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Performance Enhancement of Concrete Incorporating Demolition Waste Aggregates using PC-200 Superplasticizer

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Abstract: The rising amounts of construction and demolition waste lead to several environmental problems, thus necessitating the need to recycle such materials in concrete production. In this paper, the use of demolition concrete waste aggregate in concrete mixes in replacement ratios of 0-100% is considered. Furthermore, the effects of PC-200 superplasticizer in combination with decreased water-cement ratio on mechanical and fresh properties of the investigated concrete are evaluated. Two groups of mixes were analyzed such as ordinary concrete mixes containing a water-cement ratio of 0.42 and modified concrete mixes with 1.2% PC-200 superplasticizer and a decreased water-cement ratio of 0.28. The experimental results show that the use of demolition waste aggregate reduces the mechanical properties and workability of ordinary concrete mixes, while modified mixes have better results under the given experimental conditions. It was found that the mechanical properties, such as compressive strength, tensile strength, and flexural strength, and the modulus of elasticity increase with the rise in replacement ratios in modified mixes. Nevertheless, it must be noted that these results are obtained by the effect of a combination of a decreased water-cement ratio and superplasticizer and are only valid in the context of the current experiment. However, the lack of information regarding durability testing, microstructure investigation, and long-term performance makes it difficult to implement the findings into practice, and further investigations are needed for practical implementation.

Keywords: Demolition concrete waste, Superplasticizer, Sustainable concrete, Mechanical properties, Environmental, Structural Applications.

1. Introduction

Construction and demolition of buildings and infrastructure around the world escalated very rapidly, resulting in a massive and undeniable construction waste phenomenon with significant economic, environmental, and social consequences [1-3]. The discarded old concrete constitutes a major fraction of construction waste, and disposing it in landfills reduces our natural resource stock, emits carbon, and occupies large areas of land. Schools, scholars, and industry have taken an enormous interest in sustaining construction. To use materials and recycling approaches that produce roughly equivalent performance with a significantly reduced environmental impact [4-6]. Offset of demolition concrete waste as aggregate in the production of fresh concrete can provide an effective solution for construction-sector sustainability for dealing with the waste problem and reducing the consumption of natural aggregates, which are increasingly being depleted by overextraction [7-9]. Although reusing demolition concrete waste as aggregate has multiple benefits, its use in structural applications is hindered by several technical challenges.

Previous research explored that demolition concrete waste aggregates possess high porosity, higher water absorption, weaker interfacial transition zone, and residual adhered mortar in comparison to concrete made with natural aggregates [10-12]. This has been widely reported to result in reduced workability, density, and deterioration of response in terms of compressive strength, tensile strength, flexural strength and their modulus of elasticity. As a result, the traditional concrete made with recycled or demolition aggregates tends to fail to meet the performance requirements of structural components, especially for high replacement ratios. This has been extensively reported in the literature which has led most researchers and consensus to recommend partial replacement levels or non-structural use of demolition waste concrete, thus not fully exploiting the potential of recycled aggregates and still continuing the reliance on virgin materials in the construction industry, despite growing efforts on sustainability [13-15].

Several recent studies have reported the mechanical and durability behavior of concrete made with demolition waste aggregates [16-18]. It was found that partial replacement of natural aggregates with recycled concrete aggregates is possible; however, higher replacement rates often yield significant reduction in strength and stiffness [19-21]. Strength loss is primarily attributed to heightened water demand, inefficient particle packing, and a fragile bond between old mortar and new cement paste. To counteract these detrimental effects, several methods have been practiced, including the pre-treatment of recycled aggregates, mix proportions optimization, water–cement ratio reduction and application of different types of chemical admixtures. In recent years, it is documented that the superplasticizers can greatly improve the performance of concrete containing demolition waste aggregates as they can provide much better separation among particles, reduce internal pores and strengthen the interface transition zone [22-25]. The strength loss associated with recycled aggregates can be fully or partially compensated by the use of optimum amounts of admixtures along with reduced water–cement ratio [26-28]. However, most of the existing studies mainly consider low replacement levels of natural aggregates, a certain type of superplasticizer, or individual mechanical properties. There is a lack of investigation to verify the achievability of high-performance concrete with complete replacement of natural coarse aggregates. In addition, comparative studies on the fresh and hardened properties of ordinary and modified demolition waste concrete under the same experimental conditions are relatively limited in the literature [29-30].

Although there has been considerable advancement in the application of recycled aggregate concrete, some critical areas that require further investigation concerning the feasibility of high replacement level of demolition waste aggregates without compromising acceptable performance of concrete are still lacking. In particular, the combined effect of lowering the water-to-cement ratio together with chemical admixtures for enhancing the characteristics of concrete has not yet been clearly addressed, particularly when replacement reaches up to 100 percent. Most of the previous research works have either applied partial replacement level or observed deteriorated performances due to full replacement level, thus resulting in lack of sufficient assurance in its use for structural purposes.

On this note, this study is conducted to determine the feasibility of utilizing demolition waste concrete aggregates as a partial/full replacement material of natural coarse aggregates, and to examine the effect of PC-200 superplasticizer in conjunction with lower water-to-cement ratio on concrete workability and mechanics. This research's importance is due to its contribution to the understanding of the possibility of achieving better results through optimization of mix designs of recycled aggregates concrete through experimentation. This research adds to the existing knowledge base about sustainable construction materials, although the challenges that need to be addressed have been identified. It is important to note that the current research deals mainly with the properties of fresh concrete and its behavior during 28 days after casting. No information was obtained about any durability parameters including permeability, water absorption, drying shrinkage, sulfate resistance, and long-term performance. Therefore, despite the positive changes in mechanical properties observed in the research, they cannot prove durability by themselves.

Novelty of this research is its systematic study on demolition waste concrete at high replacement ratio and use of PC-200 superplasticizer to improve workability as well as mechanical performance. This study provides experimental evidence that, under controlled conditions, the combined use of superplasticizer and reduced water–cement ratio can significantly enhance the performance of recycled aggregate concrete, even at high replacement levels. Most of the studies showed that performance of the concrete goes down as content of recycled aggregate increases, but with use of proper admixture and optimizing water–cement ratio, performance loss can be compensated and achieve higher mechanical properties, which has been demonstrated in this work. In addition, the research has provided a comprehensive comparison between the use of ordinary mix and modified mix of fine and coarse aggregates, use of incorporated and unincorporated PC-200 superplasticizer mixes, providing experimental evidences and demonstrating that high-performance and environmentally-friendly concrete can be produced and implemented for structures. Not only that the current study would support the development of sustainability materials engineering, but it is an informative document for engineers and researchers, who would consider the use of demolition waste aggregates in modern construction. Materials and experimental methods that have been utilized to achieve the objective of the study are presented in the following section, followed by a detailed discussion of the observed results and concluding remarks, highlighting the significant findings and future studies.

2. Materials and Methods

For the presented study, an experimental program had been planned to investigate the influence of using demolition concrete waste coarse aggregate on the fresh and mechanical properties of concrete and the effect of using PC-200 superplasticizer to improve the quality of such mixes. Sulfate-resisting Portland cement was used as a binding material for all the concrete mixes to secure durability and identical performance, even for a severe environmental condition. Natural fine aggregate and natural coarse aggregate were used as control reference materials. Demolished concrete waste from a demolished concrete structure was used as a source of as recycled coarse aggregate. Firstly, dust, waste and other impurities were removed from the demolition waste. Then it was manually crushed into smaller pieces. After that, it was sieved and the crushed material passing the 20 mm sieve was used as coarse aggregate. The recycled aggregate was used as partial as well as complete replacement of natural coarse aggregate. The natural coarse aggregate was replaced with recycled aggregate at different replacement levels (0%, 25%, 50%, 75% and 100%) by weight. The grading of the natural and recycled aggregates was assessed by sieve analysis following Indian Standard Procedure IS 383. The grading of the aggregates was within the recommended limits for concrete aggregates. The fine aggregate used in the study satisfied the grading requirement of Zone II. The grading of natural and recycled coarse aggregates showed an acceptable particle size distribution appropriate for structural concrete usage. Table 1 describes the particle size distribution of the coarse aggregate used in the present study. It can be observed that the grading of the aggregate used in the present work satisfied the specified limits of IS383; 96.6% passing 20 mm sieve and 25.7% passing through 10mm sieve. Hence, it can be used for structural concretes. For each experiment, there were three samples analyzed and the mean and standard deviation were computed for them. The dispersion of results is described by the expression ± standard deviation to serve as a measure of the experimental scattering. As there was a small number of the samples taken (n=3), the statistical analysis of the differences between normal concrete mixes and improved ones was carried out by two-tailed Student's t-test at 95% confidence level.

The particle size distribution of the fine aggregate is summarized in Table 2, indicating compliance with Zone II grading requirements of IS 383, with 94.1% passing the 4.75 mm sieve and 81.5% passing the 2.36 mm sieve, confirming the suitability of the fine aggregate for concrete production. Along with sieve analysis, the physical properties of the recycled coarse aggregate were tested in order to analyze their effects on concrete properties. It should be noted that the recycled aggregates had high water absorption levels because they had adhered mortar from old concrete on their surfaces, making them more porous than natural aggregates. The specific gravity of the recycled aggregate was found to be lower than that of the natural aggregate, whereas its bulk density decreased as well. Adhered mortar was seen on the surfaces of recycled aggregates, having an effect on the interfacial transition zone and mechanical performance of the aggregate. This corresponds to usual properties of demolition waste aggregates presented in research papers.

The physical characteristics of PC-200 superplasticizer used in the present study are based on the following: a liquid brownish appearance, a specific gravity of 1.04, a freezing point of −1 °C and an air entrainment of less than 2%, which can be considered a high-range water-reducing admixture for the use in concrete. The concrete mix proportions were taken based on standard mix design procedures and were kept constant for all mixes so that they could be meaningfully compared. The physical properties of the PC-200 superplasticizer used in this study are presented in Table 3. The present study consisted of two types of concrete mix proportions.

Table 1. Sieve analysis for coarse aggregate used in work

Sieve size, size	Passing by Weight, (%)	Passingby Weight, (%)
40 mm	100	100
20 mm	96.6	95-100
10 mm	25.7	25-55
4.75 mm	2.9	0-10

Table 2. Sieve analysis for fine aggregate used in the study

Sieve size mm	Passing By Weight (%)	% passing for Zone 2 limits
10 mm	100	100
4.75 mm	94.1	90-100
2.36 mm	81.5	75-100
1.18 mm	70.3	55-90
600 micron	44.5	35-59
300 micron	15.0	8-30
150 micron	4.2	0-10

Table 3. Physical properties of PC-200 superplasticizer used in the study

State	color	Specific gravity	Freezing point	Air entrainment
Liquid	Brownish	1.04	-1	Less than 2%

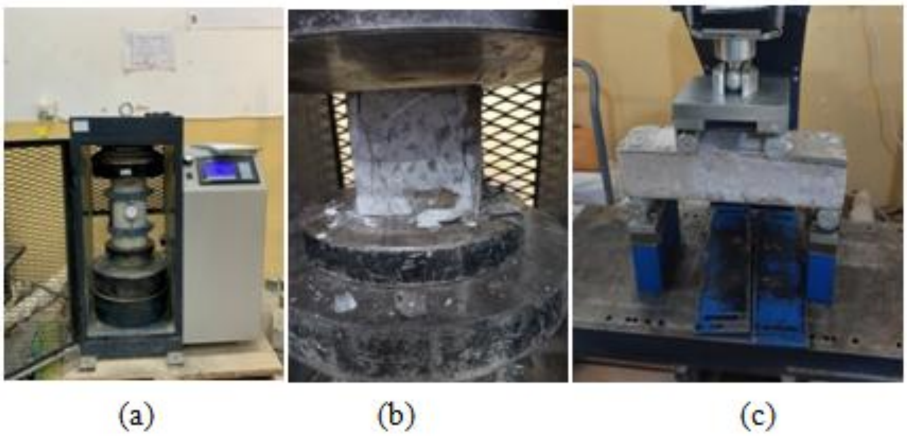

Figure 1. Experimental testing setup and failure modes of concrete specimens: **(a)** compressive strength test, **(b)** specimen failure during compression, and **(c)** flexural strength test under two-point loading

Table 4. Physical Properties of Natural and Recycled Coarse Aggregates

Property	Natural Aggregate	Recycled Aggregate
Specific Gravity	~2.65	~2.30–2.45
Water Absorption (%)	~0.5–1.0	~4–8
Bulk Density (kg/m³)	~1600	~1350–1500
Surface Condition	Smooth	Rough with adhered mortar

The first type of concrete mix proportion comprised ordinary concrete mix proportions made with a water-cement ratio of 0.42, demolition waste aggregates were tested at different replacement levels and no chemical admixture was used. The second type of mix proportion consisted of modified concrete mix proportion containing PC-200 superplasticizer, by reducing the water-cement ratio of 0.28 and hence achieving high strength and better microstructural characteristics. The high-range water-reducing admixture used in the present study was PC-200 having a brownish liquid appearance, a specific gravity of approximately 1.04, a freezing point of −1 °C and an air entrainment of less than 2%. The PC-200 dosage of 1.2% by weight of cement was used for all modified mixes, as a result of preliminary considerations and the manufacturer recommendations, to assure effective dispersion of cement particles and better work ability of the mixes with lower water.

Before mixing, the coarse recycled aggregates were employed in an air-dry state. With reference to their increased ability to absorb water, proper moisture allowance was made during batching to ensure that the desired water-cement ratio is maintained. Although there was no soaking process conducted, the possible effect of the water-absorption capability of recycled aggregates on the workability of fresh concrete, including slump, was examined. Initially dry mixing was performed to homogenize the dosage design of cement, fine aggregate and coarse aggregate, and water was added gradually. In the case of mixes with superplasticizer, PC-200 was pre-mixed with part of the mixing water prior to entering the mixer, to assure its uniform dispersion. Fresh concrete was immediately tested for work ability according to standard testing procedure. Slump test using the standard truncated cone - the upper diameter of 100 mm, lower diameter of 200 mm and the height 300 mm were made using the three layers of concrete. The concrete was poured into the mold in three equal layers, each of which was compacted uniformly. The vertical slump in millimeters was determined to check the influence of demolition waste aggregates and superplasticizer on the behavior of fresh concrete. Table 4 presents the comparative physical properties of natural and recycled coarse aggregates used in the study. The experimental testing setup and typical failure modes of the specimens under compressive and flexural loading are illustrated in Figure 1.

After workability test, fresh concrete was cast in standard molds for hardened property test. Compressive strength specimens were made in cube mold of 100 x 100 x 100 mm.

Table 5. Mix Proportions of Concrete Mixtures (kg/m³)

Mix ID	Cement (kg/m³)	Fine Agg. (kg/m³)	Natural CA (kg/m³)	Recycled CA (kg/m³)	Water (kg/m³)	w/c	PC-200 (% by cement)
OC-0	400	600	800	0	168	0.42	0
OC-25	400	600	600	200	168	0.42	0
OC-50	400	600	400	400	168	0.42	0
OC-75	400	600	200	600	168	0.42	0
OC-100	400	600	0	800	168	0.42	0
MC-0	400	600	800	0	112	0.28	1.2
MC-25	400	600	600	200	112	0.28	1.2
MC-50	400	600	400	400	112	0.28	1.2
MC-75	400	600	200	600	112	0.28	1.2
MC-100	400	600	0	800	112	0.28	1.2

For each mix, three cubes were cast for repeatability and statistically reliable results. The average value was then reported. Splitting tensile strength test was performed on cylindrical specimens of 100 x 200 mm. Beam specimens of 100 x 100 x 400 mm were cast for flexural strength test using two-point loading method. Cylindrical specimens of 150 x 300 mm were cast for modulus of elasticity test. All specimens were compacted in proper manner to avoid entrapped air and uniform density. Surface of the specimens was finished properly to obtain smooth and level surface. After casting, the specimens were covered to avoid loss of humidity. The covered specimens were demolded after 24 hours. After demolding, all specimens were cured in water at room temperature for 28 days before testing. The compressive strength test was performed on cube specimens after 28 days of curing using calibrated compression testing machine. The amount of load applied was increased stepwise until the specimen failed. The maximum load was divided by the area of cross-section of the specimen to determine the compressive strength. The splitting test for tensile strength was conducted on cylindrical specimens as per the standard procedure. The cylinder was laid sideways and a compressive force was applied normal to the cylinder till the specimen failed. The result of tensile strength was computed by the standard formula for splitting test. Flexural strength was determined using beam specimens. The beam was supported at two points and loaded at two points. The test was conducted to determine the modulus of rupture, in accordance with BS EN 12390-5. The modulus of elasticity was determined using cylindrical specimens, in accordance with ASTM C469, using the chord MOE approach. A stress–strain output was obtained during the loading of the specimen, and a modulus of elasticity value was computed from the slope between a strain of 0.00005 and a stress value at 40% of the ultimate compressive stress.

The proportioning of mixtures mentioned in Table 5 was carried out based on the ratio of 1:1.5:2 (cement: fine aggregate: coarse aggregate). The amount of coarse aggregate remained constant, whereas natural coarse aggregate was substituted by recycled aggregate at various percentage ratios by weight. Water requirement was decided based on the adopted water-cement ratios of 0.42 for normal mixtures and 0.28 for modified mixtures. The use of PC-200 superplasticizer remained constant at 1.2% of cement weight in all modified mixes. Small variations in mixing water were taken into consideration due to the moisture content and absorption capacity of recycled aggregates. All the mechanical strengths were tested at 28 days. Three samples of a particular mix were used for each mechanical strength test, and the average value was reported for each, in order to minimize sample variation. All mechanical testing took place after 28 days of curing, to guarantee maturity and to ensure comparability of results. Three specimens per test and per mix type were tested and the average value reported to minimize the effects of experimental variability. Specimen behavior was also visually observed during the mechanical testing to assess failure mode and other general performance characteristics. The experimental program was designed to allow systematic comparison between ordinary concrete and concrete modified with PC-200 superplasticizer at different replacement levels with demolition waste aggregates. This broad approach allowed the combined effects of recycled aggregate content and chemical admixture incorporation on workability, strength, and stiffness to be evaluated and reliable experimental data obtained on the feasibility of using demolition concrete waste for producing high-performance and sustainable concrete.

3. Results and Discussion

The experimental results clearly show how the incorporation of demolition concrete waste aggregates and PC-200 superplasticizer affect the fresh and mechanical properties of concrete and illustrate a clear contrasting effect between the behavior of ordinary mixes and the modified mixes. The workability test results indicated a continuous slump decrease as a function of the percentage of natural coarse aggregate replacement by the demolition waste in the ordinary concrete mixes. The slump value of the reference concrete was 18 mm and gradually reduced to 15, 11, 9 and 7 mm at 25 %, 50 %, 75 % and 100 % of the demolition waste replacement, respectively. This was due to the higher water absorption and surface roughness and higher porosity of the demolition waste aggregates, which require more mixing water and limits the free movement of the fresh concrete. However, there was a contrasting effect in the modified mixes, when PC-200 superplasticizer was added. The slump value for the reference modified mix was 52 mm, but the modified mixes, with 25, 50, 75 and 100 % of the demolition waste aggregates, showed 47, 41, 39 and 36 mm, respectively. Though, the water–cement ratio is 0.28, the superplasticizer enabled an effective particle dispersion and lubrication, which counteracted the negative influence of recycled aggregates, leading to workable concrete that could be successfully placed and compacted. Such behavior suggests the synergistic effect of PC-200 superplasticizer and decreased water-cement ratio on improving the fresh properties of demolition waste concrete. Because these factors change simultaneously, it is not possible to measure their relative effects in isolation within the current experiment. Table 6 summarizes the workability and mechanical performance of ordinary concrete mixes prepared with different percentages of demolition waste aggregates. It can be observed a gradual reduction of the slump from 18 mm for the reference mixture to 7 mm at 100% replacement, accompanied by reduction in compressive strength from 35.76 MPa to 30.89 MPa, in tensile strength from 2.33 MPa to 1.76 MPa, in flexural strength from 3.18 MPa to 2.65 MPa and in modulus of elasticity from 25.42 GPa to 23.60 GPa, with increasing replacement level.

Table 7 presents the workability and mechanical properties of concrete mixes with PC-200 superplasticizer. The data demonstrated a significant enhancement in fresh and hardened properties with slump ranging from 52 mm for the modified reference mix to 36 mm at 100% replacement. The compressive strength increased gradually from 43.09 MPa to 52.51 MPa, and tensile strength, flexural strength, and modulus of elasticity were also considerably improved and reached to 4.17 MPa, 5.34 MPa, and 30.53 GPa at full replacement respectively.

Table 6. Mechanical Properties of Ordinary Concrete with Recycled Aggregate Replacement

Mix type	Slump mm	Compressive Strength (MPa)	Tensile Strength, (MPa)	Flexural Strength, (MPa)	Modulus of Elasticity (MPa)
Ordinary concrete	18 mm	35.76	2.33	3.18	25421
25%, Replacement	15 mm	34.54	2,12	2.97	25334
50 % replacement	11mm	32.97	1.93	2.82	24712
75% replacement	9 mm	31.53	1.81	2.78	24344
100% replacement	7 mm	30.89	1.76	2.65	23599

Table 7. Mechanical Properties of Concrete Modified with PC-200 Superplasticizer

Mix type	Slump mm	Compressive Strength (MPa)	Tensile Strength, (MPa)	Flexural Strength, (MPa)	Modulus of Elasticity (GPa)
Ordinary concrete with super-plasticize	52 mm	43.09	2.63	3.68	26.31
25%, Replacement Modified mix	47 mm	44.12	2.81	3.84	27.28
50 % replacement Modified mix	41 mm	46.58	3.15	4.75	27.95
75% replacement Modified mix	39 mm	49.62	3.82	4.90	28.61
100% replacement Modified mix	36 mm	52.51	4.17	5.34	30.53

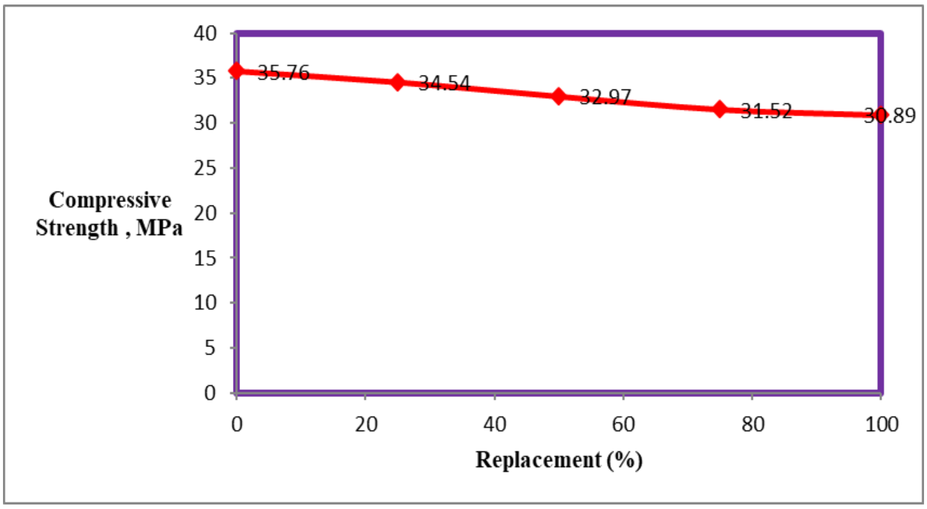

Figure 2. Relationship between replacement (%) and compressive strength of concrete

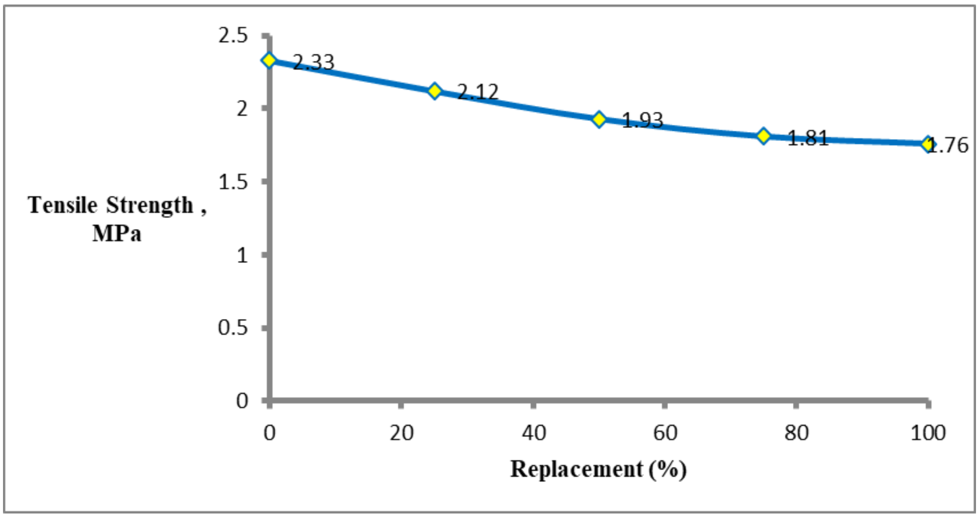

Figure 3. Relationship between replacement (%) and Tensile strength of concrete

The variation of compressive strength with increasing demolition waste aggregate replacement in ordinary concrete is illustrated in Figure 2, showing a gradual reduction from 35.76 MPa at 0% replacement to 30.89 MPa at 100% replacement.

The effect of demolition waste aggregate replacement on the splitting tensile strength of ordinary concrete is presented in Figure 3, where the tensile strength decreased from 2.33 MPa for the reference mix to 1.76 MPa at full replacement.

The relationship between demolition waste aggregate replacement and flexural strength of ordinary concrete is depicted in Figure 4, indicating a reduction in flexural strength from 3.18 MPa at 0% replacement to 2.65 MPa at 100% replacement.

The variation in elastic stiffness of ordinary concrete with increasing demolition waste aggregate replacement is shown in Figure 5, where the modulus of elasticity decreased from approximately 25.42 GPa for the reference mix to 23.60 GPa at 100% replacement, reflecting the reduced stiffness associated with recycled aggregates.

Figure 6 shows a comparison of compressive strengths between ordinary and PC-200 modified concrete mixes. As can be seen, compressive strength of ordinary concrete mix decreased gradually from 35.76 MPa to 30.89 MPa during replacement, unlike modified mixes where it increased gradually and reached to 52.51 MPa at 100% replacement. The trends noted in this research should be viewed against the backdrop of current literature on recycled aggregate concrete. Many researchers have found that an increase in the percentage of recycled aggregates is usually accompanied by a decrease in compressive strength, tensile strength, and modulus of elasticity owing to the increased porosity and water absorption characteristics of recycled aggregates, as well as their lower strength interfacial transition zone [3-6]. Nevertheless, it has been pointed out that the application of superplasticizers along with a decrease in the water-cement ratio is capable of overcoming or compensating for such decreases through enhancing workability and providing a denser cement matrix.

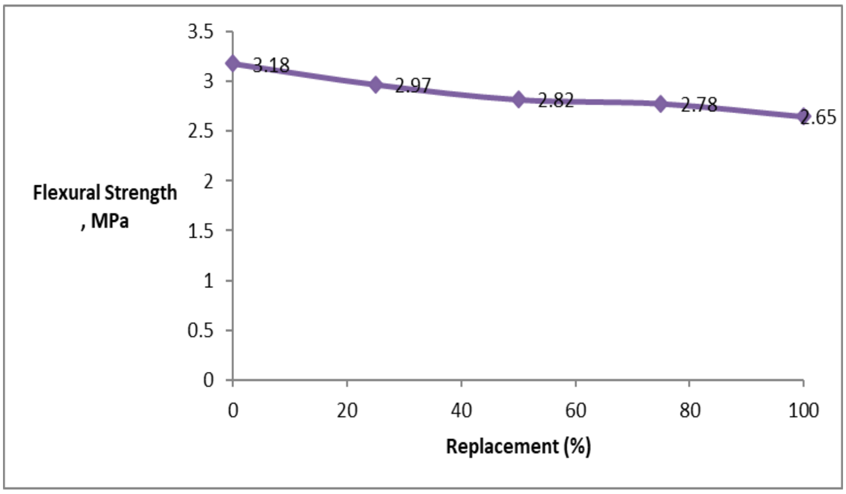

Figure 4. Relationship between replacement % and flexural strength of concrete

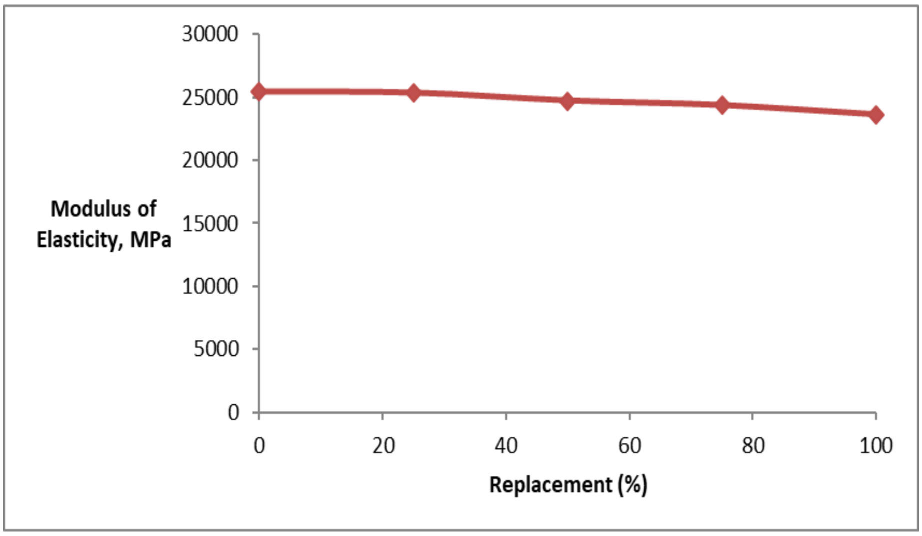

Figure 5. Relationship between replacement and modulus of elasticity of concrete

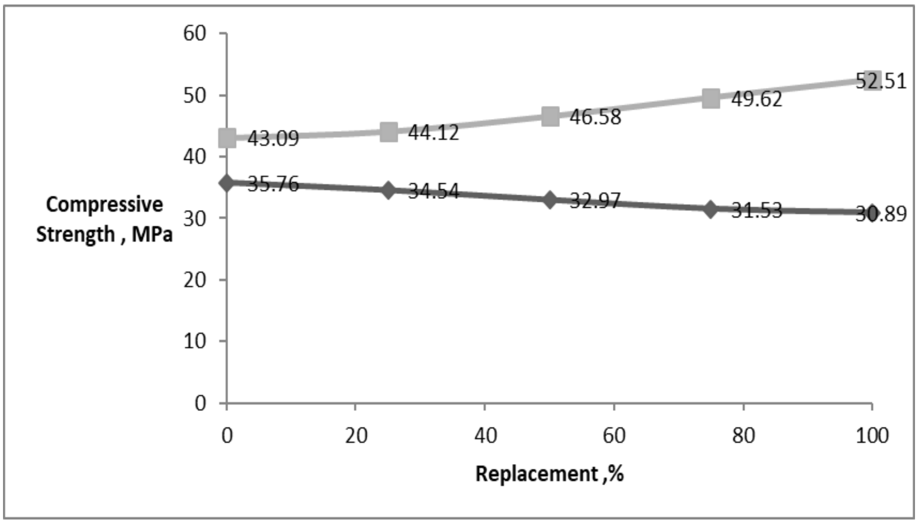

Figure 6. Comparison between waste aggregate concrete and mixes modified with PC-Super-Plasticizer (in compression)

Contrary to the generally accepted weakening of strength at higher levels of replacement, in the current research, it is possible to observe an ongoing growth in the performance properties in all mixes with up to 100% replacement. The difference between the results obtained and those generally accepted might be explained by the interplay between the low water–cement ratio and proper dispersion of cement grains by means of the use of the superplasticizer. Nevertheless, it is important to highlight that previous researches have also shown that the superplasticizer may not perform as efficiently as in other cases because of the high absorbency and heterogeneity of the recycled aggregates.

The effect of PC-200 superplasticizer on the tensile performance of demolition waste concrete is illustrated in Figure 7, where the splitting tensile strength increased from 2.63 MPa in the modified reference mix to 4.17 MPa at full replacement, in contrast to the decreasing trend observed in ordinary concrete.

The comparison of flexural strength between ordinary concrete containing demolition waste aggregates and mixes modified with PC-200 superplasticizer is illustrated in Figure 8, showing a significant enhancement in flexural performance for the modified mixes, with the flexural strength increasing to 5.34 MPa at 100% replacement, compared to 2.65 MPa for the corresponding ordinary concrete mix.

The influence of PC-200 superplasticizer on the stiffness characteristics of demolition waste concrete is illustrated in Figure 9, where the modulus of elasticity of the modified mixes increased markedly, reaching approximately 30.53 GPa at 100% replacement, compared to about 23.60 GPa for the corresponding ordinary concrete mix.

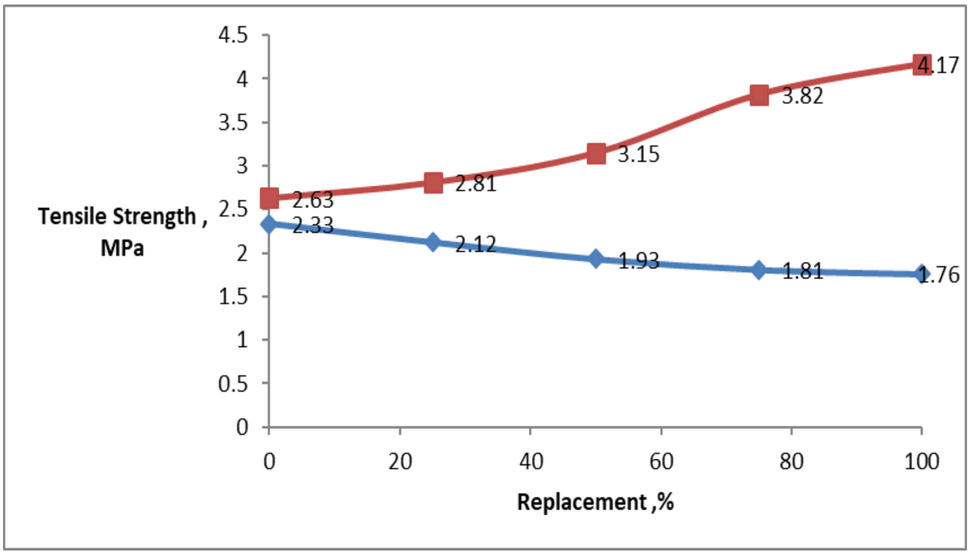

Figure 7. Comparison between waste aggregate concrete and mixes modified with PC-Super-Plasticizer (in Tension)

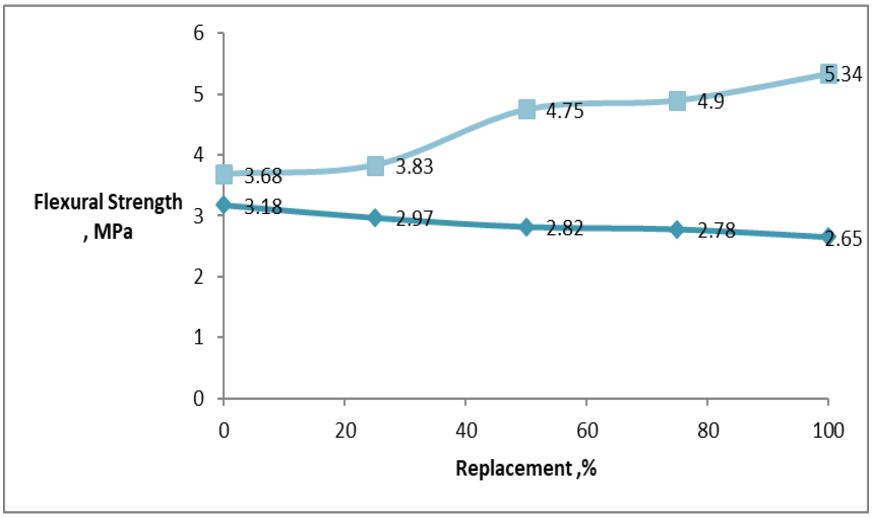

Figure 8. Comparison between waste aggregate concrete and mixes modified with PC-Super-Plasticizer (in Flexure)

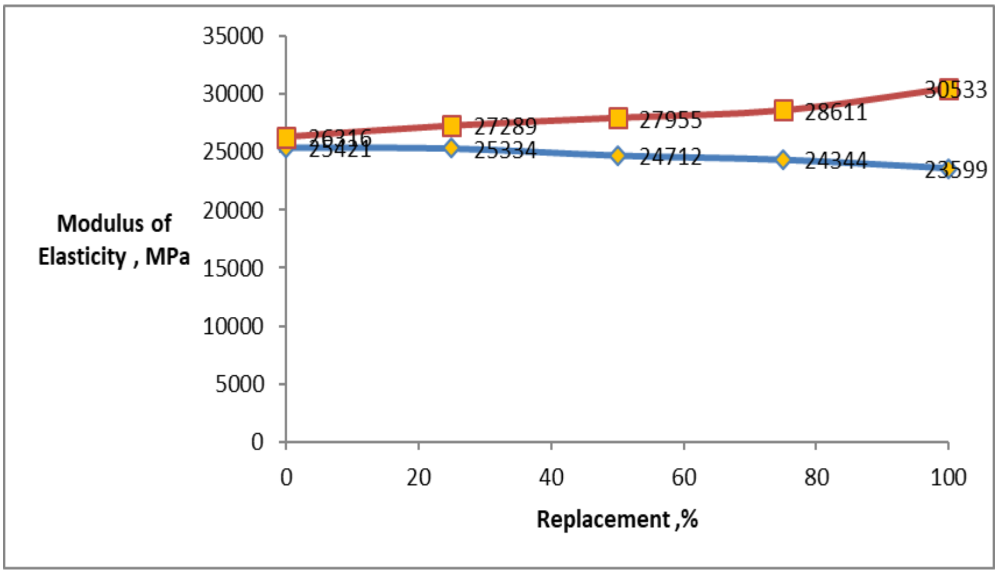

Figure 9. Comparison between waste aggregate concrete and mixes modified with PC-Super-Plasticizer (in Modulus of Elasticity)

The results of compressive strength indicate the impact of demolition waste aggregates and chemical reactions on the performing properties of concrete. For non-superplasticizer mixes, the reference had strength of 35.76 MPa at 28 days. With increasing percentage of natural aggregate substitution, the values dropped gradually to 34.54 MPa at 25%, 32.97 MPa at 50%, 31.53 MPa at 75% and 30.89 MPa at 100%. The total drop of about 13.6% at 100% substitution is attributed to the weak demolition waste aggregates containing old mortar and micro cracks. Such characteristics reduce the load bearing capacity and deteriorate the bonding of new- and old-cement matrix. These observations are consistent with the earlier studies in which recycled aggregate concrete was found to be weak, possibly due to the low quality of aggregates and higher porosity. On the other hand, superplasticizer PC-200 mixtures exhibited markedly higher strength values for all the replacement percentages. The modified reference mix had strength of 43.09 MPa, about 20.5% higher than the regular reference mix. In addition, the compressive strength also increased with an increased amount of demolition waste; 44.12 MPa, 46.58 MPa, 49.62 MPa and 52.51 MPa at 25%, 50%, 75% and 100% respectively. When using a full 100% replacement rate, the compressive strength is about 21.9% greater than the modified reference mixture, indicating that perhaps the combination of the lower water-to-cement ratio and the use of PC-200 superplasticizer might be able to compensate for the weaknesses of the demolition aggregate material. The reason for the higher strengths was caused by the decrease in the number of capillary pores together with the improved arrangement of particles and bonding between the aggregate and paste, which is again contingent on the effective use of water and better distribution of cement particles.

The splitting tensile strength was very similar to the compressive strength, and confirmed the superior results of the PC-200 superplasticizer. No added ingredients, normal concrete has a tensile strength of 2.33 MPa, which decreased to 2.12 MPa, 1.93 MPa, 1.81 MPa and 1.76 MPa with 25%, 50%, 75% and all respectively. The decrease of about 24.5% in the full replacement case reflects a higher brittleness and lower tensile resistance due mainly to the lower quality of the recycled aggregates and due to the weak interfacial zones. Tensile strength is most sensitive to microcracks and internal defects, which are more colossally occurring in demolition waste aggregates. However, in the presence of superplasticizer PC-200 in the modified mixes tensile strength instead improved significantly. The tensile strength of the reference modified mix was 2.63 MPa, while it was 2.81 MPa, 3.15 MPa, 3.82 MPa, and 4.17 MPa in the cases of 25%, 50%, 75%, and 100% replacement mix, respectively. At full replacement the tensile strength increased by about 58.6% with respect to the ordinary reference mix and by more than 137% with respect to the ordinary mix with 100% replacement. It reflects a higher cohesion of the cement matrix and a higher aggregate–paste interactions due to the combined effect of water reduction and superplasticizer, which reduces the crack nucleation and its propagation under tensile loading. Whereas there is a trend towards higher compressive strength in mixes modified, there is no significance between the data ($p > 0.05$) in case of low replacements, whereas the difference is significant ($p < 0.05$) for high replacements.

The results on flexural strength confirm the mechanical behavior trends. In ordinary mixes, flexural strength was 3.18 MPa for the reference mix and reduced to 2.97 MPa, 2.82 MPa, 2.78 MPa, and 2.65 MPa at 25%, 50%, 75% and 100% replacement, respectively. This decrease in flexural strength is due to the lower stiffness and bonding capacity of demolition waste aggregates, generally leading to a decrease in bending resistance. Conversely, a significant enhancement in flexural performance was observed with modified mixes: 3.68 MPa was obtained for the reference modified mix, while 3.84 MPa, 4.75 MPa, 4.90 MPa and 5.34 MPa were obtained with mixes with 25%, 50%, 75% and 100% replacement of aggregates, respectively. The improvement in full replacement levels is about 68% compared to the reference mix for ordinary concrete, which is a very noticeable improvement in bending capacity. This behavior can be associated with an effective stress transmission mechanism at the matrix–aggregate interface and with the presence of a dense microstructure promoting resistance to crack propagation under flexural loading. In addition, the stiffness of demolition waste concrete is discussed with the results of modulus of elasticity. The modulus of elasticity of ordinary concrete was found to be 25.42 GPa, which decreased gradually to 25.33 GPa, 24.71 GPa, 24.34 GPa and 23.60 GPa respectively with the increasing replacement, corresponding to a drop of around 7.2% at full replacement. This is due to the low stiffness of recycled aggregates and the presence of old mortar leads to a reduction in overall elastic response. At the same time, the modified mixes achieved a more consistent increase in the elastic modulus. The modulus of elasticity of the reference modified mix was found to be 26.32 GPa with replacement mixes of 25%, 50%, 75%, and 100% obtained values of 27.29 GPa, 27.96 GPa, 28.61 GPa and 30.53 GPa respectively. The modulus of elasticity at full replacement improved by around 20.1% over the ordinary reference mix implying that the stiffness can be improved even at full substitution of natural aggregates if the mix is modified appropriately. This was due to improvement in internal structure, lower void content and better stress distribution within the concrete matrix. Finally, the comparative study between the ordinary and modified mixes clearly indicated that demolition concrete waste aggregates as such will not improve the workability and mechanical attributes, and hence cannot be directly utilized in structural concrete. However, the introduction of the PC-200 superplasticizer and the decrease of water–cement ratio can overcame those shortcomings and improve fresh and hardened concrete. Numerical values indicate that 100% replacement of natural coarse aggregate becomes not only possible but also beneficial when appropriate chemical modification is employed. The compressive strength (at 52.51 MPa), the tensile strength (at 4.17 MPa), the flexural strength (at 5.34 MPa), and the modulus of elasticity (at 30.53 GPa) of concrete improve to an extent that shows that well-made demolition waste concrete can be used in ways and conditions where ordinary concrete is expected to perform at the highest level. These results provide an important experimental foundation for using demolition waste aggregates in superior performance and eco-friendly concrete and can be used as a reference for research and engineering. Such an improvement in the material's mechanical performance at increasing replacement levels in modified mixes can be caused by several mechanisms occurring simultaneously. First, it should be considered that due to lower W/C ratio, the cement matrix will become more dense and contain less pores. Superplasticizer also promotes better dispersion of cement particles and better hydration of the paste. Besides, due to their angular shape and rough surface texture, recycled aggregates might form mechanical interlocking with cement matrix. In a properly dispersed system, it can contribute to better stress transmission through the ITZ layer. However, all this occurs under specific mix composition and processing conditions. At the same time, it is necessary to acknowledge that mixes under investigation include two changes simultaneously – the application of PC-200 superplasticizer and decrease in water–cement ratio. As a consequence, it is impossible to separate the individual impact of these two variables using the current experimental approach. Thus, observed positive trends should be regarded as the result of a combination of both factors. Further research on this topic is suggested to use a factorial experimental design with independent variation in the ratio of water to cement and amount of superplasticizer applied. The tendency of decrease in slump with increase in the amount of recycled aggregate is in agreement with many researches, whose explanation for this phenomenon lies in the high water absorption capacity and rough surface texture of recycled aggregates; therefore, less free water is present in the mixtures [10-12]. Nevertheless, the positive effect obtained for modified mixes in this research is in accordance with the literature findings, which have shown that the use of superplasticizer can improve the dispersion of particles and offset this negative effect [26–28]. The current research has some drawbacks that need to be mentioned. Firstly, it should be noted that the sample size was small (n = 3 per test) and, therefore, could have an impact on the accuracy of the reported results. Secondly, all the properties were tested at one single curing age of 28 days, hence, long-term performance was not considered. Thirdly, no tests related to the durability were performed; in particular, no data was obtained about water absorption, sorptivity, permeability, shrinkage, and resistance to harsh environmental factors. Fourthly, no microstructural investigation was carried out using SEM. Thirdly, the experiment includes variation of the amount of superplasticizer added to the mix along with the reduction of water-cement ratio; this makes it impossible to separately observe their impacts. This is why it must be noted that the findings of the study must be seen as those for combination effect under lab-controlled conditions. In addition, it is essential to note that the behavior exhibited in this research cannot be generalized because it was specific to the materials used. Thus, the recycled aggregate came from a certain demolition site that had its unique characteristics; therefore, the conclusions made regarding this aggregate do not necessarily apply to other materials used. Furthermore, the positive performance was achieved due to the specific dosage of PC-200 superplasticizer (1.2%) and specific reduction of water-cement ratio.

4. Conclusion

In this study, the use of demolition concrete waste as a substitute to the natural coarse aggregates was analyzed, and the effects of modifications on the mix through reduction of the water-cement ratio and addition of the superplasticizer were investigated. It has been found out that although the recycled aggregate in its untreated form has adverse effects on the workability and mechanical behavior of the concrete, suitable modification of the mix could greatly enhance these parameters in controlled laboratory tests. One important finding from this study is that the combination of water-cement ratio reduction and superplasticizer addition could effectively contribute to the densification of the matrix and mechanical behavior of the recycled aggregate concrete mix. However, the conclusions made from the findings of the experiment need to be considered within the context of this particular research. This study only focuses on the mechanical performance of the recycled aggregate concrete for up to 28 days, without conducting any further evaluation of the material's durability and long-term performance. It is also important to remember that the current findings are only valid for the concrete mixture tested in this study. Nonetheless, this experiment has successfully shown how the process of mixing design could have an impact on the performance of the concrete made from recycled aggregate.

References

[1] A.C. Freire, I. Martins, C. Ferreira, E. Correia, J. Neves, A. Roque, E. Fortunato, A. Paixão, S. Rios, (2026) Use of construction and demolition waste and steel slag. Transportation Geotechnics for Green, Digital, and Modern Infrastructures, CRC Press. https://doi.org/10.1201/9781003530220-5

[2] J.S. Sudarsan, S. Vaishampayan, V. Srihari, H. Gavali, Optimizing construction waste management: A study on recycling practices in residential building projects. Clean Technologies and Environmental Policy, 28(2), (2026) 54. https://doi.org/10.1007/s10098-025-03365-9

[3] R.K. Sakthibala, P. Vasanthi, C. Hariharasudhan, P. Partheeban, A critical review on recycling and reuse of construction and demolition waste materials. Cleaner Waste Systems, 12, (2025) 100375. https://doi.org/10.1016/j.clwas.2025.100375

[4] Y. Song, J. Feng, F. Wang, S. Wu, H. Xu, Advanced and sustainable approach for large-scale, high-quality recycling of predominant pavement waste and its life cycle environmental impact assessment. Environmental Impact Assessment Review, 118, (2026) 108263. https://doi.org/10.1016/j.eiar.2025.108263

[5] C. Cascioli, L. Castagnini, A. Morri, L. Ceschini, Improving the performance of recycled EN 45500: A sustainable approach through heat treatment optimization. Journal of Cleaner Production, 544, (2026) 147718. https://doi.org/10.1016/j.jclepro.2026.147718

[6] A. Islam, E. Rashid, T.A. Kanon, R. Khan, B. Uddin, N. Islam, H. Rahman, A. W. Fahim, R. Uddin, S. Ray, Y. Khan Rijuan, M. Haque, Upcycling colored brush fiber waste through siro yarn production: A sustainable approach to reduce environmental impact in textile manufacturing. Cleaner Waste Systems, 13, (2026) 100474. https://doi.org/10.1016/j.clwas.2026.100474

[7] J. Xiao, C. Yu, B. Wang, H. Liu, C.S. Poon, J. de Brito, X. Xiao, J. Liu, S.P. Shah, Recycled aggregate concrete design, application and challenges. Nature Reviews Clean Technology, 2, (2026) 67–83. https://doi.org/10.1038/s44359-025-00125-2

[8] A.A. Firoozi, A.A. Firoozi, Recycled aggregate concrete: A sustainable approach to concrete production. Recent Developments and Innovations in the Sustainable Production of Concrete, (2025) 415–459. https://doi.org/10.1016/B978-0-443-23895-6.00016-9

[9] A. Mandal, A. Shiuly, Exploring mechanical characteristics of recycled concrete aggregates from demolition waste: Advancements, challenges, and future directions for sustainable construction: A review. Discover Civil Engineering, 2(10, (2025) 33. https://doi.org/10.1007/s44290-025-00185-0

[10] Z. Jia, S. Cunha, J. Aguiar, C. Shi, Enhancing the durability of concrete with construction and demolition waste aggregate through its functionalization with phase change materials (paraffin). Cement and Concrete Composites, 162, (2025) 106135. https://doi.org/10.1016/j.cemconcomp.2025.106135

[11] P. Wang, B. Chen, A. Hashmi, X. Yao, J. Dong, Two-stage deterioration mechanisms in recycled aggregate concrete: From pore interface degradation to aggregate interface defect control. Buildings, 15(24), (2025) 4480. https://doi.org/10.3390/buildings15244480

[12] X. Xie, Y. Zheng, F. Lee, Y. Zeng, H. Wu, Y. Yang, S. Xu, (2026) Sound insulation and mechanical properties of recycled aggregate-rubber cement-based mortar with hierarchical porous heterogeneous structure. SSRN. https://dx.doi.org/10.2139/ssrn.6082133

[13] J. Rajprasad, A comprehensive review and

evaluation of recycled aggregates as a sustainable construction material. Engineering Research Express, 8(4), (2026). https://doi.org/10.1088/2631-8695/ae3a35

[14] M. O. Kim, Can microplastics (MPs) replace conventional mineral aggregates? A brief review. Polymers, 18(4), (2026) 505. https://doi.org/10.3390/polym18040505

[15] M. AlSieedi, Z. Jiang, A. Al-Bodour, M. Atilhan, L. M. Colosi, G. Arce, O. E. Ozbulut, Influence of biochar feedstock and particle size on cementitious composites incorporating biochar as a partial cement replacement. Journal of Cleaner Production, 555, (2026) 148202. https://doi.org/10.1016/j.jclepro.2026.148202

[16] J. Jiang, H. Yang, M. Li, F. Chen, Y. Wang, Failure criterion and constitutive model of concrete incorporating recycled coarse aggregate subjected to true-triaxial compression after freeze-thaw cycles. Structures, 84, (2026) 111115. https://doi.org/10.1016/j.istruc.2026.111115

[17] E. Pahsha, R. Gupta, V. Agrawal, Evaluation of strength, durability, and environmental impact of self-compacting concrete incorporating ground-granulated blast-furnace slag, granite cutting waste, and recycled concrete aggregate. Arabian Journal for Science and Engineering, (2026) 1–23. https://doi.org/10.1007/s13369-026-11257-3

[18] R. Cherif, A. Bousleh, S.E.E. Khay, Sustainable sand concrete incorporating fine recycled aggregates for structural applications. Engineering Research Express, 8(1), (2026) 015101. https://doi.org/10.1088/2631-8695/ae2f24

[19] G.A. Junior, J.C. Leite, G.D.P. Mendez, A.N. Haddad, J.A. Silva, B.B. da Costa, A review of the characteristics of recycled aggregates and the mechanical properties of concrete produced by replacing natural coarse aggregates with recycled ones—fostering resilient and sustainable infrastructures," Infrastructures, 10(8), 2025) 213. https://doi.org/10.3390/infrastructures10080213

[20] A. Alibeigibeni, F. Stochino, M. Zucca, F. L. Gayarre, Enhancing concrete sustainability: A critical review of the performance of recycled concrete aggregates (RCAs) in structural concrete. Buildings, 15(80, (2025) 1361. https://doi.org/10.3390/buildings15081361

[21] L. Prasittisopin, W. Tuvayanond, T.H.K. Kang, S. Kaewunruen, Concrete mix design of recycled concrete aggregate (RCA): Analysis of review papers, characteristics, research trends, and underexplored topics. Resources, 14(2), (2025) 21. https://doi.org/10.3390/resources14020021

[22] D.K. Ashish, H. Sharma, R. Maddalena, Recent advances in utilizing industrial wastes for enhanced concrete performance. Recent Trends in the Sustainability Improvement and Use of Wastes in Cementitious Materials, (2026) 131–148. https://doi.org/10.1016/B978-0-443-15670-0.00006-5

[23] Z. Shui, X. Chen, S. Cheng, R. Zhao, (2026) Development of an environment friendly ultra-high performance concrete containing recycled fine aggregates using magnesia expansive agents: Mechanical properties, shrinkage characteristics and microstructure. SSRN. https://dx.doi.org/10.2139/ssrn.6083049

[24] A. Raj, P. Yamkasikorn, A. Kunawisarut, C. Ngamkhanong, P. Jongvivatsakul, L. Prasittisopin, J. Panpranot, S. Kaewunruen, Enhancing recycled aggregate concrete with graphene quantum dots (GQDs): Refining wastes from construction demolitions and out-of-service railway sleepers. Developments in the Built Environment, 23, (2025) 100729. https://doi.org/10.1016/j.dibe.2025.100729

[25] G. Silva, M. Tudela, O. Rojas, C. Llontop, A. Perrot, R. Aguilar, Printable concrete with multi-source recycled aggregates: Particle packing design, rheological behavior, and 3D printing validation. Materials and Structures, 59(3), (2026) 169. https://doi.org/10.1617/s11527-026-03063-y

[26] S. Barbhuiya, B.B. Das, D. Adak, Effects of chemical admixtures on the properties of concrete. Binding Materials for Sustainable Construction, (2025) 329–362. https://doi.org/10.1016/B978-0-443-26566-2.00009-X

[27] A. Fatah, A.R. Prasetia, A. Dudi, S.M. Muhammad Afif, L. Azan Muzahab, (2025). The Use of Type D and Type F Admixtures Concrete and Their Effects on Setting Time and Compressive Strength. Journal of Social Research, 4(8), 1796-1808. https://doi.org/10.55324/josr.v4i7.2664

[28] Z. Jia, N. Li, S. Cunha, J. Aguiar, C. Zheng, Evaluation of the residual strength of concrete incorporating high quantity of functionalized recycled aggregates and free PCM exposed to elevated temperatures. Construction and Building Materials, 518, (2026) 145783. https://doi.org/10.1016/j.conbuildmat.2026.145783

[29] N.R. Pandjab, B. Bakri, M.A. Caronge, M.W. Tjaronge, N.H.A. Khalid, Exploratory study on fresh and hardened properties of mortar using recycled concrete powder towards environmental impact assessment. Next Materials, 11, (2026) 101994. https://doi.org/10.1016/j.nxmate.2026.101994

[30] B.R. Rashmi, R. Hemanth, A comparative study of two-stage mixing concrete against nominal mixing concrete. E3S Web of Conferences, 702, (2026) 06003.

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes