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Original Article

Evaluation of Durability and Microstructural Properties of Waste Foundry Sand as A Sustainable Alternative to M-Sand in Concrete Production

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Abstract - *High-quality natural river sand is becoming harder to find and is becoming less readily available. There is a limited amount of this resource; hence, attempts are being made to investigate alternatives. Naturally occurring river sand is considered a non-renewable resource because it takes millions of years for it to be produced. It is possible for manufactured sand to completely replace natural sand. Waste foundry sand has been used in place of produced sand in the manufacturing of concrete due to a lack of investigation. Concrete's durability and mechanical qualities are enhanced by the addition of reclaimed foundry sand. This work explores the long-term performance and microstructure of concrete, including both synthetic and recycled foundry sand. At intervals of 7, 14, 28, 56, and 90 days, we evaluated M40 grade concrete, both as a control combination and as mixtures comprising different percent (10%, 20%, 30%, 40%, and 50%) of waste foundry sand with manufactured sand in concrete. Tests for acid resistance ($MgSO_4$), chloride attack (HCL), and rapid chloride permeability were performed on the specimens made and tested to learn more about the WFS concrete's durability features. Thermogravimetric Analysis (TGA/DSC), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), and Fourier Transform Infrared (FTIR) are some of the cutting-edge techniques used to examine the microstructural properties of concrete made using M-sand with WFS. The findings are compared concerning particle morphology and elemental composition. In order to make WFS work as a substitute for fine aggregate in concrete, the right quantity was added based on results from microstructure and durability tests.*

Keywords - *Fourier Transform Infrared (FTIR), Thermogravimetric Analysis (TGA/DSC), Waste Foundry Sand, Manufactured Sand, Durability Properties.*

1. Introduction

By utilising cutting-edge methods that increase productivity and quality, the construction sector is adjusting to the times. Concrete is a crucial material in building. The coming crises in the usage of natural resources as physical materials are driving up the already excessive prices even further. We have to find a solution to this issue of the depletion of our natural resources. One of the main causes of the current environmental issues brought on by the metal casting industry's excessive output is waste foundry sand. Reducing the foundry's environmental impact could be achieved by using its leftovers in the building. Ferrous and non-ferrous metals are cast using foundry sand due to its uniform grain size and malleability. It is sand made of fine silica. Sand that is exceptionally fine is used while casting metal. The sand that is used in metal casting has a long lifespan before it is considered useless and thrown away [1]. Every year, India produces almost 2 million metric tons of waste foundry sand. Foundry sand can be substituted for fine aggregate to produce inexpensive, lightweight, and long-lasting concrete. The aggregates (both coarse and fine), water, and additives that make up concrete all work together to make the material as strong as it is.

Consequently, it is possible to modify the properties of concrete by adjusting the proportions of the various materials used to replace the original ones. It is feasible to produce affordable, ecologically friendly building materials by using waste products that harm the environment. This study [2] explores different ratios of fine aggregate and discarded foundry sand in an attempt to find a way to produce affordable and environmentally friendly concrete. Over the past ten years, aggregate consumption has surpassed the expansion of many countries' economies and building sectors. Because artificial aggregate manufacturing requires very expensive transportation, it may not be as advantageous when natural aggregate sources are located distant from the construction site. The environmental effects of extracting natural aggregates must also be considered. When this occurs, the countryside typically experiences long-term repercussions [3]. When aggregates created from industrial waste are utilised instead of excavation, less damage is done to the environment and both natural and artificial aggregate resources [4]. Foundries generate numerous unwanted by-products during casting. Non-ferrous alloys consist of non-iron-based metals such as aluminium, copper, brass, and bronze. Because it is abundant and inexpensive, more than 70 percent of the waste material is moulding sand [5]. The organic components and binder utilized in the moulds make the mixture simple to assemble. The moulding and casting processes in foundries require silica sand. This type of sand is not found in standard banks or nature. Sand can be reused indefinitely in foundries. Waste foundry sand is non-recyclable foundry sand that has been discarded (WFS). It is also known as used-foundry sand (UFS) and SFS [6]. Waste foundry sand could be a viable substitute for natural sand in concrete, providing recovered fine aggregate. The economy and the environment will benefit from the discovery of natural sand (fine aggregate) replacements that are at least as strong and long-lasting as the original materials. The possibility of using these by-products as concrete additives is not well understood. Managing WFS from foundries is among the main problems. Waste sand (WFS) has a black colour due to the little particles in it. The typical physical and chemical characteristics of WFS are dependent on a number of factors, including the metal, casting process, technology, type of furnace, and finishing methods [7].

To find out how much stronger concrete constructed with synthetic sand (WFS) than with natural sand (NSS), Gurpreet Singh et al. (2012) ran an experiment. We used five different weight percent of WFS to substitute natural sand: zero, five, ten, fifteen, and twenty percent. The proportions of concrete mixes with and without WFS have been developed using five different approaches. The concrete's durability was assessed at 7, 28, and 91 days by compression and splitting tensile strength tests. Ultrasonic pulse velocity and elastic modulus were assessed at 28 and 91 days, respectively. The time required to kill out each combination was assessed in a Rapid Chloride Permeability test. It was found that by replacing some of the fine aggregates in conventional concrete with WFS, its strength and durability were somewhat improved. Concrete is a ubiquitous and indispensable material in all building projects. Research is still being done on the use of waste foundry sand (WFS) in place of natural sand in concrete.

The workability, split tensile strength, and compressive strength of this concrete in both its flexible and hardened states were evaluated and contrasted with standard concrete. A conventional cube and cylinder were put through seven, fourteen, twenty-eight, fifty-six, and ninety-day testing to ascertain the concrete's characteristics.

1.1. Relevance to Research

A sustainable substitute for natural sand in concrete is discarded foundry sand. A by-product of the metal casting business, waste foundry sand is normally thrown away. We can lessen the metal casting industry's negative environmental effects while simultaneously conserving natural resources by employing leftover foundry sand in concrete. Sand found naturally is a finite resource that is becoming harder to find. Natural sand mining may have a detrimental effect on the environment, resulting in habitat loss and river contamination. Waste foundry sand is a more environmentally friendly option since it does not call for further quarrying or mining. It has also been shown that waste foundry sand functions just as well as manufactured sand in concrete. Studies have shown that the properties of concrete produced with leftover foundry sand may be on par with or even better than those of concrete prepared with natural sand. It is because discarded foundry sand, which has fine-grained properties and may fill cavities in the concrete mixture and give strength and can be used. Waste foundry sand may benefit both the environment and the economy when it is used in concrete. It may help lessen the negative effects of the metal casting industry on the environment, save natural resources, and provide employment in the building and recycling sectors.

2. Material and Experimental Procedure

The proportion of the mixture in concrete influences its qualities. In order to maintain quality, the concrete mix must be evaluated. Throughout the construction, the mixture should be homogenous constant, and we cast all the cube cylinders using M40 grade concrete in this present study. The mixing is done in a pan mix with a capacity of 40 kg. The research here makes use of M Sand as its fine aggregate.

Besto Mining Private Limited of Yalagalahalli, Chikkaballapur, Karnataka, was the miner of the M-sand that was purchased. To ensure this M Sand is suitable for use in concrete, it has been appropriately graded. The diameter of the granules can range between 150 microns and 4.75 millimetres. Graphs of particle size analysis for each alternative, calculated using IS 383-1970, are used to generate particle size analysis graphs for each mix of WFS + M-sand (Figure 1). In this investigation, to prevent balling, the Polycarboxylate Ether (PCE) Superplasticizers are used regularly. Using surplus foundry sand, these superplasticizers are added to concrete mixtures. The composite mixtures were introduced and thoroughly mixed for two or three minutes before cement and water were added.

Following industry standards, this combination is combined. The combination was then mixed in accordance with industry standards.Waste foundry sand should be distributed evenly throughout the mixture. The powder may clump together and not spread if it is added to the moist liquid right away. JSW brand cement, i.e. Portland slag cement, was employed in this study. It meets the specifications of IS: 12269-1987. Table 1 displays the physical features of the aggregates. Table 2 shows the concrete mix proportions using leftover foundry sand.

Table 1. Physical properties of aggregate as per IS 2386 PART III-1963.

S.No	Properties	Coarse aggregate	M-Sand	WFS
1	Specific gravity	2.64	2.59	2.32
2	Bulk density (loose)	1325 kg/m^3	1693	1350 kg/m^3
3	Bulk density (Compacted)	1685 kg/m^3	1790 kg/m^3	1598 kg/m^3
4	Fineness modulus	7.68	2.64	1.74

Table 2. The mix proportions of concrete with waste foundry sand per 1 Cubic m of concrete and SP is constant at 4170 ml for all mixes

Mixes	Cement kg	WFS (%)	WFS kg	M- Sand kg	C.A kg	Water Lit
0%WFS+100%MS	417	0	0	797	1211	146
10%WFS+90%MS	417	10	79.7	717.3	1211	146
20%WFS+80%MS	417	20	159.4	637.6	1211	146
30%WFS+70%MS	417	30	239.1	557.9	1211	146
40%WFS+60%MS	417	40	318.8	478.2	1211	146
50%WFS+50%MS	417	50	398.5	398.5	1211	146

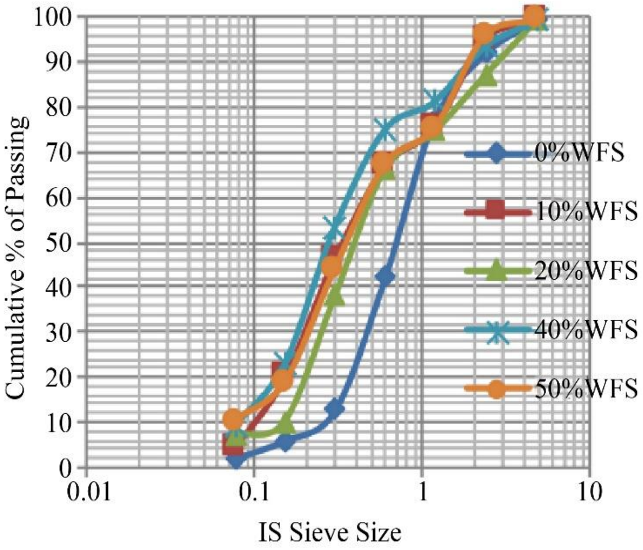


Fig. 1 Particle size analysis of casted mixes

3. Results and Discussion

Research in this area aims to examine the impact of waste foundry sand (WFS) on concrete properties via the examination of durability studies: rapid chloride permeability test, acid attack (MgSo4), and chloride attack (HCL).

The Microstructural attributes of concrete produced with M-sand and WFS are analysed using advanced methods like Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), Thermogravimetric Analysis (TGA/DSC), and Fourier Transform Infrared (FTIR). The purpose of this research is to find out how the addition of WFS affects the overall qualities of concrete.

3.1. Compressive Strength

The compressive strength of various concrete mixes is exhibited in Figure 2. WFS-enhanced concrete will eventually outlast regular concrete. Nonetheless, the finished product was still superior to the control mix despite a 30% increase in strength and a 40% decrease in toughness from 0% to 50% WFS.

In comparison to the control concrete, the compressive strength of blends containing 10, 20, 30, 40, and 50% WFS increases by 3.94%, 6.98%, 19.48%, 11.65%, and 11.34% after 28 days, respectively. At 56 days, the respective strength gains for 10%, 20%, 30%, 40%, and 50% WFS are 5.44 percent, 8.66 percent, 16.72 percent, 10.76 percent, and 8.38 percent. Following 90 days, there are five distinct percent increases: 4.55 percent, 7.95 percent, 12.35 percent, 9.09 percent, and 7.55 percent.

Results from different ages show that the compressive strength grows from zero to thirty percent replacement in a steady manner. It starts to decrease at thirty percent, but at fifty percent, you still have much influence over it. It is consistent with this pattern regardless of age. When used in place of sand, the fine fragment of WFS increases the densification and strength of the paste framework because of its higher silica content and lower elastic modulus than conventional sand.

Over time, the ability of concrete to withstand compression has increased. It seemed plausible that WFS could be used to partially replace coarse aggregate in concrete mixes, given that concrete made with WFS had a higher compressive strength.

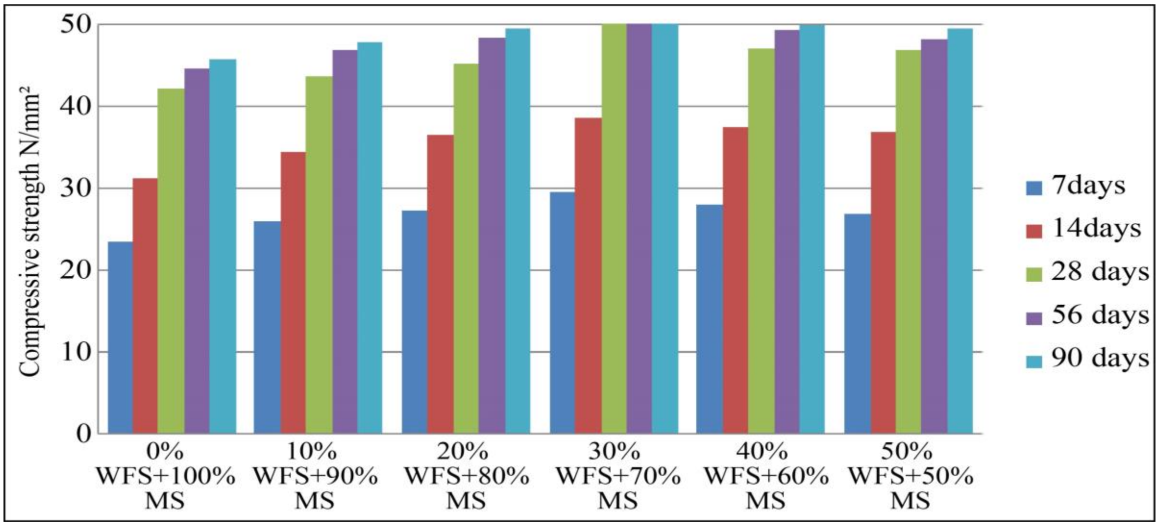


Fig. 2 Results of compressive strength tests conducted on various mixer configurations

3.2. Acid Attack

To determine the durability of concrete, a specimen must be submerged in a highly concentrated MgSo$_4$ solution. Figure 3 shows the curing of specimens in MgSo$_4$ solution. After 28 days, 56 days, and 90 days in Figure 3, weight loss was already evident. The table displays the percent of concrete sample weight loss. From 0 to 50 percent WFS, a reduction in strength loss of 30 percent and a reduction in the toughness of 40 percent produced a material that was superior to the control blend. After 28 days, the strength loss of concrete mixtures containing 10, 20, 30, 40, and 50 percent WFS is increased by 1.52 percent points, 1.38 percent points, 1.27 percent points, 1.02 percent points, 1.16 percent points, and 1.22 percent points, respectively, compared to control concrete. After 56 days, the WFS of 10%, 20%, 30%, 40%, and 50% rose by 1.79 percent, 1.68 percent, 1.53 percent, 1.36 percent, 1.43%, and 1.64% rise, respectively. Within the next three months, you may see a growth of 2.02%, 1.84%, 1.72 %, 1.54%, 1.65.7%, or 1.78.7 %.

Fig. 3 Curing of cubes in MgSo$_4$ solution

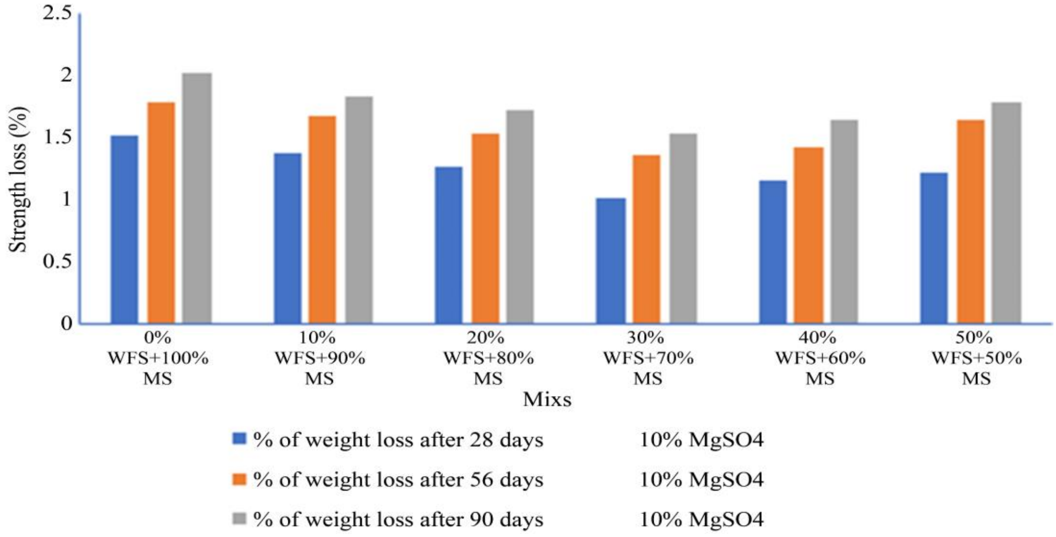


Fig. 4 Strength loss in acid attack

3.3. Chloride Attack

To evaluate the specimen's durability, it needs to be submerged in a highly concentrated HCL solution. Figure 5 depicts the specimens being cured in an HCL solution. In Figure 6, there was a discernible decline in weight at 28 days, 56 days, and 90 days. The table displays the percent of weight loss for a given sample. Between 0 and 50% WFS, strength loss was reduced by 30% and toughness loss by 40%, resulting in a material that outperformed the control mix. After 28 days, the strength loss of the concrete mixtures containing 10, 20, 30, 40, and 50% WFS is higher than that of the control concrete by 11.93%, 11.12%, 10.56%, 9.98%, and 10.49%, respectively. After 56 days, the WFS was 20.56 percent, 19.21 percent, 17.96 percent, 16.43%, and 17.34% for 10%, 20%, 30%, 40%, and 50%, respectively. A rise of 31.51, 27.77, 25.36, and 23.82 percent is possible. Following ninety days, 25.92 and 26.48 percent were noted.

Fig. 5 Curing of cubes in HCL solution

3.4. RCPT

There is no evidence that Waste Foundry Sand (WFS) has ever been utilised in place of M-sand in concrete mixtures. Figure 7. illustrates the Rapid Chloride Permeability Test (RCPT) setup for concrete specimens. The final results of the rapid chloride permeability test for concrete specimens containing WFS and M-sand are shown in Figure 8. The results indicate that the Coulomb value decreases as the proportion of WFS in M-sand increases, up to 30% of WFS, suggesting densification of the concrete and enhanced resistance to chloride penetration. By contrast, the Coulomb value is somewhat higher at 40% WFS than at 30% WFS. Based on the concrete's state at 90 days, several observations have been made. According to the requirements set by ASTM C 1202-2012, all of the concrete mixes had low permeability, with Coulomb values varying between 1000 and 2000. Permeability to chloride ions should be kept low to moderate in order to guarantee excellent endurance.

Reduced calcium ion concentrations and resulting pH depletion are responsible for the enhanced penetration resistance in gel pore fluids. The increase in pore structure and subsequent reduction in the conductivity channel for ions is a consequence of the pozzolanic process. The fluxes of chloride ions entering and leaving concrete are monitored. The microstructures of concrete are improved with a 28-day curing period and lower test values (indicating better hydration). After 28 days, the RCPT values for 30% waste foundry sand were 1,239.400 coulombs, compared to 310 coulombs for the controlled concrete. This study has shed light on the significance of fine-to-coarse aggregate material ratios, waste by-product utilization, and curing/testing processes.

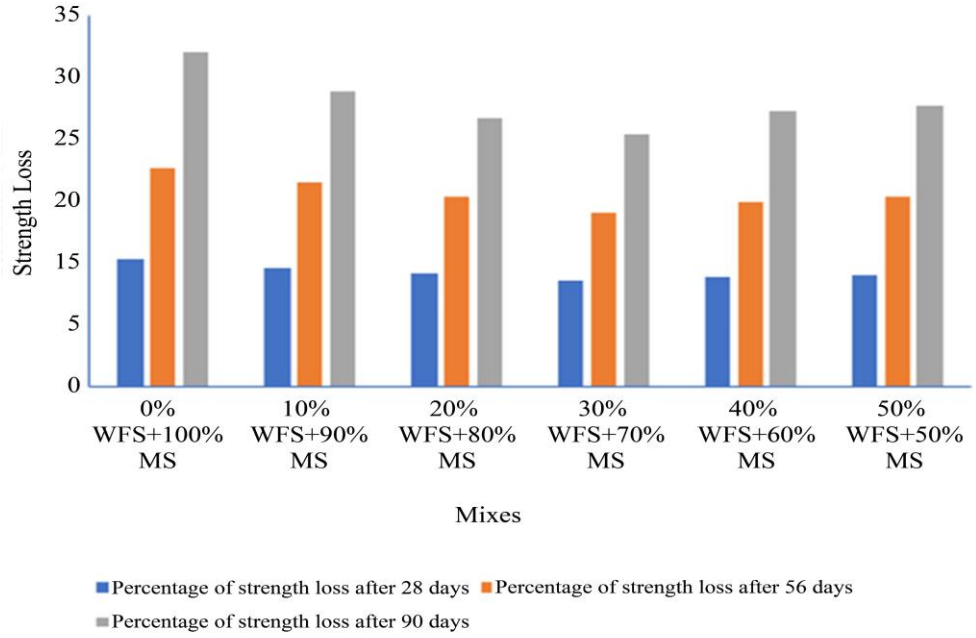


Fig. 6 Strength loss in chloride attack

Fig. 7 Test setup for RCPT

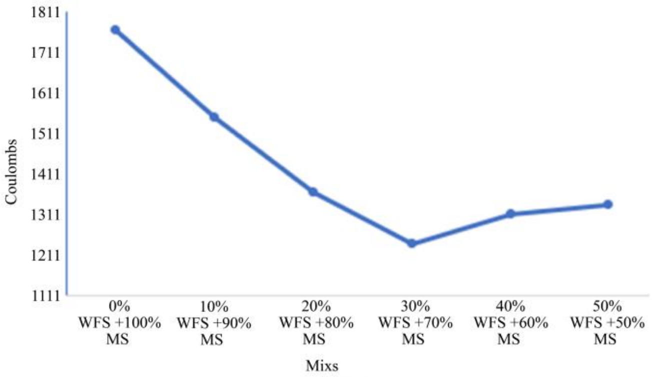
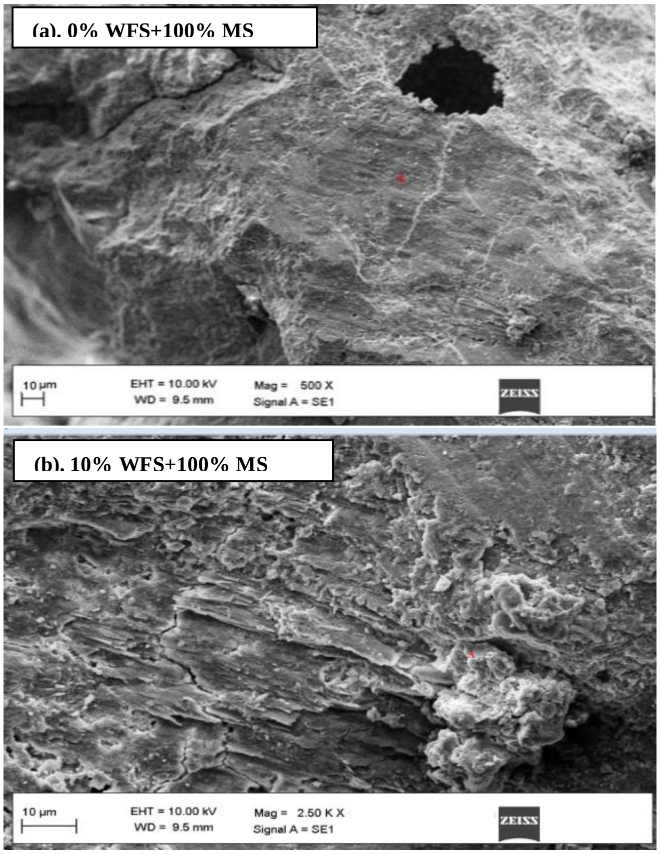


Fig. 8 RCPT test results

3.5. Scanning Electron Microscopy (SEM)

In the Figure, after 28 days of curing, the SEM images of CC, WFS10%, WFS20%, WFS30%, WFS40%, and WFS50% are shown. Chapters 9 (a) through 9 (f).



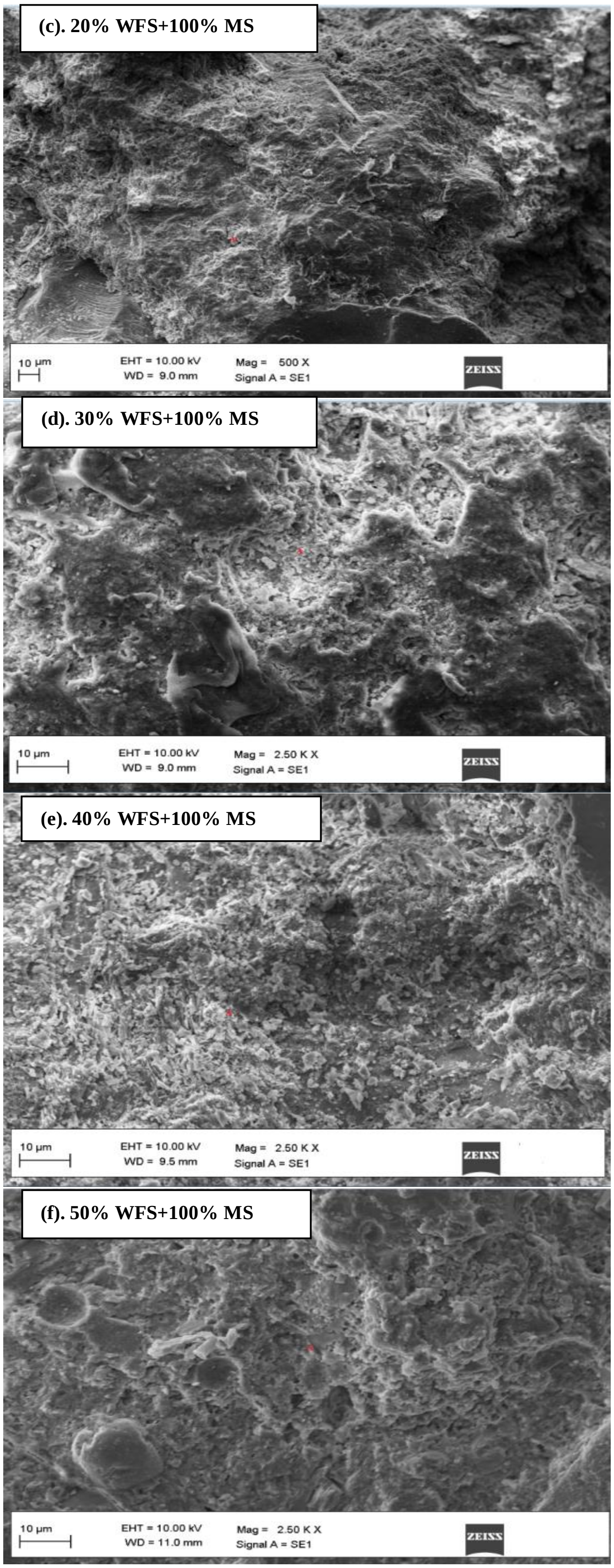


Fig. 9 Scanning Electron Micrographic images of various mixer compositions

In Figure 9 we can see the control concrete's SEM micrograph at 500x. (a). We see the several steps in creating C-S-H gels. The production of gel is clearly seen in the photograph. Large reinforcements of chalky gel and luminous masses of C-S-H gel with nodules scattered across the micrograph are visible. The WFS 10% mixture's scanning electron micrograph is displayed in Figure 9. (section B). There are now fewer gaps than there were in the CC. In comparison to the control mixture, the C-S-H mixture has higher dispersion. Furthermore, various areas of the microstructure may contain WFS particles of different sizes.

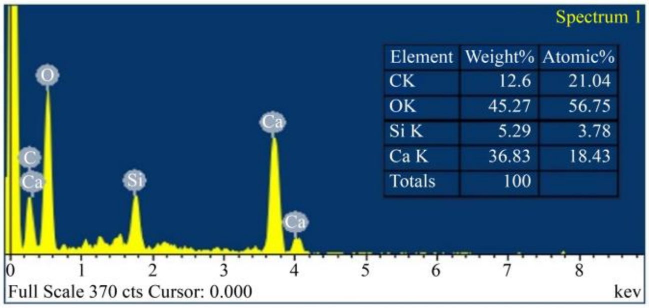
Figure 9(c) displays scanning electron micrographs of a WFS20% mixture, which demonstrate an increase in the number of WFS particles at different locations. The C-SH gel showed better dispersion and more nodule growth than the CC and WFS10 percent gels. Two examples of SEM images of concrete with different percent of WFS are shown in Figures 9(d)and 9(e), respectively (e). In comparison to CC, WFS10%, WFS20%, WFS40%, and WFS50%, WFS30% exhibits a greater C-S-H gel formation and a finer distribution. A more robust material than CC is produced by this gel-forming process.

This R30 mixture outperforms all others in terms of WFS reaction and overall potency. The dispersion of C-S-H gels and the creation of nodules are both expedited in concrete, as stated by Siddique et al. (2011). 30% of the time, the maximum number of tendrils is produced due to the rapid setting of the concrete. The results of the SEM analysis are consistent with the mechanical properties of the concrete. When all possible replacement rates are considered, 30% replacement yields the best results. Formerly, there were many more people available to fill these positions, but now there are far fewer. The control concrete shows worse strength and gel formation when compared to various percent of replacement, such as 10%, 20%, and 40%.

3.6. Energy-Dispersive X-ray Spectroscopy (EDS)

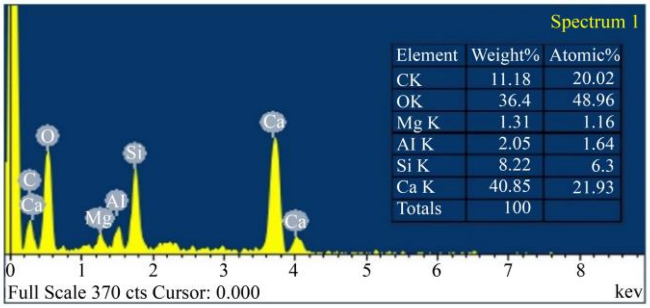
X-ray Energy Dissipated Spectroscopy can be used to determine the compositions of other samples and thin films (EDX). Not only is it possible to plot the relative abundance of each element throughout our samples, but we can also do it for individual elements. Using a PANalytical®, Xpert-Pró model, the mineral content was calculated using the Bogue equation (Hewlett, 2003).

The results of qualitative chemical analysis carried out on each sample are shown in Figures 10a–10f. Because of its distinct mineralogy and shape, quartz silica was utilised in the foundry to make alloys, as shown by the rounder grains in the spectrograms. The EDS analysis indicates that silicon, potassium, titanium, iron, magnesium, and calcium in their non-oxide forms are present at large levels. The most prominent peaks in the EDS data corresponded to calcium and oxygen, corroborating the XRD findings.



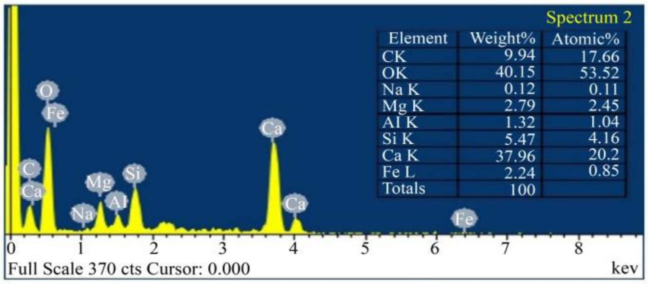
Element	Weight%	Atomic%
CK	12.6	21.04
OK	45.27	56.75
Si K	5.29	3.78
Ca K	36.83	18.43
Totals	100	

(a) 0% WFS+100% MS



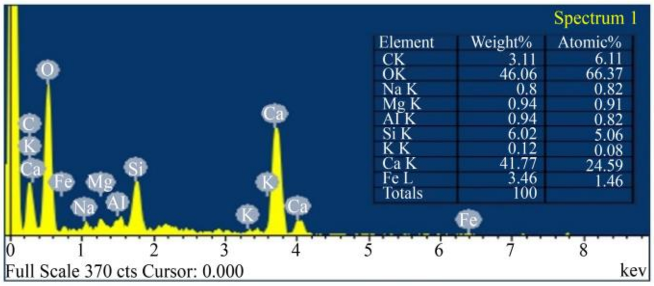
Element	Weight%	Atomic%
CK	11.18	20.02
OK	36.4	48.96
Mg K	1.31	1.16
Al K	2.05	1.64
Si K	8.22	6.3
Ca K	40.85	21.93
Totals	100	

(b) 10% WFS+90% MS



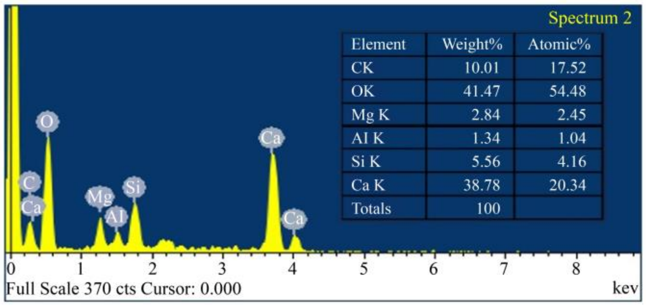
Element	Weight%	Atomic%
CK	9.94	17.66
OK	40.15	53.52
Na K	0.12	0.11
Mg K	2.79	2.45
Al K	1.32	1.04
Si K	5.47	4.16
Ca K	37.96	20.2
Fe L	2.24	0.85
Totals	100	

(c) 20% WFS+80% MS



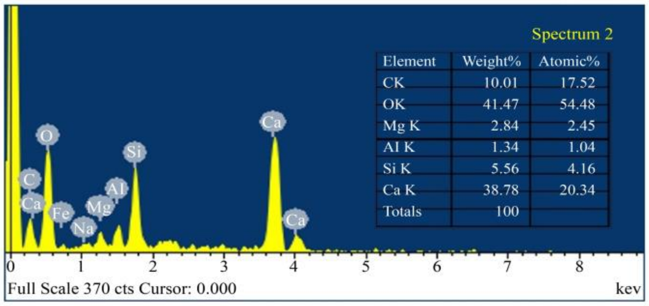
Element	Weight%	Atomic%
CK	3.11	6.11
OK	46.06	66.37
Na K	0.8	0.82
Mg K	0.94	0.91
Al K	0.94	0.82
Si K	6.02	5.06
K K	0.12	0.08
Ca K	41.77	24.59
Fe L	3.46	1.46
Totals	100	

(d) 30% WFS+70% MS



Element	Weight%	Atomic%
CK	10.01	17.52
OK	41.47	54.48
Mg K	2.84	2.45
Al K	1.34	1.04
Si K	5.56	4.16
Ca K	38.78	20.34
Totals	100	

(e) 40% WFS+50% MS



Element	Weight%	Atomic%
CK	10.01	17.52
OK	41.47	54.48
Mg K	2.84	2.45
Al K	1.34	1.04
Si K	5.56	4.16
Ca K	38.78	20.34
Totals	100	

(f) 50% WFS+50% MS
Fig. 10 EDS images for different mixer combinations

3.7. TGA and DSE

Thermogravimetric analysis (TGA) research is one of the most popular applications of TGA. When cement hydrates are tested using TGA, they typically go through three different phases of breakdown. Free water is lost, and water from hydrates (dehydration) is lost between 105 and 400 degrees Celsius during the first phase, which lasts from 25 to 105 degrees Celsius.

The Portlandite needs to be dehydroxylated at 400–600 degrees Celsius in the following stage. In the third step, carbon dioxide is extracted from CaCO3 by heating it to temperatures between 600 and 800 degrees Celsius. Figures 11 and 12 show the waste garnet TGA curves. In leftover garnet, endothermic cooling was seen between 150 and 200 degrees Celsius. This reduction is typically caused by surface water loss and dihydroxylation.

An exothermic peak, or heat release, developed between 250 and 500 degrees Celsius as the organic stuff in the waste garnet oxidised, resulting in a 0.4% drop in weight. Hematite does oxidise at these temperatures as well, but waste garnet's organic components showed a far stronger oxidation response, winning first place.

The sample lost 0.2 percent of its weight between 300 and 450 °C because of the dissolution of calcite into CaO at 768.5 °C and the dehydration of quartz between 350 and 400 °C. The existence of C-S-H at 110-1200 °C and Ca (OH)2 at 460-4800 °C are shown by the TGA curves of slag cement that has been cured in water at 200 °C in this study. The wider range of peaks in the TGA curves indicates that the hydration and pozzolanic reactions of the Portland slag cement paste were improved when WFS was used instead of the reference mix.

3.8. Fourier Transform Infrared (FTIR)

By Using Infrared Spectroscopy, the chemical linkages in foundry exhaust sand were identified. The composition and properties of cement concrete can be examined using Fourier Transform Infrared (FTIR) spectroscopy. It is used in quality assurance, research, and development of cement concrete.

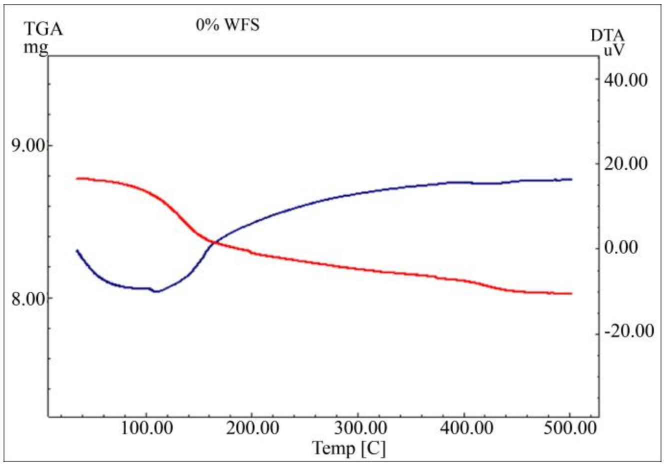


Fig. 11 Shows the graphs of the TGA and DSE curves for 0%WFS+ 100%MS

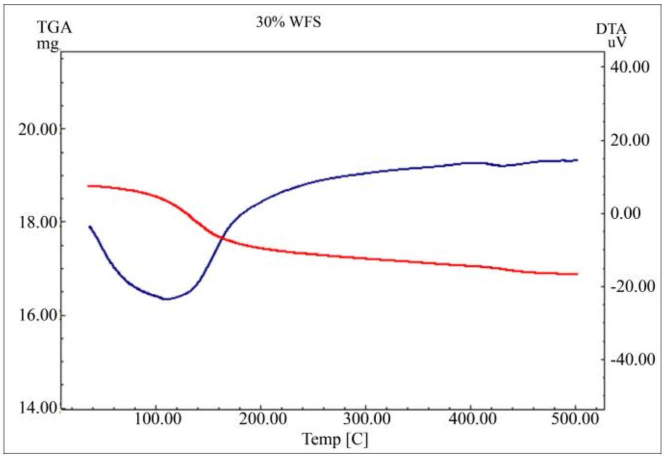


Fig. 12 TGA and DSE curve graph with 30% WFS + 70% MS

There is great interest in exploring the technique's potential applications with cementitious materials due to its many advantages. The quartz FTIR spectra in Figure 13 exhibit silica oxide (SiO2)-related peaks at 1080.33 cm-1, 796.67 cm-1, and 778.44 cm-1. Compared to other peaks, the Al2O3-indicating 693.61 cm-1 band was present.

The results obtained here are remarkably similar to those obtained by Santos, Dalla Valentina, and Souza [31]. Souza [32] discovered the bands 980 and 1182 cm-1, which are connected to Si-O bonding and may be connected to quartz. Santos [33] has found bands related to silicon at 1090, 798, and 779 cm-1. The Al2O3 bands were found at wavelengths of 684 and 980 cm-1 in reference [34].

Given that higher concentrations of aluminium, barium, lead, total chrome, iron, manganese, and nitrate were discovered than those stated in the residue does not appear to be inert. The results led to the classification of WFS waste as Class II A, which denotes that it is neither inert nor hazardous.

The sample's pH was 9.51 after being mixed 1:1 with water. As a result, it was concluded that it did not corrode in accordance with the limit specified in [35]. The result in this case validates the decision in [31]. These techniques could lead to a deeper understanding of a substance's chemical composition. When combined, these additional techniques offer an abundance of information that is crucial for the identification and characterization of materials.

Waste Foundry Exhaust Sand has a composition similar to that of natural sand and is non-toxic, non-corrosive, and non-ionic. It was discovered that quartz (SiO2) made up the WFS mineralogy. Thus yet, no chemical has been discovered that can cause the dangerous agents that arise from the interaction between alkali and silica to expand, crack, and then penetrate.

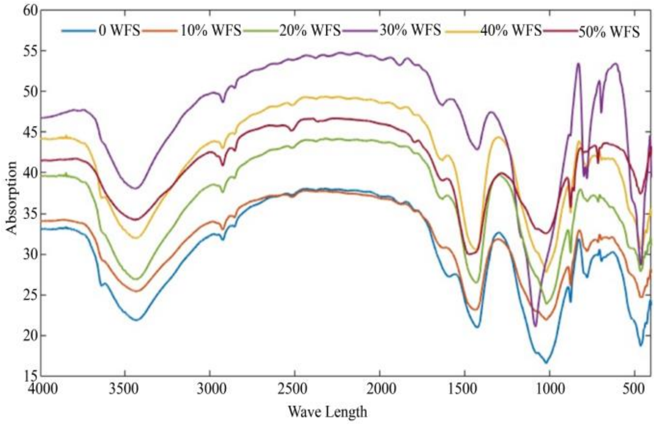


Fig. 13 FTIR analysis of WFS+M-sand Mixes

4. Conclusion

Compression strength is merely one of several markers of the quality of concrete. Numerous details regarding the concrete's characteristics can be learned from just one test. There exists a clear correlation between the compressive strength of concrete and several other attributes. One reliable measure of the quality of the concrete is its compressive strength. The compressive strengths of the concrete for various WFS concentrations are displayed in Figure 2. Bilal et al. [20] report that the compressive strength of concrete containing a proportion of WFS substitutes is greater than that of concrete containing a proportion of reference materials. Because of its smaller grain size, WFS was a great filler that made the concrete denser [21].

Granular materials occupy voids in the matrix of hardened concrete, which makes it frequently extremely packed. Silica may have aided in the formation of the Calcium Silicate Hydrates (CSH) gel [23]. Calcium Hydrate (CH), which is created when cement hydrates, mixes with the SiO2 in WFS to form Calcium Sulphate (CSH). CSH increases the strength of concrete in a number of ways, one of which is by improving its binding properties. In a different study, similar results were found when WFS was substituted for 30 percent of M-sand. An identical event occurred there. It is recommended that up to 30 percent of WFS be replaced with natural sand for optimal performance [24-26]. With the aid of statistical analysis, we can determine whether the addition of waste products altered the results or whether they would have been the same with or without them.

Ahmad et al. [27] state that WFS was used to substitute the natural sand found in rivers partly. Because of the increase in porosity caused by the small dust particles in the WFS, the structure becomes less dense [28]. While cement concretes with up to 30 percent WFS replacement, have split tensile strengths that are almost the same as the reference mix, concretes with more than 30 percent WFS replacement do not exhibit similar split tensile values. Prabhu et al. [29] state that the control mix's performance would be similar to concrete constructed from prewashed and sun-dried wood with a WFS replacement ratio of up to 20%. However, the strength decreases a little at 30% replacement and significantly more as WFS dosages increase. The split tensile strength of WFS was found to be 19% lower than RM at a 50% replacement ratio. The use of additional foundry sand waste over time dramatically reduces the tensile strength of concrete, as found by Basar et al. [30].

The previous researcher found that the tensile strength of concrete constantly declined as the substitution ratio of WFS increased [31]. When compared to the control concrete, concrete mixes, including WFS+M-Sand, show better resistance to chloride ion permeability at the 28-day mark, according to the results of the rapid chloride permeability test (RCPT). In particular, the concrete's resistance to chloride ion permeability is improved by adding 30% WFS in place of M-sand. Moreover, when subjected to an HCl acid environment, the 30% WFS mixture demonstrates the least amount of weight and strength loss compared to the other mixtures. Similarly, concrete containing 30% WFS shows the least amount of weight and strength loss when exposed to a MgSO4 acid environment during acid resistance testing compared to all other combinations.

The microstructural examination of several sand samples included in concrete using SEM, EDX, TGA, and FTIR confirms the development of hydration products. It shows silica sand to be competitive with nominal sands. All of the concrete samples with various sand contents had consistent and well-developed microstructures. All mixes appear to have some small calcium hydroxide phases, indicating that they are being used to their full potential during cement hydration. Well-formed CSH crystals can be seen in microstructural images; these are especially dense in the mixture of silica sand. Quartz (SiO_2) and CSH were identified as the predominant peaks in all mixes, while minor peaks of C2S and C3S indicate their near-complete consumption during cement hydration. A favourable CSH gel composition was obtained by replacing up to 30% of the M-sand with WFS sand. All of the concrete samples showed consistent bending and stretching spectra according to FTIR analysis, indicating a similar elemental makeup, especially for WFS+M-sand combinations. All of these results point to the possibility of using leftover foundry sand as a fine aggregate in place of M-sand up to 30% of the time, which can help produce high-grade concrete and building materials.

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