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Experimental Study On Effect Of Blast Furnace Slag As A Partial Replacement Of Course Aggregate On Compressive Strength Of M20 And M30 Grade Concrete Mix

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Abstract
Meeting the increasing demand for aggregates while reducing the environmental implications of natural resource extraction is a major challenge for the building industry. In this study, we look at the feasibility of using Blast Furnace Slag (BFS), a waste product from the steel industry, to make M20 and M30 grade concrete instead of using natural coarse aggregates. Aside from helping with trash recycling, using BFS is a great method to cut back on using natural aggregates. In order to generate twelve separate concrete mixtures for M20 and M30 grades, we used BFS in place of natural coarse aggregates at various percentages (15%, 30%, 45%, 60%, and 75%). A control sample consisted of only natural aggregates. In order to maximize the concrete's performance, a high-performance additive was applied after all of the ingredients had already met the necessary standards. By replacing 15% of the natural aggregates in M20 concrete with BFS, the compressive strength was brought up to standard concrete values, with a small decrease at 30% BFS and above. With 15% BFS, the maximum strengths for M20 were 34.086 N/mm² and for M30, they were 55.442 N/mm². Strength decreased by 15.36% for M20 and 11.63% for M30 at 75% BFS replacement. In order to promote sustainable construction practices such waste recycling and reduced carbon emissions, the results indicate that BFS is a valuable fractional alternative to natural aggregates. Optimal usage of BFS and investigation of its effects on other concrete qualities necessitate additional research.
Keywords: *Blast Furnace Slag, Natural Aggregate, Compressive Strength, Industry By-products.*

1. INTRODUCTION

Concrete is a common building material used all over the world because of its fire resistance, durability, and adaptability. Cement, aggregates, water, and other admixtures make up the majority of it. According to Sawant et al., aggregates comprise a substantial amount of concrete, usually between 60% and 75% of its volume, and are essential to the material's overall composition and functionality [1]. Mehta and Monteiro estimate that approximately 11 billion metric tons of concrete will be used annually worldwide, with an average of more than 1.5 metric tons consumed per person [2]. The demand for concrete has significantly increased as a result of growing infrastructure and urbanization; India alone uses over 3 million tons annually [3]. According to Jahren and Sui, India's cement consumption is expected to reach 860 million metric tons by 2030 [4], which implies that aggregate and concrete use will also increase in tandem. India contributes around 1.6 billion metric tons of the estimated 16.5 billion metric tons of aggregates consumed annually, according to Mani and Reddy [5].According to Peduzzi [6], it is becoming more and more unsustainable to meet the existing demand for aggregates through the extraction of natural resources. Finding substitutes for sand is now essential to preserving equilibrium between aggregate availability and demand.On the other hand, the massive amounts of non-organic waste and industrial by-products that are steadily building up urgently need to be disposed of properly or recycled [7]. According to Katoch et al., India's housing policy, the expansion of industrialization, and infrastructure projects have all contributed to a noticeable rise in the demand for steel. Significant by-products and industrial waste, especially blast furnace slag (BFS), which is created during the steel production process, have been

produced as a result of this increased demand [8]. Approximately 24 million tons of BFS are generated annually in India. Therefore, effective recycling or disposal methods for these industrial byproducts are urgently needed [9].
The building industry is gradually learning about the possibility of using Blast Furnace Slag (BFS) in place of natural coarse particles in concrete in order to allay these worries. Using BFS improves concrete's overall performance in addition to helping with waste control. BFS encourages more environmentally friendly building methods when it is utilized in place of natural aggregates. According to studies, BFS has qualities that make it a good substitute for sand or fine aggregates. In addition to encouraging the advantageous reuse of industrial by-products in construction, adding BFS to concrete provides an eco-friendly solution to the problems related to sand extraction. For instance, BFS can increase concrete's strength and durability, which enhances the material's performance as well as the environment.The possible use of BFS and other industrial by-products in the manufacturing of concrete has been the subject of numerous research projects. Chatzopoulos et al. found that adding slags to C25/30 and C30/37 concretes instead of traditional aggregates enhanced or preserved their mechanical and durability qualities, with a significant 50% increase in compressive strength after seven days. The incorporation of slag in both fine and coarse aggregates improved the concrete's resistance to carbonation and chloride ingress, so substantially prolonging its service life. For common reinforced concrete applications, these slag-based concretes are advised [10]. According to a study by Rao et al., using ground granulated blast furnace slag (GGBS) in concrete as a partial replacement for natural sand increases compressive strength by 18.36% while marginally decreasing tensile and flexural strengths. The results demonstrate how GGBS can improve concrete performance and offer a sustainable sand substitute, solving environmental issues and encouraging the use of industrial waste materials in building. To increase tensile and flexural strength, more optimization is required [11]. Ozkan and Kabay looked on replacing coarse aggregates in concrete with ground granulated blast furnace slag (GGBFS) and washing aggregate sludge (WAS). Their study examined the effects of various materials on the durability, mechanical, and physical characteristics of the concrete. The purpose of the study was to evaluate the possible advantages of employing these substitutes in the manufacturing of concrete [12]. Sawant et al. claim that although BFS concrete had a lesser compressive strength than traditional concrete, it nonetheless achieved the necessary mean strength, proving to be a good substitute. 15% and 30% of natural aggregates (NA) with BFS were the most successful replacement levels, providing a good compromise between sufficient strength and environmental advantages. With a 15% BFS replacement, a maximum compressive strength of 40.302 N/mm^2 was attained, suggesting that BFS has the ability to create concrete with strengths comparable to those of conventional combinations [13]. According to the experimental findings, strength and durability decreased as the percentage of CSA rose. Compressive strength and split tensile strength dropped by 39.08% and 37.50%, respectively, upon 100% coarse slag aggregate (CSA) replacement, whereas penetration depth for durability rose by 69.84%. For replacements up to 40%, the loss of these qualities was negligible [14]. Goyal et al. tested the compressive strength of a reference batch (RB) that had 0% replacement and tartaric acid-treated steel slag (TTSS) added at 30%, 40%, and 50% replacement levels. According to the findings, TTSS outperformed non-tartaric acid-treated steel slag (NTSS) in terms of mechanical and physical qualities by 7.44% and 10.92%, respectively[15]. An essential step toward more sustainable practices is the use of BFS and other industrial byproducts in construction. Concrete performs better and has less of an impact on the environment when natural aggregates are swapped out for BFS. This approach promotes more effective waste management while protecting the environment. In the end, the application of BFS supports industrial innovation and advances more general sustainability goals.
The purpose of this study is to examine and contrast the characteristics of M20 and M30 concrete grades when natural aggregates are substituted with Blast Furnace Slag (BFS) aggregates. Natural resource depletion and the environmental effects of traditional aggregate extraction have grown to be major concerns as the demand for building materials increases. By encouraging more environmentally friendly building techniques and lowering dependency on natural aggregates, the use of industrial by-products like BFS presents a possible option. This study will investigate the effects of using BFS in place of natural aggregates on the mechanical characteristics of concrete of grades M20 and M30. The goal of this study is

to offer insightful information about whether BFS is a feasible substitute that will support economical building methods as well as environmental sustainability.

2. Methodology used for incorporation of BFS aggregate in concrete

The requisite qualities of concrete material are contingent upon the quality and compatibility of its ingredients, namely cement, aggregates, water, and admixtures. Preparatory testing is essential to determine the compatibility of these components for a certain mix design and to predict the final properties of concrete. These tests are crucial for ensuring that the concrete meets durability and structural standards.The cement utilized was Ordinary Portland Cement of grade 53 in accordance with IS 8112-2013 [16], possessing a specific gravity of 3.15 as determined by IS 2386-3 (1963) [17], with a Standard Consistency of 30%, an Initial Setting Time of 103 minutes, and a Final Setting Time of 231 minutes.The natural aggregates comprised locally sourced crushed stone with a maximum dimension of 20 mm. Furthermore, BFS (Blast Furnace Slag) coarse aggregates possess a maximum grain size of 20 mm, with primary chemical constituents including SiO2 (27-38%), Al2O3 (7-15%), and CaO (34-43%), indicating the existence of calcium silicates, aluminum silicates, and calcium aluminosilicates. This study examines aggregate attributes, including Sieve Analysis according to IS 383-1970 [18], density, specific gravity, crushing value as specified in IS 9376 (1979) [19], and impact aggregate value. The results acquired are presented in Tables 1 and 2 below.The fine aggregates employed were locally crushed sand (< 4.75 mm), exhibiting a specific gravity of 2.95 and a density of 1510.96 kg/m³, in accordance with IS 2386-3 (1963) [17]. The sieve analysis and fineness modulus of crushed sand is presented in Table 3.
The concrete mix included a high-performance additive, ArmixPlast 111.

Table 1: Properties of Natural Aggregates and BFS Aggregates

Properties	Natural Aggregates	BFS Aggregates
Specific Gravity	3.15	2.42
Average Loose Density	1503.97 Kg/m^3	937.83 Kg/m^3
Average Compacted Density	1677.90 Kg/m^3	1071.54 Kg/m^3
Average Crushing Value	12.10%	20.96%
Average Impact Value	6.71%	39.96%

In order to make ten distinct concrete mixes of M20 and M30 grades, BFS aggregates were used at volumes of15%,30%,45%,60%, and 75% to partially replace natural aggregates. In order to evaluate the performance of the BFS Aggregate based concrete with that of standard concrete mix designs, we used 10 different concrete mixtures, including M20 and M30 grade concrete with 100% natural aggregate use.
According to ACI 211.1-91 [20], the desired objective mean strength for M20 grade concrete is 26.6 N/mm², and for M30 grade concrete, it is 38.25 N/mm². The cement content is assumed to be 320 kilograms per cubic meter, and the water-cement ratio is chosen as 0.525 for M20 grade concrete mix design. The cement content for M30 grade is 410 kg, and the water cement ratio is 0.488. Table 4 details the mix design nomenclature for all twelve mixes, while Tables 5 contain the constituent proportions for the design mixes. Every batch of cement, water/cement ratio, and fine aggregate mix had the same amount of each grade. The amount of natural coarse aggregates was substituted according to the percentages that were indicated. The procedures outlined in IS 516-1959 [21] were followed for mixing the concrete. On a non-absorbent surface, the mixture was manually mixed by weighing the cement, fine aggregates, and coarse aggregates, and then using a shovel.

Table 2: Mix Design Nomenclature

Concrete ID	Optimization of BFS Fine Aggregate in Concrete
A1	0 % Replacement of NA in M20 Concrete
A2	15 % Replacement of NA in M20 Concrete
A3	30 % Replacement of NA in M20 Concrete
A4	45 % Replacement of NA in M20 Concrete
A5	60 % Replacement of NA in M20 Concrete
A6	75 % Replacement of NA in M20 Concrete
B1	0 % Replacement of NA in M30 Concrete
B2	15 % Replacement of NA in M30 Concrete
B3	30 % Replacement of NA in M30 Concrete
B4	45 % Replacement of NA in M30 Concrete
B5	60 % Replacement of NA in M30 Concrete
B6	75 % Replacement of NA in M30 Concrete

Table 3: Mix Design Proportions of 12 Mix Designs

Design ID	Cement	Sand Content	Coarse Aggregates	BFS	Water Content	Chemical
A1	1	2.619	3.644	0	0.525	1% of Cement
A2	1	2.619	3.097	0.414	0.525	
A3	1	2.619	2.551	0.826	0.525	
A4	1	2.619	2.004	1.24	0.525	
A5	1	2.619	1.457	1.654	0.525	
A6	1	2.619	0.911	2.066	0.525	
B1	1	2.25	3.241	0	0.488	
B2	1	2.25	2.755	0.359	0.488	
B3	1	2.25	2.27	0.717	0.488	
B4	1	2.25	1.783	1.075	0.488	
B5	1	2.25	1.296	1.434	0.488	
B6	1	2.25	0.81	1.792	0.488	

The compressive strength was measured at 3, 7, and 28 days of curing. Potable water is employed for mixing as well as curing. The specimens used for testing were 150 x 150 x 150 mm cubes. After curing, the specimens were dried to remove excess water, their dimensions were recorded, and their weights were measured before being subjected to compression testing.

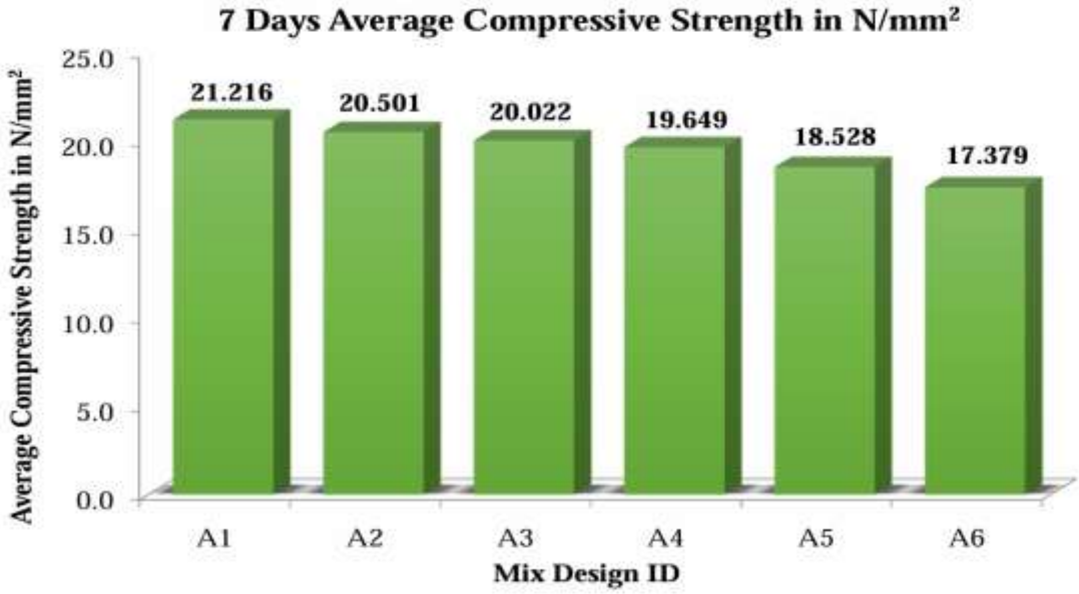
3. RESULTS

A compression test is key to determining the compressive strength, which is essential for evaluating a material's performance in structural applications. In this study, the compressive strength of the concrete mix was evaluated by testing 150 x 150 x 150 mm cubes after curing of 3, 7, and 28 days to observe the development of strength over time. Top of Form Bottom of Form.

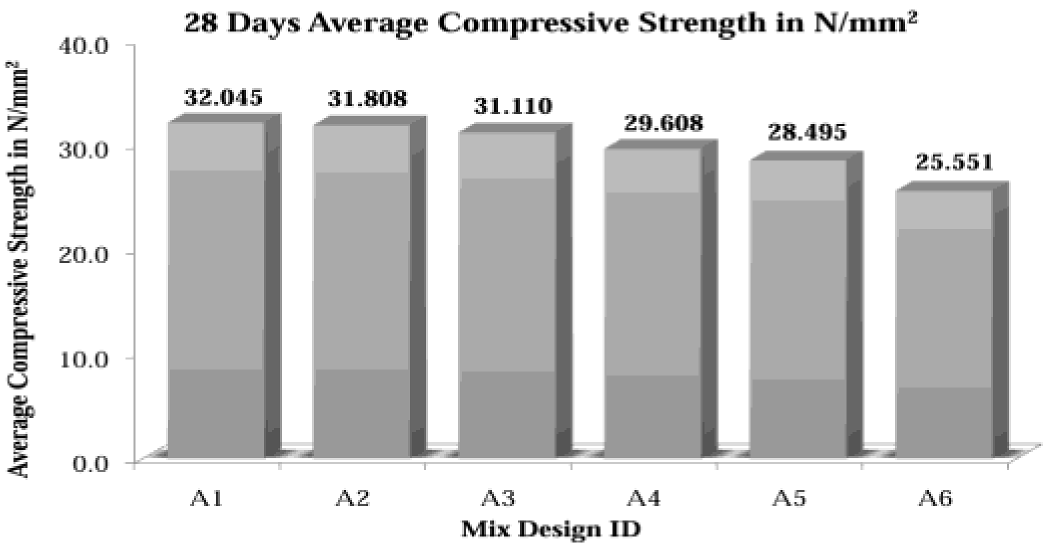
3.1 The table and graph below present the average compressive strength of M20 grade concrete at 7 days, 28 days and 56 days of curing:

Table 4: Average Compressive Strength of M20 Grade Concrete

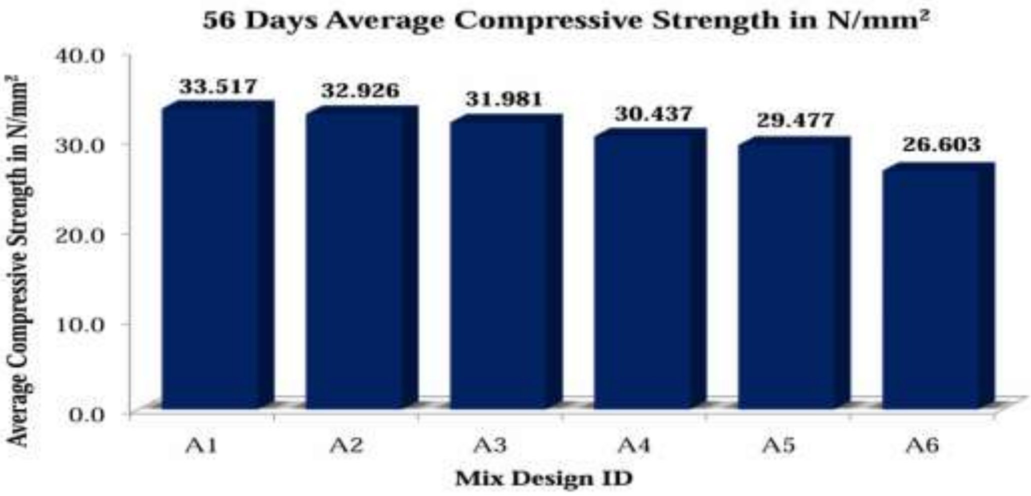
Grade of Concrete	Mix Design ID	Average Compressive Strength of Concrete in N/mm²		
		7 Days	28 Days	56 Days
M20	A1	21.216	32.045	33.517
	A2	20.501	31.808	32.926
	A3	20.022	31.11	31.981
	A4	19.649	29.608	30.437
	A5	18.528	28.495	29.477
	A6	17.379	25.551	26.603



Graph 1: 7 Days Compressive Strength M20 Grade Concrete



Graph 2: 28 Days Compressive Strength M20 Grade Concrete

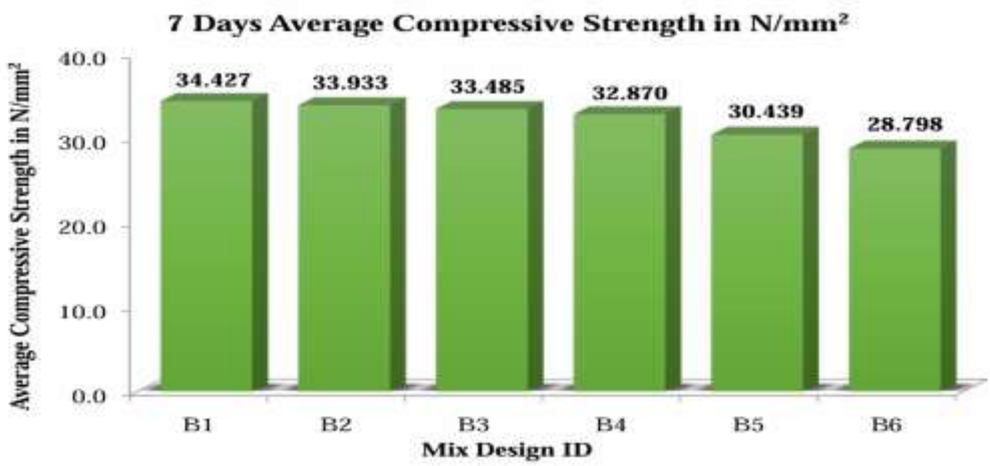


Graph 3: 56 Days Compressive Strength M20 Grade Concrete

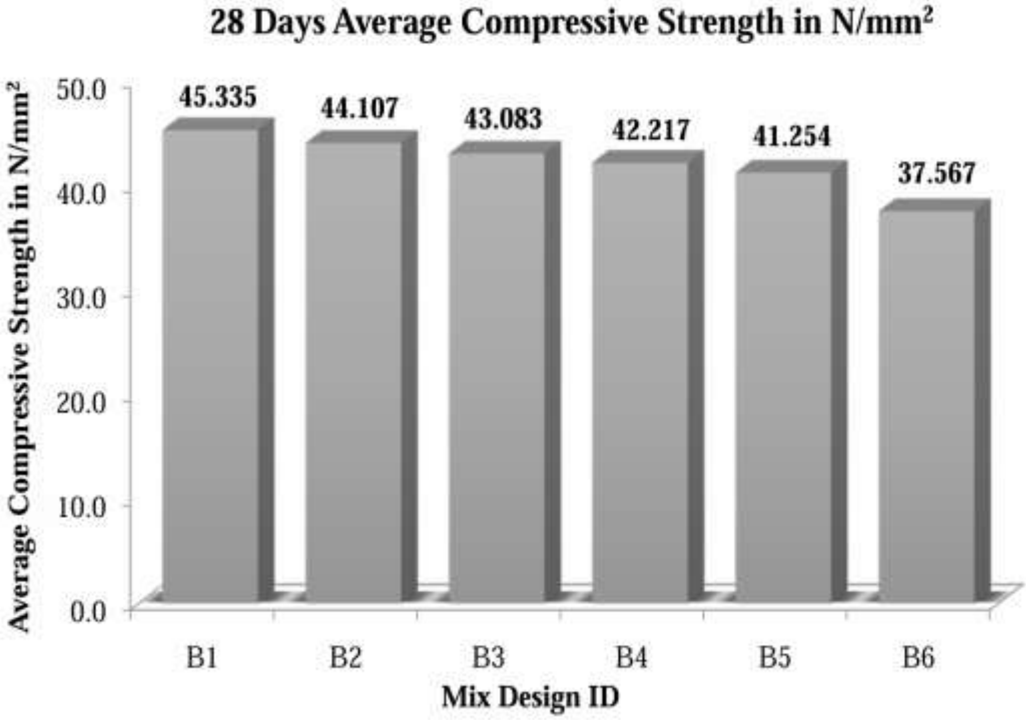
3.2 The table and graph below present the average compressive strength of M30 grade concrete at 7 days, 28 days and 56 days of curing:

Table 5: Average Compressive Strength of M20 Grade Concrete

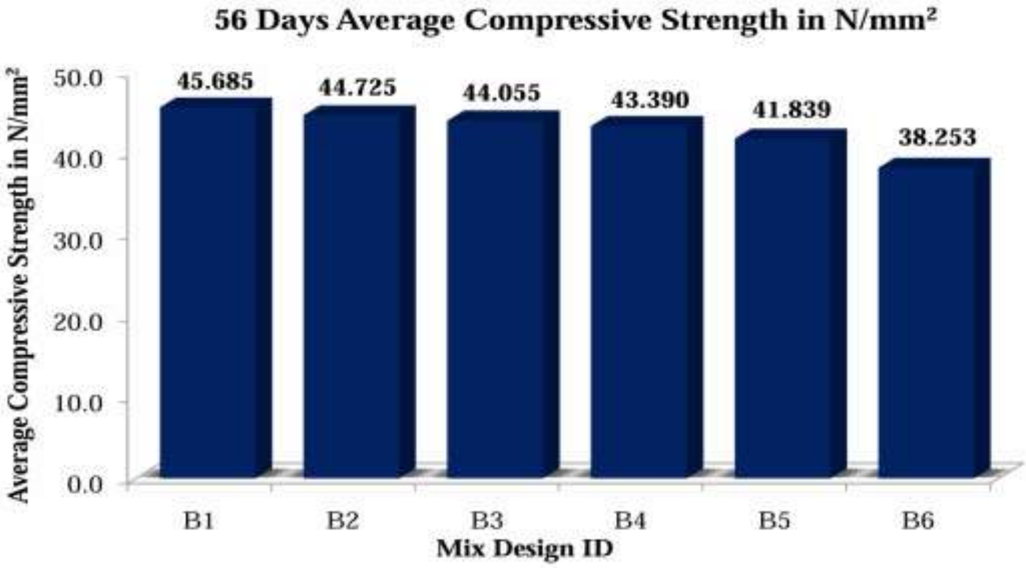
Grade of Concrete	Mix Design ID	Average Compressive Strength of Concrete in N/mm²		
		7 Days	28 Days	56 Days
M30	B1	34.427	***45.335***	***45.685***
	B2	33.933	44.107	44.725
	B3	33.485	43.083	44.055
	B4	32.87	42.217	43.39
	B5	30.439	41.254	41.839
	B6	28.798	37.567	38.253



Graph 4: 7 Days Compressive Strength M30 Grade Concrete



Graph 5: 28 Days Compressive Strength M30 Grade Concrete



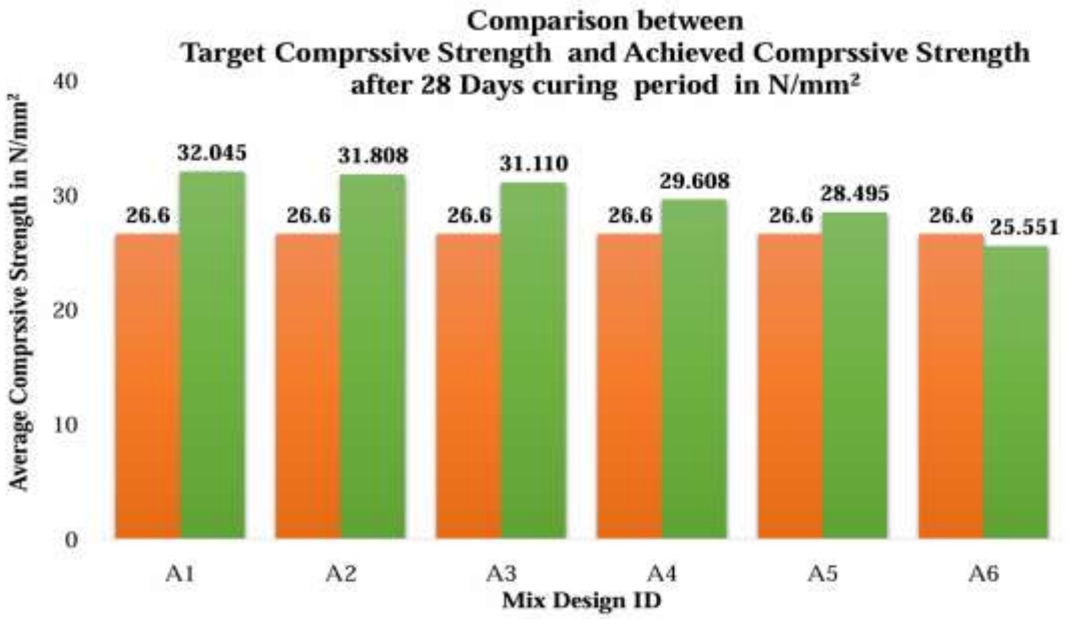
Graph 6: 56 Days Compressive Strength M30 Grade Concrete

Discussion on Effect of Partial Replacement of Natural Aggregates by BFS Aggregates on Compression Strength of Concrete

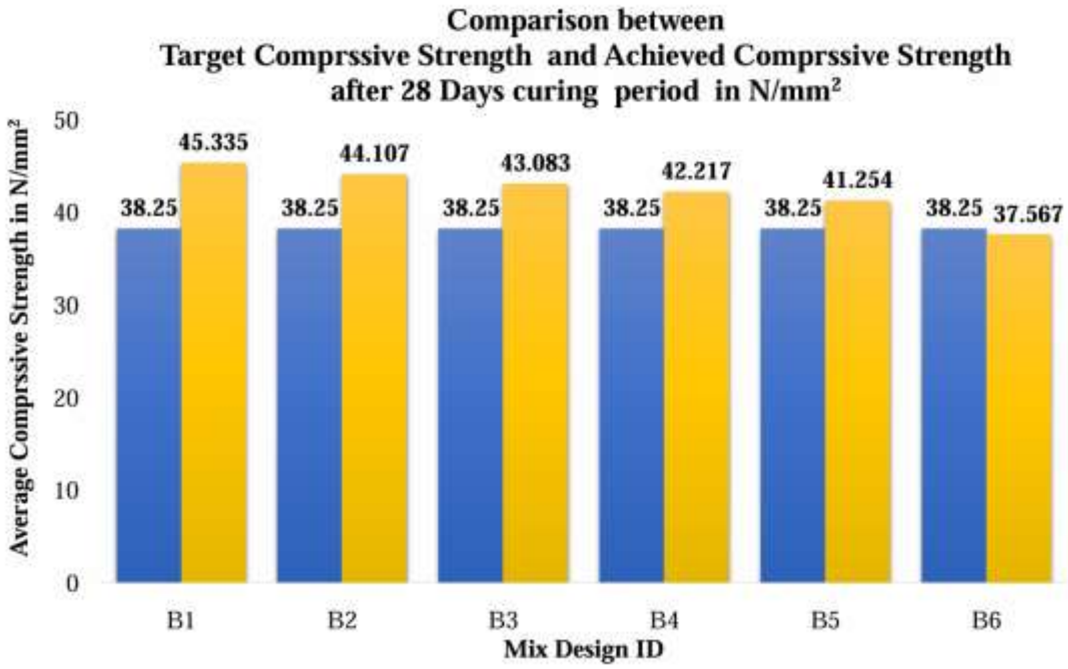
The effect of the partial replacement of Natural Aggregate by BFS aggregate on the compressive strength of the M20 and M30 grade concrete was determined by casting and testing of the cube samples in the compressive testing machine after curing period of 7 days, 28 days and 56 days. All the results obtained by tests are tabulated in Table 6 and 7 and represented by graphs in Graph 1 to Graph 6.

With reference to the graphs 7 and 8 it is interesting to note that there was a decrease in the compressive strength of concrete mixes with BFS aggregates in both the grades of concrete. For both the grades of concrete, concrete mixes with replacement levels 15%, 30%, 45% and 60% achieves the target strength, but concrete mix with 75% BFS aggregates fails to achieve the target strength in both grades of concrete mix i.e. M20 and M30 grade concrete.

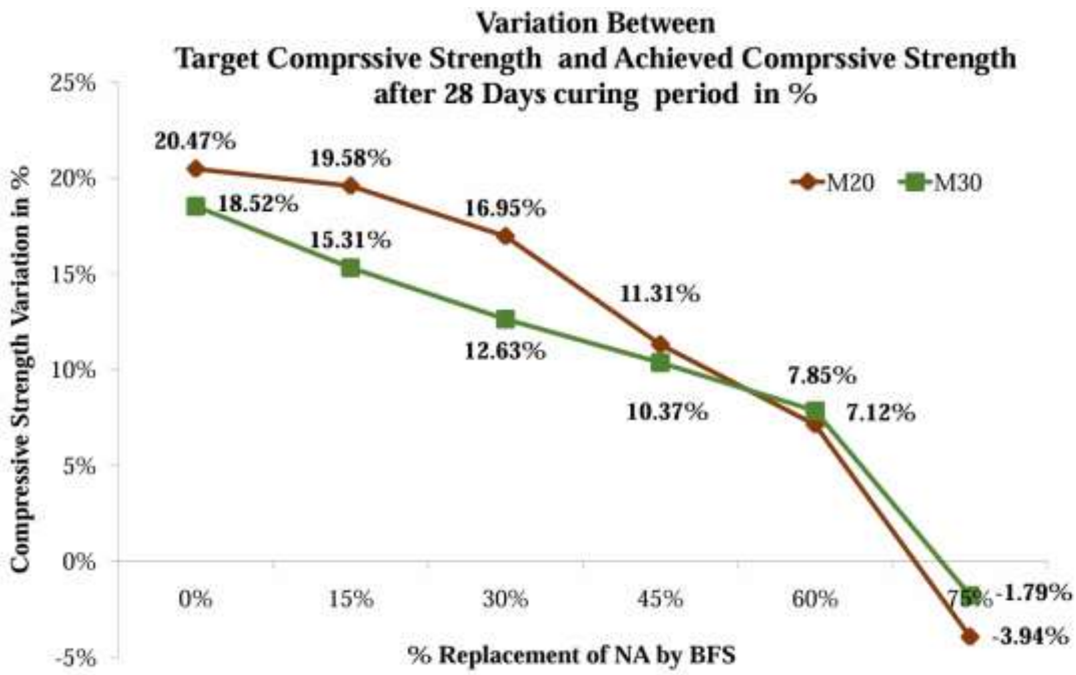
With reference to graph 9, the achieved compressive strength was 3.94 % and 1.79% less than the target compressive strength of concrete with 75% BFS aggregate in M20 and M30 grade concrete mix design respectively.



Graph 7: 28 Days Average Compressive Strength of M20 Grade Concrete Mix Design



Graph 8: 28 Days Average Compressive Strength of M30 Grade Concrete Mix Design



Graph 9: 28 Days Average Compressive Strength Comparison of M20 and M30 Grade Concrete

4. CONCLUSION

This study on the partial replacement of natural aggregates with BFS aggregates in concrete highlights its significant potential in advancing sustainable construction practices. The research, conducted on concrete gradesM20 and M30, comprehensively evaluates the influence of BFS on compressive strength of concrete. 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. When BFS replacement exceeds 60%, particularly at 75%, the compressive, tensile, and flexural strengths of the concrete decline. This is attributed to a less cohesive matrix, insufficient cement content for complete binding, and the dominance of BFS's lower crushing strength, which compromises the concrete's structural integrity. 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. 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 analysis of compressive strength, 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. Exceeding this limit, particularly at 75%, adversely affects concrete performance due to the dominance of BFS's lower crushing strength, making it unsuitable for structurally critical applications.

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