and 28-Day Split Tensile Strength of Concrete Mixes.

Overall Performance Assessment

A combined evaluation of fresh and hardened concrete properties clearly indicates that the incorporation of waste foundry sand affects concrete behavior through two competing mechanisms. On one hand, the finer particles of WFS improve particle packing and internal matrix densification, thereby enhancing compressive and tensile strength at moderate replacement levels. On the other hand, the same finer particles increase water absorption and reduce fresh concrete mobility, which adversely affects compaction when the replacement percentage becomes excessive [8], [11].

Among all the trial mixes investigated, the concrete containing 20% waste foundry sand consistently exhibited the most balanced overall performance. Although a moderate reduction in slump was observed, this mix produced the highest 28-day compressive strength and the highest 28-day split tensile strength among all trial specimens. Therefore, it can be concluded that 20% replacement provides the optimum balance between beneficial filler action and adverse moisture absorption effects.

CONCLUSION

Based on the detailed experimental investigation conducted on M20 grade concrete incorporating waste foundry sand as a partial replacement of natural fine aggregate, it can be concluded that waste foundry sand possesses considerable potential as a sustainable alternative material in concrete production. The preliminary characterization of materials established that waste foundry sand is significantly finer than natural river sand and exhibits comparatively higher water absorption, indicating its ability to influence both the fresh and hardened behavior of concrete.

The workability results demonstrated a continuous reduction in slump value with increase in waste foundry sand content. This behavior confirms that the finer gradation and higher absorptive nature of WFS increase the moisture demand of the concrete mix and reduce the amount of free water available for flow. Although the reduction in consistency was noticeable, the lower replacement mixes retained acceptable workability for practical concrete applications.

The hardened concrete properties showed that partial replacement of natural fine aggregate with waste foundry sand can significantly improve the mechanical performance of concrete when used within an optimum range. Both compressive strength and split tensile strength increased progressively from the control mix up to 20% replacement, after which a decline was observed. The maximum 28-day compressive strength and split tensile strength were recorded for the R20 mix, indicating that this replacement level provided the most effective particle packing, reduced internal voids, and improved bond development within the concrete matrix.

Beyond the optimum level, the excessive quantity of fine foundry particles increased water demand, reduced compaction efficiency, and created internal weak zones, resulting in lower mechanical strength. Therefore, while waste foundry sand contributes beneficial

filler action at moderate replacement levels, its excessive incorporation is not favorable for structural concrete without additional water modification or admixture support.

From the combined evaluation of fresh and hardened properties, it is evident that approximately 20% replacement of natural fine aggregate with waste foundry sand offers the most balanced and technically efficient concrete mix. The study therefore confirms that controlled utilization of waste foundry sand not only reduces the dependence on natural river sand but also provides a productive and environmentally responsible reuse route for industrial waste materials. Hence, waste foundry sand can be recommended as an economical, eco-friendly, and structurally viable constituent for the development of sustainable green concrete.

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