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Research on Fresh and Hardened Concrete Residences with Partial Replacement of Recycled Coarse Aggregates Obtained from Demolition and Construction Waste

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Abstract: The modern world is witnessing the development of extremely demanding structures right now. Concrete is an extremely important and widely used material. However, the reuse of construction waste is crucial when considering life cycle assessment (LCA) and the efficient recycling of construction materials. Given its potential to address sustainability and environmental challenges, using recycled materials in construction has attracted much attention. This study aims to examine what happens to concrete's compressive strength when recycled coarse aggregates (RCA) replace some of the conventional coarse aggregates. The aim is to study the impact of RCA content on the mechanical characteristics of concrete and determine its appropriateness for use in structural applications. The main objectives of this work is to determine and compare the Density, Workability, Compressive strength, split tensile strength, and Flexural strength of Recycled aggregate in relation to conventional aggregate also to ascertain the ideal percentage of aggregate replacement with recycled aggregate and to calculate the percentage change in strength for recycled aggregate at different levels of replacement. The research methodology involves carrying out laboratory experiments to examine the compressive strength, split tensile strength, and flexural strength of concrete specimens with different proportions of recycled concrete aggregate (RCA) substitutions. The typical coarse aggregates are substituted by recycled aggregates in various proportions (5%, 10%, 15%, 20%, 25%, and 30%) by weight in M25 grade concrete. The formulation of the concrete mix design is meticulously done to provide a consistent water-cement ratio and other crucial criteria. The study involves the process of casting and curing concrete specimens that contain varying amounts of recycled concrete aggregate (RCA). At certain curing ages (e.g., 7 days and 28 days), the specimens are tested for compressive strength, split tensile strength, and flexural strength in order to assess their mechanical capabilities. After that, the outcomes are contrasted with control samples made entirely of conventional coarse aggregates. Primary finding shows workability declines as the proportion of recycled trash rises, but it is kept stable with mixing.

Introduction

Recycled aggregate (RA) has emerged as a significant alternative to conventional construction materials, driven by its potential to mitigate environmental impacts and resource depletion. Studies have consistently shown distinct differences between recycled aggregates and their natural counterparts. Using Recycled aggregate Concrete (RAC) was first introduced by Nixon (1978) to recycle

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the construction waste caused by the bombardment of various cities during World War II. Hansen (1992) assumed that aggregates from concrete rubble are angular in shape like normal aggregates. The report, Mechanical Properties of Recycled Aggregate Concrete, has very well outlined the scope of using RA, published in (1992). Further in this line, the design of the mix was presented in a manual for mix Design Procedures published in 2009. Liu and Zhang's (2013) shrinkage deformation of concrete with recycled crushed brick coarse aggregate was experimentally studied, effects of curing age, strength of concrete and environmental conditions on concrete shrinkage were analysed. Research by Quattrone et al. (2016) demonstrated that recycled aggregates generally exhibit higher water absorption rates than natural aggregates. The strength properties such as compressive strength, modulus of elasticity, splitting tensile strength and flexural strength were studied by Thomas et al. (2018). Wang et al. (2021) highlighted that recycled aggregates typically possess lower specific gravity and bulk density compared to natural aggregates. It was found in the study presented by Hansen and Marga (2023) that based on equal slump, the water requirement of concrete made with both coarse and fine aggregates was 14 percent higher than that of control concretes made with natural sand and gravel. This characteristic can affect concrete's overall density and mechanical properties when used as a substitute in construction. Water absorption is another critical parameter where recycled aggregates differ significantly. This property influences the workability and durability of concrete mixtures, necessitating adjustments in mix designs to maintain desired performance standards.

Strength characteristics of concrete incorporating recycled aggregates have been extensively studied. Wang et al. (2021) observed a decrease in compressive strength as the proportion of natural aggregate is replaced by recycled concrete aggregate (RCA). However, within certain limits of replacement (up to 60%, as found by Tiwari), the concrete can still achieve satisfactory strength levels, albeit with adjustments in mix proportions and curing practices. Environmental sustainability is a key motivation for the adoption of recycled aggregates in construction. Wang et al. (2021) emphasized the importance of conserving natural resources and protecting the environment, which are pivotal considerations in modern development practices. Utilizing recycled materials reduces the demand for virgin resources and minimizes landfill waste, aligning with global sustainability goals (Haas et al., 2015; Zhong et al., 2021).

Practical applications of recycled aggregate in construction have shown promising results (Liu et al., 2015; Ness et al., 2015; Heiskanen, 2017; De Andrade Salgado and De Andrade Silva, 2022). Fanijo et al. (2023) conducted laboratory experiments confirming that incorporating even a small percentage (10%) of recycled concrete aggregate can enhance the compressive strength of concrete compared to traditional mixes. This finding underscores the potential for recycled aggregates to maintain or improve structural performance in real-world applications.

Innovative techniques such as the Two-Stage Mixing Approach (TSMA) explored by Wang et al. (2021) offer optimized strategies for integrating recycled aggregates into concrete production. By modifying the mixing process to enhance the interaction between recycled materials and cement paste, researchers achieved concrete with improved microstructural characteristics and enhanced bond strength at the interfacial zones (Van Ewijk and Stegemann, 2016; Kashkash et al., 2023). These advancements contribute to better overall performance and durability of concrete structures using recycled aggregates. Overall, the scientific literature underscores that while recycled aggregates present challenges, such as lower initial strength and higher water absorption, they offer substantial benefits in terms of environmental sustainability, resource conservation, and potential economic advantages. Continued research and technological innovations are crucial in maximizing the efficiency and effectiveness of recycled aggregates in construction, ensuring they become a cornerstone of sustainable building practices worldwide. The main objectives of this study are-

#To determine and compare the Density, Workability, Compressive strength, Split tensile strength, and Flexural strength of Recycled aggregate in relation to conventional aggregate.

To ascertain the ideal percentage of aggregate replacement with recycled aggregate.

To calculate the percentage change in strength for recycled aggregate at different levels of replacement.

Material and methods

The impact of waste aggregate on various properties of concrete was systematically investigated, aiming to assess its suitability as a partial replacement for conventional aggregate in concrete production. Waste aggregate, sourced from construction and demolition sites, was used as a replacement for a portion of the natural aggregates typically used in concrete mixtures. The investigation focused on several key properties:

workability, density, split tensile strength, flexural strength, and compressive strength of the concrete. Percentage replacement of sand, cement and aggregate by Recycled aggregate is as follows:

Table 1. Percentage replacement of sand, cement and aggregate by recycled aggregate.

Sl. No.	Cube Designation	Water Cement Ratio	Recycled Waste Aggregate %
1.	S0	0.45	0 %
2.	S1	0.45	5 %
3.	S2	0.45	10 %
4.	S3	0.45	15 %
5.	S4	0.45	20 %
6.	S5	0.45	25 %
7.	S6	0.45	30 %

The experimental setup involved casting a total of 36 cubes, 12 cylinders, and 6 beams using M25-grade concrete mixes. These specimens were crucial for evaluating the performance of waste aggregate concrete compared to traditional concrete mixes. The testing periods extended to seven and twenty-eight days of moist curing to observe how the concrete properties evolved over time under controlled conditions.

The materials utilized in the study included Pozzolana Portland Cement (P.P.C.), fine aggregates sourced locally from rivers, and coarse aggregates obtained from nearby quarries. The waste aggregate, having a particle size of 20 mm, was carefully collected from demolition sites. The inclusion of a super plasticizer (CHRYSO POLYGROUT HP) helped enhance the workability of the concrete mix, ensuring that the waste aggregate concrete could be effectively placed and compacted without compromising its performance. The concrete mixes were designed with a water-cement ratio of 0.45, a critical factor influencing concrete's final strength and durability. The super plasticizer dosage was optimized at 1.2% of the cementitious material's weight to maintain the desired workability without delaying the setting time excessively. Importantly, the absence of chloride content in the super plasticizer ensured that the concrete would not be susceptible to corrosion, which is essential for its long-term structural integrity.

The primary objective of this research was to determine the ideal percentage of waste aggregate that could be substituted in concrete mixes while still achieving comparable or even superior properties to conventional concrete. By systematically varying the percentage of waste aggregate in the mixes, researchers sought to identify the optimal balance that would maximize sustainability without compromising structural performance.

Results and Discussion

Workability

In concrete engineering, the workability of a concrete mix is a crucial parameter that determines its ease of handling and placement during construction. Workability is typically assessed through tests like the slump test, which measures the consistency and flowability of the concrete. When using recycled garbage aggregate (RGA) as a replacement for conventional aggregate in concrete mixes, there are significant considerations regarding how this substitution affects workability.

The statement highlights that the workability of the replacement concrete differs from that of the reference concrete, and this difference becomes more pronounced as the percentage of recycled garbage aggregate increases. This observation suggests that the incorporation of RGA can alter the physical properties of the concrete mixture, potentially impacting its handling characteristics. Lower workability can complicate the pouring, compacting, and finishing processes during construction, potentially leading to increased labour and time costs.

However, the results reported in Table 1 and illustrated in Figure 1 indicate that the concrete mixes still meet the design mix criteria despite the varying percentages of RGA used as replacement. This implies that careful adjustment of other components, such as the use of admixtures, has effectively compensated for any potential decrease in workability due to the incorporation of RGA. Admixtures are additives used in concrete to modify its properties, including enhancing workability, controlling setting time, or improving durability.

Specifically, at a 5% replacement of recycled aggregate (labeled as S1), the highest slump value is observed compared to other mixtures. A higher slump value generally indicates better workability, as the concrete flows more easily and is easier to place and compact. This finding suggests that within certain limits, the inclusion of RGA can be managed effectively to maintain or even improve workability with appropriate adjustments in mix design and the use of admixtures. While the workability of concrete does vary with the percentage of recycled garbage aggregate used as a substitute for conventional aggregates, strategic engineering and the use of admixtures can mitigate these effects. The careful balance between sustainability goals (such as reducing environmental impact by using recycled materials) and practical engineering considerations (such as maintaining adequate workability) is crucial in developing and implementing sustainable concrete practices. This scientific approach ensures that concrete mixes meet structural requirements and contribute positively to environmental stewardship.

Table 2. Workability of the Waste Recycled Aggregate.

S.No.	Set No.	Workability (mm)
1	S0	115
2	S1	109
3	S2	104
4	S3	99
5	S4	92
6	S5	102
7	S6	98

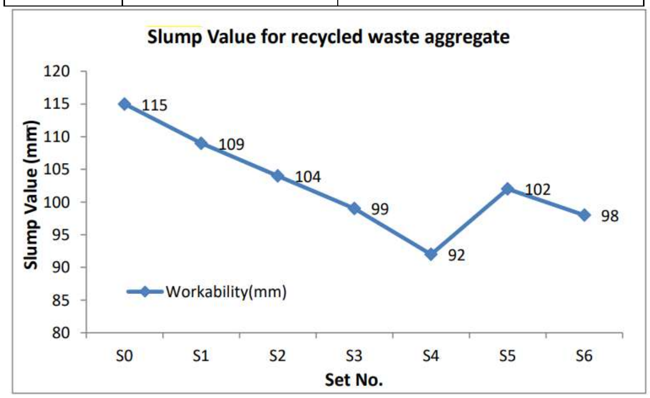

Figure 1. Workability (Slump) of Recycled Waste Aggregate.

Compressive strength

In the conducted experiment, the effect of replacing natural aggregates with waste recycled aggregates on the compressive strength of concrete was systematically investigated over curing periods of 7 and 28 days. Six sets of cubic specimens measuring 150x150x150mm were prepared for each replacement percentage ranging from 0% to 30%. The water-cement ratio was maintained at 0.45 across all mixes to ensure consistency in hydration conditions.

Upon analyzing the results presented in Table 3 and Figure 2, distinct trends emerge regarding compressive strength development at different curing periods and replacement levels. At the 7-day curing period, mix S3, which likely corresponds to a specific replacement percentage (though exact percentages are not detailed), exhibited superior compressive strength compared to other mixes. This suggests an early strength gain advantage possibly attributed to favourable particle packing or other material properties introduced by the recycled aggregates at this replacement level. Conversely, at the 28-day curing period, mix S1, which denotes a 5% replacement of recycled aggregates, achieved the highest compressive strength among all replacement percentages tested. This finding indicates that at longer curing durations, the mix with a modest replacement of recycled aggregates outperformed others, possibly due to improved bonding between cement paste and aggregates or effective hydration over time.

The observed variation in compressive strengths across different replacement percentages underscores the complex interplay between materials in concrete mixes. At lower replacement levels, such as 5%, the recycled aggregates might enhance overall strength without significantly compromising the matrix's integrity, thereby contributing to optimal mechanical performance. This optimal performance could be attributed to a balanced distribution of recycled aggregate particles within the cement matrix, promoting efficient load transfer and enhancing overall structural integrity. In contrast, higher replacement percentages (e.g., 20% to 30%) may introduce challenges such as increased porosity or weaker bonding interfaces, which could lead to reduced compressive strength compared to mixes with lower replacement levels. These results highlight the importance of judiciously selecting replacement percentages to achieve desired concrete properties, balancing sustainability goals with structural performance requirements.

The experimental findings underscore the potential of incorporating recycled materials in concrete production to achieve sustainable construction practices while optimizing material properties such as compressive strength at various stages of curing. Future research could explore additional mechanical properties and durability aspects to comprehensively assess recycled aggregates' viability in concrete production.

Table 3. Compressive strength (Cubes)of Recycled aggregate (W/C=0.45).

S. No.	Set no	Water cement ratio	Average compressive strength (at 7 days) (Mpa)	Average compressive strength (28days)(Mpa)
1	S0	0.45	19.12	32.26
2	S1	0.45	22.27	33.74
3	S2	0.45	21.76	32.02
4	S3	0.45	23.65	32.45
5	S4	0.45	25.34	30.13
6	S5	0.45	26.82	26.89
7	S6	0.45	21.98	25.92

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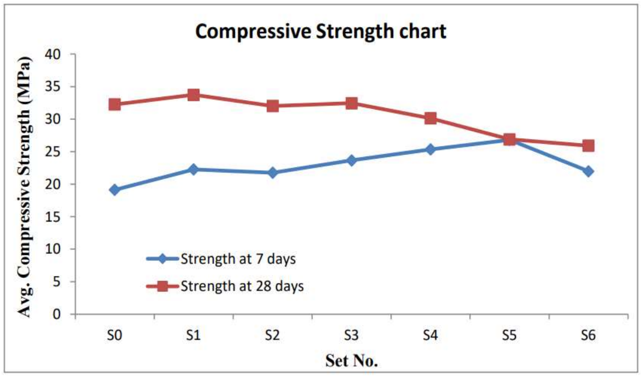

Figure 2. Compressive strength of Recycled Waste Aggregate.

Split tensile test

In the conducted experiments, six sets of cylindrical specimens were cast, each with a diameter of 75 mm and a height of 150 mm. These sets were denoted as S0, S1, S2, S3, S4, and S5, with an additional set labelled as S6. Each set varied in the percentage of waste recycled aggregate substituted for conventional aggregates, ranging from 0% to 30% in increments of 5%. The experiments aimed to evaluate these substitutions' effect on the concrete's mechanical properties. The specimens were tested at two distinct curing periods: 7 days and 28 days, with a consistent water-cement ratio of 0.45 across all mixes.

The primary focus of the investigation was the split tensile strength of the concrete specimens, a critical mechanical property that indicates the material's ability to resist tensile stresses. Split tensile strength is crucial in assessing the durability and performance of concrete in various applications. Upon analysis of the experimental results presented in Table 4 and Figure 3, it was observed that the mix denoted as S1 consistently demonstrated superior split tensile strength compared to the other mixes. This finding suggests that the specific combination of aggregates and proportions in S1 resulted in enhanced tensile strength characteristics, potentially due to improved interfacial bonding between the cement paste and aggregates or other favourable micro structural changes.

The results further indicate that varying the percentage of waste recycled aggregate within the concrete mixes influenced the mechanical properties differently. Generally, as the percentage of recycled aggregate increased, there may have been changes in the concrete's workability, density, strength characteristics, and potential effects on long-term durability. However, the specific effects observed in each mix set require detailed analysis beyond the scope of this summary. The experimental data underscore the importance of precise aggregate selection and proportioning in concrete mix design, particularly when incorporating recycled materials. The findings suggest that mix S1 holds promise for applications requiring robust tensile strength properties, warranting further investigation into its underlying mechanisms and potential applications in sustainable concrete construction practices.

Table 4. Split Tensile test (cylinder) of Recycled aggregate (W/C=0.45).

S. No.	Set no	Water cement ratio	Average split tensile test (at 7 days) (Mpa)	Average split tensile test (at 28days) (Mpa)
1	S0	0.45	4.61	7.24
2	S1	0.45	6.02	11.88
3	S2	0.45	4.89	11.12
4	S3	0.45	4.47	8.15
5	S4	0.45	7.13	10.65
6	S5	0.45	4.64	10.24
7	S6	0.45	4.26	9.86

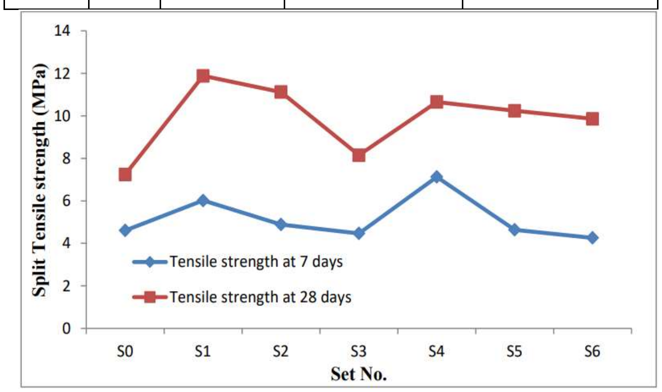

Figure 3. Split tensile strength of Recycled Waste Aggregate.

Flexural strength test

The curing period of 28 days was utilized to investigate the effects of varying percentages of waste recycled aggregate (WRA) on the flexural strength of concrete beams. Six sets of beams measuring 500mm x 100mm x 100mm were cast and labelled S0 to S5. These sets incorporated different proportions of WRA as a replacement for regular aggregates, specifically 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The water-cement ratio (w/c) maintained throughout the experiment was 0.45. The experiment aimed to assess how the inclusion of WRA influenced the mechanical properties of the concrete, particularly its flexural strength. Flexural strength is crucial in determining a material's ability to withstand bending forces, making it a significant parameter in structural applications.

From the results presented in Table 5 and Figure 4, it was observed that certain mix ratios, such as S1,

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exhibited superior flexural strength compared to others. This finding suggests that the specific percentage of WRA used in S1 resulted in a formulation that enhanced the flexural properties of the concrete. This outcome can be attributed to various factors, including the particle size distribution of the recycled aggregate, its bonding characteristics with the cement matrix, and the overall micro structural integrity achieved in the curing process. Concrete mixtures incorporating WRA are of interest due to environmental considerations, as they utilize recycled materials that would otherwise contribute to landfill waste. However, the effectiveness of WRA in concrete depends heavily on factors such as its quality, cleanliness, and the method used to incorporate it into the mix. The results indicate that optimizing the percentage of WRA can lead to concrete formulations that meet or exceed the performance of conventional mixes, particularly in terms of flexural strength.

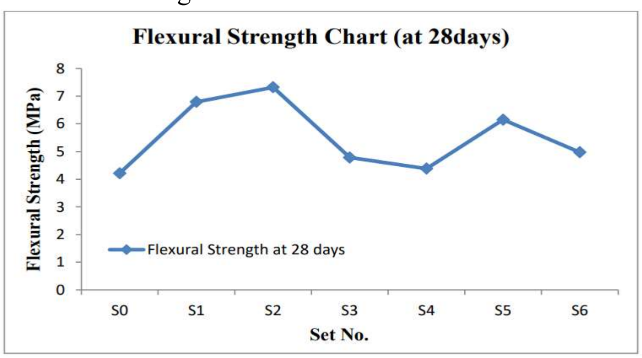

Figure 4. Flexural strength of Recycled Waste Aggregate.

Further analysis and interpretation of these results would involve assessing additional mechanical properties, such as compressive strength and durability, to fully understand the implications of incorporating WRA in concrete mixes. This comprehensive approach is essential for evaluating the feasibility and practicality of using recycled aggregates in structural applications, ensuring that environmental benefits are balanced with performance requirements.

Table 5. Flexural strength test (beam) of Recycled aggregate (W/C=0.45).

S.NO	Set no	Water cement ratio	Average flexural test (at 28days) (Mpa)
1	S0	0.45	4.21
2	S1	0.45	6.79
3	S2	0.45	7.32
4	S3	0.45	4.78
5	S4	0.45	4.38
6	S5	0.45	6.15
7	S6	0.45	4.97

Density

Density refers to the mass of concrete per unit volume and is a critical parameter affecting its mechanical and durability characteristics. In practical terms, denser concrete typically exhibits fewer voids within its structure compared to less dense variants. These voids, which can occur between particles and around aggregate grains, have both strength and durability implications. The relationship between concrete density and mechanical strength is well-established. Generally, denser concrete tends to possess higher compressive and flexural strengths. This correlation arises because a denser matrix provides better interlocking of particles and reduces the likelihood of voids that could act as weak points under load. As a result, structures made from denser concrete are often more capable of withstanding external forces and stresses over their service life.

Beyond mechanical strength, the density of concrete plays a crucial role in its durability characteristics, particularly in terms of water absorption and resistance to chemical ingress. Concrete with lower porosity, achieved through higher density which is depicted in Table 6 and Figure 5, tends to exhibit reduced permeability to water and aggressive chemicals. This is due to the smaller size and fewer number of voids, which restrict the movement of water and dissolved substances through the concrete matrix. As a result, denser concrete is anticipated to have superior durability, experiencing less deterioration from environmental exposure and minimizing the risk of reinforcement corrosion over time. The concept of pore structure further illustrates the impact of density on concrete properties. Pores within concrete can vary significantly in size and connectivity, influencing permeability and other factors such as thermal conductivity and resistance to freeze-thaw cycles. Denser concrete generally features a finer pore structure with smaller, more uniformly distributed pores, enhancing its resistance to harmful agents' ingress and improving its long-term performance in various environmental conditions. Concrete density is a critical parameter affecting its mechanical properties, durability, and overall performance in construction applications. Higher-density concrete typically translates to improved strength, reduced permeability, and enhanced durability due to fewer and smaller voids within its structure. Understanding and optimizing concrete density is fundamental to achieving resilient and long-lasting concrete structures capable of meeting the demanding requirements of modern construction practices.

Table 6. Density of Recycled Waste Concrete.

S. No.	Set No.	Density (Kg/m3)
1	S1	2360
2	S2	2413
3	S3	2442
4	S4	2426
5	S5	2415
6	S6	2390

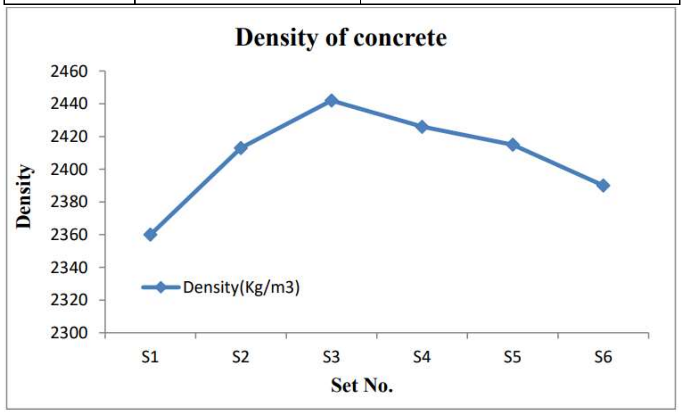

Figure 5. Density of Recycled Waste Aggregate.

Conclusion

The density of recycled waste concrete decreases from S4 to S6 and increases from S1 to S3 as recycled garbage increases, when the percentage of recycled waste increases, workability decreases yet remains constant when mixed. The compressive strength of concrete made from recycled waste increases up to a replacement level of 15% before declining. The recommended replacement rate for recycled waste is five to ten percent. The optimal compressive strength percentage increase in strength between S0 and S6 is higher at S1, as S1 strength drops as the quantity of recycled garbage increases when compared to traditional concrete. A small increase is seen when comparing S3's strength to the reference concrete. In addition to compressive strength testing, split tensile and flexural strength tests are also performed to evaluate the quality of concrete, although their results are much lower. Furthermore, there are other criteria besides split tensile and flexural strength tests to evaluate the quality of concrete. The 28-day recycled waste concrete's split tensile strength rises from S0 to S2, falls from S2 to S3, rises from S3 to S4, falls from S4 to S5, and rises from S5 to S6. But at S1 (11.88 MPa), the maximal 28-day split strength is attained. The maximum flexural strength is reached at S2 (7.32 MPa) in the 28-day recycled waste concrete flexural strength test. It then declines from S2 to S4, increases from S0 to S2, and lowers from S2 to S4. Based on the findings of this study, it is possible to employ recycled garbage in place of some aggregates, and doing so improves the concrete's compressive strength. Recycled waste concrete typically exhibits better mechanical characteristics than regular concrete. Furthermore, it was observed that, in comparison to regular concrete, the use of natural aggregate in S0, S1, S2, S3, S4, S5, and S6 increased their compressive strength.

Future Scope of Work

Additional testing and experimentation should be conducted on recycled waste concrete to accurately determine its strength properties for regular or low-rise structural concrete use. Here are some suggestions for additional research:

1. The experiment involves altering the water/cement ratio to investigate the changes in strength metrics when sodium silicate is added, with the aim of improving workability.
2. Non-destructive testing methods, such as the Rapid Chloride Penetration Test (RCPT), can be conducted to assess the appropriateness of the structural concrete.
3. The utilization of garbage can help maintain the environment and ecosystem as a whole; thus, there is ongoing study on recycled waste.
4. The environmental impact is minimized, making it more attractive to governments and customers and reducing the amount of space wasted in landfills.

Conflict of Interest

I, Suyash Tamboli, declare that I have no conflict of interest related to this research paper. I have no financial or personal relationships that could inappropriately influence my work. I have not received any financial support or funding that could be perceived as a conflict of interest. My contribution to this research was conducted independently and without bias.

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