Effect on Compressive Strength of M30 and M40 Concrete with Blast Furnace Slag as a Partial Replacement of Course Aggregate

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Abstract: Concrete remains an indispensable material in the construction industry due to its strength, durability, and adaptability. However, the increasing demand for concrete, coupled with environmental concerns such as depletion of natural aggregates and high carbon emissions from cement production, necessitates sustainable alternatives. This study investigates using Blast Furnace Slag (BFS) as a partial replacement for coarse aggregates in concrete. The aim is to evaluate BFS's impact on these concrete grades' mechanical properties and sustainability and compare their performance. The research substitutes natural aggregates with BFS at varying levels from 15% to 75% in M30 and M40 grade concrete. Results reveal that BFS enhances the sustainability of both M30 and M40 concrete while maintaining structural integrity. In M30 concrete, BFS replacement up to 45% demonstrated optimal performance. M40 concrete, with its higher cement content and reduced water-cement ratio, exhibited enhanced strength and durability across all BFS replacement levels, achieving higher performance metrics than M30 for similar substitution percentages. A comparison of M30 and M40 grades indicates that while both benefit from BFS replacement, M40 demonstrates superior compressive strength. However, M30 offers a cost-effective solution for general construction applications, especially when using BFS. Both grades showed reduced reliance on natural aggregates and improved environmental performance, aligning with sustainable construction goals. In conclusion, BFS serves as a viable partial replacement for coarse aggregates in both M30 and M40 concrete. The study highlights the comparative advantages of each grade, providing a pathway for selecting appropriate concrete mixtures based on specific project requirements. This approach supports eco-friendly construction practices, resource conservation, and efficient use of industrial by-products, addressing the dual challenges of performance and sustainability.

Keywords: Concrete, M30, M40, BFS, coarse aggregates, compressive strength, sustainability, durability, workability, eco-friendly construction, resource conservation.

1. Introduction

Aggregates, which mark up 60% -75% of the total volume of concrete, as highlighted by Sawant et. al.[1].The hurriedjump of urbanization has ominously increased the demand for concrete, with India alone consuming nearly 3 million tons annually [2]. The study of Cao &Nawaz focuses on enhancing Ultra-High-Performance Fiber-Reinforced Concrete by making it more lightweight, cost-effective, and environmentally friendly through the use of waste materials [3].

According toPratap&Zain,the use of fly ash and Granulated Blast Furnace Slag in concrete is mainly motivated by their economic advantages and improvements in durability [4]. The build up of non-degradable waste materials leads to significant environmental issues and challenges in their disposal. As a result, there is a pressing need for efficient methods to recycle or manage these industrial by-products [5].The construction industry is turning to BFS as a replacement for natural aggregates (NA) in lightweight concrete to address environmental challenges. This shift supports waste reduction efforts while improving concrete performance and sustainability. In lightweight structures, BFS offers durability benefits and reduces environmental impact.

Numerous studies have explored the use of BFS and other industrial by-products in concrete. Research by Bayat,et. al. examines the use of industrial and natural supplementary cementitious materials (SCMs) to create self-consolidating concrete (SCC) with lower embodied carbon. The research investigates binary and ternary mixtures of ground granulated blast furnace slag (GGBS) to enhance sustainability.[6]. Sainia and Vattipalli explored the use of GGBS in Self-Compacting Geopolymer Concrete (SCGC), emphasizing the advantages of incorporating industrial by-products into contemporary concrete mixtures [7]. The shift towards using BFS and other industrial by-products in construction not only helps address waste management challenges but also supports sustainable development objectives. BFS presents a viable alternative to natural aggregates (NA), contributing to the reduction of environmental impacts while improving concrete performance. By replacing traditional aggregates with BFS, the construction industry can take significant steps toward more sustainable practices, reducing the reliance on natural resources and minimizing waste.

This study focuses on assessing the compressive strength of concrete when coarse aggregates are replaced with BFS. Evaluating the impact of BFS on compressive strength is essential for determining its suitability as a substitute for conventional aggregates. This analysis will contribute to ongoing efforts to improve sustainability in construction by making better use of industrial by-products and lowering environmental footprint

2. Components of Concrete and Its Characteristics

2.1. Cement

- **Type:** 53-grade ordinary Portland cement (OPC).
- **Standards:** Complies with IS 8112:2013 [8].
- **Properties:**
    - Specific Gravity: 3.15 [9].
    - Physical properties determined as per IS 4031:1988 [10]

2.2.Fine Aggregate

- **Material:**Locally manufactured crushed sand.
- **Specifications:**Passes through a 4.75 mm sieve.
- **Properties:**
    - Specific Gravity: 2.95.
    - Bulk Density: 1510.96 kg/m³ [9]

2.3. Coarse Aggregate

2.3.1. Natural Aggregate

- **Source:** Locally available crushed stone.
- **Properties:**
    - Specific Gravity: 3.15.
    - Loose Density: 1503.97 kg/m³.
    - Compacted Density: 1677.90 kg/m³ [9]

2.3.2. Blast Furnace Slag

- **Source:** Green Age Agro Engineers, GokulShirgaon, Kolhapur, Maharashtra.
- **Processing:** Large slag pieces were hand-crushed to achieve a 20 mm maximum
- **Properties:**
    - Specific Gravity: 2.42.
    - Loose Density: 937.83 kg/m³.
    - Compacted Density: 1071.54 kg/m³ [9].

2.4. Water

- Potable water is utilized for mixing and curing.

2.5. Chemical

- ArmixPlast 111, a high-performance concrete admixture.

3. Mix design

The concrete mix was prepared following the ACI 211.1-1991 guidelines [12].

3.1 M30 Grade concrete

1.	Grade Designation	:	M30
2.	Cement Used	:	OPC 53 grade
3.	Maximum Nominal Size of Aggregate	:	20mm
4.	Cement Content	:	410 kg/m3
5.	Water-cement Ratio	:	0.488
6.	Workability	:	75 mm (slump)
7.	Exposure Condition	:	Severe (for reinforced concrete)
8.	Degree Of Supervision	:	Good
9.	Type Of Aggregate	:	Crushed rough aggregate
10.	Chemical Admixture Type	:	Superplasticizer

Target Strength[f_c] = $f_{ck} + 1.65 \times S$
= $30 + 1.65 \times 5$
= $38.25\ N/mm^2$

11. **Mix proportions**

Cement	Sand	Aggregate (10 mm)	Aggregate (20 mm)	Water
1.000	1.430	1.070	1.600	0.488

3.2 M-40 Grade concrete

1.	Grade Designation	:	M 40
2.	Cement Used	:	OPC 53 grade (IS 8112 compliant)
3.	Maximum Nominal Size of Aggregate	:	20mm
4.	Cement Content	:	380/m^3
5.	Water-cement Ratio	:	0.45
6.	Workability	:	75mm (slump)
7.	Exposure Condition	:	Severe exposure
8.	Degree Of Supervision	:	Good
9.	Type Of Aggregate	:	Crushed rough aggregate
10.	Chemical Admixture Type	:	Superplasticizer

11. **Target strength for mix proportion**

Target Strength = $F_{ck} + 1.65 X S$
= $40 + 1.65 X 6$
= $49.9 N/mm^2$

12. **Mix Proportion**

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

4. Introduction ofBFS aggregate in conventional concrete (m30)

4.1 Determination of mix design

In this study, various proportions of coarse aggregates (15%, 30%, 45%, 60%, and 75%) were substituted with BFS coarse aggregates to assess their impact on strength and compare the results with those of natural aggregates (NAs). The specific details of the mix design are outlined below.

B	**Improvement of BFS Aggregate in Conventional Concrete M30)**
B1	0 % Replacement of NA
B2	15 % Replacement of NA
B3	30 % Replacement of NA
B4	45 % Replacement of NA
B5	60 % Replacement of NA
B6	75 % Replacement of NA
C1	0 % Replacement of NA
C2	15 % Replacement of NA
C3	30 % Replacement of NA
C4	45 % Replacement of NA
C5	60 % Replacement of NA
C6	75 % Replacement of NA

4.2. Methodology

Concrete was mixed according to IS 516-1959 [13]. The quantities of cement, fine aggregates, and coarse aggregates were determined by weight. The mixing was done manually on a non-absorbent platform using a shovel. Concrete specimens were cast in 150 x 150 x 150 mm steel moulds and were compacted using a table vibrator. After one day, the specimens were removed from the moulds and cured until the specified testing days. AS per IS 516 – 1959 [13], the cubes were tested on the 3rd, 7th, 28th, and 56th days of curing.

5. Results

The tables and graphs below present the compressive strength of M30 and M40 grade concrete :

Table 1: 7 Days Compressive Strength (M-30)

Design ID Mark	**Weight of Cube in Kg**	**Load in KN**	**Compressive Strength in N/mm²**	**Average Compressive Strength in N/mm²**
B1 (0%)	9.276	760	33.420	**32.898**
	9.277	750	32.490	
	9.279	750	32.785	
B2 (15%)	9.055	740	32.742	**32.384**
	9.051	725	32.222	
	9.024	730	32.186	
B3	8.799	730	32.444	**31.933**

Design ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm²	Average Compressive Strength in N/mm²
(30%)	8.775	710	31.305	
	8.754	720	32.049	
B4 (45%)	8.532	720	31.641	**31.329**
	8.519	700	30.962	
	8.509	715	31.385	
B5 (60%)	8.291	660	29.099	**28.891**
	8.268	645	28.371	
	8.238	655	29.205	
B6 (75%)	8.110	625	27.312	**27.251**
	8.152	605	27.113	
	8.058	620	27.328	

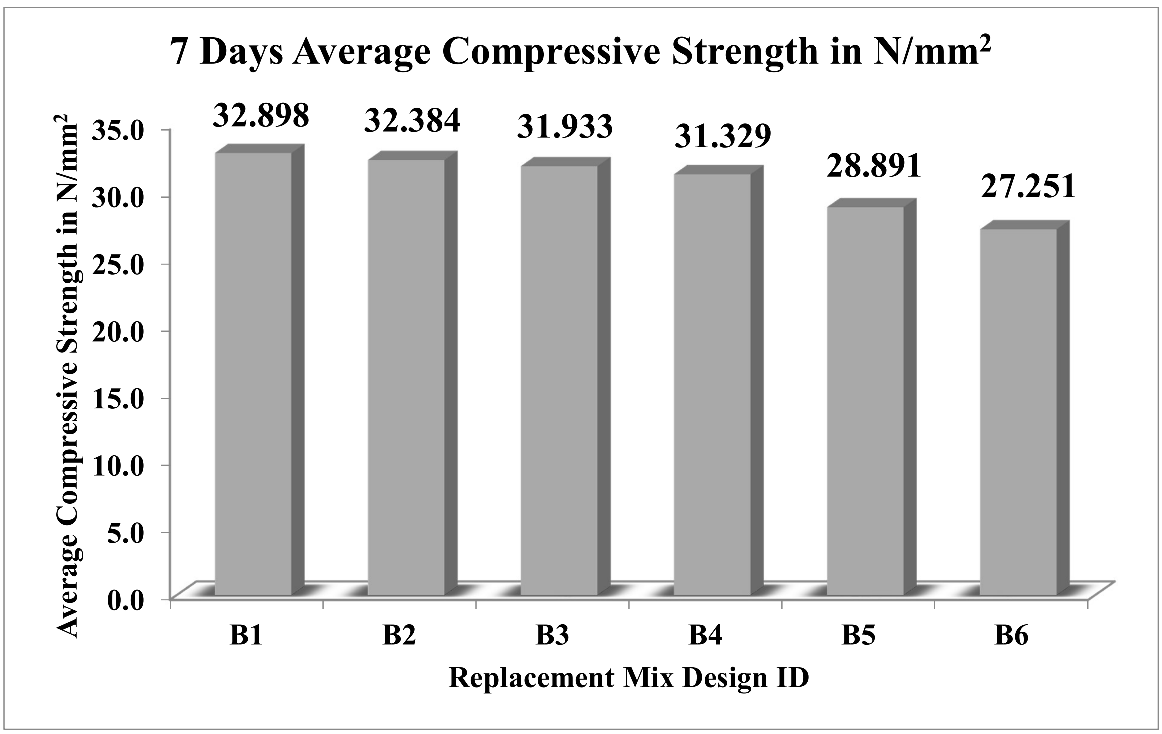

Figure 2: 7 Days Compressive Strength M30 Concrete

Table 2: 7 Days Compressive Strength (M-40)

Cube ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm²	Average Compressive Strength in N/mm²
C1	9.229	785	35.062	**34.555**

Cube ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm^2	Average Compressive Strength in N/mm^2
(0%)	9.209	750	33.568	
	0.923	790	35.034	
	8.949	770	34.104	
C2 (15%)	8.931	730	32.820	**33.658**
	0.896	775	34.051	
	8.684	760	33.452	
C3 (30%)	8.656	730	32.332	**33.228**
	0.868	770	33.899	
	8.413	730	31.931	
C4 (45%)	8.382	705	30.852	**31.757**
	0.842	735	32.487	
	8.078	720	32.000	
C5 (60%)	8.112	690	30.561	**31.553**
	0.807	720	32.098	
	7.903	675	30.165	
C6 (75%)	7.882	645	28.518	**29.568**
	7.901	675	30.020	

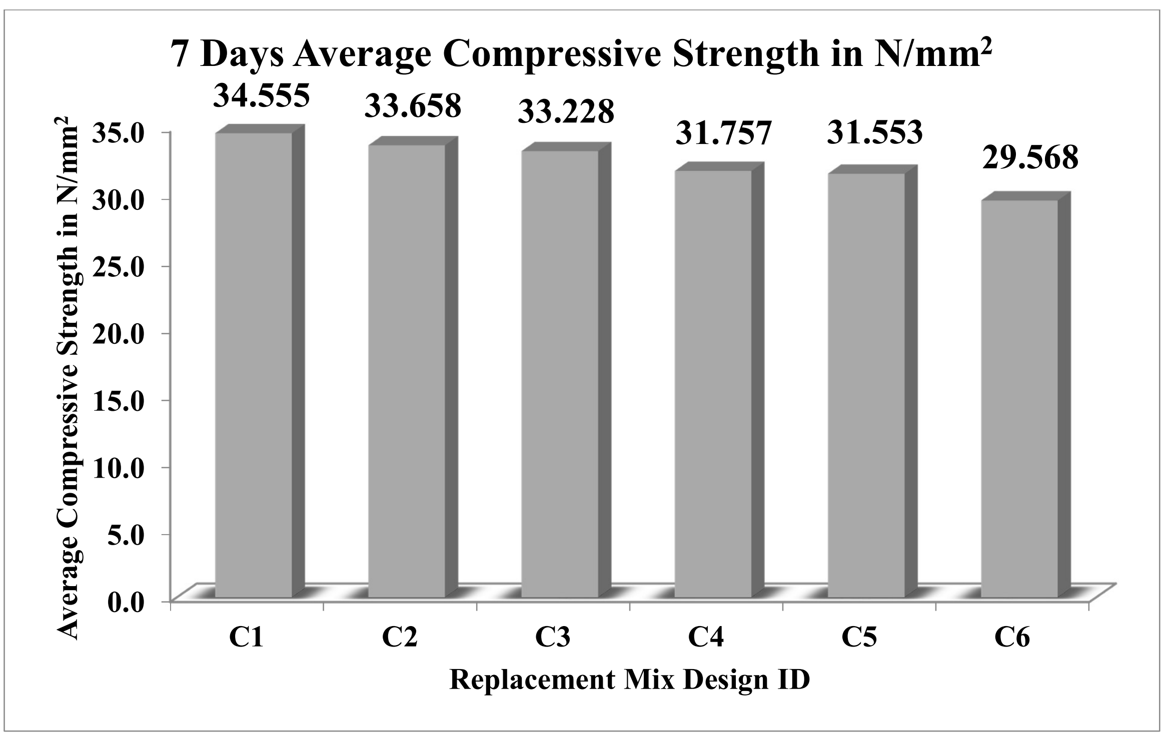

Figure 2: 7 Days Compressive Strength M40 Concrete

Table 3: 28 Days Compressive Strength (M-30)

Design ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm^2	Average Compressive Strength in N/mm^2
B1 (0%)	9.250	1115	49.801	**47.047**
	9.231	1045	46.771	
	9.213	1005	44.569	
B2 (15%)	9.010	985	43.626	**44.033**
	8.994	1015	45.633	
	8.974	975	42.838	
B3 (30%)	8.738	970	42.695	**43.156**
	8.733	1000	44.291	
	8.703	965	42.483	
B4 (45%)	8.488	960	41.992	**42.508**
	8.478	995	43.543	
	8.454	950	41.990	
B5 (60%)	8.228	940	41.778	**41.625**
	8.224	925	40.969	
	8.195	945	42.129	
B6 (75%)	8.081	845	37.762	**37.862**
	8.044	875	38.688	
	8.049	835	37.136	

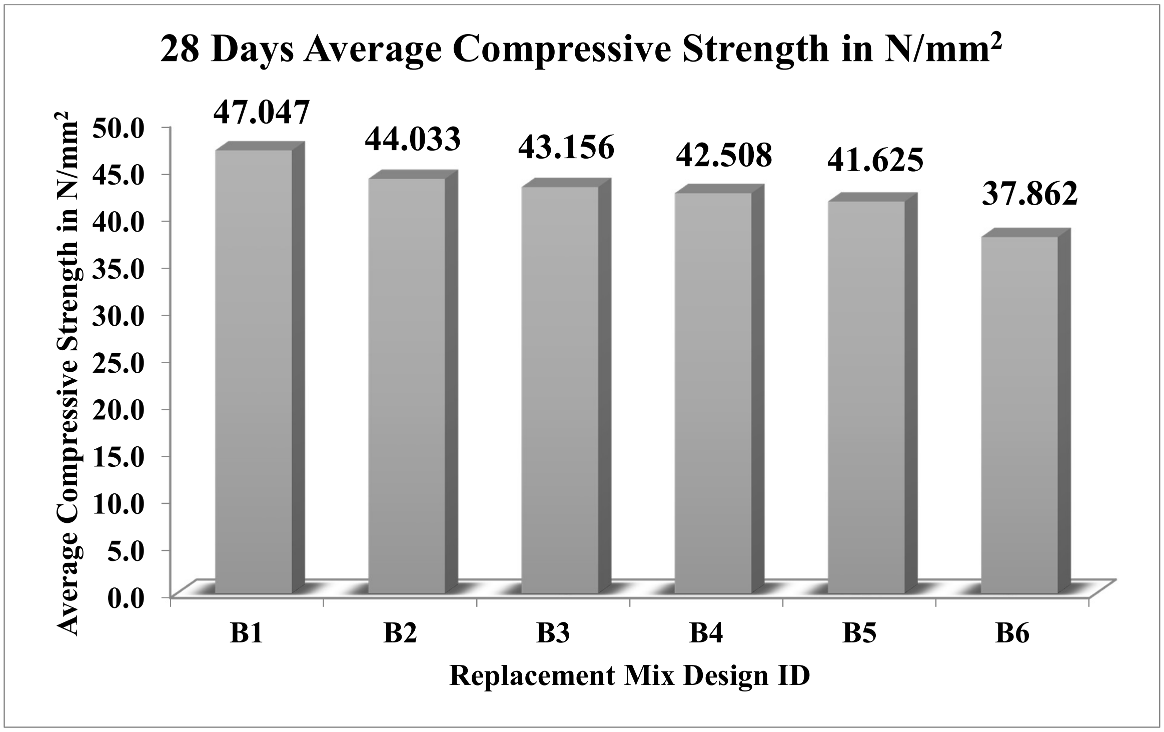

Figure 3: 28 Days Compressive Strength M30 Concrete

Table 4: 28 Days Compressive Strength (M-40)

Cube ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm^2	Average Compressive Strength in N/mm^2
C1 (0%)	9.219	1215	53.557	**54.143**
	9.217	1205	53.481	
	7.144	1255	55.391	
C2 (15%)	8.946	1195	52.637	**53.015**
	8.938	1185	52.415	
	6.929	1225	53.994	
C3 (30%)	8.666	1195	52.261	**53.156**
	8.670	1185	52.065	
	6.716	1225	55.141	
C4 (45%)	8.403	1155	51.588	**52.243**
	8.399	1175	52.590	
	6.503	1185	52.551	
C5 (60%)	8.057	1155	51.156	**51.273**
	8.080	1145	51.478	
	6.292	1165	51.186	
C6 (75%)	7.889	1075	47.317	**47.564**
	7.892	1065	47.170	
	7.893	1095	48.207	

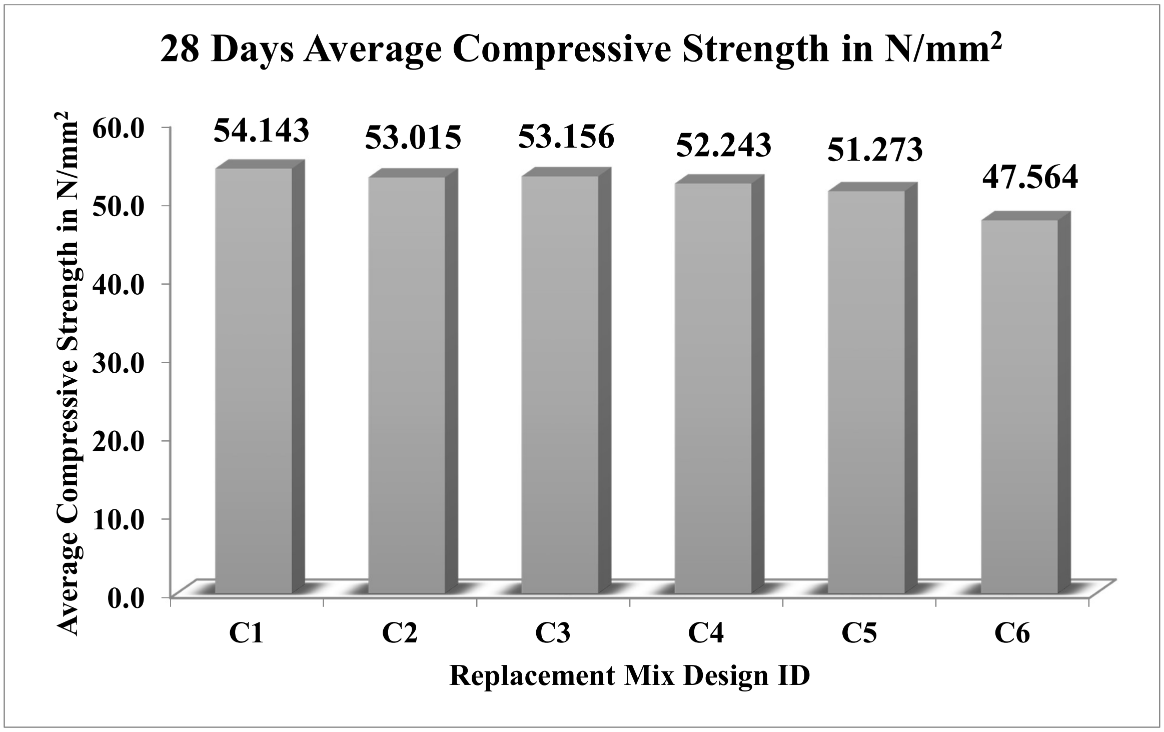

Figure 4: 28 Days Compressive Strength M40 Concrete

Table 5: 56 Days Compressive Strength (M-30)

Design ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm^2	Average Compressive Strength in N/mm^2
B1 (0%)	9.235	1130	49.804	**47.154**
	9.226	1060	46.886	
	9.219	1020	44.773	
B2 (15%)	9.006	1000	43.560	**44.431**
	8.996	1030	45.799	
	8.972	990	43.933	
B3 (30%)	8.742	985	43.043	**43.908**
	8.727	1015	45.487	
	8.702	980	43.195	
B4 (45%)	8.485	975	42.978	**43.465**
	8.473	1010	44.826	
	8.456	965	42.591	
B5 (60%)	8.235	955	42.065	**41.986**
	8.221	940	41.578	
	8.192	960	42.314	
B6 (75%)	8.071	860	37.610	**38.325**
	8.074	890	39.104	
	8.029	850	38.261	

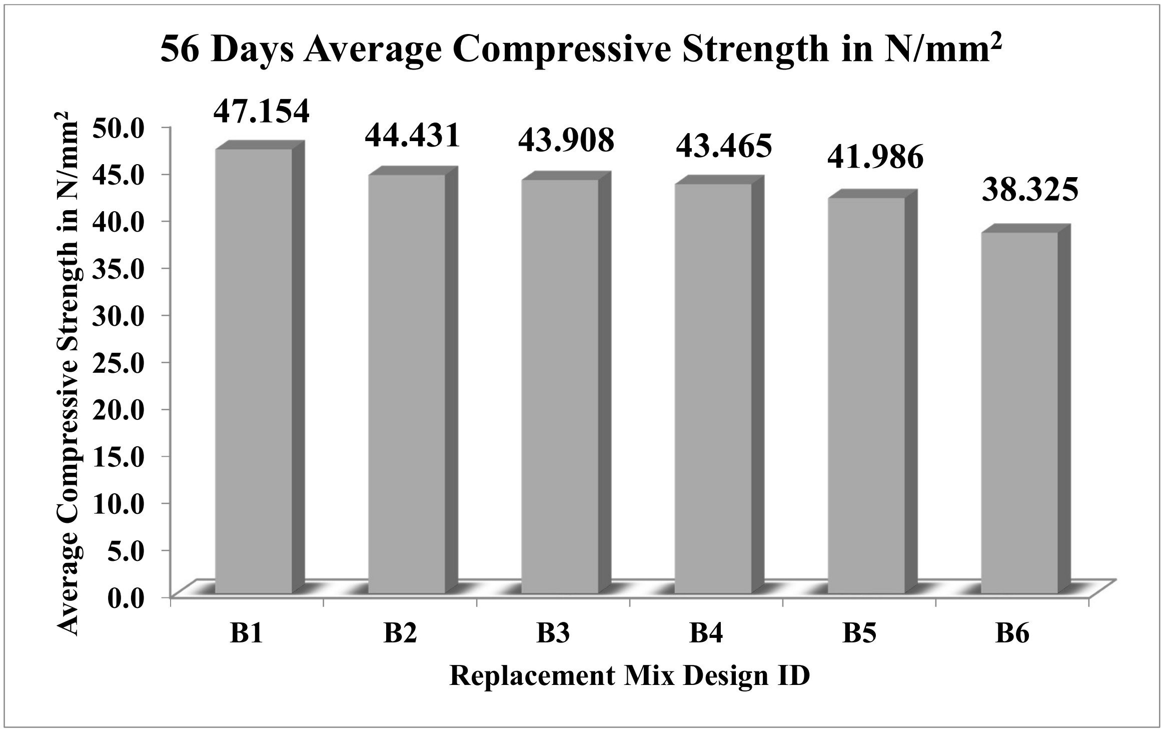

Figure 5: 56 Days Compressive Strength M30 Concrete

Table 6: 56 Days Compressive Strength (M-40)

Cube ID Mark	Weight of Cube in Kg	Load in KN	Compressive Strength in N/mm²	Average Compressive Strength in N/mm²
C1 (0%)	9.216	1230	54.367	**54.834**
	9.211	1220	54.147	
	6.104	1270	55.989	
C2 (15%)	8.942	1210	53.073	**53.784**
	8.932	1200	53.616	
	5.921	1240	54.663	
C3 (30%)	8.665	1210	52.872	**53.604**
	8.664	1200	53.351	
	5.738	1240	54.590	
C4 (45%)	8.401	1170	51.574	**52.295**
	8.392	1190	52.501	
	5.557	1200	52.812	
C5 (60%)	8.056	1170	51.920	**51.764**
	8.082	1160	51.312	
	5.375	1180	52.060	
C6 (75%)	7.888	1090	48.211	**48.182**
	7.886	1080	47.348	
	7.890	1100	48.987	

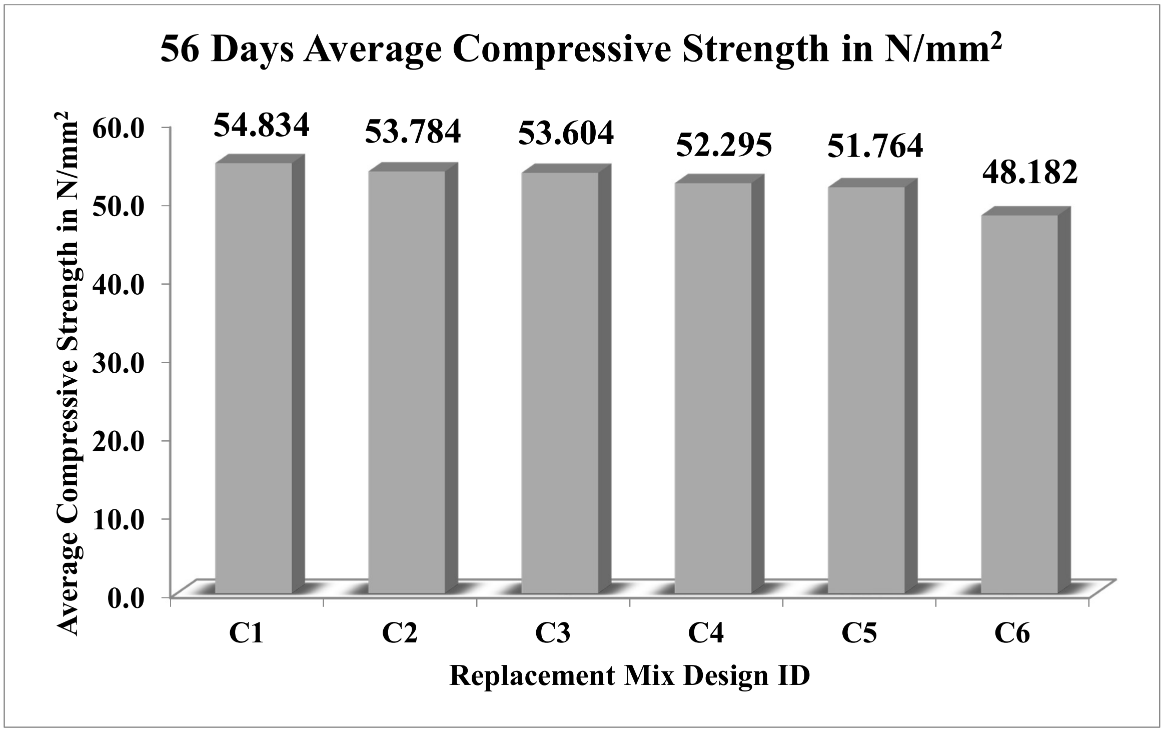

Figure 6: 56 Days Compressive Strength M40 Concrete

5. Conclusion

1. While BFS exhibits lower compressive strength compared to conventional concrete, it is able to reach its intended mean strength over time expect the mix design with 75% replacement level.
2. The findings of this study indicate that replacing 15% to 30% of coarse aggregates with BFS results in the most optimal performance for both M30 and M40 grade concrete mixes. this optimal performance was observed across various curing periods, including 7, 28, and 56 days.
3. In28 days of curing, mixes containing 75% BFS coarse aggregate exhibited a noticeable decrease in compressive strength, ranging from 10.96% in M-30 concrete to 12.15% in M-40 concrete which is less than target mean strength.
4. As the curing period extended, the difference in strength reduction became less significant.

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