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RESEARCH ARTICLE OPEN ACCESS

Sustainable Cement Concrete from GGBS and Demolished Waste

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ABSTRACT
In today's fast-paced era of growth and innovation, the production of waste materials is increasing, while natural resources are becoming scarce. This creates an urgent need to reutilize waste materials. Within the construction industry, debris from demolished structures can be used for smaller construction works and road projects. This study explores the uses of demolished aggregate, GGBS, and admixtures in different proportions of M30 grade of concrete. Demolished aggregate, substituted natural coarse aggregate at 5%, 10%, 15%, 20%, and 25% levels and then recycled concrete was then compared to that of traditional concrete having 0% demolished waste also cement was partially replaced by GGBS at 0%, 5%, 10%, 15%, 20%, and 25%, with a water-reducing admixture added, 2% by weight of cement. A physical test such as toughness, workability and abrasion tests as to be performed. Concrete cubes were cast and evaluated for compressive strength at 7 and 28 days, as well as flexural strength at 28 days.

Keywords- Compressive strength, Demolished aggregate, Flexural strength, Ground Granulated Blast-Furnace Slag (GGBS), Natural aggregate

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I.

II. INTRODUCTION

The modern construction industry faces an exceptionally high demand for materials due to the constant pace of building projects and the simultaneous demolition of old structures. This generates a significant accumulation of concrete and civil debris every year. In India, managing this demolished waste is a pressing challenge, primarily because of the large quantities involved, which require vast areas for disposal. Improper waste disposal further exacerbates environmental pollution. Therefore, the conservation of natural resources, including land, water, rivers, soil, and air, has become increasingly crucial.

One notable example of this issue is the extraction of sand, a critical material in civil construction. Overextraction depletes natural resources and is a major environmental concern. Removing sand from riverbeds increases slope instability, leading to erosion and disturbing aquatic ecosystems. This process damages the habitats of various marine species and disrupts the natural balance of climatic conditions. Additionally, the diminishing supply of sand negatively impacts both the environment and the construction sector.

To address these challenges, it is vital to explore sustainable alternatives and adopt innovative practices in construction. Recycling and reusing construction and demolition waste can help ease the pressure on natural resources and reduce environmental harm. Recycled materials, such as aggregates from demolished structures, can be processed and incorporated into new construction, reducing the demand for natural aggregates and limiting the need for virgin materials.

Furthermore, the adoption of advanced construction techniques can improve the efficiency of resource use. For example, methods that enhance the durability and lifespan of buildings can reduce the frequency of demolition and reconstruction, thereby decreasing waste generation. In addition, promoting the use of alternative materials like manufactured sand or crushed stone can help alleviate the strain on natural sand resources."

III. LITERATURE REVIEW

This study explores strategies to improve sustainability in construction by integrating alternative materials into Ordinary Portland Cement (OPC) concrete. Ground Granulated Blast Furnace

Slag (GGBS) is examined as a partial replacement for cement, while Demolished Waste (DW) serves as a substitute for coarse aggregates. The research investigates different GGBS replacement levels (0%, 10%, 20%, 30%, 40%, 50%, and 60%) alongside a fixed 30% replacement of coarse aggregates with DW. The mechanical and durability properties of the concrete are analyzed to assess the impact on performance. Findings reveal enhanced workability, increased mechanical strength up to 40% GGBS replacement, and improved durability under alkaline conditions. [1].

This study explores the use of Recycled Fine Aggregate (RFA) in geopolymer mortars as an eco-friendly substitute. It evaluates the effects of replacing natural aggregates with varying amounts of RFA on the fresh properties, mechanical performance, and drying shrinkage of the mortar. The findings indicate that incorporating preprocessed RFA, especially at levels above 75%, significantly enhances workability and compressive strength. [2].

This paper explores the differences in characteristics between Reclaimed Concrete Aggregate (RCA) and natural aggregate, as well as various methods for enhancing RCA performance. Physical improvement techniques include mechanical processes and thermodynamic treatments, while chemical methods involve acid washing, water glass reinforcement, carbonation, the application of inorganic slurries, and polymer strengthening. Additionally, microbial modification techniques utilize certain microorganisms to promote carbon deposition. [3].

This review examines the characteristics of recycled aggregates, various treatment methods, and their effects on concrete performance. Techniques such as incorporating pozzolanic materials are highlighted for enhancing the quality of recycled aggregates. The study identifies ideal replacement ratios and combinations, suggesting a 30% substitution of recycled aggregates with appropriate treatments to achieve optimal workability, strength, and durability. [4].

He analyzes 17 different concrete mixtures, evaluating workability, density, compressive strength, flexural strength, tensile strength, elastic modulus, and water absorption. The results reveal that a 25% substitution with Recycled Fine Aggregate (RFA) improves compressive strength, while mixtures with 50% RFA and 35% GGBS achieve even greater compressive strength. The elastic modulus remains consistent for mixtures with 25% FS/RFA replacements, and GGBS or FA/GGBS blends show values comparable to conventional concrete. These findings underscore the potential of waste-based concrete mixtures to minimize environmental impact. [5].

This research examines the impact of using Metakaolin and Ground Granulated Blast Furnace Slag (GGBS) as partial cement replacements, along with the substitution of coarse aggregates with debris from demolished structures. The research assesses the properties of both fresh and hardened concrete, focusing on the use of recycled coarse aggregates and different GGBS proportions. [6].

IV. EXPERIMENTAL WORK AND METHODOLOGY ADOPTED

Material Properties

Cement

In this experimental study, Ordinary Portland Cement (OPC) compliant with IS 12269:2013 was employed as the main binding agent for different structural elements. This type of cement primarily consists of clinker, gypsum, and trace amounts of other additives. The clinker, which provides the cement's binding characteristics, is produced by subjecting limestone and other raw materials to high temperatures, initiating the chemical reactions necessary for cement manufacturing.

Sand

Sand is an essential natural resource and a key raw material in the construction sector. It is mainly obtained from river erosion, resulting in high-quality sand that is widely utilized in construction. The importance of sand extends to its contribution to the economic development of the nation. The sand used in this research meets the specifications of Zone II according to IS 383-2016.

Aggregate

Aggregates consist of materials such as gravel, crushed stone, recycled concrete, and others that are crucial for construction activities. In this study, the coarse aggregates used were those retained on a 10 mm sieve and passing through a 20 mm sieve. All tests conducted on the natural coarse aggregates followed the guidelines set out in IS 383-2016.

Demolished Aggregate

Reclaimed aggregate, also known as concrete debris, is utilized in construction to lower expenses and promote environmental sustainability. This approach is vital for effective waste management and helps mitigate the excessive use of natural resources. Reclaimed aggregates are often employed as sub-base material in construction projects. In this study, the demolished aggregates used were those passing through a 20 mm sieve and retained on a 10 mm sieve.

Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct produced in the process of manufacturing iron and steel. According to IS 16714:2018, it is created by rapidly cooling molten blast furnace slag with water, which is then processed into a fine powder. GGBS has remarkable cementitious properties and is frequently used as a partial substitute for Portland cement in concrete manufacturing. Its key characteristics include high durability, enhanced resistance to chemical attacks, and a lower heat of hydration. GGBS improves the long-term strength and performance of concrete, reduces environmental impact, and supports sustainable construction practices.

Admixture

Aura Mix 400 is a high-performance superplasticizer formulated for applications that demand considerable water reduction and prolonged workability retention. It is specifically designed for self-compacting concrete, pumped concrete, and applications where maintaining workability over extended periods is essential. Additionally, it enhances the cohesiveness of concrete in accordance with ASTM C 494: Types A and D, as well as IS: 9103:1999 and IS: 2645-2003.

TESTING OF MATERIAL (NATURAL COARSE AGGREGATE AND DEMOLISHED AGGREGATE)

Impact Value Test

The impact value assesses the toughness of natural coarse aggregates, reflecting their capacity to withstand impact. This toughness indicates the energy the material can absorb before failure occurs. Natural coarse aggregates are often used in concrete applications, such as railway tracks and pavements, where they must endure the effects of moving vehicles and their weight. According to IS 2386 (Part IV) 1963, natural coarse aggregates that pass through a 12.5 mm sieve and are retained on a 10 mm IS sieve are suitable for these applications. Per IS 383: 2016, clause 5.4.2, an impact value of 30% or less is acceptable for concrete used in wearing surfaces, while a value of 45% or less is permissible for other concrete applications. The impact value for natural aggregates is 10.4%, indicating good resistance to sudden impacts, whereas the impact value for demolished aggregates is 26.5%, suggesting they are less resistant to impacts compared to natural coarse aggregates.

Water Absorption of Aggregates and Specific Gravity of Aggregate

The water absorption test measures the varying capacities of natural coarse aggregates to absorb water, which is affected by the voids and pores present in the rock. The specific gravity of an aggregate sample is determined by the ratio of its dry weight (when measured in air) to the weight of an equal volume of water. According to IS 2386 (Part III) 1963, a water absorption percentage of less than 2% is considered acceptable. The water absorption rate for natural aggregates is 0.53%, while for demolished aggregates, it is 2.17%, indicating a higher water absorption capacity compared to natural coarse aggregates. As specified in IS 2386 (Part III) 1963, the specific gravity of most coarse aggregates typically falls between 2.5 and 3.0. The specific gravity of natural coarse aggregate is 2.71, reflecting its density in relation to water, while the specific gravity of demolished aggregate is 2.35, indicating it is lighter than natural coarse aggregate.

Particle Size Distribution Test (IS 2386 -Part 1: 1963)

Particle size distribution is assessed by weighing the aggregates that remain on different sieve sizes as outlined by Indian standard codes. The weight retained on each sieve reflects the size distribution of the aggregates within the sample. This test is conducted using a 3000 g sample. According to IS 383: 2016, Tables 1 and 2, and Clauses 6.1 and 6.2, we adhere to the specified limits for the percentage of passing aggregates.

Table 1: *Particle size distribution test of natural aggregate.*

IS. Sieve Size	Weight Retained (gm)	%Weight Retained	% of Cumulative Retained	% of Passing	Limit as IS 383:2016
I.S.25mm	0	0	0	100	100
I.S.20mm	276	9.20	9.20	90.8	85-100
I.S.10mm	2606	86.86	96.06	3.94	0-20
I.S.4.75mm	106	3.53	99.59	0.44	0-5
Pan	12	0.40	100	0	00

Table 2: *Particle size distribution test of demolished aggregate.*

IS. Sieve Size	Weight Retained (gm)	%Weight Retained	% of cumulative retained	% of passing	Limit as IS 383:2016
I.S.25mm	65	2.16	2.16	97.84	100
I.S.20mm	1138	37.93	40.09	59.91	85-100
I.S.10mm	1741	58.03	98.12	1.88	0-20
I.S.4.75mm	51	1.70	99.82	0.18	0-5
Pan	5	0.17	100	0	00

Slump Cone Test

The slump cone test follows a defined procedure and can be conducted either in a laboratory or in the field. This test measures the slump in millimeters, which reflects the workability and consistency of cement concrete. The procedures for this test are outlined in IS 1199-1959, clause 5. The highest slump observed was 95 mm, while the lowest was 85 mm. Consequently, an increase in the amount of demolished aggregate leads to a reduction in the slump of the concrete.

Loss Angles Test

The interaction between aggregates and steel balls leads to weight loss in the aggregates and the formation of crushed residue. A lower weight loss signifies greater abrasion resistance of the aggregate. Generally, the abrasion resistance of recycled aggregate is lower than that of natural coarse aggregate. This is specified in IS 2386 (Part IV) 1963 and further supported by IS code 383: 2016, clause 5.4.3, which states that an impact value of 30% or less is suitable for concrete used in wearing surfaces, while a value of 50% or less is acceptable for other concrete applications. The Los Angeles abrasion test shows a weight loss of 16.90% for natural aggregate and 42.76% for demolished aggregate, indicating that demolished aggregate is significantly less resistant to abrasion and wear compared to natural coarse aggregate.

Specific Gravity of Sand (Fine Aggregate)

The specific gravity of fine aggregate is a crucial factor in concrete mix design calculations. This value is measured using a Pycnometer; as per IS 2386 (Part III) 1963, clause 2.4, the typical specific gravity for fine aggregate in Zone II ranges from 2.5 to 2.9. For this study, the specific gravity of the sand in Zone II was found to be 2.44.

Experimental results indicated that demolished aggregate exhibited higher water absorption compared to conventional concrete. This increased absorption can be attributed to the old mortar that remains attached to the demolished aggregate. Additionally, the specific gravity of demolished aggregate is greater than that of natural aggregate due to the presence of this adhered mortar. Toughness, which refers to an aggregate's capacity to endure impact loads, is a vital property for aggregates used in road construction, where heavy traffic can lead to frequent impacts. The impact value for demolished aggregate is lower than that for natural coarse aggregate. Although the particle size distribution of both natural coarse and demolished aggregates is nearly identical, the Los Angeles abrasion test reveals a significant difference between the two. These tests were conducted following Indian Standards.

MIX DESIGN

Mix Design Proportion

The mix design for M30 concrete entails choosing appropriate materials and their ratios to reach a target strength of 30 MPa. According to IS 10262:2019 and IS 456:2000, specifically Table 3, the process involves establishing the water-cement ratio, determining the cement content, and modifying the proportions of fine and coarse aggregates to ensure workability, durability, and strength, while taking into account the specific requirements of the project.

Table 3: *Mix proportion details.*

Mix Proportion			
Cement	**Sand**	**Aggregate**	**Water**
394	647.30 kg	1224.13 kg	157.6
1	1.64	3.10	0.4

Material Quantity for 1 m^3 Concrete

The material quantity of a concrete cube involves calculating the required amounts of cement, sand, aggregate, and water for a standard size one meter cube. Accurate proportioning ensures proper strength and durability in testing. The five different percentages demolished aggregates with 5%, 10%, 15%, 20%, and 25% also ggbs with 5%, 10%, 15%, 20%, and 25% replacement ratios shown in Table 4.

Table 4 : *Material quantity of 1m^3 concrete*

S. No.	DA%	GGBS%	Cement (m^3)	Sand (m^3)	NCA (m^3)	DA (m^3)	GGBS (m^3)	Admixture(m^3)
1.	0%	0%	394	647.30	1224.13	-	-	7.88
2.	5%	5%	374.3	647.30	1162.92	61.20	19.7	7.88
3.	10%	10%	354.6	647.30	1101.87	122.41	39.4	7.88
4.	15%	15%	334.9	647.30	1040.65	183.61	59.1	7.88
5.	20%	20%	315.2	647.30	979.44	244.82	78.8	7.88
6.	25%	25%	295.5	647.30	918.22	306.03	98.5	7.88

DA -Demolished Aggregate
NCA- natural Coarse Aggregate
GGBS – Ground Granulated Blast Furnace Slag

CASTING OF TEST SPECIMEN (IS 10262:2019 and IS 456:2000)

Preparation of Mold

Cubic molds measuring 150 mm x 150 mm x 150 mm are utilized to evaluate compressive strength. Prior to use, these molds are meticulously cleaned and coated with oil. For assessing flexural strength, beam molds with dimensions of 150 mm x 150 mm x 700 mm are used.

Mixing of Concrete

Cubic molds measuring 150 mm x 150 mm x 150 mm are utilized for testing compressive strength. Achieving a uniform concrete mix is essential for ensuring a consistent mixture. The mixing process was carried out both manually and with the aid of a tilting drum, where the concrete was thoroughly combined within the drum.

Slump Cone Test

It is observed that as the amount of demolished aggregate in the concrete mix rises, the slump of the concrete decreases. The highest slump measured was 95 mm, whereas the lowest was 85 mm. Therefore, a higher proportion of demolished aggregate leads to a reduction in concrete slump.

Casting of Test Specimen
To cast the concrete, cube molds measuring 150 mm x 150 mm x 150 mm and beam molds of 150 mm x 150 mm x 700 mm were used. The materials were mixed thoroughly to prepare the concrete for both the cubes and beams. Before use, the molds were cleaned and the nuts and bolts were tightened to ensure security. The concrete mixture was then poured into the molds, and the top surface was leveled with a trowel for a smooth finish. The specimens were created using different proportions of demolished aggregates for testing purposes.

Curing of Cubes and Beams
Following 24 hours of preparation, the cube specimens were exposed to various curing conditions, including open-air, laboratory, and standard curing methods. The cubes were immersed in a water tank for durations of 7 days and 28 days, while the beams were cured for a period of 28 days. Both the beams and cubes were placed in a large water tank for the curing process.

TESTS AND RESULTS ON CONCRETE (Compressive Strength and Flexural Strength Test)

Compressive Strength of Cube Test
A total of 36 cube specimens were cast and subsequently tested for compressive strength after curing for 7 and 28 days. From each batch, a minimum of 3 specimens were selected for testing. The cubes were taken out of their molds and allowed to acclimate in the laboratory environment for a period. The testing machine was operated with care, ensuring that the cubes were properly aligned within the apparatus. The compressive strength of the hardened concrete was then assessed at both the 7-day and 28-day marks, in accordance with the standards set forth in IS 10262:2019 and IS 456:2000, as illustrated in figure 1.

Figure 1 : *Compressive strength test.*

Compressive Strength of Cube Result
The compressive strength of concrete cubes is evaluated in accordance with IS 516:2021, Part 1, which details the procedure for measuring compressive strength under laboratory conditions. The clauses within IS 516 provide guidelines for cube preparation, curing, and testing at both 7 and 28 days. For acceptance criteria, IS 456:2000, Clause 16, is referenced to verify that the concrete fulfills the specified strength requirements for structural applications, as presented in Table 6 and Figures 2 and 3.

Mix Ratio	7 Days Compressive Strength (N/ mm²)	Average Strength of Cube (N/ mm²)	28 Days Compressive Strength (N/ mm²)	Average Strength of Cube (N/ mm²)
0% DA + 100% NCA	23.91	23.72	32.97	32.86
	23.43		32.91	
	23.82		32.70	
5% DA + 95% NCA	23.67	23.70	32.84	32.43
	23.79		32.37	
	24.64		32.08	

10% DA + 90% NCA	23.10	23.41	32.22	32.35
	23.55		32.53	
	23.58		32.30	
15% DA + 85% NCA	23.31	22.88	31.76	32.09
	22.25		32.28	
	23.08		32.23	
20% DA + 80% NCA	22.24	22.32	31.79	31.76
	22.63		31.96	
	22.09		31.53	
25% DA + 75% NCA	21.48	21.96	31.42	31.60
	22.12		31.65	
	22.28		31.73	

Table 5 : *Compressive strength for demolished aggregate concrete.*

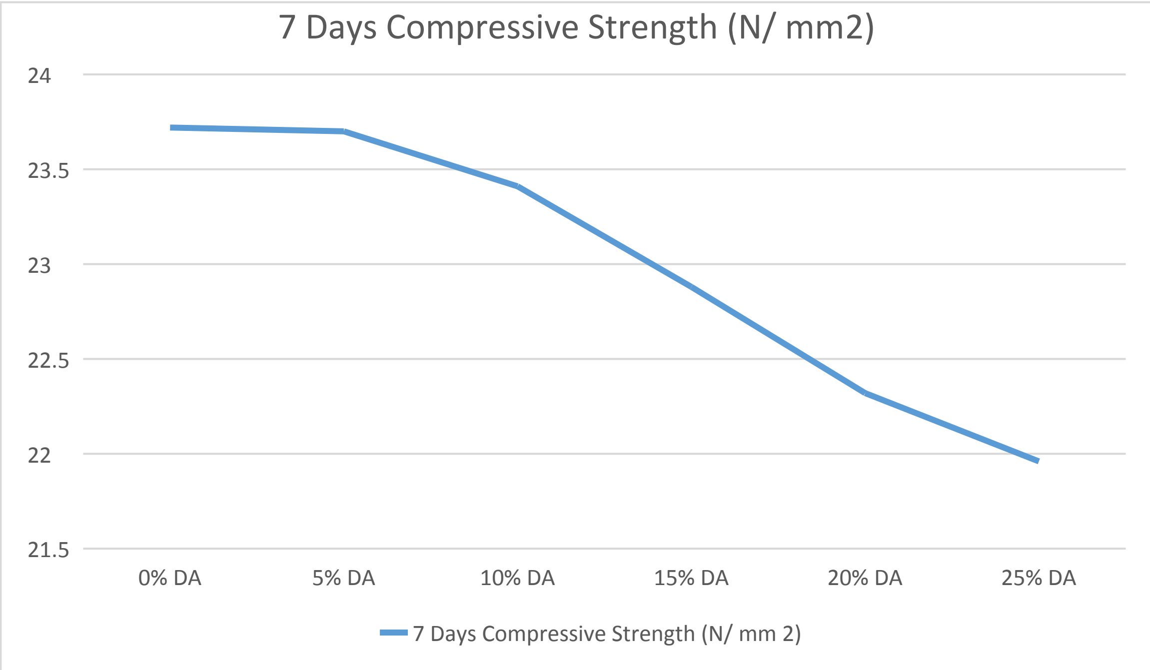

Figure 2 : *7-day compressive strength of demolished aggregate concrete.*

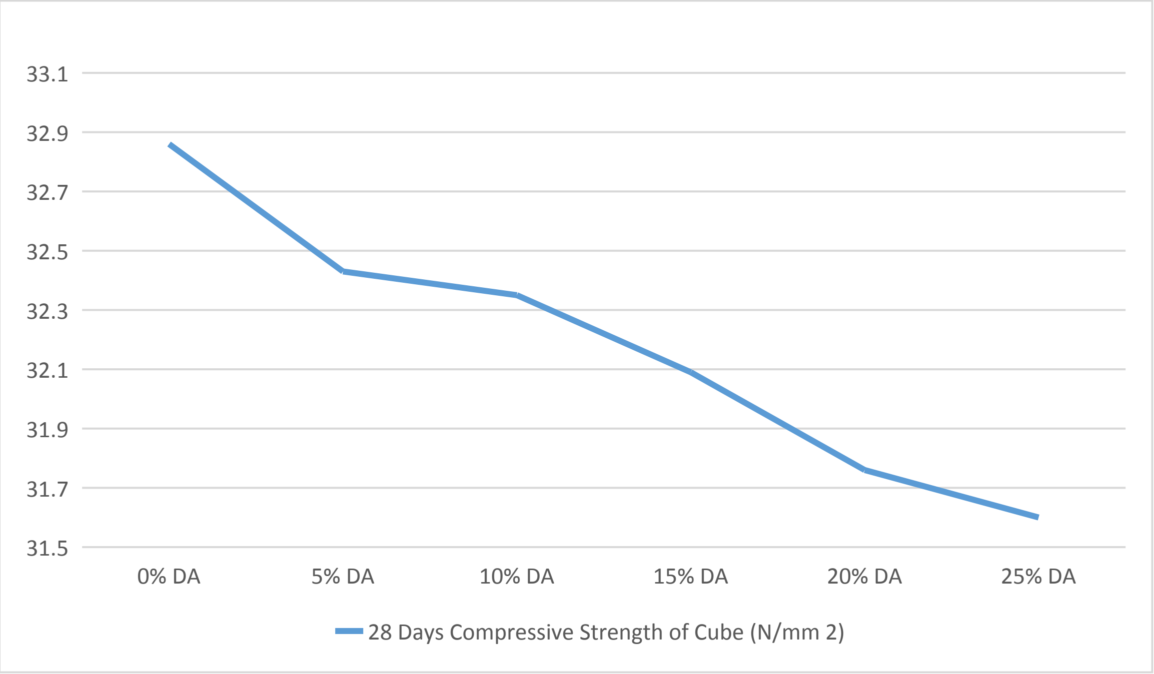

Figure 3 : *28 days compressive strength of demolished aggregate concrete.*

Flexural Strength of Beam Test

In accordance with IS 10262:2019 and IS 456:2000, 18 beam specimens were cast and evaluated for flexural strength after a curing period of 28 days. The beams were submerged in a large water tank for curing. During testing, the machine was operated with care, and the beams were positioned correctly in the apparatus to measure the flexural strength of the hardened concrete at 28 days, as depicted in Figure 4.

Figure 4 : *Flexural strength test.*

Flexural Strength of Beam Result

The flexural strength of a beam is evaluated to measure its resistance to bending, typically in accordance with the procedures specified in IS 516:2021. The beam specimen is loaded until failure occurs, and the maximum stress prior to cracking is noted as the flexural strength. This measurement is vital for assessing the beam's performance under load in structural contexts. The results for the flexural strength of beams made with demolished aggregate concrete after 28 days are presented in Table 7, while Figure 5 graphically illustrates the 28-day flexural strength of these beams.

Table 6 : *Flexural strength for demolished aggregate concrete.*

Mix Ratio	28 Days Flexural Strength Test (N/ mm²)	Average Strength of Beam (N/ mm²)
0% DA + 100% NCA	5.22	5.17
	5.13	
	5.18	
5% DA + 95% NCA	4.98	4.93
	4.87	
	4.94	
10% DA + 90% NCA	4.75	4.77
	4.86	
	4.70	
15% DA + 85% NCA	4.64	4.68
	4.63	
	4.72	
20% DA + 80% NCA	4.50	4.52
	4.47	
	4.59	
25% DA + 75% NCA	4.46	4.35
	4.32	
	4.27	

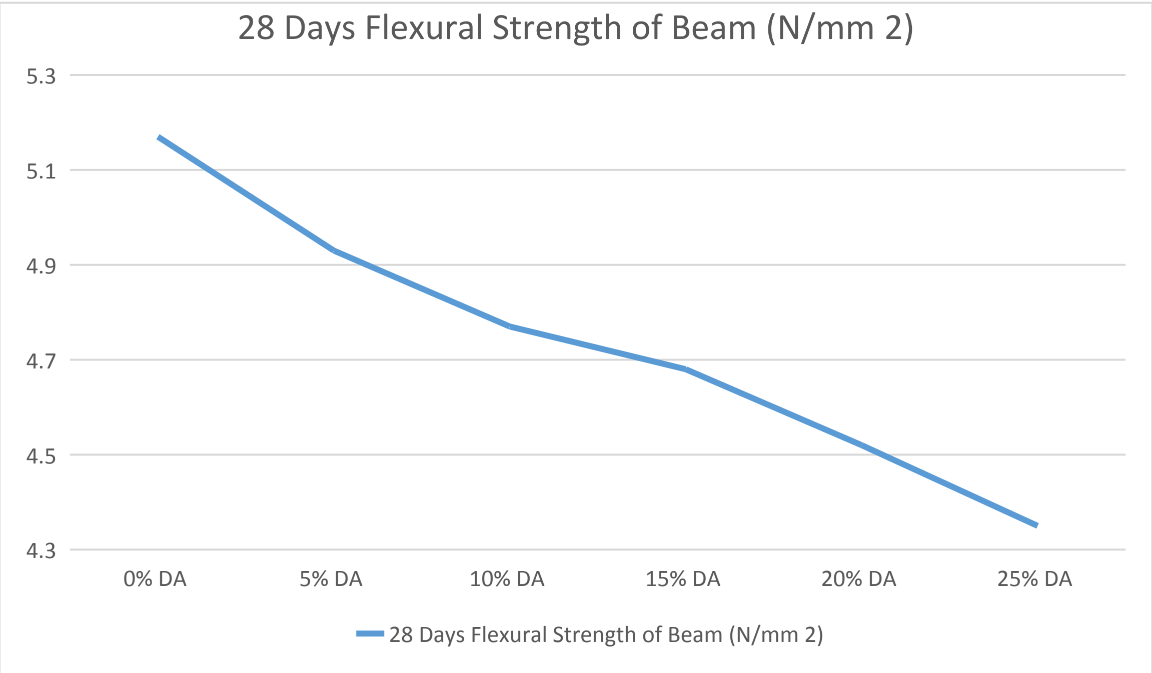

Figure 5 : *28 days flexural strength of demolished aggregate concrete.*

V.

VI. CONCLUSION

- Average compressive strengths for varying percentages of demolished aggregate (0%, 5%, 10%, 15%, 20%, and 25%) are measured as 32.86 N/mm², 32.43 N/mm², 32.35 N/mm², 32.09 N/mm², 31.76 N/mm², and 31.60 N/mm², respectively. This data suggests that 5% to 25% demolished aggregate can be effectively used in cement concrete can substitute natural coarse aggregate with demolished aggregate.
- With 25% demolished aggregate and GGBS, average Compressive strength results for 7 days are 73% of the total strength of cement concrete (at least 65% compressive strength achieved for 7 days of the concrete as per IS

456:2000) and 28 days are greater than 100% of the total strength of cement concrete (at least 99% compressive strength achieved for 28 days of the concrete as per IS 456:2000). This finding confirms that concrete incorporating demolished aggregate meets the necessary compressive strength standards, making it appropriate for construction applications.

- For Abrasion value, natural aggregates exhibit 16.90% material loss of the total weight of sample, whereas demolished aggregates have 42.46% material loss of the total weight of sample, which indicates abrasion resistance of recycled aggregate is lower than natural coarse aggregate.
- For toughness value, natural aggregates exhibit 10.40% material loss of the total weight of sample, whereas demolished aggregates have 26.05% material loss of the total weight of sample, which indicates toughness resistance of recycled aggregate is lower than natural coarse aggregate.
- As the percentage of demolished aggregate increases, a corresponding decrease in concrete slump has observed. Workability can be enhanced through the use of a 2% plasticizer, with its effectiveness influenced by the timing of addition, dosage, and the quality of the cement used.
- The flexural strength diminishes as the proportion of demolished aggregate rises with 0% demolished aggregate, the average flexural strength is measured at 5.17 N/mm². At 5%, it drops to 4.93 N/mm², and further decreases at 10%, 15%, 20%, and 25%, but it achieves its required strength with 25% demolished aggregate and GGBS in cement concrete. So, it's useful for pavement and small residential construction projects.

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