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EXPERIMENTAL INVESTIGATION ON MECHANICAL AND FLEXURAL BEHAVIOUR OF CONCRETE WITH FOUNDRY SAND AS PARTIAL FINE AGGREGATE REPLACEMENT

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SUMMARY

Waste Foundry Sand (WFS) is the disposal that has been of great concern to the environment and this is as a result of high volumes generated in the process of metal casting. The building sector is developing eco-friendly alternatives to the natural aggregates in order to minimize environmental degradation and save natural resources. In this paper, the application of WFS as a partial substitute of fine aggregate in the concrete is explored and its impact on the major mechanical properties such as compressive strength, split tensile strength, and flexural properties of reinforced concrete beams assessed. Concrete samples were prepared using foundry sand as a substitute of fine aggregate at 0%, 5% 10% 15 and 20 weight proportions and cured at 7, 14 and 28 days. The achievements of the experiment indicated that the compressive and tensile strengths improved significantly by up to 6.8 and 7 % respectively at 5-10 % replacement levels and higher replacement percentages (15 and 20 %) showed strength decline. Flexural tests revealed that 5% replacement mix was most effective with 20 % increment in load bearing capacity accompanied by enhanced crack resistance. These results show that WFS can be effectively applied as a natural fine aggregates substituent in concrete production, especially in the replacement levels of up to 10% and can be part of more environmentally-friendly construction.

Key words: *WFS, concrete sustainability, mechanical properties, fine aggregate, compressive strength, reinforced concrete beams.*

INTRODUCTION

The increasing demand of infrastructure and the fast urbanization has put a strain on the natural resources. One of the most impacted materials is natural river sand that is used extensively as the fine aggregate in production of concrete. Excessive use of this resource has led to ecological disequilibrium, increased construction prices as well as a shortage in most areas. Simultaneously, the industrial sector produces huge volumes of waste materials and by-products that become a significant conservation problem without proper disposal [1][2]. Using industrial by-products is one of the sustainable solutions in the reduction of resource depletion and environmental contamination.

The foundry sand waste is another more promising by-product of metal casting industry [3]. It is largely composed of silica sand of high grade, and of remnants of binders and other substances employed in the molding process [4]. The sand becomes wastage after being used severally in foundries due to loss of binding power [5][6]. Disposal of foundry sand causes serious environmental issues, such as the pollution of the land, dust pollution, and pollution of the groundwater [7]. At the same time, the corporal properties of foundry sand, such as grain size, texture can be compared to natural fine aggregate. This resemblance gives a good justification on the application of natural sand as a semi-alternative to concrete [8].

Some of the examiners reported that the use of foundry sand in concrete can improve or retain its mechanical properties at reduced replacement levels [9]. This has led to the formation of developments in the strength of compression and tensile up to certain %ages when foundry sand is utilized. Conversely, replacement levels are usually increased with a decrease in level as a result of poor bonding and greater voids. Besides the strength properties, the foundry sand has been found to enhance the stability properties, including the resistance to chemical attack, because of the high-density of the particles. The degree of these enhancements however differs with the mix proportions, curing age and replacement %ages [10][11].

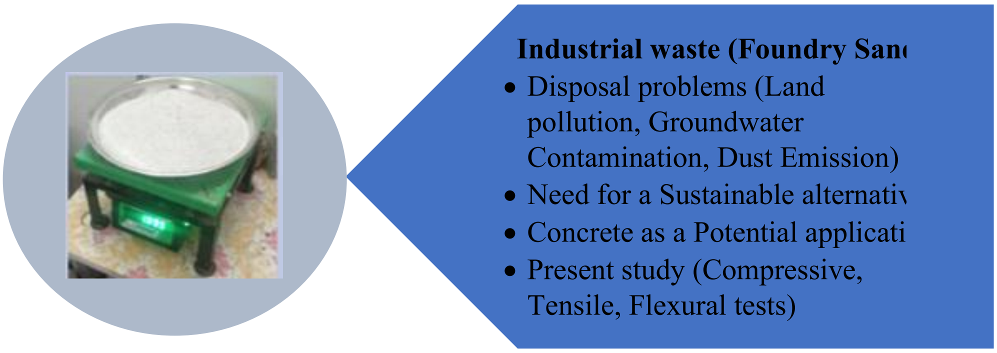

Figure 1. Conceptual representation of foundry sand, its disposal issues, and its utilisation in the present study for concrete performance evaluation

Besides the elements of strength and durability, the sustainability element of the use of foundry sand is also very interesting. Millions of tones of sand are byproducts of foundries, in the world annually and a small %age of it is used again or recycled. Most of them find their way into the trash heaps, not only causing disposal problems, but also posing a risk to the environment because of the leakage of chemicals and the use of the valuable resources that are represented by land [12][13]. A two-fold advantage with two sides can be realized by channeling this waste material into construction projects, especially into the production of concrete: natural river sand is saved and environmental pollution caused by industrial waste will be reduced [14]. Besides, the reuse of foundry sand upholds the concepts of a circular economy and sustainable development that foster the efficient use of resources and minimize industrial waste. Given the magnitude of construction in developing world, implementation of these waste-based options can play a major role in ensuring an eco-friendlier infrastructure [15][16] as illustrated in Figure 1. Nevertheless, the prevalence of the use of foundry sand in structural works can be explained as long as its mechanical and flexural behavior is proven by the experiments under the close-to-realistic conditions [17]. This highlights the need to conduct extensive research on the potential of foundry sand not only in laboratory experiments but also in structural components like beams which directly translate to on-site performance [18][19].

Although the above are positive findings, majority of past researches have solely been confined to cube compressive strength and cylinder tensile strength with few studies having been conducted on flexural behavior and load-displacement response of structural components [20] [21]. Beams are important elements in reinforced concrete structures, therefore, their response to flexural loading gives important information about the practicability of foundry sand concrete [22]. Flexural behavior is a manifestation of the ability of the substance to resist bending, but also the ductility and the resistance to crack propagation, which are crucial to the structural safety and life-cycle. Hence, an apparent research gap lies in the correlations of the cube/ cylinder strength performance and flexural load-displacement behavior of beams filled with the foundry sand [23].

Effect of Waste Foundry Sand (WFS) in concrete on compressive, tensile, and flexural strengths has been mainly into the scope of the previous models and studies. Although such researches have shown that moderate and low replacement levels of WFS (up to 10 %) can enhance the strength of concrete, it has also been found that when it reaches higher levels, it starts to weaken because of bonding and high porosity. Numerous works have devoted attention to laboratory tests only, investigating the simplest parameters of strengths, without considering the performance of WFS-based concrete in the conditions of their real-life, structural use. Additionally, the effect of WFS on the long-term sustainability of concrete e.g. resistance to chemical attacks, freeze-thaw, and ingress of chlorides has been under studied. Flexural behavior, which is an important aspect of the concrete beam performance in real life, has received little research thus there is a gap in the knowledge on the complete potential of WFS in structural concrete.

The proposed model will fill these gaps by not only assessing the mechanical characteristics of the concrete that has different WFS replacement rates but also emphasize on flexural performance of the reinforced concrete beams. The research will be based on real-world loading conditions in contrast to past research that will examine the long-term sustainability of WFS concrete especially its ability to sustain environmental stresses. The model will also cover the best %age of WFS replacement which will increase mechanical strength as well as structural performance without affecting the durability which will give a better insight into the applicability of the model in the production of sustainable concrete. This holistic solution will provide the practical advice to utilize WFS in the real-life construction and overcome the constraints of previous studies and offer new perspectives on its ability to be used as a viable alternative to natural fine aggregates.

The purpose of the study is to determine the possibility of utilizing WFS as a partial substitute of fine aggregate in concrete, and how it influences the mechanical properties of concrete including compressive strength, split tensile strength, and flexural behavior of reinforced concrete beams as examples. The major findings of this paper are:

- Measuring the effect of WFS as a partial replacement of fine aggregate: In this study, the mechanical performance of concrete with WFS replacement at different levels (0%, 5, 10, 15 and 20 %) is actually carried out, which will give a complete picture of how the material affects the structural strengths of concrete.
- Assessment of flexural behavior of concrete beams using WFS: Unlike most studies which center on compressive and tensile strength, this research is one of its kind to consider the flexural behavior of concrete beams and provide an insight on load displacement response, crack resistance and ductility.
- Setting the optimum WFS replacement level: The research finds the optimum %age of WFS replacement required (5-10%), which will improve the mechanical properties of concrete as a valuable recommendation on the sustainable use of the material in the construction industry.

It is hoped that the results of this study will give meaningful recommendations to other engineers, academicians, and decision makers on the adoption of sustainable construction techniques. The usage of WFS will not only facilitate the ecological construction but also facilitated the proper management strategy over waste disposal in the foundry industry. The practicality of partially replacing natural aggregates with foundry sand is critically evaluated in this piece of experimental work thus adding to the body of knowledge in sustainable concrete technology.

The paper explores the concept of using the Waste Foundry Sand (WFS) as a partial alternative of fine aggregate in concrete in terms of compressive, split tensile, and flexural strengths. Section 1 presents the environmental issues and the necessity of alternatives of sustainability. In Section 2 the experimental program, materials, mix design and testing procedure is described. Section 3 has the results and discussion which discusses the mechanical properties of concrete at different levels of replacement of WFS. Section 4 provides the future research directions and recommendations, and Section 5 is the conclusion of the main findings and the potential of WFS as sustainable alternative of natural fine aggregates in the production of concrete.

EXPERIMENTAL PROGRAM

Materials

Ordinary Portland Cement (OPC) with a 53 grade was adopted as the major cementitious constituent in any concrete mix design. Its physical characteristics were checked and confirmed to suit the corresponding standards that are established in Indian specifications. The cement was found to be of normal consistency of 30%. The first and last setting phases were set at 190 minutes and 330 minutes, respectively. The relative density (specific gravity) of the cement was determined to be 3.06 and the fineness which is a measure of the particle size was determined to be 2.07%. The material characteristics that were used in this investigation are outlined in Table 1.

Table 1: Properties of Cement, Fine Aggregate, and Coarse Aggregate

Test	Cement	Fine aggregate	Coarse aggregate
Consistency, %	30. 00	-	-
Initial setting time, mins.	190.00	-	-
Final setting time, mins.	330.00	-	-
Specific gravity	3.06	2.67	2.69
Fineness	2.07	3.06	
Absorption of water, %	-	3.11	3.76
content of silt, %	-	3.18	-
Bulk density, kg/m^3	Loose	1616.20	1378.10
	Compact	1842.30	1576.40

The fine aggregate in concrete mix was locally sourced river sand that was sieved through a 4.75 mm sieve. The specific gravity of this sand was 2.67, its water absorptive capacity was 3.11 and silt content was 3.18. It was found to have a bulk density of 1616.2 kg/m 3 when in the loose form and of 1842.3 kg/m 3 when compacted. The coarse component used was crushed angular coarse aggregates with a nominal maximum size of 20 mm. The specific gravity, water absorption, and bulk densities of these aggregates were 2.69, 3.76 and 1378.1 kg / m 3 (loose) and 1576.4 kg/ m 3 (compacted), respectively. Besides traditional materials, WFS was used partially as a replacement of fine aggregate at the replacement %age of 0, 5, 10, 15 and 20 by weight. This is foundry sand that has been procured in a local metal casting plant and sieved to remove large size particles and impurities. Both the mixing and curing processes were always done with potable water. High-yield strength deformed (HYSD) bars of 12 mm diameter were inserted longitudinally on the top and bottom faces of the beams to perform the assessment of flexural strength of beam specimens. The reinforcement was done at 8 mm diameter stirrups, at 150 mm center to center to provide shear resistance.

Mix Proportion

The concrete mix design at the grade of M30 was developed as per those provisions which were given in the IS 10262:2009 whereas the structural design provisions concerning concrete beams were observed in the IS 456:2000. It was expressly prepared so as to attain a target compressive strength of 30 MPa at 28 days of curing. At the end of this, the proportional mix was fixed to 1:1.83:2.87 of cement, fine aggregate and coarse aggregate respectively with the water to cement ratio maintained at a constant figure of 0.45. Five concrete batches were made to explore the appropriateness of WFS as a partial substitute of natural river sand. River sand was substituted by foundry sand in all the 0, 5, 10, 15, and 20 % increments. The control mix whose sand was not foundry sand was named C-FS0, whereas the other ones were named C-FS5, C-FS10, C-FS15, and C-FS20 depending on their replacement %ages.

The concrete specimens were made in the form of cubes, cylinders, and rectangular beam in order to explore compressive and split tensile strength properties. Each batch had a constant water-cement ratio so that the results of the tests could be compared. Table 2 summarizes the specific mix compositions to be used in each type of concrete.

Table 2: Mix Proportion of Concrete with Foundry Sand Replacement

Mix ID	Cement (kg/m³)	Natural Sand (%)	Foundry Sand (%)	Coarse Aggregate (kg/m³)	Water–Cement Ratio
C-FS0	1	100	0	2.87	0.45
C-FS5	1	95	5	2.87	0.45
C-FS10	1	90	10	2.87	0.45
C-FS15	1	85	15	2.87	0.45
C-FS20	1	80	20	2.87	0.45

Testing Procedures

The mechanical and flexural strength of concrete was tested and found to depend on the effects of foundry sand by the casting and testing of different specimens. Each mix variation was represented by concrete samples (cylinders 100 200 mm) in shape of cylinders, cubes (150 150 150 mm) and beams (700 150 150 mm). All of the specimens were demoulded after 24 hours of initial setting and put in water in order to cure them till the specified days of testing. The cube specimen was used to calculate compressive strength under a Universal Testing Machine (UTM) as required by the IS 516 procedures. Three cubes were used to take the average result of each curing stage. Split tensile strength was measured by cylindrical testing as per IS 5816 in which a load was applied to the cylinder along its diameter till it failed. Each mix had an average of three mix specimens. The reinforced concrete beam that was reinforced with steel was used as samples in a UTM to examine flexural performance with two-point loading. A total of two high yield strength deformed (HYSD) 12 mm bars were used to reinforce each beam, both in the tension and compression areas. Shear was resisted by using eight-millimetre stirrup distance of 150 mm between them. Upon testing, the load at first crack, ultimate load capacity and the response to load-deflection were recorded as some of the key parameters. The measurement of the deformation under loading was monitored by dial gauges to measure deflection at the mid-span. Close monitoring of all tests was done and failure modes recorded to facilitate interpretation of results as will be discussed in the following section.

Software Details

The software and hardware involved in testing and data collection was the Universal Testing Machine (UTM) that was used in all tests of mechanical nature (compressive, tensile, and flexural strength). The UTM had load sensors and displacement transducers which were connected to a data acquisition system to measure the data accurately and record it in real time. The UTM was controlled and tests monitored using the LabView software and the data collected included load, displacement, and deflection and the mechanical properties of compressive strength, tensile strength and flexural strength were also automatically calculated. In flexural tests, dial gauges were applied under the midpoint of both beams to measure the deflection and the readings were recorded manually or added to the LabView system and were tracked and analyzed automatically. The obtained data was measured and analyzed with the help of statistical programs, like Excel or SPSS and the findings were summarized by means of the descriptive statistics (mean, standard deviation, and range) and comparative analysis evaluated according to the effect of the different levels of WFS replacement on the mechanical properties of the concrete.

Performance Metrics

Compressive strength, split tensile strength and flexural strength which are the mechanical properties of the concrete were assessed using the following formulas:

Compressive Strength: Compressive strength is defined as the capacity of the concrete to resist compressive push or strain or compressive resistance. It is calculated by straining a concrete specimen (in most cases cubes or cylinders) and dividing the maximum load by the cross-sectional area. This is one of the basic characteristics in determining the capacity of concrete to sustain loads.

$$f_c = \frac{P}{A} \qquad (1)$$

In Equation 1, Where:

- f_c= Compressive strength (MPa or N/mm²)
- P= Peak stress on the specimen (N or kN)
- A= cross-sectional area of specimen (mm² or cm²)

Split Tensile Strength: Split tensile strength is a test that is performed by using compressive force on the diameter of cylindrical specimen. The cylinder is loaded under the loading machine and at its horizontal position to determine the tensile strength the maximum load at failure is used. This test is a simulation of behavior of concrete, when it is under tensile stresses, frequently observed in the form of a beam or slab.

- $$f_t = \frac{2P}{\pi DL} \qquad (2)$$

In Equation2, Where:

- f_t= Split tensile strength (MPa or N/mm 2)
- P = Failure load (N or kN) at maximum.
- D= Diameter of specimen (mm or cm)
- L= Length of the specimen (mm or cm)

Flexural Strength: Flexural Strength is used to determine the capacity of the concrete to resist deformation or cracking with flexural or bending. It is established by loading a beam at two points (in three point or four points bending test) and determining the highest maximum stress to failure through the applied load and dimension of the beam. Such property is essential in the concrete elements such as beams and slabs which are prone to bending in practical applications.

$$f_r = \frac{PL}{bd^2} \qquad (3)$$

In Equation 3, Where:

- f_r= Flexural strength (N/mm 2 or Mpa)
- P= Failure load (N or kN) at maximum.
- L= Length of the distance between the supports (mm or cm)
- b = Width of the beam (mm or cm)
- d = Depth of the beam (mm or cm)

They are formulas applied to determine the performance of the concrete specimens that are subjected to different tests to give an overview of the mechanical properties of the material.

RESULTS AND DISCUSSION

Compressive Strength of Cube Specimens

The compressive strength values of the concrete cubes after 7, 14 and 28 days of curing are tabled in Figure 2, with varying %ages of foundry sand being used as a partial replacement of fine aggregate. The results have been investigated in detail in Figure 3a to 3c. The compressive strength of the control mix (C-FS0) after 7 days of the curing process was 22.03 MPa. Addition of 5% foundry sand also enhanced the strength to 23.57 Mpa which is almost 7 % better than the control. It was found when the replacement rate was 10 % that there was a marginal decrease with a strength of 22.91 Mpa (however still greater than that of the control). Nevertheless, the replacement levels of 15 and 20 % exhibited an apparent decrease in the strength, and the values of 19.17 MPa and 18.99 MPa were the results of lower early-age performance, as presented in Table 3.

Table 3. Average Compressive Strength of Cube Specimens at Different Curing Ages

Mix ID (Cubes)	**7 Days (MPa)**	**14 Days (MPa)**	**28 Days (MPa)**
Conventional (C-FS0)	22.03	26.84	33.96
FS-5%	23.57	28.72	36.34
FS-10%	22.91	27.92	35.32
FS-15%	19.17	24.70	28.87
FS-20%	18.99	21.47	25.47

Figure 2. Moulding and testing of concrete specimens to determine compressive resistance

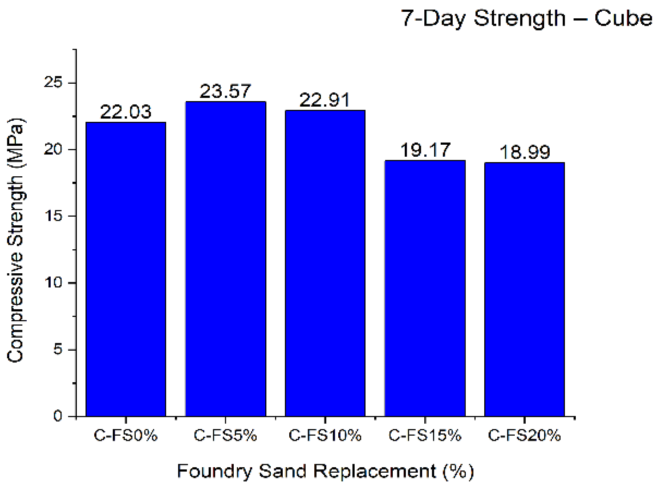

Figure 3a. Compressive strength value for 7 days for cubes incorporating varying %ages of foundry sand.

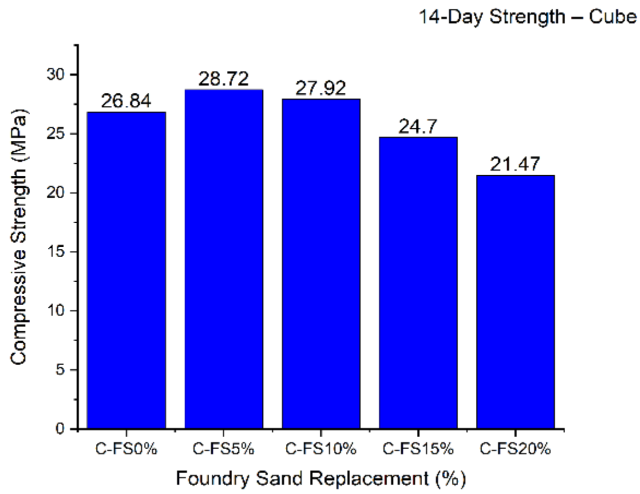

Figure 3b. Compressive strength value for 14 days for cubes incorporating varying %ages of foundry sand.

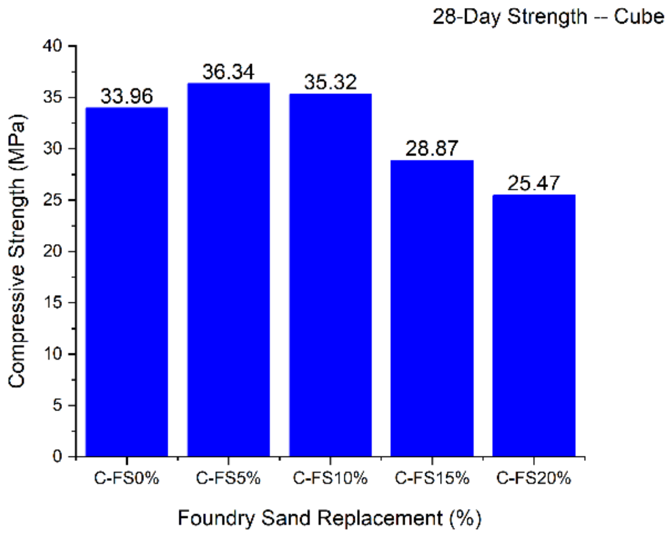

Figure 3c. Compressive strength value for 28 days for cubes incorporating varying %ages of foundry sand.

A related development was found at 14 days of curing. The maximum strength of 28.72MPa was reached at a 5% replacement level, and the control mix reached 26.84MPa. Similar performance was also seen in the 10% mix which had 27.92 MPa. Contrary, 15 % and 20 % replacement level mixes reduced to 24.70 Mpa and 21.47 Mpa respectively, which points to the negative outcome of increased contents of foundry sand. The positive effect of foundry sand at lower concentrations was again confirmed by the long-term development of the strengths at 28 days. Control mix was 33.96 MPa and control 5 % and 10 % mixes were 36.34 MPa and 35.32 MPa, respectively. After 10, the values of strengths decreased to 28.87 MPa (15) and 25.47 Mpa (20).

Overall, the results show that a moderate replacement of natural sand with foundry sand in the proportion of between 5-10 % always leads to an increase in the compressive strength of concrete at all the curing stages. On the contrary, higher substitution rates have the tendency to reduce strength which can be attributed to lack of bonding and there would be more internal holes in the matrix. Therefore, the best %age of foundry sand that should be used to combine compressive performance is 5-10 %.

Split Tensile Strength of Cylinder Specimens

Figure 5a to 5c depicts the change in the split tensile strength of cylindrical concrete samples with 7, 14, and 28 days curing with a ratio of foundry sand replacement. The tensile strength of the control mix (CY-FS0) was 2.86 Mpa in 7 days of curing. The 5 % foundry sand replacement mix exhibited the maximum strength of 3.06 Mpa which is equivalent to a %age of approximately 7 % higher than the control. On the same note, the 10-% replacement mix had a slightly higher strength of 2.98 Mpa. Nonetheless, the strength decrease was observed with an increase in replacement levels with the 15 % and 20 % mixes giving 2.78 MPa and 2.75 Mpa strength respectively as in Table 4.

Table 4. Variation in Average Split Tensile Strength of Cylindrical Samples Over Curing Time

Mix ID (Cylinder)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
Conventional (CY-FS0)	2.86	5.21	6.04
FS-5%	3.06	5.57	6.46
FS-10%	2.98	5.42	6.28
FS-15%	2.78	5.05	5.86
FS-20%	2.75	4.79	5.62

Figure 4. Testing of cylinder specimens for split tensile strength evaluation.

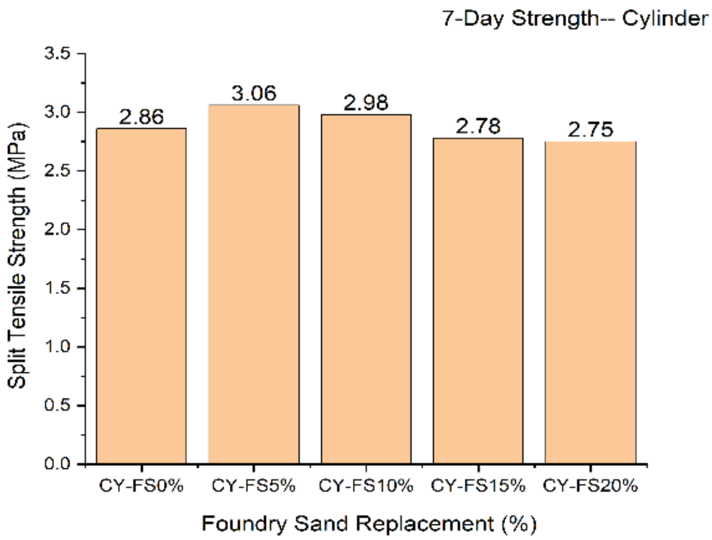

Figure 5a. 7-day split tensile strength results cubes

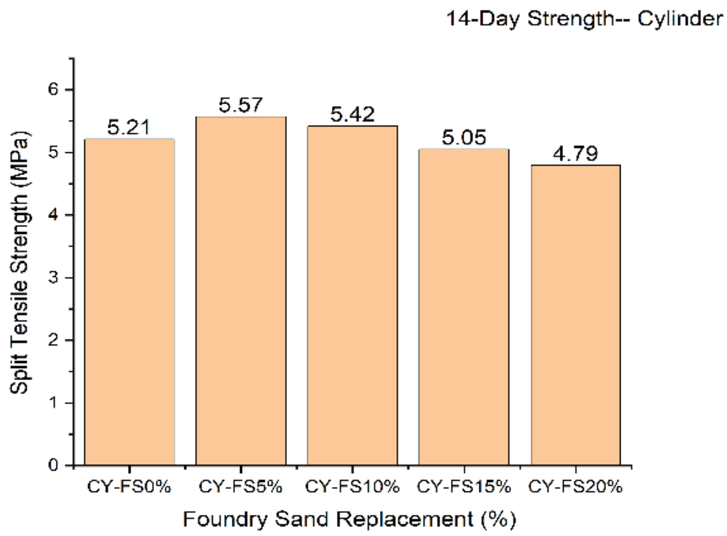

Figure 5b. 14-day split tensile strength results for cubes

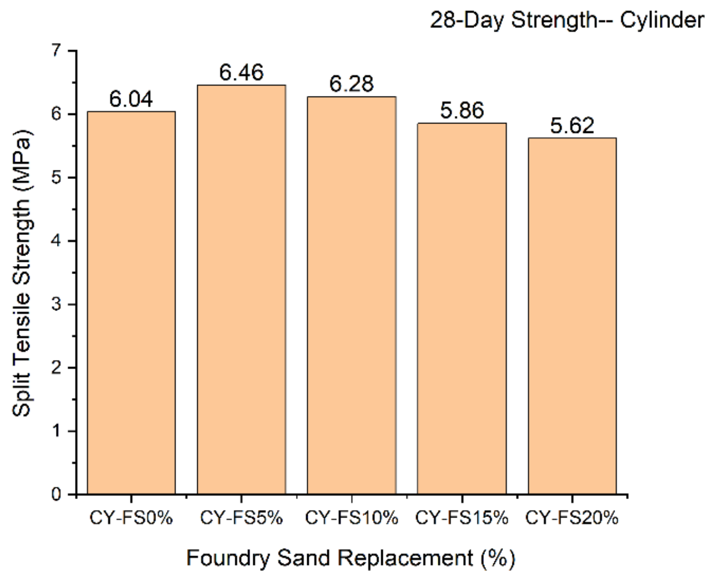

Figure 5c. 28-day split tensile strength results for cubes incorporating varying %ages of foundry sand.

This trend was observed at a tender age of 14 years. The control mix was 5.21 MPa and the 5 % replacement level was maximum 5.57 Mpa. The 10 % mixture registered a pressure of 5.42 MPa, once more a bit higher than the control. On the contrary, both 15% and 20% blends had lower values of 5.05 MPa and 4.79 MPa, respectively, and showed that it lost strength with increased replacement. The results of the 28 days also supported the positive behavior of foundry sand in lower %ages. The split tensile strength was 6.04 Mpa. Comparatively, 5% and 10% replacement with foundry sand had better strengths of 6.46 and 6.28 MPa respectively. Further increases in extra levels, however, led to the descent and the extra level of 15% and 20% showed lower strengths of 5.86 MPa and 5.62 MPa respectively (Figure 4).

The evaluations indicate that the replacement of a fine aggregate by foundry sand at a %age of 5 to 10 will result in an increment in split tensile strength of concrete. But with replacement exceeding 10, tensile strength has been found to decrease. The improvement at the low substitution rate is probably attributed to the presence of well distributed particles and improvement in adhesion of the cementitious matrix and the aggregates. On the other hand, the decrease in strength at the higher %ages will be anticipated because of the existence of excess fines and formation of weaker interfacial transitions zones.

Flexural Behaviour of Beams

The flexural loading of structural performance of the RC beams as represented in (Figures 6 and 7) with and without replacement of foundry sand was undertaken under the two-point loading. These load-displacement curves are respectively given in (Figures 8-10). Beams that were experimented on were of three types: conventional beams (CB-0), beams with 5% foundry sand replacement (FS-5), and beams with 10% replacement (FS-10). In the case of the traditional beams, the major visible crack was observed to be at a mean load of 5055kN, and the deflection of the mid-span was around 1.111.29 mm. The final load that was achieved by these beams varied between 89 kN and 95 kN and the corresponding displacements were 2.73mm and 3.80mm. Conversely, beams that had 5% replacement with foundry sand had better flexural performance. The initial load under crack was attained to 6065 kN and corresponding deflections were 1.311.47 mm, which is an enhancement of the crack resistance. The final load was also enhanced and it constantly reached 100 kN, with the highest deflections of 3.00-3.05 mm. This points out that the incorporation of foundry sand at 5 % contributed to the increased cracking resistance as well as the load carrying capacity of the beams that were on display in Table 5.

Table 5. Flexural Performance of Beams with Foundry Sand Replacement

Mix ID (Beams)	Load at First Visible Crack (kN)	Deflection at First Crack (mm)	Maximum Load Capacity (kN)	Maximum Deflection at Failure (mm)
Conventional (CB-0)	~50–55	~1.11–1.29	89–95	2.73–3.80
FS-5%	~60–65	~1.31–1.47	100	3.00–3.05
FS-10%	~55–60	~1.26–1.36	95	2.70–2.74

Figure 6. Casting process of RC beams with foundry sand replacement.

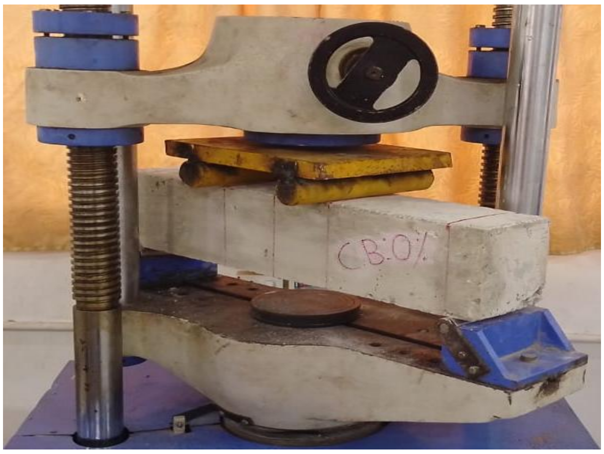

Figure 7. UTM was employed to examine the flexural strength of reinforced concrete beams.

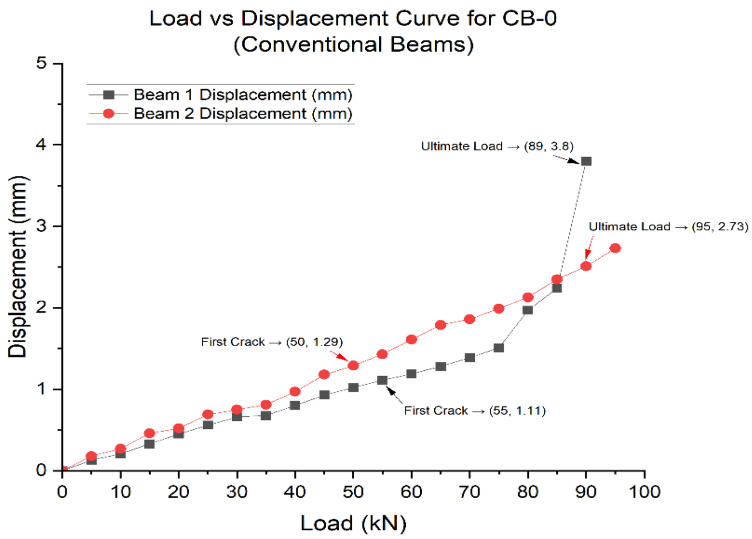

Figure 8. curve for load displacement in conventional beams (CB-0)

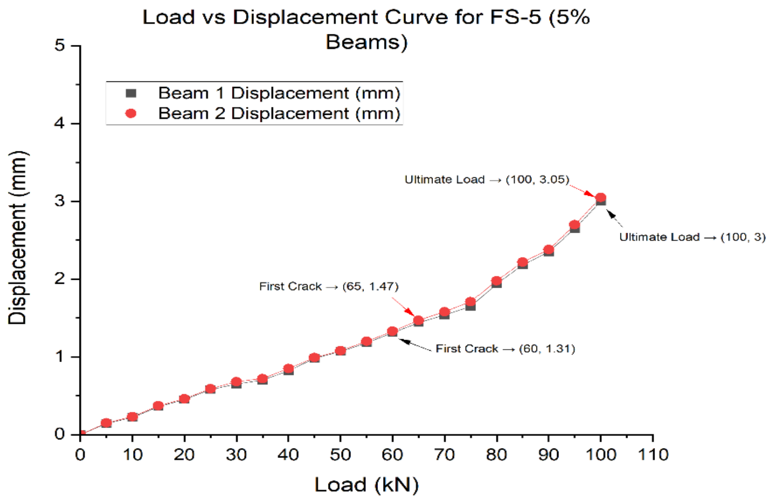

Figure 9. curve for load displacement of beams with 5% foundry sand replacement (FS-5)

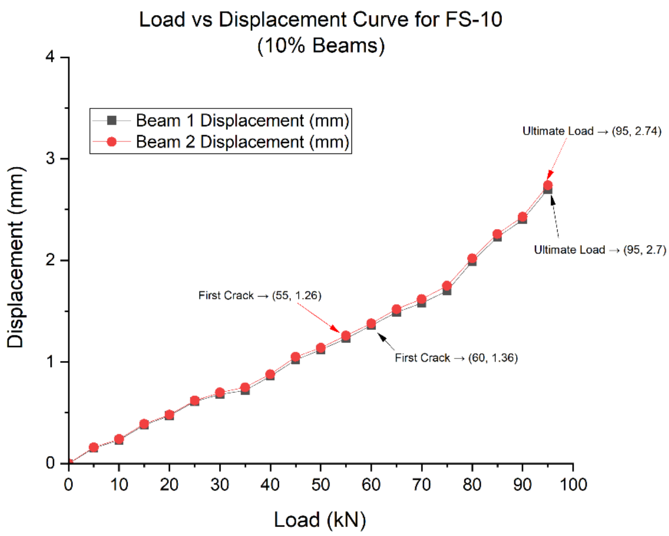

Figure 10. Load-displacement curve of beams with 10% foundry sand replacement (FS-10)

The FS-10 beams also exhibited enhanced behaviour related to the control, although slightly lower than that of the FS-5 beams. The first crack load was observed to be 55 kN to 60 kN with deflections ranging between 1.26 and 1.36mm. The final load was 95 kN and displacements were 2.70-2.74 mm. Though FS-10 was much superior concerning the conventional beams, when it came to flexural behaviour it was not so significant, as compared to the FS-5 beams which indicated a slight loss of efficiency beyond the optimum level. In general, the findings show that beams with 5% foundry sand replacement showed the most favorable flexural response, which was marked by increased first crack loads, ultimate loads and ductility, thus showing that low contents of foundry sand replacement have a positive effect on structural performance.

Load–Displacement Characteristics

The first crack load was observed to be 55 kN to 60 kN with deflections ranging between 1.26 and 1.36mm. The final load was 95 kN and displacements were 2.70-2.74 mm. Though FS-10 was much superior concerning the conventional beams, when it came to flexural behaviour it was not so significant, as compared to the FS-5 beams which indicated a slight loss of efficiency beyond the optimum level. In general, the findings show that beams with 5% foundry sand replacement showed the most favorable flexural response, which was marked by increased first crack loads, ultimate loads and ductility, thus showing that low contents of foundry sand replacement have a positive effect on structural performance.

The load dislocation behavior of the beams using foundry sand was researched to find out its flexural behavior and ductility. Figure 11 shows the results of the conventional beams (CB-0), 5 % foundry sand beams (FS-5) and 10 % foundry sand beams (FS-10).

The final loads of the traditional beams were determined as 89 kN of Beam 1 and 95 kN of Beam 2 respectively. FS-5 beams performed better in the assessment and the two beams supported both ultimate loads of 100 kN. The positive effect on load-carrying capacity due to a minor %age of foundry sand is mentioned in this enhancement. Improved behaviour was also observed with the FS-10 beams with a 95 kN recorded across Beam 1 and Beam 2, as well as the control. The FS-10 beams were as equal in capacity with respect to the conventional beams whereas they performed slightly lower compared to FS-5 beams.

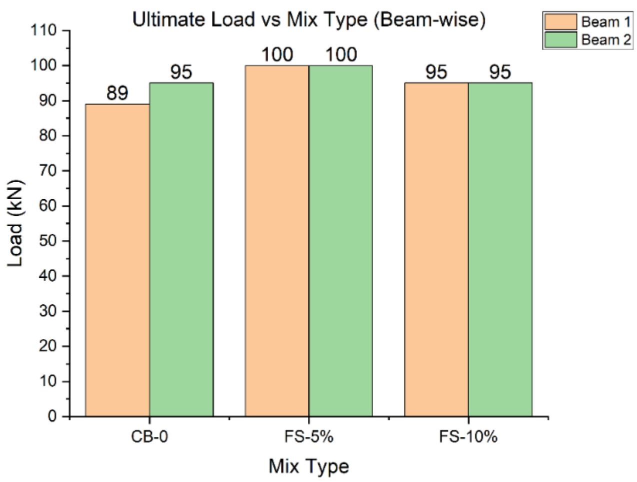

Figure 11. Ultimate load comparison with (CB-0), 5% foundry sand (FS-5), and 10% foundry sand (FS-10)

The above load-displacement curves also support further the fact that FS-5 beams were more ductile and took longer to reach cracks as compared to conventional ones. Initial crack loading was noted to be high in FS-5 (60-65kN) than the CB-0 (50-55kN) which indicates a superior crack resistance. FS-10 beams recorded improvements in the first crack load (5560 kN) as well but not as high as that of FS-5. Also, the ultimate load values of the displacement of FS-5 beams were bigger, which implies increased energy absorption capacity.

All in all, it can be seen that the 5 % replacement of foundry sand offers the best flexural behavior as it has higher first crack loading, increased ultimate load capacity, and enhanced ductility. Beams with 10 % replacement were better than the traditional beams but failed to be better compared with the FS-5 beams. The results affirm the fact that a managed alternative to fine aggregate like foundry sand enhances the behaviour of beams in flexural loading.

FUTURE SCOPE AND RECOMMENDATIONS

The current study has revealed that foundry sand can effectively be employed as a constituent of fine aggregate in concrete especially at %ages (510%), at which, improvement in the flexural, compressive and tensile properties were apparent. Though the study offers some useful information, there are a number of prospects of future research and practice. The new directions and recommendations are proposed as follows:

To gain a better idea of the durability of foundry sand concrete the future researches will determine how sustainable a foundry sand concrete will be under adverse conditions such as exposure to sulphate, entry of chloride, carbonation and freeze thaw cycles.

Fine studies with SEM, XRD and other sophisticated methods can assist in explaining the interfacial transition zone (ITZ) and the micro-filler effect of foundry sand so as to explain the observed variations in strength at changed replacement value.

Concrete sand can be also enhanced by the addition of concrete, and the same process is achieved by mixing up the sand with the other cementitious materials, such as fly ash, silica fume/GGBS that can effectively counterbalance the equal strength and strength as well as durability characteristics.

The practicality of implementing the foundry sand concrete in structural members like slabs, columns, and composite systems in the laboratory will be confirmed by expanding the research to other large members of the structural elements.

The benefits of using foundry sand in concrete in terms of sustainability should be quantified by conducting a thorough life-cycle analysis cost and environmental impact, which will justify its usage within the construction codes and industry practice.

CONCLUSION

In this research, the researcher examined the potential of Waste Foundry Sand (WFS) as a green substitute to fine aggregates in concrete, in terms of its effect on compressive, split tensile and flexuring strengths. The experimental findings showed that the compressive and tensile strengths were significantly improved as up to 10 % of natural fine aggregates were substituted with WFS with compressive strength improving by 6.8 % and tensile strength by 7 % at the best levels of 5-10 % substitution. There was also an increase in flexural strength especially when 5% WFS was used as a replacement; this increased the load bearing capacity by 20 % and also increased the crack resistance. These results indicate that WFS may be successfully used in the manufacture of concrete and provides a green solution to natural sand, and retains or enhances the mechanical properties of the material. The results of the study have a high implication on sustainable construction practices especially on the environmental impact of the sand extraction and waste disposal in the foundry industry.

Nevertheless, the given research is also restricted with respect to short-term mechanical performance in laboratory conditions, where no assessment of the long-term performance of WFS-based concrete in real-world environmental conditions including freeze-thaw cycles, sulfate attack, and chloride ingress is conducted. The long-term performance of WFS concrete and its performance in the severe environmental conditions and its application on the large-scale structures should also be investigated in the future. Moreover, further research may also be done on the possibilities of combining the use of WFS with other auxiliary materials, fly ash or silica fume, to make the concrete more sustainable and longer lasting.

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