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Effect of Polymer Fiber on Concrete Made with Artificial Fine Aggregate from Demolished Buildings

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Abstract

This research describes an experimental investigation that assesses the impact of polymer fiber and artificial fine aggregate on concrete properties. Polymer fiber, on the other hand, has the potential to function as a superplasticizer additive, which might lead to concrete's superior elasticity, higher strength, and reduced rate of water absorption. Thus, an experimental inquiry was conducted to ascertain the ideal admixture dose and investigate the consequences of admixture overdosage. Also, this study highlights the potential for recycling in the construction industry by examining the physical properties of fine aggregate made from dismantled building components. This study's main goals are to evaluate the quality and suitability of artificial fine aggregate made from demolished building materials for use in construction applications, to ascertain whether the fine aggregate's physical properties meet the requirements for producing concrete, and to assess the sustainability and potential environmental benefits of using recycled fine aggregate. Thus, it was found in this study that adding polymer and artificial fine aggregate throughout the polymer concrete-forming process alters the concrete's properties, increasing the concrete's compressive strength. Aside from this, it has been discovered that polymers have enhanced the mechanical qualities of concrete, such as their flexural, and compressive strengths.

Keywords: Fine aggregates, polymer fiber, construction demolition waste, dismantled building components

INTRODUCTION

In engineering, materials are utilized to design and build buildings as well as to develop and produce new goods. Most recent developments have been concentrated on the synthesis of polymeric and composite materials[1]. When two or more different materials are combined, either physically or by other means, to produce significant structural components, composite materials are created. Many materials containing two or more elements, such as metallic alloys and polymer blends, are not classified as composites since the structural unit is produced by chemical changes at the microscopic level as opposed to the macroscopic level [2]. Straw brick, paper, wood, reinforced concrete, and polymers reinforced with glass or graphite Fibers are a few examples of composite materials. Conversely, carbon-containing materials with a macromolecular structure made up of very big molecules with repeating molecular units are known as polymeric materials. These materials can be either naturally occurring or man-made[3].

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Timber, rubber, polyester, polyethylene, wool, cotton, silk, Starch, and cellulose are a few examples. Most polymers are easily formed into a wide range of shapes because they are plastic. The necessity of resource efficiency and environmental conservation has made sustainable construction practices extremely relevant in recent years. Using recycled materials reduces waste and uses fewer natural resources, making it an essential component of sustainable building materials. Fine aggregates are essential to construction, especially in concrete production, where they are an important component [4]. Crushed residual bricks, shattered glass, powdered plaster, and other remnant refuse from demolished buildings form factitious flake aggregates. Construction castoffs are conserved from landfilling by using these artificial fine materials to fabricate fresh concrete, reducing requisite natural asset acquisition. However, to ensure that manufactured mineral minutiae are suitable for edifice employment, their actual attributes must be precisely probed preceding prevalent practice[5]. The sustainability and performance of innovative construction elements are fundamentally reliant on the essence and excellence of diminutive constituents. With a concentration on recycling potentialities within the industry, this investigation examines the physical traits of factitious fine fragments fabricated from eradicated edifice remnants. We aspire to address the ecological issues affiliated with traditional building materials while assisting the progress of more sustainable construction methods by focusing on reprocessed fine particles [6].

This investigation seeks to thoroughly analyze the quality and suitability of artificial fine aggregates generated from demolished construction materials for usage in building applications. We aim to ascertain whether the physical attributes of fine recycled aggregates meet the requirements for producing concrete. Additionally, we will examine the potential advantages of employing fine recycled aggregates regarding sustainability and environmental impact [7]. Fine recycled aggregates derived from demolished construction materials represent a viable alternative to natural aggregates, as they possess the necessary physical properties for implementation in construction. Fine recycled aggregates are anticipated to demonstrate mechanical qualities such as density, water absorption, and particle size distribution that fall within acceptable parameters or are comparable to those of traditional fine aggregates. Further analysis is still necessary to verify these expectations. The utilization of fine recycled aggregates could play a role in reducing the exploitation of natural resources and is shown to perform adequately for the manufacturer of concrete[8].

The systematic examination of physical attributes in recycled fine aggregates involves a meticulous process. Dismantled construction materials are gathered, and delicate aggregate is retrieved through the application of suitable processing techniques. Sieve analysis is carried out to determine the distribution of granular sizes within the recycled fine material. The recycled substance's density is assessed to evaluate its suitability for engineering applications. Water absorption trials are conducted to appraise the moisture-related characteristics of the recycled fine aggregate[9,10]. By investigating these intrinsic qualities, this study aspires to provide significant insight into the potential of recycled fine aggregates to serve as a sustainable construction material [29,30]. On occasion, longer or more intricate sentences are interspersed among shorter, simpler constructions. This study covers the experiment of incorporating polymer fiber and artificial fine aggregate into the concrete mixture before and after mixing [11].

LITERATURE REVIEW

Fine aggregates play an important role in the construction sector, particularly in the production of concrete. They constitute a key component of concrete mixtures, adding to the finished construction material's overall strength, durability, and workability [12]. The right selection and quality of fine particles greatly influence the performance of concrete constructions. Traditional sources of fine aggregates, such as river sand, are becoming increasingly scarce, prompting the exploration of alternative and sustainable sources [31,32]. Numerous scientific investigations have delved into the viability of integrating a fine fraction of recycled aggregates [RA] into the formulation of brick mortars [13,14].

The references we've read point to a variety of allowed replacement percentages, which can, in part, be attributed to the diversity of RA. For example, Vegas et al. [2009] demonstrated that mortars can include up to 25% of fine RA without having adverse effects on their mechanical properties, workability, or shrinkage, and without the requirement for further additives. Evaluating the water absorption of concrete comprises techniques such as immersion and capillarity tests[14]. Immersion tests primarily examine the open porosity, while capillarity tests gauge the capillary absorption originating from the pressure difference between the liquid's free surface on the exterior of the concrete and the free surface within the concrete's capillaries. Coutinho argues that the smaller the diameter of the pores in concrete, the higher its capillary absorption [15].

In Wainwright et al.'s investigation, water absorption was assessed by immersing concrete, including coarse and fine RA made from crushed concrete. According to their research, porosity appears to be more significantly influenced by the quality of the concrete that the artificial fine aggregate originates from than by the anticipated strength of the finished concrete. Furthermore, Jimenez et al. found that, aside from density and workability, adding up to 40% of ceramic waste during the mortar-making process had no discernible effect on the qualities of cement mortar in either its fresh or cured state[16].

In 2009, Corina, Desi, and Moriconi investigated the mechanical and rheological properties of cement mortars constructed using three different categories of recycled aggregates. Rejected precast concrete material, recovered brick waste, and plant recycling rubble. In each instance, the total mortar composition included 100% artificial fine aggregate [17,18]. The results showed that these recycled mortars presented reduced mechanical strength but exhibited increased adhesion strength between the mortar and bricks when compared to conventional mortars.

In a similar perspective, Fernandez and colleagues [2015] studied the feasibility of adding a fine fraction of artificial fine aggregates into masonry mortars that utilized CEM II/BL 32.5 cement. The findings revealed that a replacement rate of 50% in mortars intended for indoor applications was achievable. This study primarily aimed to analyze the features of recycled mortars in both the fresh and hardened states while altering the amounts of natural sand replacement with three different types of RA acquired from participating recycling plants. The results of this research contribute to the existing knowledge and may provide insights to enhance the recycling rates of CDW, thereby reducing the use of natural resources within the construction industry [4,19].

Studies have demonstrated that the integration of recycled aggregates in concrete can contribute to waste reduction, energy savings, and a lower carbon footprint. Nonetheless, the physical properties of fine recycled aggregates remain less investigated, impeding a thorough understanding of their appropriateness for concrete production. While the literature on recycled aggregates is substantial, there is a significant void concerning fine aggregates obtained from dismantled building components. Existing research largely focuses on coarse aggregates, and the special constraints and opportunities connected with fine aggregates from sources such as concrete, bricks, and tiles have not been adequately explored. This research intends to address this gap by researching the physical properties of fine aggregates from deconstructed building components [20]. Understanding the particle size distribution, density, water absorption, and specific gravity of these recycled fine aggregates is essential for assessing their conformity with concrete manufacturing standards. Furthermore, the lack of thorough studies on concrete performance using fine recycled aggregates highlights the necessity for an in-depth review of their mechanical properties and durability.

According to Somayaji's Civil Engineering Materials textbook, "cement admixture is a material other than water, aggregates, cement, and Fiber added to plastic concrete or mortar to change one or more of its properties at the fresh or hardened stages." There are two types of mixtures: chemical and mineral. "When Portland cement is replaced by a polymer, the resulting concrete has a lower rate of water absorption, higher resistance to freezing and thawing cycles, better resistance to chemicals, greater strength, and excellent adhesion qualities compared to most other cementitious materials," According to McGraw Hill's Civil Engineering Handbook. To achieve complete polymerization, aggregates are combined with the most widely used resins, a catalyst, and a cross-linking agent. Typically, glass fiber matting, metal fibers, or glass fibers are used to strengthen polymer concrete. Polymer-impregnated concrete, or PIC, is Portland cement concrete that has been cured and impregnated with a monomer by a pressure or vacuum process [21,22]. The American Concrete Institute [ACI] Committee has reported on the status of the development of the mechanics for Fiber-reinforced Portland cement concrete with metallic, glass, plastic, and natural Fibers. This includes methods for mixing and mixing proportioning, placing, finishing, and real and potential applications [23].

METHODOLOGY

Identify and collect varied demolished building materials [concrete, bricks, tiles] from demolition sites, providing a representative sample. Select materials with different compositions and conditions to capture the diversity of potential sources. Sorting and Segregation: Categorize the collected items based on kind to support a systematic approach to collecting. Remove non-aggregate components [metal, wood, plastics] through manual sorting to enhance material purity. Crushing and Grinding: Utilize mechanical crushers and grinders to break down materials into smaller pieces. Control particle size distribution using sieves, with a focus on obtaining a fine fraction suitable for aggregate manufacturing. Washing & Cleaning: Thoroughly wash the crushed material to eliminate impurities, dust, and residual pollutants. Implement water-based separation procedures to enhance the purity of the fine aggregates. Drying: Subject the washed fine aggregates to controlled drying to achieve a consistent moisture content. Verify that aggregates are free from excess moisture, which may impact subsequent physical property analyses.

A solution is created by dissolving powdered polymer fiber in water to the appropriate water content for the mix design. After a whole day, the solution will be completely absorbed. The class "A" viscous liquid solution is added at a 1:1.5:3 proportionate mix ratio to the cement, artificial fine aggregate, and coarse aggregate. The percentage of cement by weight in kilograms determines the percentage of polymer fibers utilized. Using a rod, the concrete mix is tamped layer by layer as it is poured into the mold, Water is being sprayed on the produced specimen to cure it[Table1-4]. The corresponding curing ages are 7, 14, and 28 days. Its compressive strength will be determined by testing it on a hydraulic press after it has cured for a specific number of days [Figure 1-2]

LABORATORY TESTING RESULTS & DISCUSSION

Particle Size Distribution Analysis

The aggregate's mean particle size is determined by calculating the fineness modulus, a numerical index. The fineness modulus [FM] is used to grade the provided aggregate for the most cost-effective mix and workability with the least amount of cement assumption [Figure 3] A lower FM results in an unfavorable mix, while a higher FM results in a tough mix. The phrase "fineness modulus" refers to the average cumulative percent retained by 100 [24].

Figure 1. CDW source.

Figure 2. Obtained artificial aggregate after crushing.

Figure 3. Indian standard test sieves set.

Table 1. Fineness modulus for Natural Aggregate.

S.N.	IS sieve size	Wt. retained Gm	Cumulative weight retained	% Cumulative weight retained	% Cumulative passing
1	4.75mm	38	38	4.76	95.24
2	2.36mm	53	91	11.40	88.6
3	1.18mm	1328	223.8	28.03	71.97
4	600 μ	232.5	456.3	57.16	42.84
5	300 μ	303.0	759.3	95.12	4.88
6	150 μ	29.5	788.8	98.80	1.2
7	PAN	9.5	798.3	100	0

Fineness Modulus of Natural Aggregate = 3.952 %

Table 2. Fineness modulus for artificial fine Aggregate.

S.N.	IS sieve size	Wt. retained Gm	Cumulative weight retained	% Cumulative weight retained	% Cumulative passing
1	4.75mm	108	108	5.4	94.6
2	2.36mm	1198.5	1306.5	65.325	34.675
3	1.18mm	5.5	1312	65.6	34.4
4	600 μ	196.5	1508.5	75.425	24.575
5	300 μ	11.5	1520	76	24
6	150 μ	382.5	1902.5	95.125	4.875
7	PAN	97.5	2000	100	0

Fineness Modulus of artificial fine Aggregate = 4.82 %

DISCUSSION

The Fineness Modulus values suggest that the recycled aggregate has a slightly higher value [4.82%] than the natural aggregate [3.952%]. This indicates that, on average, the particles in the recycled aggregate are coarser than those in the natural aggregate. In general, a higher Fineness Modulus implies a coarser aggregate, and the specific application and requirements of the construction project will determine the acceptability of the aggregate. Concrete mix designs may have target Fineness Modulus values depending on the desired properties of the final concrete. While Fineness Modulus is an essential factor in aggregate characterization, it's crucial to consider other properties such as particle shape, angularity, and the distribution of particle sizes. These factors collectively influence the concrete mix's workability, strength, and durability. Both natural and recycled aggregates fall within the typical range of Fineness Modulus values for many construction applications. The suitability of these aggregates will depend on the specific needs of the project and the mixed design requirements. In summary, the above Fineness Modulus values indicate that the recycled aggregate is slightly coarser than the natural aggregate.

Specific Gravity Test

The Specific Gravity Test for artificial fine aggregate from construction demolition waste is an essential procedure in civil engineering [Figure.4] By providing vital information about the density of the aggregate, this test ensures the quality and performance of concrete structures while promoting sustainable practices using recycled materials [25].

Figure 4. Apparatus for specific gravity test.

Table 3. Specific gravity for natural fine aggregate.

S.N.	Description	Observed value
1	The dry container weight, P1	1735.5 g
2	The dry container weight +Artificial fine aggregate, P2	2173.5 g
3	The dry container weight + Artificial fine aggregate +water, P3	4812.5 g
4	The dry container weight + water, P4	4513.5 g
5	G= $\frac{P2-P1}{[P2-P1]-[P3-P4]}$	2.048

Table 4. Specific gravity for artificial fine aggregate.

S.N.	Description	Observed value
1	The dry container weight, P1	1735.5 g
2	The dry container weight +Artificial fine aggregate, P2	2185.5 g
3	The dry container weight + Artificial fine aggregate +water, P3	4712.5 g
4	The dry container weight + water, P4	4431 g
5	G= $\frac{P2-P1}{[P2-P1]-[P3-P4]}$	2.67

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DISCUSSION

This value suggests that the natural aggregate is relatively lightweight. Natural aggregates with lower specific gravity values are generally desirable in certain applications, such as lightweight concrete, where reduced density is a key consideration. The higher specific gravity of recycled aggregate indicates a higher density compared to the natural aggregate. Recycled aggregates may include materials from demolished structures or construction waste. The higher specific gravity might be due to the presence of materials like concrete, which tends to be denser than some natural aggregates. It's important to note that the specific gravity alone doesn't provide a complete picture of the quality or suitability of an aggregate for a specific application. Other properties, such as particle shape, angularity, gradation, and absorption, also play crucial roles in determining the performance of an aggregate in concrete or other construction materials. The above specific gravity values fall within the typical range for natural and recycled aggregates, but the acceptance or suitability of these aggregates also depends on the specific requirements of the intended use. Engineers and construction professionals often consider a combination of material properties to ensure that aggregates meet the desired specifications for a given project.

Silt Content Test

The Silt Content Test for artificial fine aggregate from construction demolition waste is an essential procedure in evaluating the quality and suitability of the aggregate for use in concrete production [Figure.5] By determining the percentage of silt present, this test helps to ensure the desired properties and performance of concrete structures while promoting the effective utilization of recycled materials [26,27].

a. Natural Aggregate
   Percentage of silt content = [V1 /V2] X 100 = 7.14% Volume of silt [V1]: - 10 ml
   Volume of settled sand [V2]: - 140 ml.
b. Artificial Fine Aggregate
   Percentage of silt content = [V1 /V2] X 100 = 8.46% Volume of silt [V1]: - 11 ml
   Volume of settled sand [V2]: - 130 ml.

DISCUSSION

The natural aggregate has a lower percentage of silt content [7.14%] compared to the recycled aggregate [8.46%]. In general, lower silt content is often preferred in construction materials like aggregates, as excessive silt can negatively impact the properties of concrete. The volumes of silt and settled sand for both aggregates provide additional insights into their composition. For natural aggregate, the volume of settled sand is higher [140 ml], indicating a larger proportion of coarse particles. On the other hand, the recycled aggregate has a smaller volume of settled sand [130 ml], suggesting a relatively higher proportion of finer particles. The silt content values for both aggregates are within a reasonable range. However, it's important to consider the specific requirements of the intended application. Different construction projects may have different tolerance levels for silt content, depending on factors such as the type of concrete or asphalt mix being used. Engineers and construction professionals often assess a combination of properties, including silt content, particle size distribution, and other physical and chemical characteristics, to ensure that aggregates meet the desired specifications for a particular project. The data indicates that the natural aggregate has a slightly lower silt content and a higher volume of settled sand compared to the recycled aggregate. The suitability of these aggregates would also depend on the specific requirements of the construction project in question.

Both natural and recycled aggregates fulfill industry standards, showing their suitability for concrete manufacture. Slight changes in particle size distribution may need adjustments in the mix design. The higher specific gravity of recycled aggregate signifies a denser material. Mix changes may be needed to account for variances in mass per unit volume. Slightly greater silt content in recycled aggregate does not exceed acceptable limits. Proper batching and quality control techniques can reduce any adverse impacts on concrete qualities. Despite slight variances, the recovered fine aggregates exhibit qualities suitable for concrete manufacture. With suitable adjustments in mix design, these aggregates can be effectively used in construction applications. The proper exploitation of recycled fine aggregates can help to sustainability goals by reducing the demand for natural resources. Continuous monitoring and quality control techniques are critical to maintaining consistency in recycled aggregate qualities. The researched recycled fine aggregates demonstrate interesting physical properties for construction applications. While slight differences exist compared to natural aggregates, correct changes in mix design can ensure their successful use, leading to sustainable and environmentally conscious construction practices.

Compressive Strength of Concrete

The design of the current study was done through the application of experimental research methods. It has been utilized by the researcher to give precise measurements for more suitable compressive strength test findings [9]. Five distinct groups participated in the studies, which measured the percentage of polymer fibers to cement by weight in kg. To create concrete, this polymer fiber solution is combined with additional particles [Table.5] Moreover, a control group consisting of regular concrete mixes devoid of polymer fiber was created to serve as a benchmark for strength comparison [28].

DISCUSSION

The specimens were broken during the compressive strength test using the hydraulic press because the concrete had achieved its maximum strength, as previously noted. As shown in the tables, the experimental group's results began to demonstrate a moderate advantage over the standard group as early as the seventh day, with polymer Fiber-to-cement ratios of 3% to 97% and 6% to 94%, respectively. Similarly, it was noted that the strengths derived from the ratio of 9% to 91% appeared to be almost identical to the usual mix. Additionally, the specimens outperformed the reference group at proportions of 3% to 97% and 6% to 94% on days 14 and 28, respectively. It was also observed that the higher strength values were due to the bound aggregates, evident in the fractured specimens displaying fine aggregate textures. The findings demonstrate that polymer Fiber meets strength criteria since it performs better than the conventional blend [Figure 6].

Figure 5. Apparatus for silt content test.

Table 5. Compressive strength test results.

Specimen type	Cement content %	Polymer fiber content %	Slump [mm]	Compressive strength7	Compressive strength 14	Compressive strength 28
				Days [MPa]	Days [MPa]	Days [MPa]
Standard	100	0	90	22	24.2	28
With	97	3	70	27.6	32.4	36.4
Polymer	94	6	78	24.2	27.1	31.2
Fiber	91	9	95	21.5	24	27.8
	88	12	105	18	21	23.5
	85	15	120	16.5	19.2	21.1

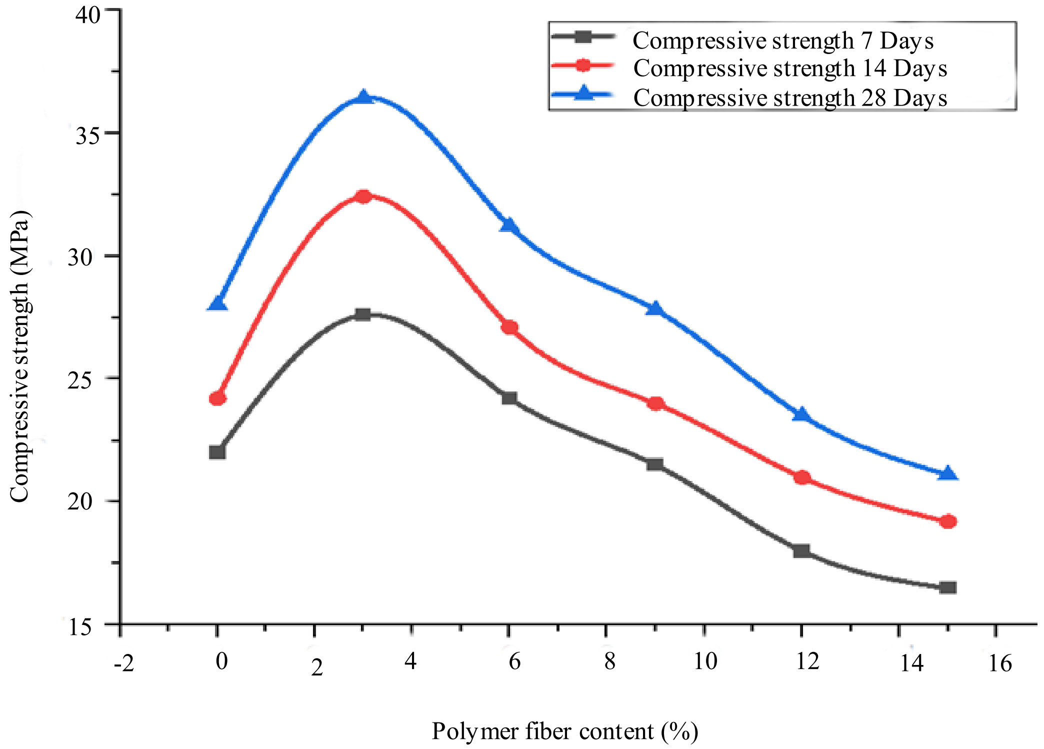

Figure 6. Variation of compressive strength at different polymer Fiber content ratio.

CONCLUSION

Physical observations and the results of compressive strength tests have led to the conclusion that concrete mixes that exhibit higher strengths than the standard mix may benefit from the use of polymer Fiber as a cement additive.

In terms of its flexibility, concrete may take on plastic qualities. Greater strength outcomes cause the concrete to distort, but it will undoubtedly revert to its initial shape when it is unloaded.

Both natural and recycled aggregates fit industry standards, with slight differences [3.952% for natural, and 4.82% for recycled]. Mix design modifications may be essential to compensate for variances in particle size distribution.

Recycled aggregates display a greater specific gravity [2.67] compared to natural aggregates [2.048]. Proper mix modifications are necessary to correct differences in mass per unit volume.

Silt percentage

Recycled aggregates show a slightly greater silt percentage [8.46%] compared to natural aggregates [7.14%]. Silt content remains within permissible limits for concrete manufacture; strict quality control is necessary.

BROADER IMPLICATIONS

The research emphasizes the potential of polymer Fiber & recycled fine aggregates as a feasible option in construction applications. Adapting mix designs and applying quality control methods will be key for effective integration into concrete manufacturing. Incorporating recycled aggregates corresponds with sustainable building methods, contributing to reduced demand for natural resources. The study encourages environmentally conscious construction practices, matching with global sustainability goals.

FUTURE RESEARCH DIRECTIONS

1. *Performance in real-world applications*: Investigate the long-term performance of concrete constructions utilizing recycled fine aggregates in real-world circumstances. Evaluate characteristics such as durability, adaptability to climatic conditions, and structural integrity.
2. *Optimization of mix designs*: Explore optimal mix designs that utilize the advantages of recycled fine aggregates while maintaining or enhancing concrete performance. Consider differences in particle size distribution, specific gravity, and silt content.
3. *Economic viability:* Assess the economic viability of using recycled fine aggregates in construction projects. Evaluate cost-effectiveness and potential economic benefits for both manufacturers and end-users.
4. *Standardization and quality control*: Develop standardized processing processes for generating recycled aggregates from deconstructed materials. Implement comprehensive quality control techniques to maintain uniformity in physical properties.
5. *Public perception and regulatory frameworks*: Investigate public perception and acceptance of constructions utilizing recycled fine aggregates.
6. Future studies should go deeper into real-world performance, optimization of mix designs, economic considerations, standardization, and public acceptance to further advance the understanding and implementation of recycled fine aggregates in the construction sector.

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