ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

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www.ijasem.org

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

www.ijasem.org

Vol 14, Issue3, 2020

Observational Studies on the Impact of Recycled Foundry Sand on the Micro-Structural Features and Strength of Concrete

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Abstract

To get high-quality, naturally occurring river sand these days, one must go considerable distances. Similarly, these items are also becoming scarce. Consequently, efforts are underway to find an alternative to river sand. The production of natural river sand takes millions of years and is not renewable. Manufactured sand entirely substitutes for natural sand. The use of waste sand from foundries instead of produced sand in concrete is due to a lack of study. Compressive strength, fracture toughness, and flexibility are just a few of the mechanical attributes that may be improved by mixing recycled foundry sand into concrete. The mechanical characteristics of concrete mixed with manufactured sand and waste foundry sand were evaluated using cube, cylinder, and unreinforced beam tests. After7,14,28,56, and 90 days of curing, the concrete's flexural, splitting, and tensile strengths were measured. Micro structural investigations were conducted on the control mixture and mixes comprising 10, 20, 30, 40, and 50% waste foundry sand using SEM, EDS, and Thermo Gravimetric Analysis (TGA/DCs). The micro structural investigations gave a better understanding of the strength changes that happen when waste foundry sand is substituted with fine aggregates in varied quantities. By carefully measuring and adding the appropriate quantity of WFS to the concrete, its usage as a substitute for fine aggregate might be supported by strength and microstructure investigations.

Keywords: Waste Foundry Sand; Manufactured Sand; Fine Aggregate; Flexural Strength; Splitting Tensile Strength; Compression Strength; SEM; EDS; Thermo Gravity Analysis.

1. Introduction

As technology advances, so does the construction industry, which is employing innovative methods to expedite and improve the quality of construction projects. The use of concrete as a construction material is critical in this industry. In addition to the high expenses, the use of natural resources as ingredients in concrete is approaching a crisis. We must either find a way to replenish our natural resources or find a way to resolve this issue. Numerous environmental issues are currently being brought on by the large-scale production of waste foundry sand by the metal casting industry. Waste from this foundry could lessen environmental stress if it is used to make building materials. Because it is evenly sized and can be used to create a mould, foundry sand, a high-quality silica sand, is used in the casting of ferrous and nonferrous metals. An unusually finer grade of sand is used in the metal casting process. Sand used in the metal casting process can be recycled numerous times, but once it loses its usefulness, it is thrown away as trash [1].

India produces about 2 million tonnes of waste foundry sand annually. Fine aggregate can be replaced with leftover foundry sand to make concrete more affordable, light, and strong. Concrete's overall strength is derived from a combination of coarse and fine aggregate, water, and admixtures, and is increased by each component. As a result, by varying the amount of material replaced, concrete's properties can be changed. Utilizing waste products that are harmful to the environment makes it possible to produce inexpensive building materials that are also good for the environment. This study experiments with various percentages of fine aggregate and spent foundry sand in an effort to create inexpensive concrete that is also environmentally friendly [2]. Over the past few years, the consumption of aggregates has increased in more and more nations faster than the growth of their economies or building sectors. Artificial aggregate production is more expensive than transporting natural aggregates, which could be a drawback if the source of natural aggregates is far from the site of use. It is also necessary to consider the extraction of natural aggregates, which is accompanied by serious environmental problems. The countryside is frequently permanently harmed as a result [3]. By using industrial waste instead of quarrying for aggregates, less damage is done to both natural and artificial aggregate resources, and the environment is also better protected from pollution [4].

The foundry industry produces a large amount of waste material while casting. A metal that is not made from a ferrous metal, such as aluminum, copper, brass, or bronze, is referred to as a non-ferrous alloy. Moulding sand makes up more than 70% of the total by-product material due to its abundance and low cost [5]. With the binder and other organic materials used in the moulds, it is simple to combine. Silica sand is used in the casting and moulding processes at foundries. This type of sand cannot be found in a typical bank or in the natural world. Sand can be recycled and used repeatedly in foundries. Foundry sand that has been discarded and cannot be recycled is known as waste foundry sand (WFS). SFS and used-foundry sand (UFS) are additional names for it [6].

Scrap foundry sand may be an effective recycling choice for the leftovers when used as a fine aggregate substitute in concrete. An obvious win-win from an economic and environmental perspective is the development of substitutes for natural sand (fine aggregates) that do not reduce the strength or durability of concrete mixtures — or even improve them. There hasn't been much research done on the use of these waste materials in concrete. The control of foundry waste (WFS) is a significant issue. (Waste sand: WFS appears black because of the tiny particles in it. The typical physical and chemical properties of WFS are influenced by a variety of factors, including the metal used, the casting process, the technology used, the type of furnace, and any finishing procedures used [7]. This experiment was performed by Singh et al. (2012) [8] to investigate the strength and longevity of concrete mixtures that used synthetic sand in place of natural sand (WFS). Five different weight percentages of WFS were used in place of natural sand: 0, 5, 10, 15, and 20%. To create concrete mix proportions that include and exclude WFS in the mix, five different techniques have been used. At intervals of seven, twenty-eight, and ninety-one days, compression and splitting tensile strength tests were used to gauge the strength of the concrete. The elastic modulus and the ultrasonic pulse velocity were measured at 28 and 91 days, respectively. In an animal test known as the Rapid Chloride Permeability test, the survival time of each mixture was calculated. According to test results, using WFS as part of the fine aggregate replacement slightly increased the strength and durability of plain concrete. Concrete is a crucial and frequently used material in the construction industry. The addition of waste foundry sand (WFS) to regular concrete is a current research focus. Workability, compressive strength, and split tensile strength of this concrete were evaluated and compared to those of regular concrete in both its plastic and hardening states. To determine the characteristics of the concrete in question, tests were conducted on a typical cube and cylinder for seven, fourteen, twenty-eight, fifty-six, and ninety days.

The study's goal was to ascertain the impact of using waste foundry sand as a partial replacement for fine aggregates (using 100% manufactured sand as a fine aggregate) in varying percentages (0 to 50%) with a 10% interval on concrete properties like mechanical traits and micro-structural analysis using EDS, SEM, and thermo-gravity analysis (TGA). Waste foundry sand will be diverted from landfills and used in the production of concrete thanks to this practice. This study sheds light on the mechanical properties and behavior of concrete. Additionally, the impact of adding waste foundry sand to concrete on its mechanical strength properties and micro-structural properties was assessed in order to better understand its environmental and economic value.

2. Experimental Materials

2.1. Cement - PSC

Portland slag was used as the cement. This cement was made by Jindal South West Cement (JSW). According to BIS standard IS 455 – 1989 [9], the amount of slag used in slag cement is between 25 and 70%. It was subjected to extensive testing in accordance with Indian Standard Specifications IS 12269-2013, and IS 4031 (Part 11) – 1988 [10, 11]. Mold and mildew were kept at bay by humidity-controlled storage of the cement. Table 1 displays the cement's physical characteristics.

Table 1. Physical properties of Portland slag cement

S. No.	Physical test	Results obtained	Permissible range	IS code
1	Normal Consistency	33%	Permissible range 30-35%	IS 12269: 2013
2	Initial Setting Time	52 min	Should not be less than 30 min	IS 12269: 2013
3	Final Setting Time	540 min	Should not be more than 600 min	IS 12269: 2013
4	Fineness (Residue retained on 90 micron sieve)	3.2 %	Should not be greater than 10%	IS 12269: 2013
5	Specific Gravity	2.89	Permissible range 3.1 – 3.15	IS: 4031 (Part 11)– 1988

2.2. Manufactured Sand

M Sand is used as the fine aggregate in this investigation. BESTO Mining Private Limited, Yalagalahalli village, Chikkaballapur in Karnataka state (India), provided the M-sand that was acquired. Crushing hard granite stone produces manufactured sand. This M Sand has been graded specifically for use in concrete. Granules range in size from 150 microns to 4.75 millimetres. Table 2 has this information Based on IS 383-1970 [12], Particle size analysis graph of each replacement as provide in Figures 1 (a, and b).

Table 2. Properties of Manufactured sand

S. No.	Property	Value

1	Bulk density(Compacted)	1790 kg/m^3
2	Bulk density(Loose)	1693kg/m^3
3	Specific gravity	2.59
4	Fineness modulus	2.64
5	Zone Conforming to	II
6	Water absorption %	1.6

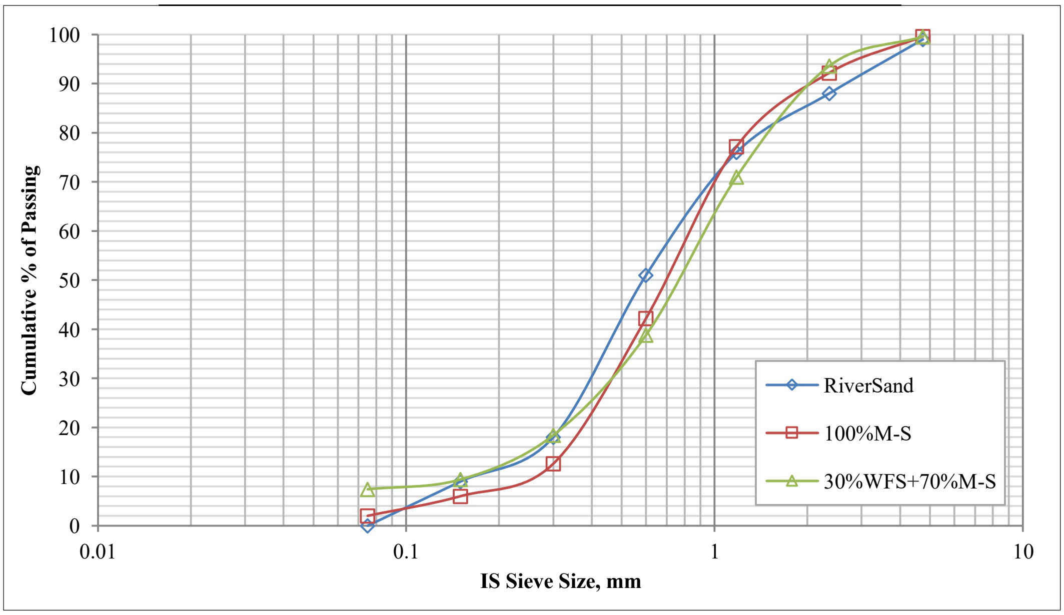


Figure 1-a. Particle Size Analysis Graph of River sand, 100% M-sand and 30%WFS &70% M-Sand combinations

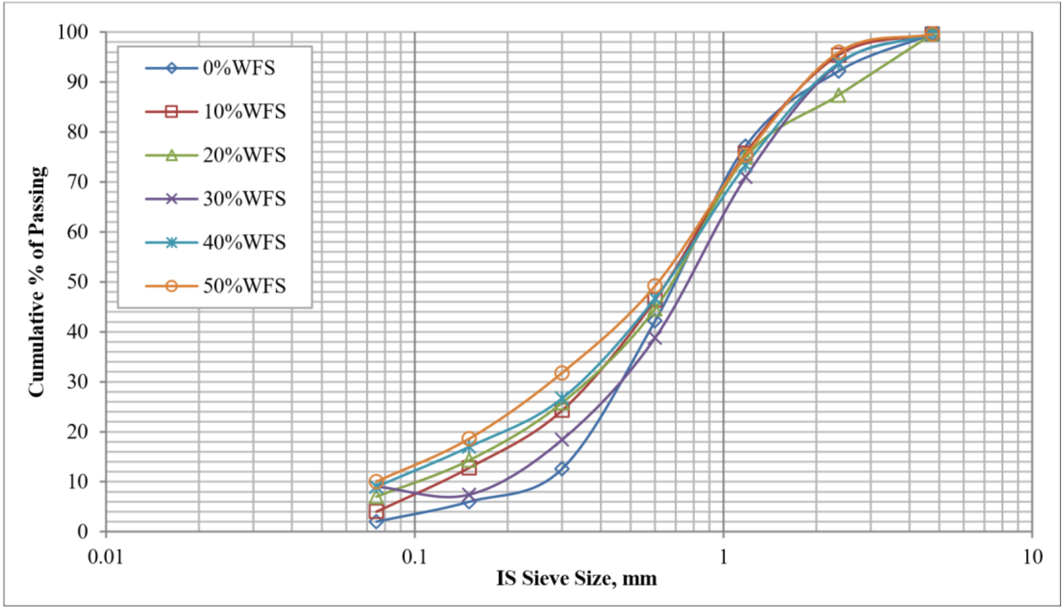


Figure 1-b. Particle Size Analysis Graph of WFS & M-Sand combinations

2.3. Waste Foundry Sand

Ferocious sand procured by different foundry enterprises, such as Sai Krishna Alloy Casting, Amrutha Sai Casting, and Martoppe Art Alloy Cast, was analysed in Patancheru Industrial Park in Medak Dist. of Telangana for the purpose of conducting a study on ferrous foundry sand. The list of physical parameters conducted in this study is presented in Table 3.

Table 3. Physical properties of Waste Foundry sand

S. No.	Property	Value

1	Bulk density (loose)	1350 kg/m^3
2	Fineness modulus	1.74
3	Bulk density (Compacted)	1598 kg/m^3
4	Color	Grey – Blackish
5	Specific gravity	2.32

2.4. Super Plasticizers

An admixture of Poly carboxyl was employed in the experiment. It was bought from the New Delhi-based Sri Krishna Overseas Company, which manufactures it (Table 4). This addition is a great choice for creating high-strength concrete that is easy to work with.

Table 4. Typical properties of PCE Super plasticizer up to 25°C

Properties	Value
Appearance/Color	Dark Brown Liquid
Form	Liquid
Chloride content	Nil
Density	1.2±0.02 kg/l

3. Mix Proportion and Designation

Properly proportioning the components in concrete is critical to its quality. This study's mix design adhered to the Indian standard IS 10262-2009 [13]. The concrete mix proportion for M40 was achieved as 1:1.98:2.75; mix proportion details were tabulated in Table 5.

Table 5. Quantity of materials in kg for 1m^3, M40 grade concrete grade production

TMS=48.25 MPa	Cement (kg)	FA (kg)	CA (kg)	Water(kg)	W:C	S.P –0.8%
1 m^3	417	797	1211	146	0.40	3.36 (l)

It was found that the concrete mixtures (0%WFS+100%MS, 10%WFS+90%MS, 20%WFS+80%MS, 30%WFS +70%MS, 40%WFS+60%MS, 50%WFS+50%MS) were proportioned when M-sand (fine aggregate) was replaced by weight for each. All concrete mixes were prepared using a water-to-cement ratio of 0.4. Days of 7, 14, 28, 56, and 90 of the curing process were considered. The total number of specimens includes all five concrete mix proportions.

4. Experimental Programme

The concrete ingredients were weighed and properly mixed in a laboratory concrete mixer until the desired consistency was attained. The properties of new concrete, including slump flow and compaction factor, were assessed using IS: 1199-1959 [14], an Indian Standard. For compressive strength, 150 mm concrete cubes and 150×300 mm cylinders were created, as well as cylinders for split-tensile strength and 100×100×500 mm unreinforced beams (Figure 2). In all, 90 cubes, 90 cylinders, and 90 beams were cast using varying proportions of synthetic and waste foundry sand for testing purposes. After the required curing time, the specimens were removed from the curing tank and their surfaces were wiped clean. The various tests performed were compressive strength tests of cubes (150 mm side), cylinders (150×300 mm) for split-tensile strength) and flexural strength for unreinforced beams at 7, 14, 28, 56 and 90 days, as per IS: 516-1959 [15].

Figure 2. Casting of specimens

4.1. Compressive Strength Test

This test gives us a good picture of how concrete behaves. We can use this test to see if the concreting was done correctly. Furthermore, compressive strength refers to a structure's capacity to support stresses placed directly on its surface without fracturing or deflecting (Figure 3). Compression tends to shrink the size of a substance, while tension causes it to expand.

Figure 3. Compressive strength setting

4.2. Splitting Tensile Strength

Concrete's tensile strength is essential because structural loads can cause tensile cracking in the material. Steel is used to support tension loads since concrete's tensile strength is far lower than its compressive strength. Concrete's tensile strength is thought to be 10% of its compressive strength, according to certain estimates. Indirect methods are used to measure tensile strength since the direct method is too complicated. The uniaxial tensile test yields lower values while these approaches yield greater ones (Figure 4).

Figure 4. Splitting Tensile strength Mechanism

4.3. Flexural Strength Test

Flexible modulus and the flexibility of a material can both be measured with flexure (bend) tests (Figure 5). The cost of a flexure test is less than that of a tensile test, but the findings are not exactly the same. An applied force is supplied to the material's top until the sample fails at one of two horizontal places. The maximum recorded force is used to calculate the flexural strength of a sample. A flexure test is widely used to gauge a person's flexural strength and modulus. There are two types of flexural strength: compression and tension flexural strength. Flexible modulus is calculated by looking at the stress-strain deflection curve. By comparing these values to the sample material, it is possible to determine flexure or bending forces. In contrast to a compression or tensile test, a flexure test does not assess the material's inherent properties. There are three primary stresses that affect a specimen's flexural properties: tensile, compressive, and shear. These three stresses are integrated with one another, as well as the geometry of a specimen and how quickly it is loaded.

Figure 5. Flexural Strength Test equipment

4.4. Scanning Electron Microscope (SEM) Analysis

A scanning electron microscope (SEM) was used to characterise the microstructure of concrete, as well as the topography and composition of the components. SEM was used to identify the type, size, shape, and distribution of phases and the microstructure of a solid. The ZEISS TESCAN Scanning Electron Microscope was used to perform SEM studies for different percentages of WFS substitution. Cement and concrete have several applications for SEM due to its better resolution, high magnification, and large depth of field, which provide three-dimensional appearances of surface textures. Researchers are now able to resolve the microstructure of materials to a fraction of a millimetre using the SEM technique. On surfaces that had been fractured, the original microstructure and morphology of the hydrate mixes were visible. All of the samples were cut into 10 mm cube prisms and one side was flattened (CC, WFS10%, WFS20%, WFS30%, WFS40%, and WFS50%). Small samples were carbon-coated in the collected prism and examined using a Scanning Electron Microscope in the back-scattered electron mode at an accelerating voltage of 30 keV. The back scatter intensity of each sample was set to the same value, and its images were taken.

4.5. EDS (Energy- Dispersive X-ray Spectra)

Energy dispersive X-ray spectroscopy (EDS or EDX) is a widely adopted analytical technique in the mineralogical phase, often performed in tandem with SEM or TEM to provide semi-quantitative elemental or compositional analysis of powder particles. EDS utilises the X-ray signals generated by the interaction of the electron beam of the SEM with the powder samples. When primary electrons collide with the surface of the powder sample, inner shell electrons are expelled, and X-rays are produced when outer shell electrons go into the inner shell to fill the hole. Due to its individual atomic structure, each element has a distinctive X-ray emission pattern that may be used to do chemical or compositional analysis using an energy dispersed X-ray spectrometer.

4.6. Thermo-Gravimetric Analysis (TGA) and DSE

At the age of 28 days, WFS concrete samples were subjected to TGA testing. On the day of testing, samples were crushed during compressive strength testing to obtain small pieces. The little samples were then pulverised using a pestle and mortar until they were fine enough to pass through 75 m sieves. The particles that passed through a 75-millimeter screen were then gathered to conclude the hydration procedure. Before being dried using an air pump, the granules were totally soaked in acetone. Before subjecting the dried powders to TGA, the soaking and drying procedure were repeated five times to ensure that hydration termination had occurred.

The TGA were performed using a PerkinElmer Diamond TG/DTA machine (Waltham, MA, USA) with115V under the air flow of 200.0 mL/min. After placing a sample into a platinum crucible in the machine, the heating program was set as:

- Hold for 15.0 min at 40 ºC;
- Heat from 40 ºC to1000 ºC at 10 ºC/min;
- Hold for 5.0 min at 1000 ºC;
- Cool from 1000 ºC to 30 ºC at 30 ºC/min.

5. Results

By measuring what starts with workability, the fresh concrete properties of Slump cone and compaction factor, hardened concrete properties of the compressive strength, split tensile strength, flexural strength, SEM images, EDS graphs, and thermal gravity analysis images (TGA) of different mixture compositions with WFS, this study investigates how WFS impacts the properties of concrete. The obtained results are shown in Figure 6.

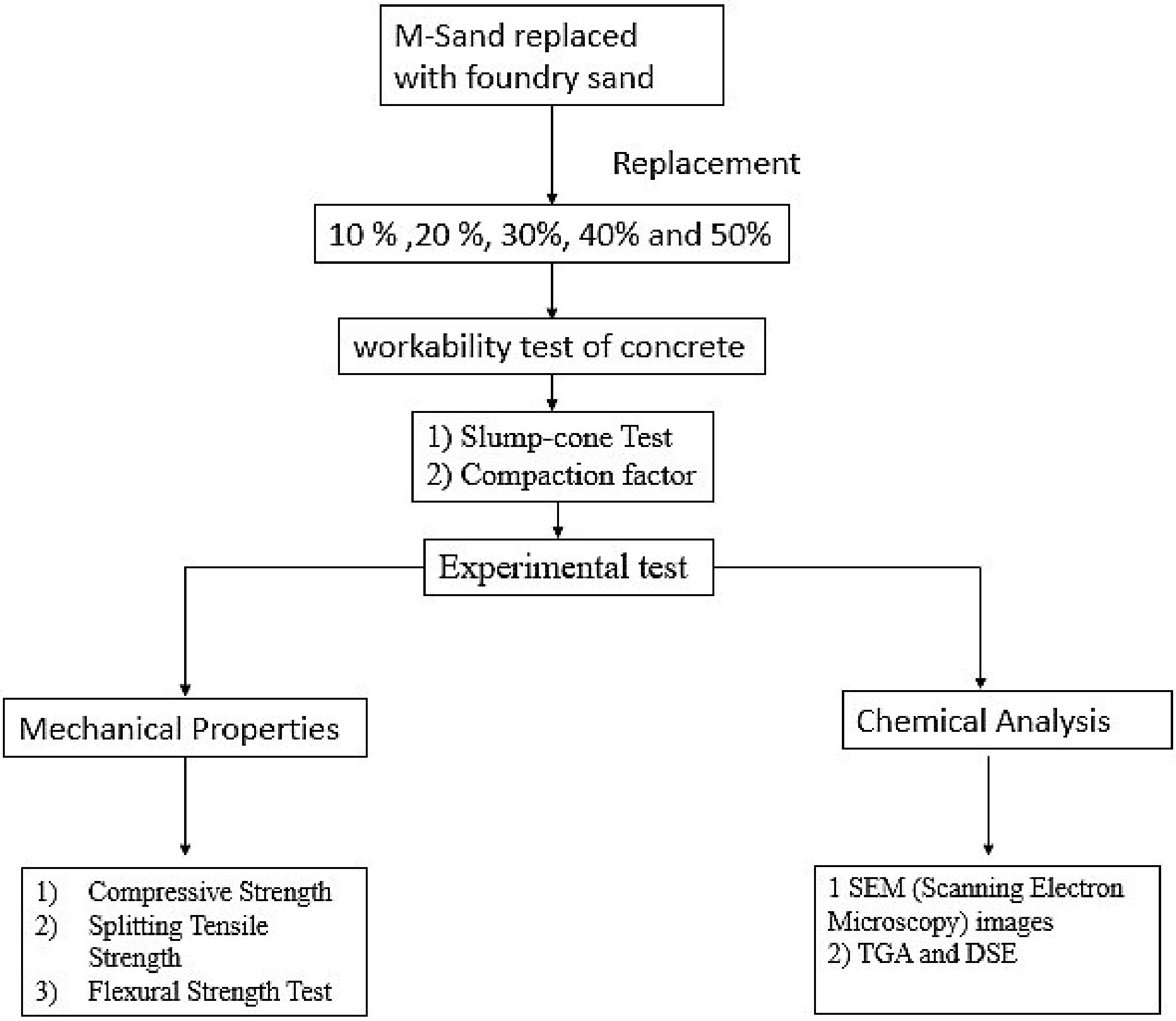


Figure 6. Flow chart: Study of methodology

5.1. Slump-cone Test

The uniformity of concrete was measured by utilising a Slump cone test examination as per IS 1159-1959 [16-18]. This usual test is used to determine the slump value of concrete with various WFS portions and is also compared with control concrete. The Slump cone test of different mixture percentages is displayed in Table 6 as well as Figure 7. The slump value of CC is 128 mm. 10, 20, 30, 40, and 50% replacing of WFS reveals 118, 116, 108, 106, and 102 mm, respectively. This shows that the Slump cone value reduces with rising WFS contrasted to CC. It showed that WFS takes in extra water. The reduction in workability is possibly due to the existence of water taking in great particles, and additionally, the systematic loss in depression value of mixes observed with an increase in WFS content is due to the huge area of WFS contrasted to fine aggregate.

Table 6. Slump values of all 6 concrete mixes

S. No.	Mix designation	Percentage of Replacement of WFS	Slump (mm)
1	0%WFS+100%MS	0	128
2	10%WFS+90%MS	10	118
3	20%WFS+80%MS	20	118
4	30%WFS+70%MS	30	108
5	40%WFS+60%MS	40	108
6	50%WFS+50%MS	50	102

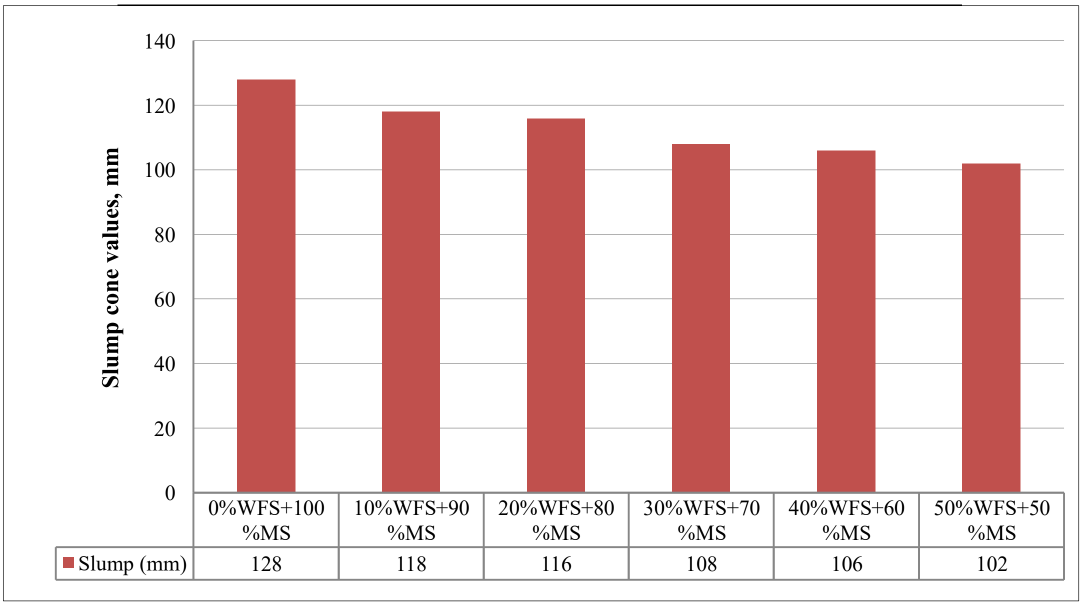


Figure 7. Flexural Strength Test equipment

5.2. Compaction Factor

The compaction factor test is more exact and also more delicate than the slump cone test. It is executed to establish the integral high quality of concrete mixes, which is extremely closely related to the workability requirement of concrete, especially for concrete mixes of much reduced workability. The compaction variable worth of various WFS blends is shown in Table 7 as well as Figure 8. Similar to slump cone examination, the compaction aspect likewise reveals a reduction in workability with a rise in WFS because of the presence of finer particles

Table 7. Compaction factor values of various concrete mixes

Sl. No.	Mix designation	Percentage of replacement of WFS	Compaction factor
1	0%WFS+100%MS	0	0.95
2	10%WFS+90%MS	10	0.94
3	20%WFS+80%MS	20	0.92
4	30%WFS+70%MS	30	0.91
5	40%WFS+60%MS	40	0.90
6	50%WFS+50%MS	50	0.89

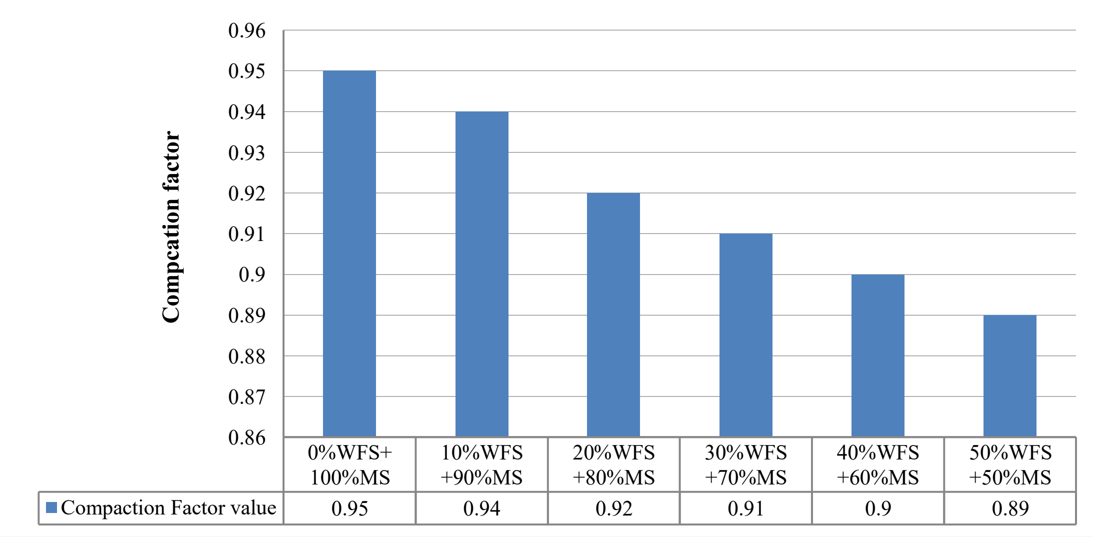


Figure 8. Compaction factor Test equipment

5.3. Compressive Strength

Table 8 and Figure 9 illustrate the compressive strength of concrete mixtures. WFS-containing concrete is more durable than standard concrete. Increasing the quantity of WFS from 0% to 50% resulted in a 30% increase in strength and a 40% decrease in toughness, although the material was still stronger than the control mix. After 28 days, the percent increase in compressive strength relative to the control concrete is 3.94, 6.98, 19.48, 11.65, and 11.34%, respectively, for blends containing 10, 20, 30, 40, and 50% WFS. The increase in strength at 56 days is 5.44, 8.67, 16.72, 10.76, and 8.38% for 10, 20, 30, 40, and 50% WFS, respectively. At 90 days, the increases are 4.55, 7.95, 12.35, 9.09, and 7.95%, respectively .When analyzing compressive toughness at different ages, it is observed that compressive toughness improves constantly from 0 to 30% replacement. It begins to drop at 30% but is still more than controllable at 50%. Without regard to age, the same pattern is seen. The increase in strength caused by the replacement of WFS for sand is attributable to the densification of the paste framework as a consequence of the fine fragment of WFS having a lower elastic modulus than that of sand, as well as the higher silica content of WFS compared to typical sand. The compressive strength of concrete has increased throughout time. The increased compressive strength of concrete containing WFS indicated that WFS might be used effectively as a partial substitute for coarse aggregate in the production of concrete.

Table 8. Compressive strength results for different mixer combinations

Mixes	7days	14days	28 days	56 days	90 days
0% WFS+100% MS	23.4	31.2	42.14	44.5	45.76
10% WFS+90% MS	25.96	34.32	43.61	46.92	47.84
20% WFS+80% MS	27.28	36.45	45.08	48.36	49.4
30% WFS+70% MS	29.44	38.64	50.35	51.94	51.41
40% WFS+60% MS	27.9	37.4	47.05	49.29	49.92
50% WFS+50% MS	26.84	36.9	46.92	48.23	49.4

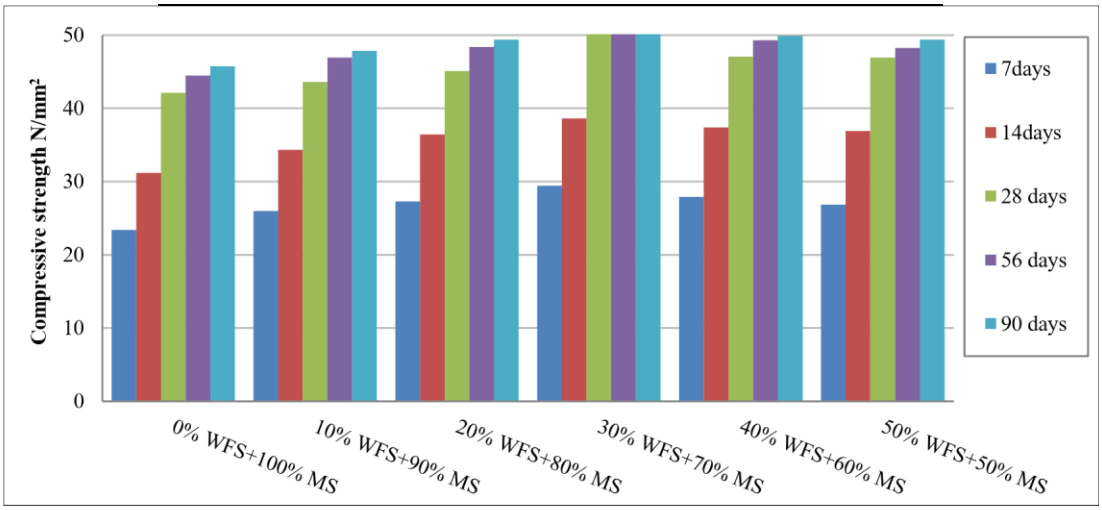


Figure 9. Compressive strength results for different mixer combinations

5.4. Splitting Tensile Strength

In accordance with IS 5816-1999, the splitting tensile strength of concrete mixes comprising 10, 20, 30, 40, and 50% was found to be 7, 14, 28, 56, and 90 days. Table 9 presents details of the results of the splitting tensile test. In comparison to CC, an increase in WFS material resulted in an increase in splitting tensile strength from 7, 14, 28, 56 to 90 days at all ages. At 28 days, the percentage increase in splitting tensile strength relative to CC is 4.25 percent for 10, 7.76% for 20, 20.36% for 30, 12.47% for 40%, and 12.16% for 50%.As with compressive strength, splitting tensile strength increases with age, with a WFS of 17.91% at 56 days and 11.64% at 90 days. Figure 10 demonstrates that the splitting tensile strength grows linearly from 0 to 30% replacement, similar to the compressive strength.

Table 9. Split tensile strength results for different mixer combinations

Mixes	7days	14days	28 days	56 days	90 days
0% WFS+100% MS	1.94	3.07	5.02	5.34	5.56
10% WFS+90% MS	2.21	3.4	5.23	5.68	5.76
20% WFS+80% MS	2.32	3.61	5.41	5.85	5.95
30% WFS+70% MS	2.5	3.83	6.04	6.28	6.19
40% WFS+60% MS	2.37	3.7	5.65	5.96	6.02
50% WFS+50% MS	2.28	3.65	5.63	5.84	5.95

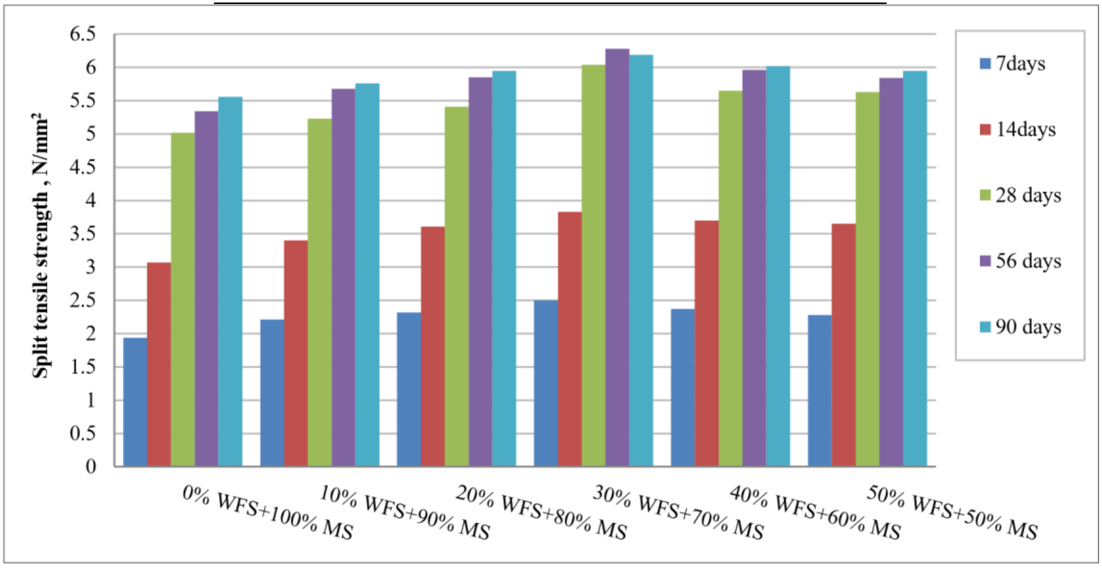


Figure 10. Splitting Tensile strength results for different mixer combinations

5.5. Flexural Strength Test

Several mixers undergo flexural toughness testing for 7, 14, 28, 56, and 90 days. Here, the experiments are conducted by substituting waste foundry sand and M-Sand for various compositions and repeating the tests. These are the findings of our study. Table 10 and Figure 11 illustrate the flexural strength of various combinations. The flexural strength of CC at 28 days is 5.28 N/mm^2. A 10, 20, 30, 40, and 50% rise in WFS corresponds to a 4.90, 8.43, 21.11, 13.17, and 12.86% increase in strength when compared to CC. This is more than the findings obtained by Siddique & Singh (2011) [19] for WFS. While the amount of WFS improves, flexural strength also rises, albeit to a lesser extent at 40 and 50% replacement compared to 30% replacement. In spite of this, it is better than concrete control. Regardless of the age of the concrete, the same pattern appears.

Table 10. Flexural Strength results for different mixer combinations

Mixes	7 days	14 days	28 days	56 days	90 days
0% WFS+100% MS	2.57	3.62	5.28	5.59	5.75
10% WFS+90% MS	2.85	3.95	5.54	5.91	6.08
20% WFS+80% MS	3	4.19	5.73	6.09	6.27
30% WFS+70% MS	3.24	4.44	6.39	6.54	6.53
40% WFS+60% MS	3.07	4.3	5.98	6.21	6.34

50% WFS+50% MS	2.95	4.24	5.96	6.08	6.27

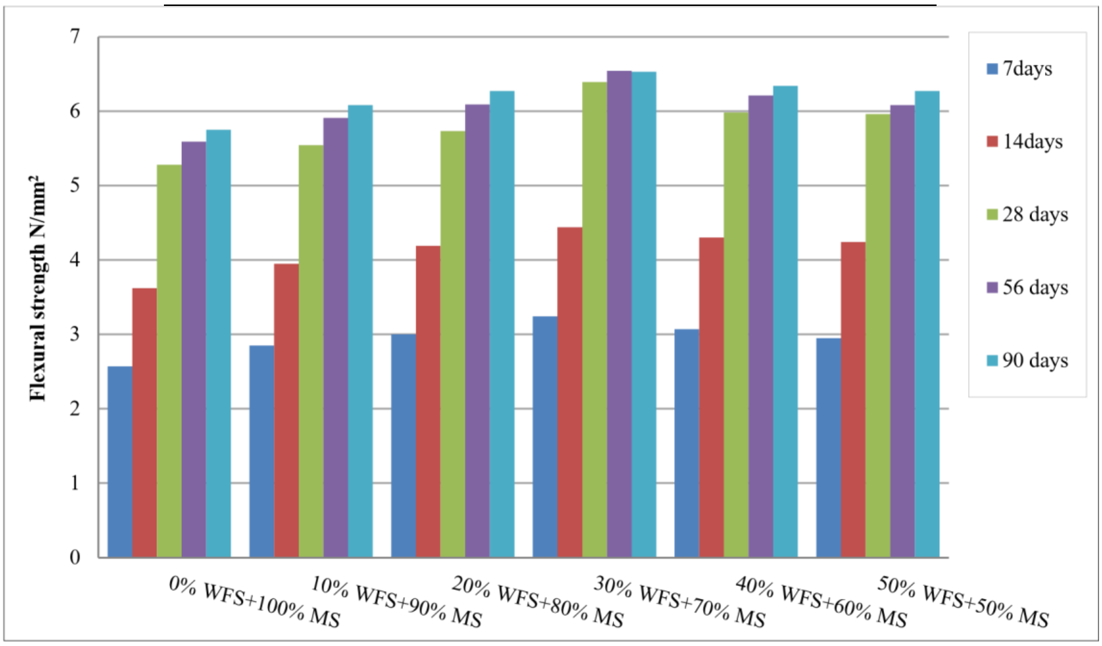
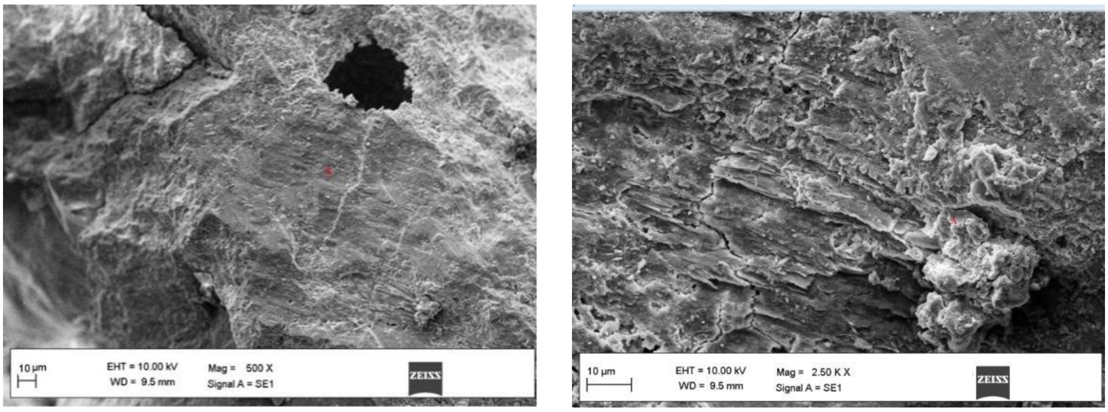


Figure 11. Flexural Strength results for different mixer combinations

5.6. SEM (Scanning Electron Microscopy) Images

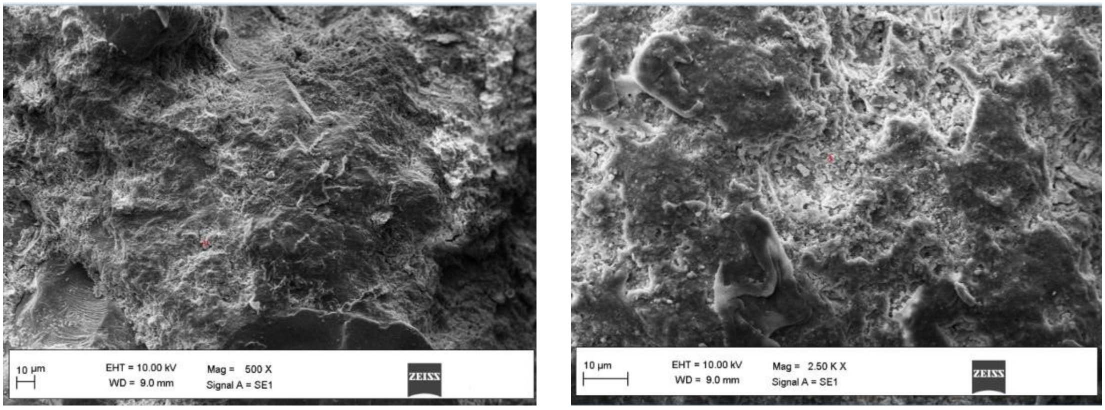
The SEM image of CC, WFS10%, WFS20%, WFS30%, WFS40% and WFS50% were taken after 28days of curing as shown in the Figures 12-a to 12-f. Figure 12 shows the SEM micrograph of control concrete at 500X magnification (a). Various phases of the C–S–H gel production procedure are shown. In the shot, the gel formation is plainly visible. The C–S–H gel's dazzling masses with nodules and vast areas of chalky gel are dispersed over the whole micrograph. Figure 12 depicts the SEM illustration of WFS10% blend (b). The number of voids has reduced when compared to the CC. The C-S-H is somewhat more dispersed than the control mix. In different regions in the microstructure, there are also WFS particles of differing sizes.

Figure 12-c depicts an SEM image of a WFS20 percent mixture, revealing the presence of more WFS particles at various locations as the percentage of WFS increases. When compared to WFS10% and CC, the C-S-H gel has better dispersion and nodule formation is significantly larger. SEM images of WFS30% and WFS40% concrete are shown in Figures 12-d and 12-e.WFS30% has a larger C-S-H gel formation and is also more finely distributed than CC, WFS10%, WFS20%, WFS40%, and WFS50%.Compared to CC, this gel formation produces a stronger substance. This R30 mix has the greatest WFS response and is the most powerful of all mixes. According to Siddique & Singh (2011) [19], concrete has a higher rate of C–S–H gel diffusion and nodule formation. In some instances, quick-setting concrete may be responsible for the generation of maximum tendrils in 30% of instances. The SEM findings correspond to the concrete's mechanical properties. When all replacement percentages are assessed, 30% replacement delivers the most desirable outcomes. The number of openings in the pool of candidates has fallen drastically. Nevertheless, when compared to the control concrete, other replacement percentages, such as 10%, 20%, and 40%, demonstrate superior strength and gel formation.

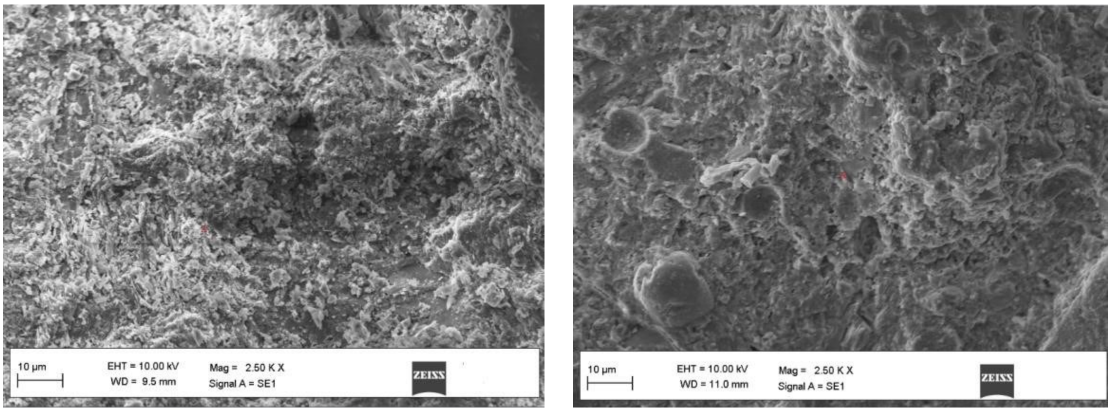


(a) 0% WFS+100% MS

(b) 10% WFS+90% MS



(c) 20% WFS+80% MS (d) 30% WFS+70% MS

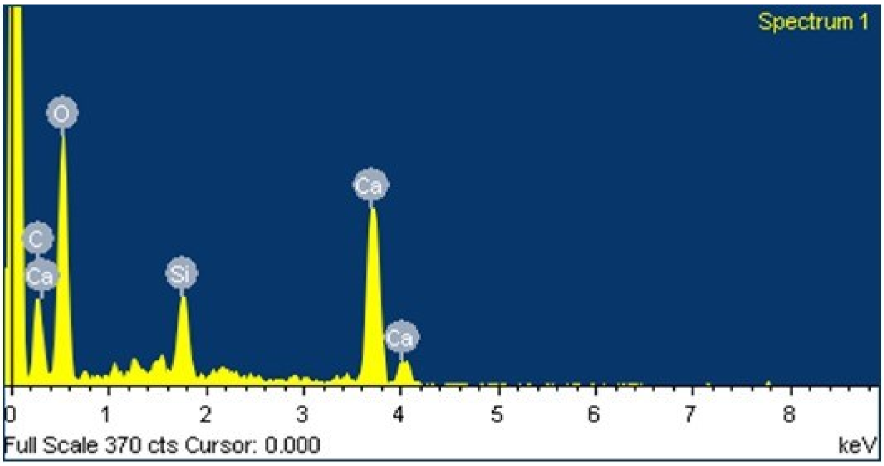


(e) 40% WFS+60% MS (f) 50% WFS+50% MS

Figure 12. SEM images for different mixer compositions

5.7. EDS (Energy-Dispersive X-ray Spectra)

Energy Dispersive X-ray Spectroscopy (EDX) is used to determine the composition of a sample such as thin films. Not only can relative amounts of each atom be measured, but the distribution of the atoms in our samples can be mapped. The mineralogical composition was calculated using the Bogue equation using a PAN alytical®, model Xpert-Pró. Qualitative chemical analysis results for all samples are shown in Figures 13-a to 13-f. The presence of rounded grains in the spectrograms suggested a quartz silica component during the manufacturing of alloys in the foundry for mineralogy and specific shape. EDS data shows that silica, potassium, titanium, iron, magnesium, and calcium are present in high concentrations, as well as high oxygen content, rather than their oxide forms. Calcium and oxygen showed the highest protuberant peaks in the EDS data, which were in agreement with the XRD records.



Element	Weight%	Atomic%
Al K	2.05	1.64
Ca K	40.85	21.93
C K	11.18	20.02
Mg K	1.31	1.16
O K	36.40	48.96
Si K	8.22	6.30
Total	100	

(a) 0% WFS+100% MS

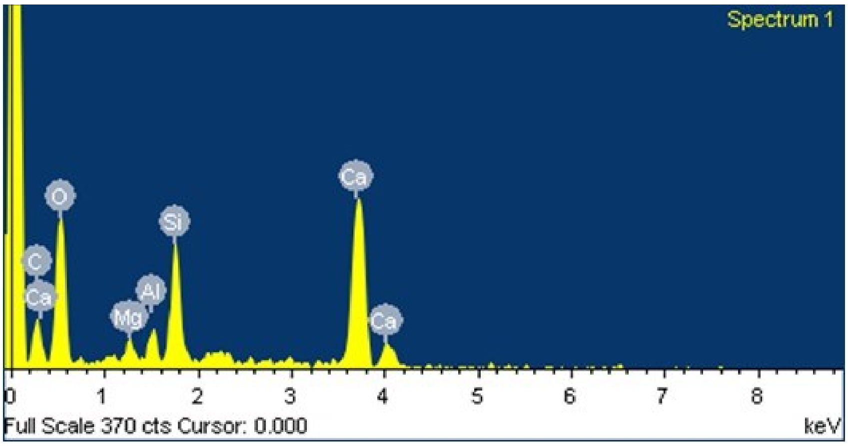
Element	Weight%	Atomic%
Ca K	37.96	20.20
C K	9.94	17.66
Na K	0.12	0.11
Fe L	2.24	0.85
Mg K	2.79	2.45
Si K	5.47	4.16
Al K	1.32	1.04
O K	40.15	53.52
Total	100	

Element	Weight%	Atomic%
O K	45.27	56.75
Si K	5.29	3.78
Ca K	36.83	18.43
C K	12.60	21.04
Total	100	

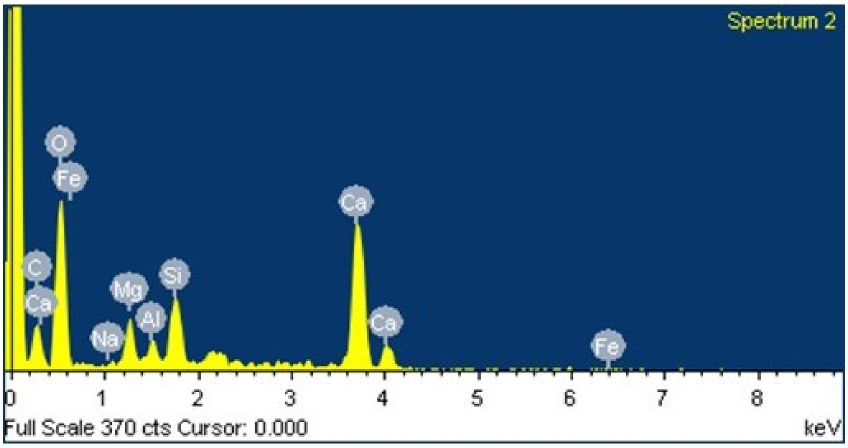
Element	Weight%	Atomic%
Mg K	2.84	2.45
C K	10.01	17.52
Si K	5.56	4.16
Al K	1.34	1.04
O K	41.47	54.48
Mg K	2.84	2.45
C K	10.01	17.52
Si K	5.56	4.16
Al K	1.34	1.04
O K	41.47	54.48
Mg K	2.84	2.45
Total	100	

Element	Weight%	Atomic%
Ca K	38.78	20.34
Mg K	2.84	2.45
C K	10.01	17.52

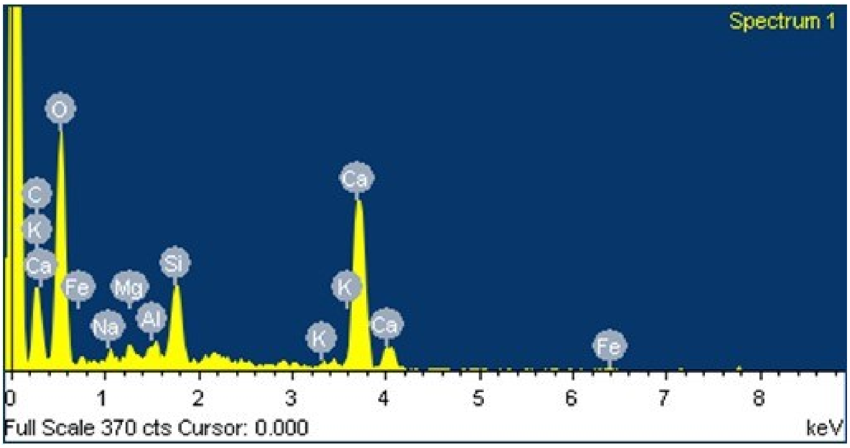
Si K	5.56	4.16
Al K	1.34	1.04
O K	41.47	54.48
Total	100	



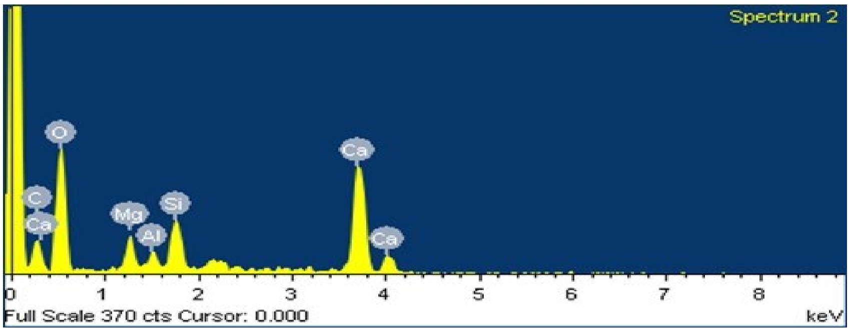
(b) 10% WFS+90% MS



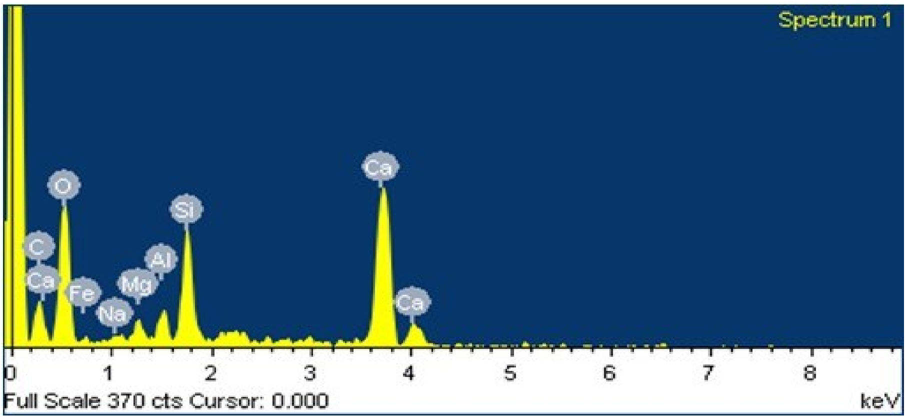
(c) 20% WFS+80% MS



(d) 30% WFS+70% MS



(e) 40% WFS+60% MS



(f) 50% WFS+50% MS

Figure 13. EDS images for different Mixer combinations

Element	Weight%	Atomic%
Na K	0.35	0.34
Al K	1.98	1.64
O K	33.58	46.74
Fe L	5.30	2.11
Mg K	1.23	1.13
Ca K	38.74	21.52
Si K	7.88	6.25
C K	10.94	20.28
Total	100	

5.8. TGA and DSE

Frequently, thermo gravimetric analysis (TGA) is performed to examine the hydration of cement. During TGA testing, cement hydrates decompose and may typically be split into three primary phases. The first stage is characterised by the loss of free water between 25 °C and 105 °C and the loss of water from hydrates (dehydration) between 105 °C and 400 °C. The second step involves the de-hydroxylation of Portlandite between 400 and 600 °C. The third step refers to the de-carbonation of CaCO3 between 600 and 800 °C. The TGA curves of wasted garnet are shown in Figures 14 and 15, respectively. The wasted garnet showed an endothermic decrease between 150 °C and 200 °C. The material's di-hydroxylation and loss of surface water are usually to blame for this drop. As the organic content in wasted garnet was oxidized, the exothermic peak (heat release) developed between 250 °C and 500 °C with a weight loss of 0.4% during this time. Hematite oxidation was also occurring in this temperature range, but hematite oxidation was masked by the much more intense oxidation reaction of organic materials in wasted garnet. The 0.2% weight loss reported for the sample between 300 and 450 °C was attributed to the disintegration of calcite into CaO at 768.5 °C and the dehydroxylation of quartz between 350 and 400 °C.

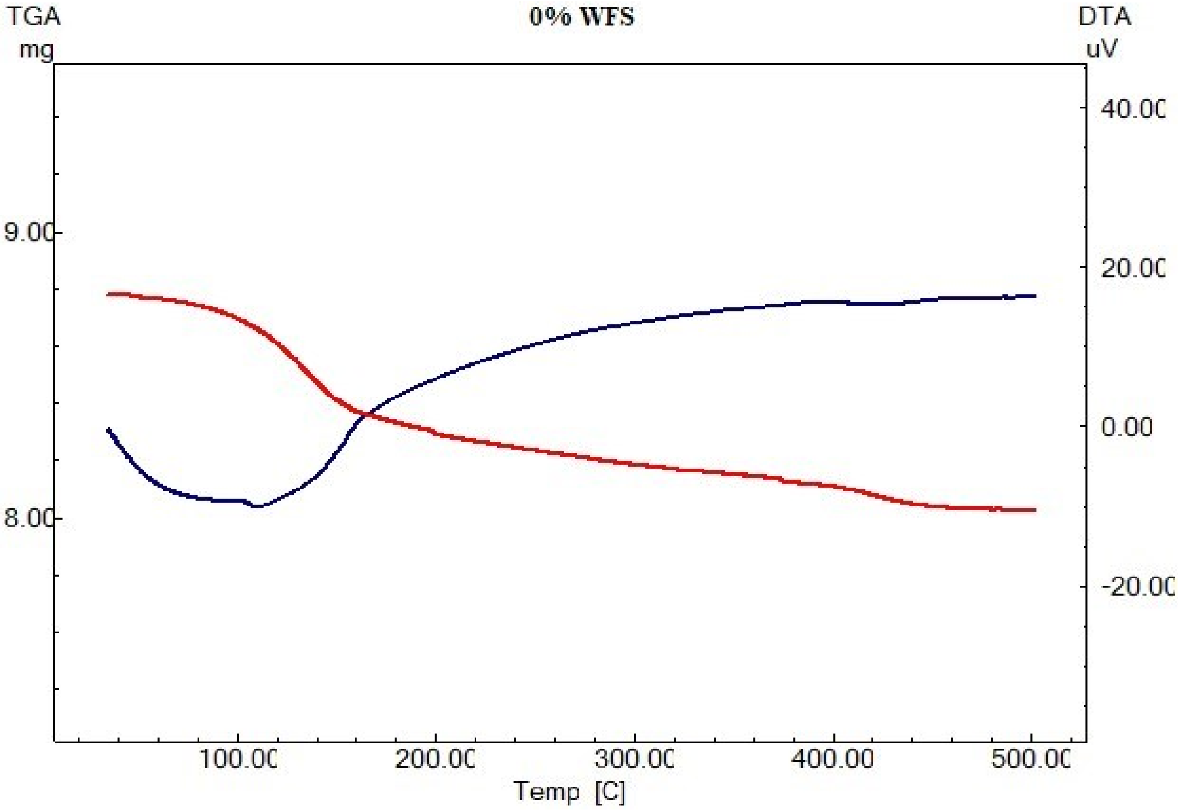


Figure 14. TGA and DSE curve graph for 0%WFS+ 100%MS

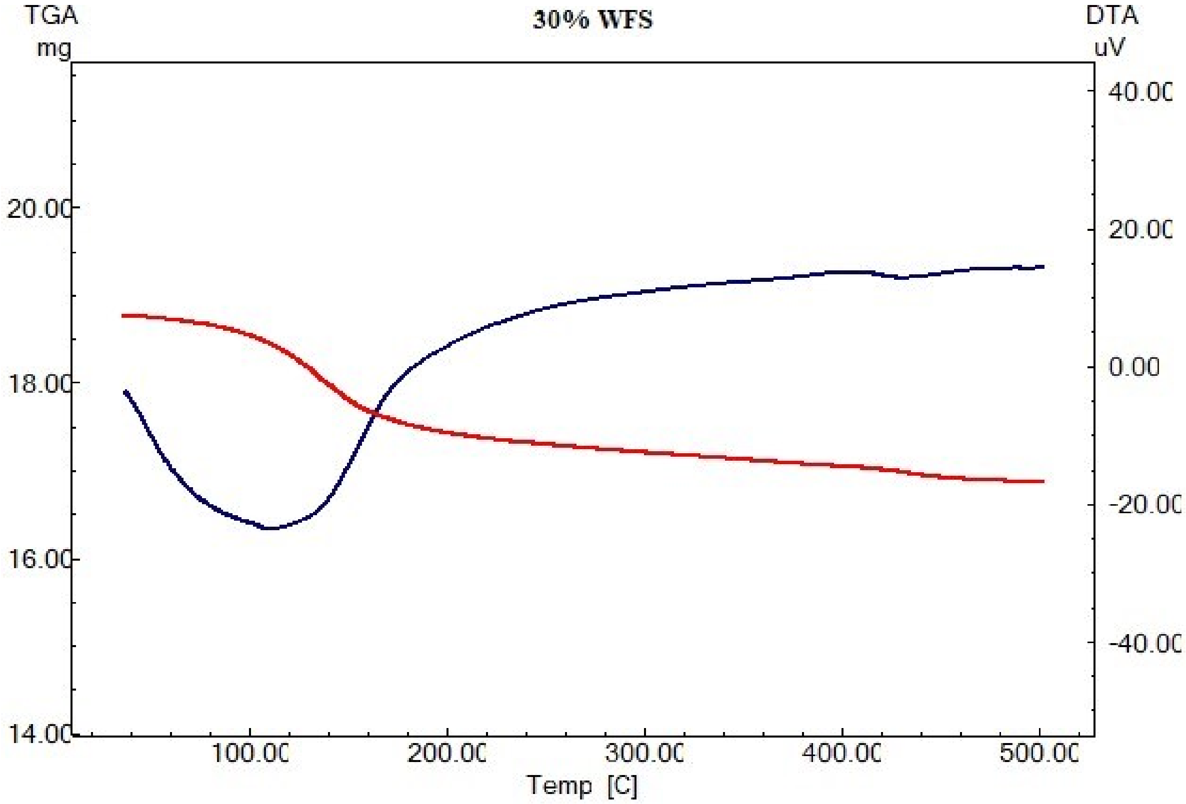


Figure 15. TGA and DSE curve graph for 30%WFS + 70%MS

The TGA curves of slag cement cured in water at 200°C reveal the presence of C–S–H at 110–1200 °C and Ca $(OH)_2$ at 460–4800°C in this research. This suggests that the reaction (both hydration and pozzolanic reaction) of Portland slag cement paste was enhanced when WFS was substituted for the reference mix, since the TGA curves had a greater range of peaks.

6. Discussion

One of the many tests used to gauge how well concrete performs is its compression strength. Information on a number of concrete properties is available from this single test. The compressive strength of concrete is directly correlated with a number of other properties. Once one is aware of the compressive strength of concrete, evaluating its quality is simple. Figures 8 and 9 display the compressive strength of concrete at various WFS doses. Concrete with partially substituted WFS has higher compressive strength than reference concrete, according to Bilal et al. [20]. This could be attributed to WFS's finer grain content, which worked well as filler and created a denser concrete mix [21]. In hardened concrete, the reduction of pore spaces brought on by the void-filling of granular materials tends to produce a matrix that is densely packed [22]. Silica may have helped in the production of the calcium silicate hydrate (CSH) gel [23]. CSH is produced chemically when SiO2 present in WFS reacts with calcium hydrate (CH), which is created during the hydration of cement. Concrete gains strength by having better binding qualities thanks to CSH. In a different study, natural sand was substituted with WFS at a rate of 30%, with satisfactory results. There, a similar result was observed. To get the best results, it would be wise to replace WFS with natural sand up to a 30% level [24–27]. An analysis of the data using statistics can show whether the inclusion of waste products had an impact on the results or whether they would have been the same without them. Remember that when examining one specific property, concrete mixtures are a culmination of many constituents that produce a range of results. In the end, the compression test results show that up to 30% of foundry waste can be substituted for natural concrete constituents without affecting RM's ability to compress.

Figure 7 displays the split tensile strength of concrete treated with various doses of WFS. Ahmad et al. [28] claim that WFS was partially substituted for natural river sand in their analysis. It is caused by the porosity enhancement, which, as a result of the presence of fine dust particles in the WFS, results in a lower density structure [29]. Despite the fact that cement concrete with up to a 30% replacement of WFS has split tensile strengths that are almost identical to the reference mix. According to Prabhu et al. [30], concrete with up to a 20% substitution ratio of WFS made from prewashed and sun-dried wood would be comparable to the control mix. However, a slight decline in strength was noticed after 30% replacement, and it decreased even more at a higher dose of WFS. The split tensile strength of WFS was found to be 19% lower than that of RM at a 50% substitution ratio. According to a study by Basar et al. [31], concrete's tensile strength gradually decreases as the quantity of foundry sand waste is significantly increased. The previous researcher noticed a comparable and consistent decline in concrete's tensile strength as the substitution ratio of WFS increased This result demonstrates a confirmed negative impact on the splitting tensile strength of RM with the inclusion of both coarse and fine foundry waste at 40% and 50% by mass replacement, respectively. However, it should be noted that at the highest replacement level of 30%, the tensile strength splits. Figure 8 shows the concrete's flexural strength in terms of flexure strength based on prior research using various doses of WFS. According to Ahmad et al. [28], the flexure strength is also decreased as the rate of (WFS). Although there was an increase in strength with the substitution of WFS in concrete, blends with up to 30% addition of (WFS) had nearly the same concrete flexure strength as RM. This result demonstrates the ability to include high percentages of foundry waste while still meeting structural design requirements if the base RM mixture is designed to meet a higher strength.

7. Conclusions

The following conclusions about the characteristics and behaviour of concrete are drawn from the above research regarding the partial substitution of fine aggregate by waste foundry sand:

- Increasing the percentage of discarded foundry sand in concrete improves the material's compressive, split tensile, and flexural strengths. In this experiment, 30% of the fine aggregate was replaced with waste foundry sand, producing the best compressive strength.
- According to the research, the amount of waste foundry sand in a split decreased as the split's strength increased. It has been reported that increasing WFS content improves flexural strength. When compared to the control mix, the microstructure of concrete, including foundry sand, reveals fewer gaps and a C–S–H gel paste that is not as widely disseminated.
- Between WFS and M sand, there was hardly any difference in bulk density, specific gravity, or grain size distribution.
- Concrete's flow ability was decreased when WFS was used in its place. This is because the WFS's physical characteristics-porous ness and greater surface area-increased water demand. However, WFS substitution up to 30% demonstrates acceptable workability.
- M sand can be substituted with WFS up to 30% of the time without negatively impacting the strength of the concrete. This is because the micro filling creates more dense concrete, which increases load resistance. However, at a higher dose of WFS, a loss in strength was noted (beyond 50%). The lack of workability, which makes compaction more challenging and causes more voids in the hardened concrete, is the cause of the reduction in strength.
- Concrete's strength properties—compressive strength, splitting tensile strength, and modulus of elasticity—increase when sand is partially replaced with WFS (up to 30%).
- With 30% WFS, the greatest increases in concrete's compressive strength, splitting tensile strength, and elastic modulus were seen between 28 and 91 days.
- WFS is a suitable material to use when producing structural grade concrete.
- A variety of combinations of particles of foundry sand were also detected at different sites. The distribution of C–S–H gel and the formation of nodules improved from WFS 20% to WFS 50% mix, with the greatest improvement at WFS 30% mix. Quick setting may have led to the formation of the greatest number of tendrils in the WFS 30% mixes.
- In addition, the SEM results for strength were similar to those of the mechanical tests. There was a significant correlation between SEM images, EDS micrographs, TGA phases, and mechanical properties. The results of this research suggest that excess foundry sand might be used as a 30% alternative in the manufacturing of high-quality concrete and construction materials. This is an ecologically friendly construction material since it uses scrap foundry sand, hence reducing the amount of trash produced by the metals sector.

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