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*Original Article*

# Performance Assessment of M20 Concrete Incorporating Blast Furnace Slag Aggregates as Partial Replacement of Natural Aggregates

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***Abstract** - This work site examines the latent of partial replacing natural aggregates (NA) at different replacement levels by volume with Blast Furnace Slag (BFS) aggregates in concrete to assess its effects on the compressive strength of M40-grade concrete. The compressive strength of the concrete was calculated after 3, 7, and 28 days of curing. Energy Dispersive X-Ray (EDX) test is carried out to analyse the effect of BFS aggregates and chemical composition of concrete after 28 days of curing. 75% replacement of NA by volume with BFS aggregate, sheared to 18.39% abridged compressive strength compared to conventional concrete, the mixes with lesser BFS content attained the mean target strength. The results support the incorporation of BFS aggregates in concrete as part of efforts to advance eco-friendly construction.*

***Keywords** - Natural Aggregate, Blast Furnace Slag, Compressive Strength, Energy Dispersive X-Ray.*

## 1. Introduction

Concrete is a broadly used construction resource universally due to its adaptability, toughness, and resistance to fire. Its vital ingredients are cement, aggregates, water, and various admixtures. According to Sawant et al. previous paper, aggregates, which make up between 60% and 75% of the concrete's total volume, are perilous to its configuration. As stated by Qi and Usman, the increasing pace of urban growth and infrastructure development has led to a surge in demand for concrete, with India consuming an estimated 3 million tons annually [1]. A similar rate is anticipated to continue over the next ten years, which could pose a threat to the ecosystem. The availability of raw materials needed to make cement and concrete is naturally restricted, as said by Sawant et. al. [2].

Reddy et. al. focus on an urgent need for substitute sources that can serve as natural aggregates in the manufacturing of concrete without sacrificing quality or structural integrity because the enormous demand for these materials is not long-term sustainable [3]. Conversely, Gowsalya and Bhagyalakshmi, large-scale industrial waste disposal is becoming a bigger issue in terms of pollution, land availability, expense, and storage [4], so there is an immediate necessity for the proper disposal or effective recycling of industrial by-products.

Scientists, engineers, and technologists are constantly searching for new materials that may be utilised to make cement and concrete instead of the traditional resources. It may be possible to use some of the waste products produced by industries throughout their manufacturing processes as components for concrete and cement. The feasibility of using these materials as alternatives to the traditional ingredients of cement and concrete is being investigated globally. These waste materials can be used in a variety of ways, including in their natural or processed state. For instance, they can be used directly as an aggregate, binding agent, or partial substitute for Portland cement. This helps reduce the cost of cement and concrete and aids in the safe disposal of this environmentally harmful material.

In India, around 24 million tons of BFS are produced each year. The goal of the current dissertation is to determine if blast furnace slag, an industry waste, may effectively substitute aggregate. A number of studies have considered the potential of BFS and other industrial by-products in concrete. For example, Rao et. al. say that the incorporation of slag particles can improve the strength and workability of the concrete mix. [5].Ozkan and Kabay investigated the use of Washing Aggregate Sludge (WAS) and Ground Granulated Blast Furnace Slag (GGBFS) as substitutes for coarse aggregates in concrete.

Their research focused on evaluating how these materials impacted the concrete's physical, mechanical, and durability properties. The study aimed to assess the potential benefits of using these alternatives in concrete production [6]. Similarly, findings of Chatzopoulos et. al., replacing conventional aggregates with slags in C25/30 and C30/37 concretes improved or maintained their mechanical and durability properties, with a notable 50% increase in compressive strength by 7 days.

The use of slag in both fine and coarse aggregates enhanced the concrete's resistance to carbonation and chloride penetration, significantly extending its service life. These slag-based concretes are recommended for typical reinforced concrete applications [7].

This investigation aims to quantify the effect of partially replacing natural aggregates with BFS aggregates on the compressive strength of M40 grade concrete. Along with this, an Energy Dispersive X-Ray (EDX) test is carried out to observe the changes in chemical composition in concrete with BFS aggregates after 28 days of curing. Inspecting how BFS influences compressive strength and chemical composition of concrete is important for assessing its potential as a replacement for natural aggregates.

## 2. Ingredients of concrete and their properties

This investigation utilizes ordinary Portland cement of grade 53, in accordance with IS 8112-2013 [8], which has a specific gravity of 3.15 [9]. Numerous tests were executed on the cement to ensure that it obeys the standards outlined in the IS specifications. The cement's physical characteristics were calculated following the guidelines provided in IS 4031 [10].

The locally manufactured crushed sand is passed through a 4.75 mm sieve, with a specific gravity of 2.95 and a density of 1510.96 kg/m³ [9]. The fine aggregate used conforms to Zone I as stated in IS 383 [11].

The Locally obtainable crushed stone is used with a maximum size of 20mm as a natural aggregate. More or less properties were estimated according to the IS code. The specific gravity is 3.15, the loose density is 1503.97 Kg/m3, and the compacted density is 1677.90 Kg/m3 [9]. Natural aggregates have a crushing value of 12.10% and an Impact aggregate value of 6.71% [12].

BFS is collected from Green Age Agro Engineers, Gokul Shirgaon, Kolhapur, Maharashtra. The big size of BFS was crushed by hand and had a maximum size of 20 mm. BFS has a Specific gravity of 2.42, a compacted density of 1071.54 Kg/m3, and a loose density of 937.83 Kg/m3 [9]. BFS aggregates have a crushing value of 20.96% and an Impact aggregate value of 39.96% [12].

These values are within the limit as suggested by IS 9376 - 1979. The primary chemical components in Blast Furnace Slag (BFS) include $SiO_2$ (27-38%) and $Al_2O_3$ (7-15%), along with CaO (34-43%), suggesting the presence of calcium silicates, aluminium silicates, and calcium aluminosilicates.

Armix Plast 111 is used. It is a High-Performance concrete admixture with a Specific gravity of approximately 1.20 and a pH of less than 7.0. Potable water is used for mixing and curing.

## 3. Mix Design

- Cement Content = 410 Kg/m3
- W/C Ratio = 0.45

**Table 1. Mix proportion**

| Cement | Sand | Aggregate (10 mm) | Aggregate (20 mm) | Water |
|---|---|---|---|---|
| 1.000 | 1.881 | 1.005 | 1.832 | 0.45 |

## 4. Identification of mix design (M40)

Through our study, we have partially replaced different percentages of natural aggregates by volume (15%, 30%, 45%, 60%, and 75%) with BFS aggregates to calculate strength and compare it with M40 grade conventional concrete. The identification of the mix design is given as follows:

**Table 2. Mix design identification**

| Design ID | Optimization of BFS Aggregate in Conventional Concrete (M40) |
|---|---|
| C1 | 0 % Replacement of NA by Volume |
| C2 | 15 % Replacement of NA by Volume |
| C3 | 30 % Replacement of NA by Volume |
| C4 | 45 % Replacement of NA by Volume |
| C5 | 60 % Replacement of NA by Volume |
| C6 | 75 Replacement of NA by Volume |

## 5. Results

### *5.1. Second-Order Heading*

A compression test is usually used to determine how the material will perform or react after applying a certain amount of compressive load. The concrete was prepared as per instructions in IS 516-1959 [13]. The compressive strength of the concrete design mix was measured using a Compression Testing Machine (CTM), which casts 150 x 150 x 150 mm cubes and cures them for 3, 7, and 28 days. The results are given below:

Table 3 and Graph 1 containing the 3-day compressive strength of concrete containing 100% NAs and concrete with NAs replaced by BFS coarse aggregates are as follows.

**Table 3. 3 days compressive strength**

| Cube ID Mark | Weight of Cube in Kg | Length in mm | Breadth in mm | Area of Cube in $mm^2$ | Load in kN | Compressive Strength in $N/mm^2$ | Average Compressive Strength in $N/mm^2$ |
|---|---|---|---|---|---|---|---|
| **C1 (0%)** | 9.156 | 149.60 | 149.66 | 22389.14 | 610 | 27.245 | **27.571** |
| | 9.057 | 149.70 | 149.25 | 22342.73 | 620 | 27.750 | |
| | 9.153 | 150.23 | 150.10 | 22549.52 | 625 | 27.717 | |
| **C2 (15%)** | 8.932 | 150.29 | 150.23 | 22578.07 | 600 | 26.574 | **26.933** |
| | 8.928 | 149.33 | 148.95 | 22242.70 | 608 | 27.335 | |
| | 8.931 | 151.33 | 150.40 | 22760.03 | 612 | 26.889 | |
| **C3 (30%)** | 8.684 | 151.23 | 150.23 | 22719.28 | 596 | 26.233 | **26.613** |
| | 8.656 | 150.29 | 150.23 | 22578.07 | 604 | 26.752 | |
| | 8.680 | 150.23 | 151.20 | 22714.78 | 610 | 26.855 | |
| **C4 (45%)** | 8.413 | 151.20 | 151.20 | 22861.44 | 576 | 25.195 | **25.581** |
| | 8.382 | 151.23 | 151.10 | 22850.85 | 584 | 25.557 | |
| | 8.420 | 150.23 | 150.60 | 22624.64 | 588 | 25.989 | |
| **C5 (60%)** | 8.064 | 149.90 | 150.10 | 22499.99 | 566 | 25.156 | **25.449** |
| | 8.091 | 150.29 | 150.23 | 22578.07 | 574 | 25.423 | |
| | 8.095 | 149.88 | 149.66 | 22431.04 | 578 | 25.768 | |
| **C6 (75%)** | 7.201 | 149.63 | 149.55 | 22377.17 | 535 | 23.908 | **24.007** |
| | 7.075 | 150.66 | 150.12 | 22617.08 | 540 | 23.876 | |
| | 7.094 | 150.10 | 149.80 | 22484.98 | 545 | 24.238 | |

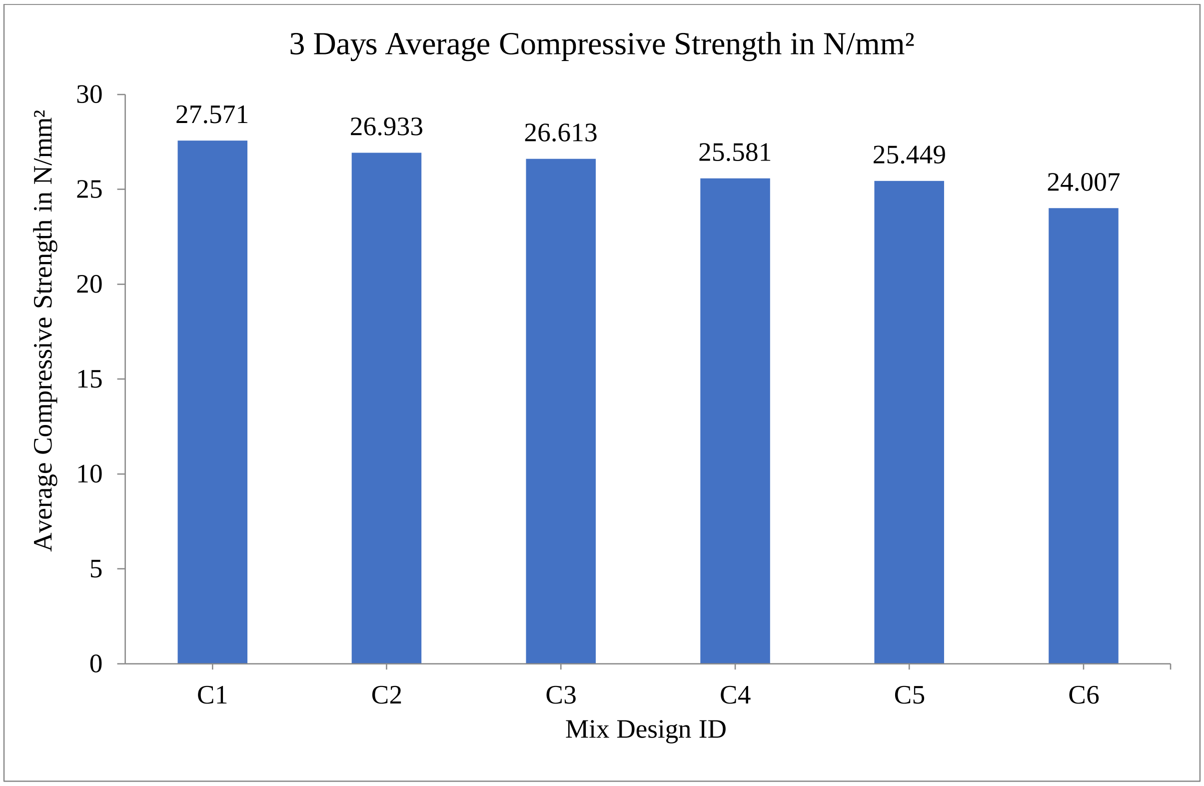



**Fig. 1 3 days compressive strength**

Table 4 and Graph 2 Containing the 7-day compressive strength of concrete containing 100% NAs and concrete with NAs replaced by BFS coarse aggregates are as follows:

**Table 4. 7 days compressive strength**

| Cube ID Mark | Weight of Cube in Kg | Length in mm | Breadth in mm | Area of Cube in mm$^2$ | Load in kN | Compressive Strength in N/mm$^2$ | Average Compressive Strength in N/mm$^2$ |
|---|---|---|---|---|---|---|---|
| **C1 (0%)** | 9.222 | 149.60 | 149.66 | 22389.14 | 830 | 37.072 | **36.561** |
| | 9.214 | 149.70 | 149.25 | 22342.73 | 795 | 35.582 | |
| | 9.224 | 150.23 | 150.10 | 22549.52 | 835 | 37.030 | |
| **C2 (15%)** | 8.974 | 150.29 | 150.23 | 22578.07 | 815 | 36.097 | **35.656** |
| | 8.921 | 149.33 | 148.95 | 22242.70 | 775 | 34.843 | |
| | 8.937 | 151.33 | 150.40 | 22760.03 | 820 | 36.028 | |
| **C3 (30%)** | 8.660 | 151.23 | 150.23 | 22719.28 | 805 | 35.432 | **35.213** |
| | 8.675 | 150.29 | 150.23 | 22578.07 | 775 | 34.325 | |
| | 8.665 | 150.23 | 151.20 | 22714.78 | 815 | 35.880 | |
| **C4 (45%)** | 8.400 | 151.20 | 151.20 | 22861.44 | 775 | 33.900 | **33.732** |
| | 8.405 | 151.23 | 151.10 | 22850.85 | 750 | 32.822 | |
| | 8.390 | 150.23 | 150.60 | 22624.64 | 780 | 34.476 | |
| **C5 (60%)** | 8.056 | 149.90 | 150.10 | 22499.99 | 765 | 34.000 | **33.553** |
| | 8.082 | 150.29 | 150.23 | 22578.07 | 735 | 32.554 | |
| | 8.097 | 149.88 | 149.66 | 22431.04 | 765 | 34.105 | |
| **C6 (75%)** | 7.165 | 149.63 | 149.55 | 22377.17 | 720 | 32.176 | **31.568** |
| | 7.085 | 150.66 | 150.12 | 22617.08 | 690 | 30.508 | |
| | 7.097 | 150.10 | 149.80 | 22484.98 | 720 | 32.021 | |

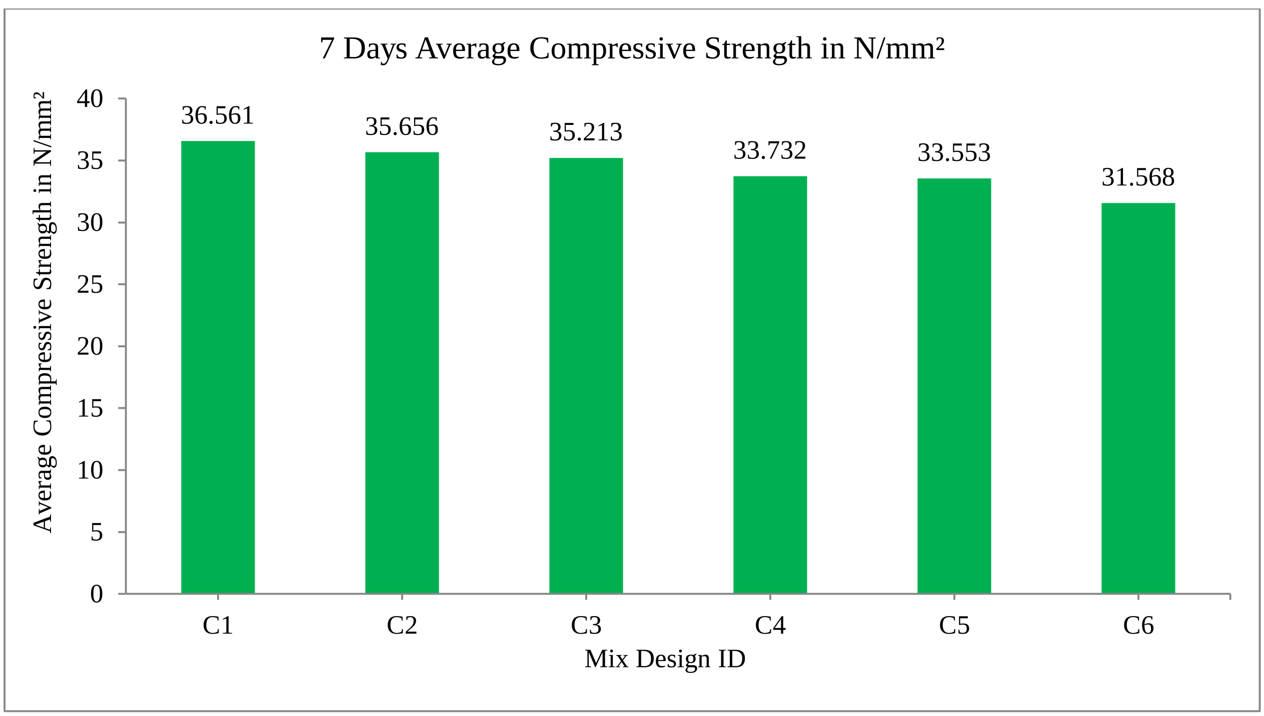



**Fig. 2 7 days compressive strength**

Table 5 and Graph 3 containing the 28-day compressive strength of concrete containing 100% NAs and concrete with NAs replaced by BFS coarse aggregates are as follows:

**Table 5. 28 days compressive strength**

| Cube ID Mark | Weight of Cube in Kg | Length in mm | Breadth in mm | Area of Cube in mm$^2$ | Load in kN | Compressive Strength in N/mm$^2$ | Average Compressive Strength in N/mm$^2$ |
|---|---|---|---|---|---|---|---|
| **C1 (0%)** | 9.215 | 151.20 | 150.04 | 22686.05 | 1270 | 55.982 | **56.574** |
| | 9.220 | 150.33 | 149.88 | 22531.46 | 1260 | 55.922 | |
| | 9.218 | 149.80 | 151.25 | 22657.25 | 1310 | 57.818 | |
| **C2 (15%)** | 8.934 | 151.02 | 150.33 | 22702.84 | 1250 | 55.059 | **55.442** |
| | 8.925 | 150.30 | 150.42 | 22608.13 | 1240 | 54.848 | |
| | 8.946 | 150.02 | 151.23 | 22687.52 | 1280 | 56.419 | |
| **C3 (30%)** | 8.672 | 151.33 | 151.10 | 22865.96 | 1250 | 54.666 | **55.588** |
| | 8.666 | 150.33 | 151.40 | 22759.96 | 1240 | 54.482 | |
| | 8.673 | 148.50 | 149.60 | 22215.60 | 1280 | 57.617 | |
| **C4 (45%)** | 8.369 | 149.60 | 149.66 | 22389.14 | 1200 | 53.597 | **53.950** |
| | 8.392 | 149.70 | 149.25 | 22342.73 | 1190 | 53.261 | |
| | 8.397 | 150.23 | 150.10 | 22549.52 | 1240 | 54.990 | |
| **C5 (60%)** | 8.057 | 150.29 | 150.23 | 22578.07 | 1130 | 50.049 | **50.763** |
| | 8.080 | 149.33 | 148.95 | 22242.70 | 1160 | 52.152 | |
| | 8.108 | 151.33 | 150.40 | 22760.03 | 1140 | 50.088 | |
| **C6 (75%)** | 7.189 | 151.23 | 150.23 | 22719.28 | 1040 | 45.776 | **46.172** |
| | 7.086 | 150.29 | 150.23 | 22578.07 | 1080 | 47.834 | |
| | 7.093 | 150.23 | 151.20 | 22714.78 | 1020 | 44.905 | |

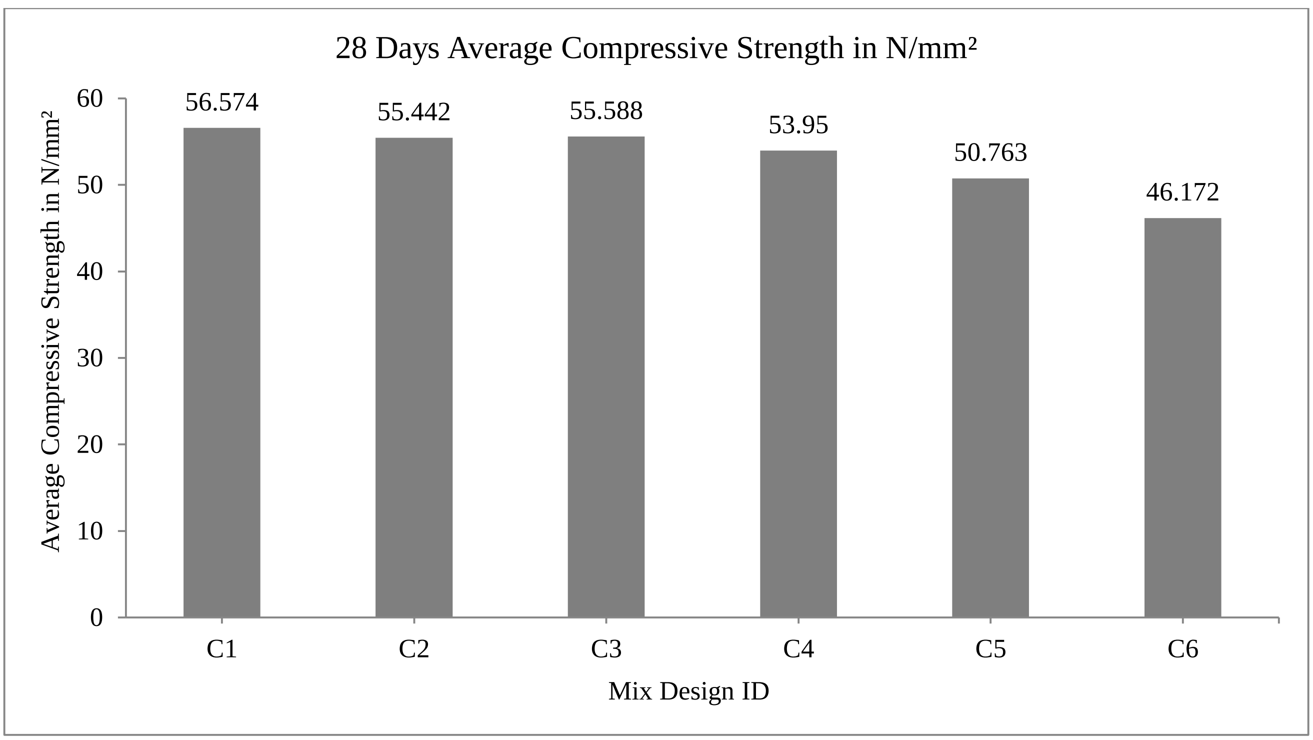
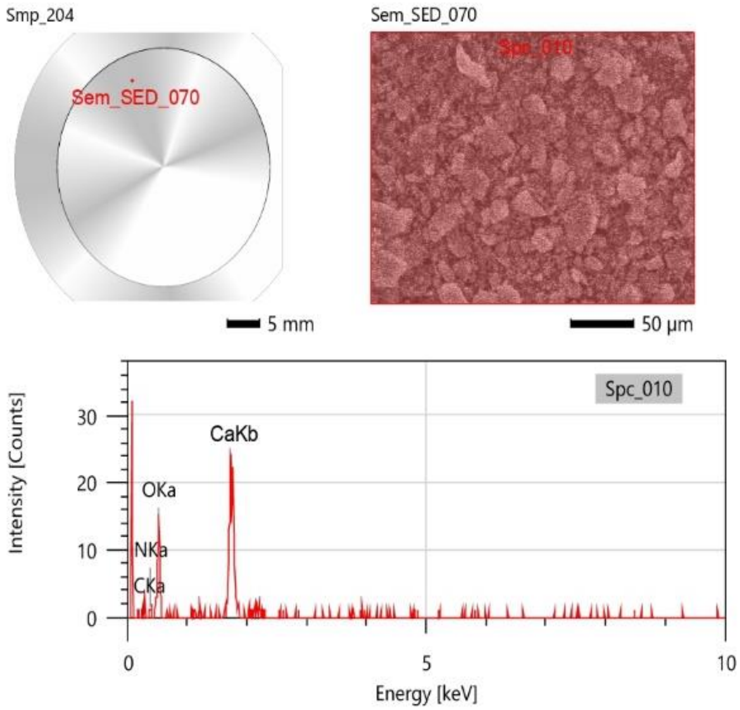



**Fig. 3 28 days compressive strength**

### *5.2. Energy Dispersive X-Ray (EDX) Test*

Energy Dispersive X-Ray (EDX) on the concrete was checked by testing the fine powder of concrete of all 6 mix designs of M40 grade concrete after the curing period of 28 days. The effects and chemical compositions of concrete with natural aggregate and BFS aggregates are observed by the Energy Dispersive X-Ray test as stated in ASTM C1723-16(2022). The obtained results are given below.

*5.2.1. EDX Results of C1*




Signal SED
Landing Voltage 20.0 kV
WD 11.8 mm
Magnification x500
Vacuum Mode HighVacuum

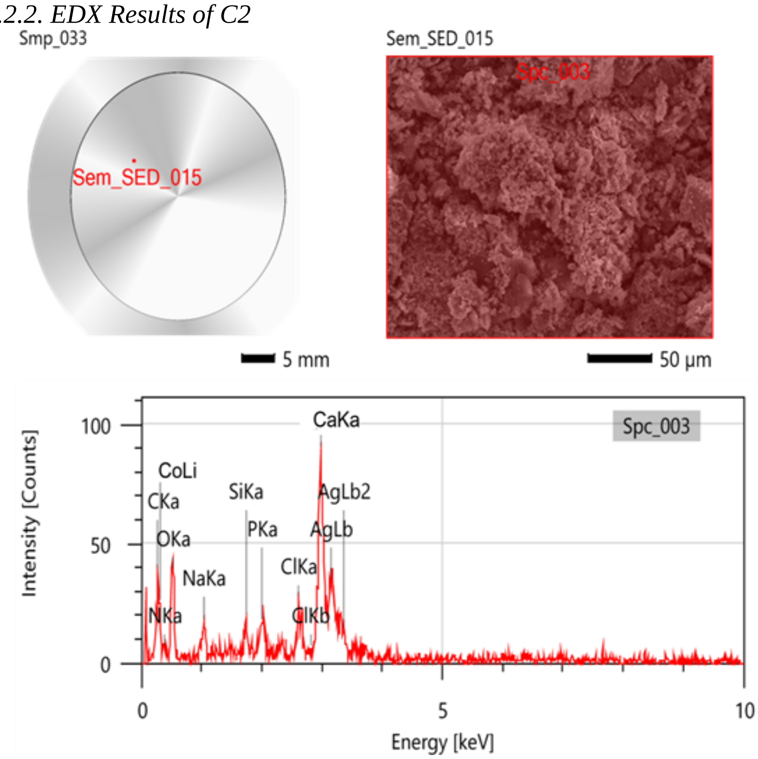
| Items | Value |
|---|---|
| measurement conditions | |
| Acceleration voltage | 20.00 kV |
| Probe current | - |
| Magnification | x 500 |
| Process time | T3 |
| Measurement detector | First |
| Live time | 30.00 seconds |
| Real time | 30.05 seconds |
| Dead time | 0.00 % |
| Count rate | 51.00 CPS |

| Display name | Standard data | Quantification method | Result Type |
|---|---|---|---|
| Spc_010 | Standardless | ZAF | Metal |

| Element | Line | Mass% | Atom% |
|---|---|---|---|
| O | K | 18.18±3.02 | 24.68±4.10 |
| N | K | 12.13±3.37 | 14.12±3.93 |
| Ca | K | 47.24±5.52 | 48.15±5.62 |
| Si | K | 22.46±2.41 | 13.04±1.40 |
| Total | | 100.00 | 100.00 |
| Spc_010 | | | Fitting ratio 0.6480 |

**Fig. 4 EDX results of concrete mix design C1**

*5.2.2. EDX Results of C2*




Signal SED
Landing Voltage 20.0 kV
WD 11.6 mm
Magnification x500
Vacuum Mode HighVacuum

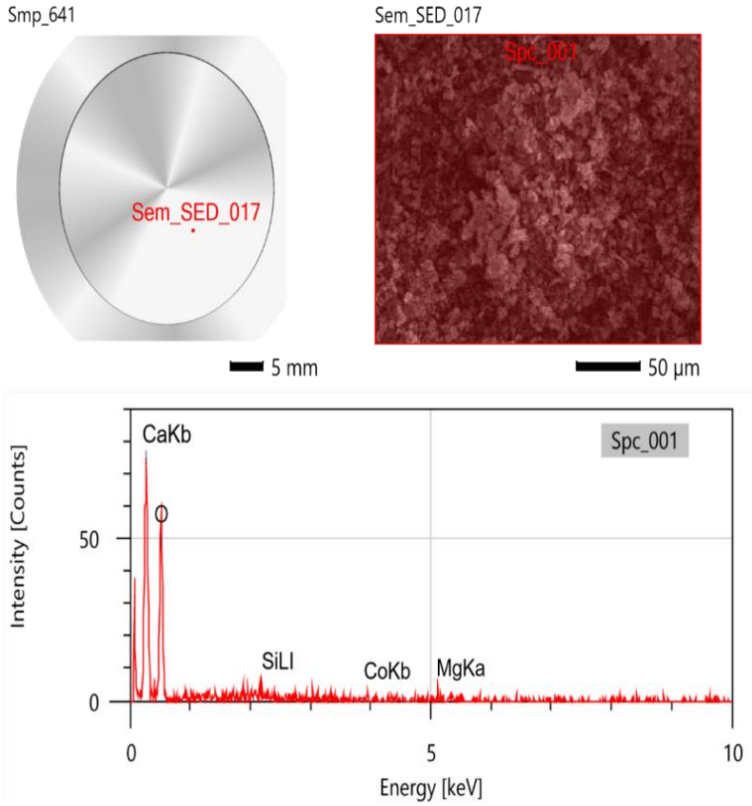
| Items | Value |
|---|---|
| measurement conditions | |
| Acceleration voltage | 20.00 kV |
| Probe current | - |
| Magnification | x 500 |
| Process time | T3 |
| Measurement detector | First |
| Live time | 30.00 seconds |
| Real time | 30.63 seconds |
| Dead time | 2.00 % |
| Count rate | 200.00 CPS |

| Display name | Standard data | Quantification method | Result Type |
|---|---|---|---|
| Spc_003 | Standardless | ZAF | Metal |

| Element | Line | Mass% | Atom% |
|---|---|---|---|
| Ca | K | 19.24±0.76 | 35.75±1.41 |
| N | K | 4.22±0.82 | 6.73±1.31 |
| CO | K | 30.25±1.88 | 42.19±2.62 |
| Na | K | 3.16±0.48 | 3.07±0.46 |
| Si | K | 1.52±0.25 | 1.21±0.20 |
| Mg | K | 2.48±0.31 | 1.79±0.22 |
| Cl | K | 2.77±0.31 | 1.74±0.19 |
| O | L | 36.35±1.49 | 7.52±0.31 |
| Total | | 100.00 | 100.00 |
| Spc_003 | | | Fitting ratio 0.3775 |

**Fig. 5 EDX results of concrete mix design C2**

*5.2.3. EDX Results of C3*




Signal SED
Landing Voltage 20.0 kV
WD 14.0 mm
Magnification x500
Vacuum Mode HighVacuum

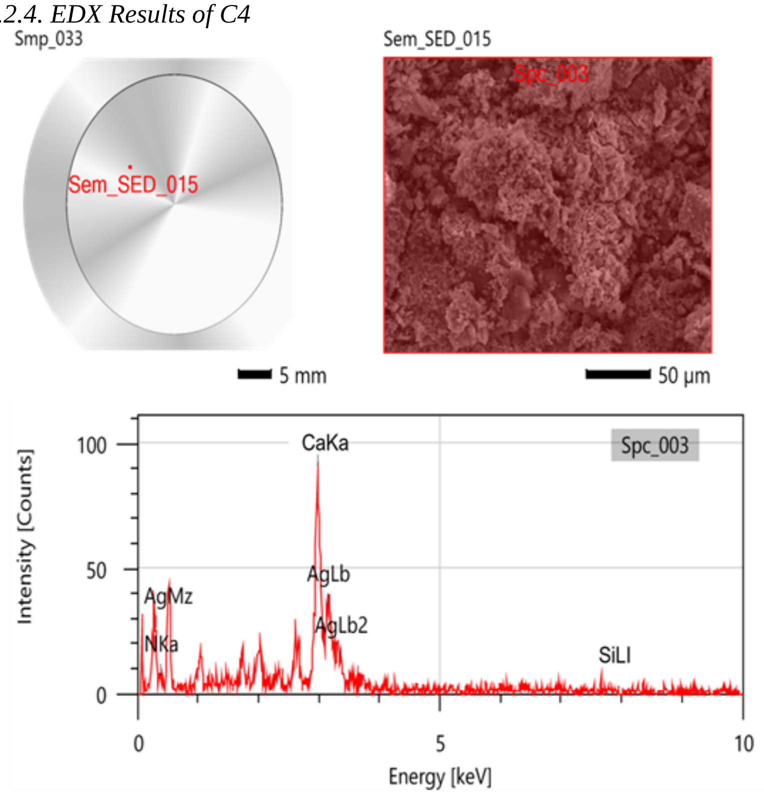
| Items | Value |
|---|---|
| measurement conditions | |
| Acceleration voltage | 20.00 kV |
| Probe current | - |
| Magnification | x 500 |
| Process time | T3 |
| Measurement detector | First |
| Live time | 30.00 seconds |
| Real time | 30.17 seconds |
| Dead time | 1.00 % |
| Count rate | 81.00 CPS |

| Display name | Standard data | Quantification method | Result Type |
|---|---|---|---|
| Spc_001 | Standardless | ZAF | Metal |

| Element | Line | Mass% | Atom% |
|---|---|---|---|
| Ca | K | 50.17±1.31 | 57.29±1.49 |
| Co | K | 49.83±2.90 | 42.71±2.48 |
| Total | | 100.00 | 100.00 |
| Spc_001 | | | Fitting ratio 0.4281 |

**Fig. 6 EDX results of concrete mix design C3**

*5.2.4. EDX Results of C4*




Signal SED
Landing Voltage 20.0 kV
WD 11.6 mm
Magnification x500
Vacuum Mode HighVacuum

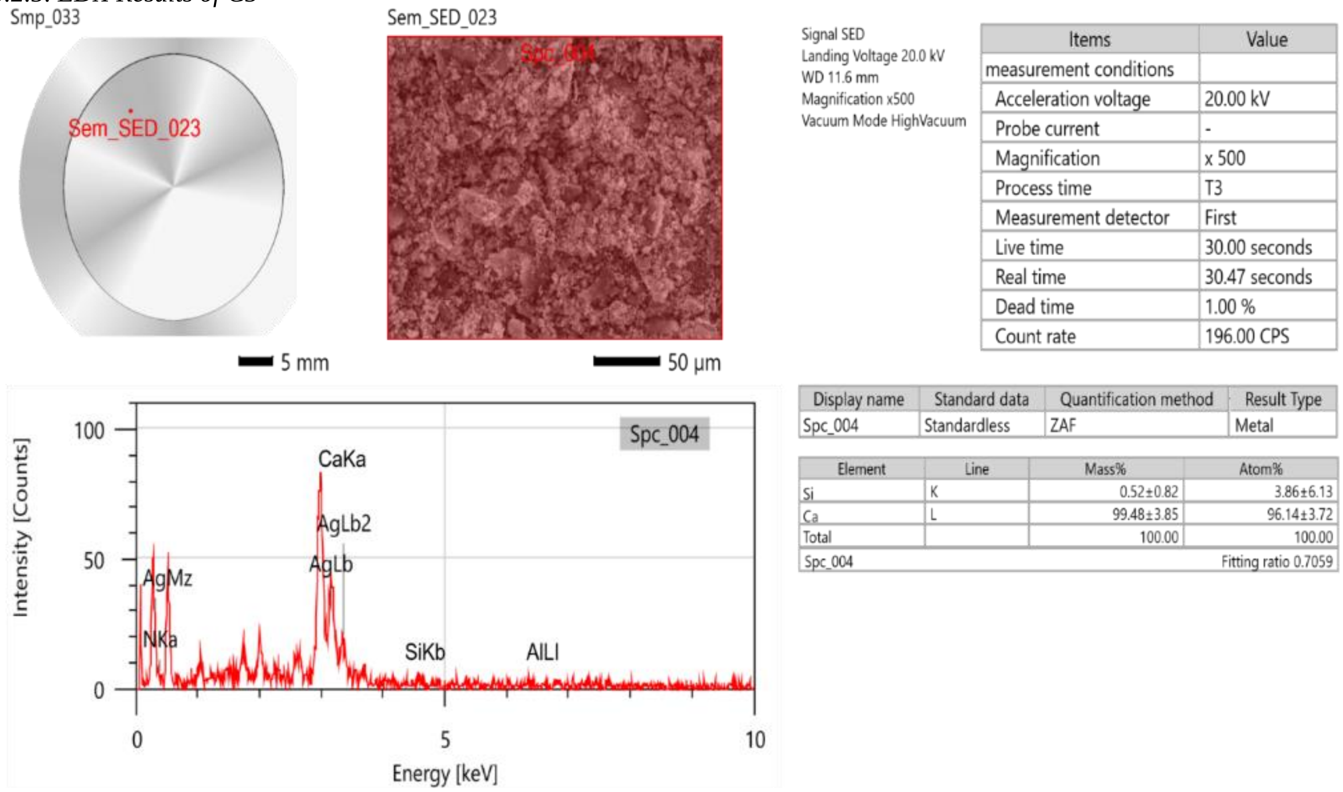
| Items | Value |
|---|---|
| measurement conditions | |
| Acceleration voltage | 20.00 kV |
| Probe current | - |
| Magnification | x 500 |
| Process time | T3 |
| Measurement detector | First |
| Live time | 30.00 seconds |
| Real time | 30.63 seconds |
| Dead time | 2.00 % |
| Count rate | 200.00 CPS |

| Display name | Standard data | Quantification method | Result Type |
|---|---|---|---|
| Spc_003 | Standardless | ZAF | Metal |

| Element | Line | Mass% | Atom% |
|---|---|---|---|
| Si | K | 9.67±1.50 | 45.18±7.00 |
| Ca | L | 90.33±3.64 | 54.82±2.21 |
| Total | | 100.00 | 100.00 |
| Spc_003 | | | Fitting ratio 0.6908 |

**Fig. 7 EDX results of concrete mix design C4**

### *5.2.5. EDX Results of C5*



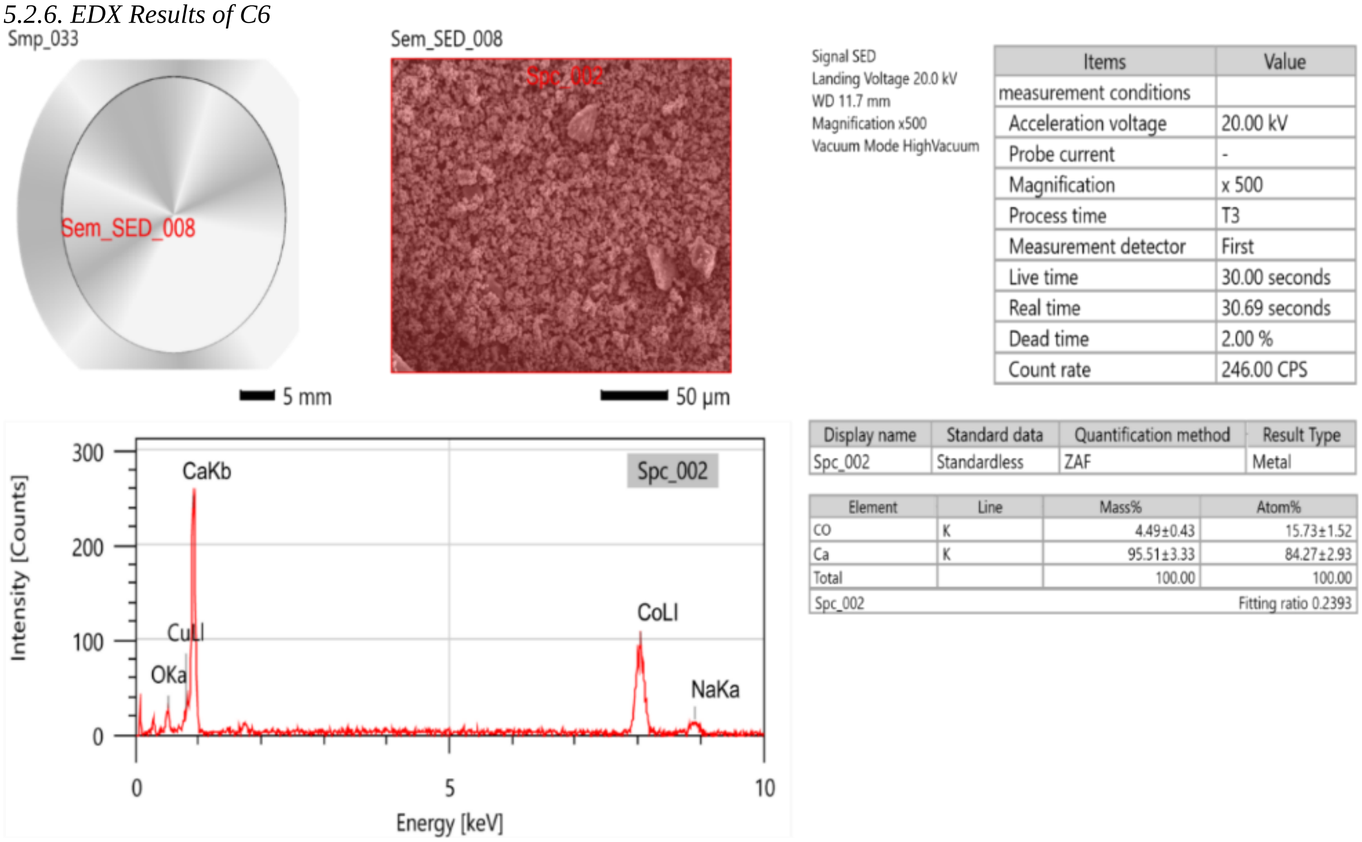

| Items | Value |
|---|---|
| measurement conditions | |
| Acceleration voltage | 20.00 kV |
| Probe current | - |
| Magnification | x 500 |
| Process time | T3 |
| Measurement detector | First |
| Live time | 30.00 seconds |
| Real time | 30.47 seconds |
| Dead time | 1.00 % |
| Count rate | 196.00 CPS |

| Display name | Standard data | Quantification method | Result Type |
|---|---|---|---|
| Spc_004 | Standardless | ZAF | Metal |

| Element | Line | Mass% | Atom% |
|---|---|---|---|
| Si | K | 0.52±0.82 | 3.86±6.13 |
| Ca | L | 99.48±3.85 | 96.14±3.72 |
| Total | | 100.00 | 100.00 |
| Spc_004 | | | Fitting ratio 0.7059 |

**Fig. 8 EDX results of concrete mix design C5**

### *5.2.6. EDX Results of C6*




| Items | Value |
|---|---|
| measurement conditions | |
| Acceleration voltage | 20.00 kV |
| Probe current | - |
| Magnification | x 500 |
| Process time | T3 |
| Measurement detector | First |
| Live time | 30.00 seconds |
| Real time | 30.69 seconds |
| Dead time | 2.00 % |
| Count rate | 246.00 CPS |

| Display name | Standard data | Quantification method | Result Type |
|---|---|---|---|
| Spc_002 | Standardless | ZAF | Metal |

| Element | Line | Mass% | Atom% |
|---|---|---|---|
| CO | K | 4.49±0.43 | 15.73±1.52 |
| Ca | K | 95.51±3.33 | 84.27±2.93 |
| Total | | 100.00 | 100.00 |
| Spc_002 | | | Fitting ratio 0.2393 |

**Fig. 9 EDX results of concrete mix design C6**

### 5.3. Effect of Partial Replacement of Natural Aggregates with BFS Aggregates on Compressive Strength of M40 Grade Concrete

The effect of partially replacing a percentage of natural coarse aggregate with BFS aggregate on the compressive strength of M40 grade concrete was calculated by testing cube samples in a compressive testing machine after curing for 3, 7, and 28 days. The compressive strength of concrete mixes with BFS was similar to that of conventional concrete.

At 28 days, concrete comprising 75% BFS coarse aggregate exhibited an 18.39% decrease in compressive strength compared to conventional concrete, and it failed to attain the target strength. All other mix designs also show the reduction in strength, but are more or less able to attain the desired target strength of 49.9 N/mm2.

By testing the concrete samples using the Energy Dispersive X-Ray (EDX) test, it can be observed that the concrete sample starts with a chemically diverse and reactive mix at 15%. By 60%, it evolves into a highly stable, calcium-dominant phase, showing clear signs of material aging and consolidation.

The presence of cobalt peaks sharply at 30%, suggesting a defined phase that soon transitions out, possibly replaced by silicate formation. Its disappearance by 45% indicates a key compositional turnover. Silicon appears only in mid-stages (notably at 45%), aligning with the formation of calcium silicate hydrates (C-S-H), which are responsible for strength in cementitious systems. The return of carbon at 75% likely results from atmospheric carbonation—a process that enhances surface stability but may reduce internal alkalinity over time.

This transformation reflects not only internal hydration reactions but also environmental interactions, resulting in a mature and chemically stable material. These insights are crucial for understanding the durability, strength development, and long-term behavior of M40 in structural applications.

## 6. Conclusion

The growing mandate for concrete in construction has sparked an interest in environmentally friendly replacements. This work discovered the practicability of including BFS aggregates into concrete, with a focus on compressive strength. By partially replacing NA with BFS aggregates at different quantities (15%, 30%, 45%, 60%, and 75%), we desired to determine the best replacement levels.

1. BFS, being a by-product of the iron and steel industry, presents a sustainable alternative to natural aggregates. Its utilization reduces the environmental impact caused by excessive mining and contributes to effective industrial waste management.
2. When BFS replacement exceeds 60%, particularly at 75%, the compressive strengths of the concrete decline. This is attributed to a less cohesive matrix and the dominance of BFS's lower crushing strength, which compromises the concrete's structural integrity.
3. BFS continues to exhibit pozzolanic behavior over extended curing periods. The prolonged formation of C-S-H gel during later stages (28 to 56 days) significantly contributes to improved long-term strength and matrix stability.
4. Within the 45% to 60% BFS replacement range, concrete exhibits excellent performance. This is primarily due to the pozzolanic activity of BFS, where its silica ($SiO_2$) and alumina ($Al_2O_3$) content react with the calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C-S-H) gel. This gel enhances the concrete's strength and durability. The rough and angular nature of BFS particles also contributes to stronger aggregate–paste bonding.

Based on physical properties, mechanical properties and durability properties, the optimal BFS replacement level lies between 45% and 60%. This range ensures a favorable balance between performance and sustainability, driven by effective pozzolanic reactions, superior aggregate–paste interaction, and adequate cement matrix formation.

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