STRENGTH CHARACTERISTICS OF RECYCLED AGGREGATE

Abstract

The goal of this research was to learn how well Recycled Concrete Aggregate (RCA) performs in terms of strength, stiffness, and durability in order to assess its viability for use in structural concrete. More and more people are looking into the qualities of building waste in an effort to discover solutions to the problem of construction waste in light of rising environmental consciousness and more stringent rules on its management. There is a need to find sustainable alternatives to substitute readily accessible materials for concrete production due to the rise in infrastructure and urban development activities. Concurrently, the rise in building is draining the planet of its natural resources due to its heavy reliance on natural building materials. In this investigation, high-quality concrete mixtures were created by repurposing RCA. Cementitious materials like fly ash (FA) and other industrial byproducts are combined with recycled building debris to create these mixtures. The higher mechanical strength attributes of these RCA mixes, in comparison to the strengths of control mixes, are examined. By lowering the amount of water needed to create the material and improving its workability, plasticizers (or water-reducing admixtures) boost mechanical strength and durability.

In this work, we compare and contrast the strength properties of recycled aggregate with those of native aggregate. Recycled aggregate, derived from the destruction of concrete buildings, may be used as a cheaper and more sustainable alternative to natural aggregate in the building industry. The methodology used includes testing concrete under compression, tension and flexure. Ultimately, the research finds that recycled aggregate may be utilized as a sustainable substitute for natural aggregate; however, it warns that more care must be taken when utilizing larger replacement percentages to guarantee necessary strength criteria are satisfied. It was found that adding fly ash upto 10% increases the overall strength of concrete.

Keywords: Recycled Concrete Aggregate, Slump test, compaction factor, compressive strength, split tensile strength.

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I. INTRODUCTION

Concrete is widely recognized as a construction material owing to its exceptional strength and durability characteristics. The performance of concrete is commonly linked to factors such as the formulation of the mix, the precise ratios of raw materials, and the quality of materials employed in the production process. Annually, the global production of concrete amounts to 12 billion tons, while the worldwide consumption of cement stands at 1.6 million tons. The utilization of recycled aggregate presents a viable and ecologically sound substitute for conventional construction materials. The process involves the fragmentation and sieving of pre-existing concrete and asphalt pavement, materials that would otherwise be deemed as disposable waste. The utilization of recycled aggregate in construction has the potential to mitigate the necessity for additional quarries and mining operations, while concurrently diminishing the volume of materials that are deposited in landfills.

Nevertheless, it is imperative to comprehend the inherent strength properties of recycled aggregate in order to ascertain its appropriateness for diverse construction purposes. This article aims to examine strength properties of recycled aggregate and provide a comparative analysis with conventional construction materials. Construction and demolition (C&D) waste represents a significant waste stream in urban areas. According to the assessment conducted by the Central Pollution Control Board in India, the annual generation of solid waste amounts to approximately 48 million tonnes (MT), with the construction industry accounting for 25% of this total. The proper management of C&D waste is a matter of both environmental significance and resource conservation, as it helps to prevent the need for extracting new raw materials through excavation. According to estimates, there is projected to be a significant increase in the worldwide demand for aggregate, with an anticipated annual growth rate of approximately 5.2%. This surge in demand is expected to result in a total demand of 55 billion metric tons by the year 2020. The utilization of C&D waste as a substitute for natural aggregates offers a solution to environmental concerns, including the need for landfill disposal and the diminishing availability of new stone quarries. This approach effectively addresses sustainability issues, as highlighted by Etxeberria et al. (2007).Alternative Cementitious Material (ACM) is commonly employed in contemporary construction practices as a partial substitute for the primary binder.

However, Fineness of binder particles vary with particle size, which fills the voids developed between the ACM and primary binder to be filled by another material finer than ACM to develop the dense microstructure (Hemalatha and Santhanam 2018). Rate of reaction, hydration properties were primarily influenced by material fineness, chemical composition, alkali content and structure (crystalline or amorphous) (Berodier 2015).

Reactive silica from different source material like silica fume, quartz powder, slag and fly ash(type-c) with considerable lime content undergo hydration process to attain cementitious property. Particle packing density of cement-composite system is improved due to nucleation of hydration of binder particles; thereby influencing the characteristics of blended binder system (Peter 2004). Xu et al. 2017 investigated fly ash as inert material and another material to be reactive; test results revealed better performance in terms of concrete workability and strength with dense microstructure.

Construction aggregate type and mortar adhering to aggregate surface are the two most important factors in the quality of Recycled Aggregate (RA) materials (De-Juan and Gutiérrez, 2007). Due to the accumulation of un-hydrated cement particles on the surface of the aggregate, RA materials tend to have a lower density and a high-water absorption rate (Li et al., 2018). Numerous researchers reported concrete produced RA material decreased strength with increased recycled content (Silva et al. 2016).

Past studies on inclusion of ACM inferred desired workability, strength and durability characteristics can be achieved. However, these studies lack the information on quantities to be optimized. As a result, ACM mixes are developed with excess blended content more than the required quantity which restricts to use for field application. Hence, into our research an attempt is taken for evaluating durability & strength properties of concrete mixes with C&D waste as aggregate.

Experiments performed by Abhishek Verma Velaga Sarath Babu made with Treated Recycled Aggregate (TRAs.) Typically, at a 50% replacement level of NA with TRA (7 min), the compressive strength reduced by 7.58%, and the rapid chloride permeability test (RCPT) value increased by 23.74% compared with the control mix. A 50% replacement level of NA with TRA (7 min) is suggested for structural concrete. Based on the present study, 72 h of soaking in mild acetic acid, followed by 7 min of the rotation time, are recommended as an optimum treatment for producing high-quality TRA.

II. LITERATURE SURVEY

Recycled aggregate (RA) is obtained by crushing and processing waste materials, such as concrete, brick, and asphalt, into aggregates. RA is widely taken like an alternate to natural aggregates (NA) due to its economic, environmental, and engineering benefits. This literature survey summarizes the recent research on the use of RA in concrete, asphalt, and other construction applications.

1. **Concrete Applications:** Several researches portray as RA can be used as a partial or total replacement of NA in concrete production. Compressive strength of concrete made with RA is observed to be lesser than that of concrete made with NA, mainly because of presence of contaminants, such as mortar and clay, in the RA. However, the use of RA was found in improving workability & durability of concrete, as well as reduce its carbon footprint. The use of high-quality RA, obtained from well- graded aggregates, was found to enhance the performance of concrete.

2. **Other Applications:** RA has been used in other construction applications, such as road sub-base and embankment materials. Studies have shown that RA can provide good engineering properties, such as strength and stability, when processed and graded properly. The use of RA in these applications can reduce the demand for virgin materials and landfill space, as well as lower the environmental impact of construction activities.

   Overall, the use of RA in various construction applications has been found to be feasible and beneficial. However, the successful use of RA requires careful selection of the RA source, processing, and grading, as well as appropriate mix design and quality control measures. Optimizing RA's utilization across applications & overcoming remaining technological & economic hurdles will need further study.

Dr. M.N.Bajad, Nandan Mutha, Hatim Husain, Nikhil Kshirsagar: This research aims to evaluate RCA's viability as a viable alternative to NCA by comparing material's workability, density, as well as compressive strength when processed with FA. We've optimized the mix design for a half-water, half-cement ratio. Compressive strength is measured after cubes are cast with varying percentages of RCA & FA substituted for the virgin material & cement. The obtained data is then utilized to develop an empirical connection between RCA percentage and FA % and concrete strength. The research indicates that RCA & FA may be employed in concrete at percentages of up to 30%.

A.N. Dabhade , S.R. Chaudari and A.R. Gajbhaye: The construction industry must employ recycling and reusing technologies due to the increasing demand for building materials and the diminishing availability of raw materials. One solution that may meet this need is to reuse the coarse aggregate. Using recycled coarse aggregate in regular building reduces expenditures on raw resources. Here, we assess the mechanical strength of concrete by replacing a portion of the native coarse aggregate with recycled coarse aggregate. Adding flyash as a cement substitute also helps boost concrete's durability. Designing the mix is complete at W/C ratio of 0.38. Virgin coarse aggregate and recycled coarse aggregate (20%, 30%, 40%, 50%, and 100%) are both used to cast cylinders and cubes. The data is fed into a Multi Linear Regression model to demonstrate an empirical connection between concrete strength & percentages of recycled aggregate, fly ash, and age. The findings indicate that a combination of 10% flyash and 40% recycled material may produce a durable and functional concrete product.

Prof. Chetna M.Vyas Prof. Jayeshkumar Pitroda: The production of fly ash is another example of an industrial consequence. It's the byproduct of coal burning. Less water and harsh chemicals may penetrate the material, which is main advantage. Utilisation of fly ash in concrete results in a denser final product with more strength and less permeability due to the smaller pore diameters. Concrete sector is a major consumer of natural resources across world, and they are quickly running out. The destruction of aging buildings along with other structures leads to the production of destroyed concrete. By employing recycled aggregate in lieu of virgin aggregate, concrete recycling has the potential to both minimize concrete landfilling and preserve natural aggregate supplies.

III. OBJECTIVES

1. **Environmental Sustainability:** One of the primary objectives of utilising RA is reducing amount of waste that goes to landfills. By reusing demolished concrete and other construction materials, this helps to reduce landfill space requirement and promotes environmental sustainability.
2. **Resource Conservation:** Recycling promotes the conservation of natural resources by reducing the demand for virgin aggregates. This helps to preserve natural resources and ensure their sustainability.
3. **Economic Benefits:** Recycling aggregates can be a cost-effective alternative to using virgin aggregates. This includes saving on transportation, disposal and processing costs, and also reduces the need for the extraction of virgin materials.
4. **Improved Carbon Footprint:** The production of new concrete uses cement. During cement production large amount of carbon di oxide is released … so be using fly ash by 20 % amount of carbon di oxide is reduced thus achieving improved carbon footprint.

5. **Enhancing the Circular Economy:** Utilisation of recycled aggregates helps to close loop in construction sector by creating a circular economy. This encourages the reuse and regeneration of materials, reducing waste, and creating economic opportunities for businesses that specialize in recycling.

IV. MATERIALS AND SPECIFICATION

1. **Materials:** In the present study, OPC-53 grade (Birla –A1) conforming to IS 12269-2013 [17], fly ash (Class- C) conforming to IS 3812-2013 [18], slag conforming to 12089-2004 [19], and Silica Fume (SF) conforming to IS 15388-2003 [20] were procured from local dealers Gulbarga, Karnataka. Chemical composition of these binder materials is portrayed into Table 1

Table 1: Chemical Composition of Binder Material

Components	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	Na_2O	K_2O	SO_3	Loss on Ignition
Cement	62.8	5.0	2.25	20.4	2.1	0.45	0.3	0.45	2.6
Flyash	19	13	7	23.5	4	0.6	0.45	0.45	1.3
Slag	37.15	14.0	1.2	37.62	8.64	--	--	--	1.41
Silica fume	0.82	0.65	0.91	86.55	4.25	1.15	1.48	0.32	2.7

2. **Cement:** The research used Ordinary Portland Cement (OPC) 53 grade that met the standards of IS 8112-1989. Table-2 provides information on a tangible cement characteristic.

Table 2: Physical Property of OPC-43 Grade

Test	Consistency	Soundness	Initial setting time	Final setting time	Specific gravity	Fineness	Compressive strength (28 days)
Results	32%	2mm	43 min	180 min	3.15	2%	32 N/mm²

Figure 1: Setting Time of Cement

3. **Coarse Aggregate:**According to IS 383-2004, the coarse aggregates utilized were 20mm crushed stone. Table-3 lists the coarse aggregate's physical properties.

Table 3: Physical Property of Coarse Aggregate

Test	Specific gravity	Bulk density	Water absorption	Fineness modulus	Flakiness index %	Elongation index %
Result	2.80	1.70	1.01	5.94	17.5	19.5

Figure 2: Coarse Aggregate

4. **Recycle Coarse Aggregate (RCA):** Aggregates obtained on-site in accordance with IS 383-2004 by crushing slabs and beams. Table 4 provides information on the physical characteristics of the RCA material.

Table 4: Physical Properties of Recycled Concrete Aggregate

Test	Specific gravity	Bulk density	Water absorption	Fineness modulus	Flakiness index %	Elongation index %
Result	2.60	1.70	4.3	6.16	17.5	19.5

Figure 3: Recycled Course aggregate

5. **Fine Aggregate:** Fine aggregate sourced from nearby rivers. This is zone-II sand, as defined by IS 383-2004. Table-5 provides data on a fine aggregate physical characteristic.

Table 5: Physical Properties of Fine Aggregate

Test	Specific gravity	Bulk density kg/m³	Water absorption	Fineness modulus
Result	2.50	1534	1.2	2.7

Figure 4: Fine Aggregate

6. **Superplasticizer:** Admixture is used to keep concrete in a workable state. Conplast SP430 DIS, a superplasticizer admixture, was employed.

Table 6: Properties (As per Fosroc Chemical Ltd. Bangalore)

Particular	Results
Specific gravity	1.220 to 1.225 @ 35⁰ C
Chloride content	Nil as per BS 5075 Part I
Appearance	Brown liquid
Air entrainment	Approx 1%
Compatibility	Compatible with all cements excluding those having high alumina content.
Dosage	0.5 - 2 litres per 100Kg of Cement

The above properties were compared with the literature and slight variation was observed however it is within the permissible limits.

7. **Flyash:** Flyash incorporated concrete mixes reduces the considerable amount of water for a desired workability than the control mix. As, it possess similar characteristics as that of chemical admixtures. This will also have positive effect on workability properties. Flyash mixes are generally less susceptible towards segregation and bleeding than conventional mixes; which provides a value addition to mixes with percentage of coarse aggregate due to reduced water content. Addition of flyash increases setting time, this phenomenon usually depends on cement, water and flyash content along-with temperature of concrete. During initial stages flyash mixes reported lower strength than control mix, which is due

to effect of dilution; due to delay in hydration by reduced quantity of cement. However, initially acts as filler material but later stages initiates pozzolanic effect of ACM. Cement particles readily reacts with water molecules to form c-s-h complexes with an addition strength contributed from ACM. Flyash shows better performance at 15% and 20% replacement level. Due to pozzolanic nature of flyash initiating hydration mechanism. However, beyond the optimal limit of ACM individual reactions get hindered.

V. METHODOLOGY

Recycled concrete aggregate is collected from the old demolished building & broken into of 20 mm downsize aggregate, the aggregate are put into abrasion testing machine & rotated for 10 to 15 min, then removed & from abrasion testing machine & sieved to remove the mortar dust & oversized aggregate, about 80 to 90% of mortar can be removed in abrasion testing machine. The cubes & cylinder are casted for M25 grade concrete with varying percentage of concrete recycled aggregate i.e. 10%, 20%, 30% & compare the results with natural aggregate. Then further to Enhance concrete strength with 30% replacement of concrete recycled aggregate Flyash where added as mineral admixtures with varying percentages to enhance the strength.

Figure 3: Crushing of Recycled Aggregate

1. **Mixing:** Concrete can be mixed with recycled aggregate to reduce the environmental impact of construction activities. Recycled aggregate is made from a variety of waste materials, including concrete, asphalt, and bricks, that are processed and graded for use in new concrete.

   The process of mixing concrete with recycled aggregate is comparable with traditional concrete mixing. Aggregates are first separated by size and then cleaned to remove any impurities or contaminants. The recycled aggregate is then mixed with cement, water, and any other desired additives to create a new concrete mix.

   When using recycled aggregate in concrete mixing, it is important to consider its properties and potential limitations. Recycled aggregate may have lower durability and strength properties compared to natural aggregates, and its use may require modifications to the concrete mix design. Recycled aggregate can be of varying quantity and quality based on its original location & processing technique.

Overall, using recycled aggregate in concrete mixing can help minimize waste and reduce environmental impacts associated with construction activities. However, careful consideration and testing of recycled aggregate is important to ensure quality and sustainability of the resulting concrete mix.

2. Test on Fresh Concrete

- **Slump Test:** Whether in a lab or on-site, slump test is go-to for gauging concrete's workability. Extremely wet or dry concrete are not good candidates for this technique. It's not a perfect indicator of how well concrete will lay, and it doesn't account for all that goes into making concrete workable. The findings of the slump test show that plastic-mixes tend to be pretty constant. For a dense mixture, this test is insensitive. There is no discernible difference between dry mixtures with varying workability. The value of rich blends is usually adequate, notwithstanding their susceptibility to fluctuations in workability. According to IS 456 of 2000, stringent control is required for "extremely poor" workability level.

Figure 4: Slump Test

- **Compaction Factor Test:** Compacting factor test was created for use in the lab but has some practical applications outside of it as well. It's more precise as well as sensitive than slump test, therefore it's ideal for extremely low workability concrete mixtures, like kind often used for vibratory compacting. Slump tests are meaningless with such dry concrete. Figure depicts a schematic of equipment.

Compacting Factor =Weight of partially compacted concrete/Weight of fully compacted concrete

Figure 5: Compaction Factor Test

3. **Molding:** In The Molding Process, The Prepared Mixture Is Poured Into A Metallic Mold And Compressed Using A Tamping Rod. The Tamping Rod Applies Pressure To Ensure Proper Filling Of The Mixture In The Mold. Afterward, The Mold Is Left To Cool In The Air. Before Filling The Mold, It Is Essential To Apply Oil On The Inner Walls Of The Mold. This Ensures Easy Removal Of The Block Once It Solidifies. Without Proper Oiling, The Block May Not Come Out Easily, And Additional Pressure May Be Required, Potentially Causing Damage To The Block Edges. Therefore, It Is Necessary To Oil The Inner Surfaces Of The Mold Before Filling It With The Mixture. The Block Can Be Removed From The Mold After Approximately One day.

Figure 6: Molding

4. **Test on Hardened Concrete:** The Investigation programme involves casting, curing and testing of cube, cylinder specimen, All the test were carried for 7 & 28 days of curing. Cubes were of dimension 150mm x 150mm x 150mm, cylinder were of dimension 150mmX300mm and prism were casted in the steel cubical moulds. Testing being carried out in the compression testing machine. The design mix M25 is taken and thoroughly mixed and casted. The specimens were casted using OPC 53 grade along with different proportion of recycled aggregate (20%, 40% &60%) with different percentage of flyash replacement of OPC (10%, 15% & 20%)

Figure 7: Compressive Strength Cube Specimen

Figure 8: Split Tensile Strength Cylinder Specimen

5. **Mix Design:** Following the guidelines established by IS 456-2000, we developed the concrete mix design for the M25 quality. We used a volume batching approach to measure out all the ingredients. To improve the workability of the concrete, we added Fly ash, ground granulated blast furnace slag (GGBS), & silica fume in precise proportions to achieve an RCA content of 10%, 20%, and 30%. We tested workability of generated uniform mixtures. In order to measure the compressive strength, cube-shaped specimens were cast using molds measuring 150 millimeters on all sides. For the young's modulus & split tensile strength tests, cylindrical specimens were cast with dimensions of 150 millimeters in diameter and 300 millimeters in height. After 24 hours in the mold, all the samples were demolded and cured in water at room temperature. There were enough casts to compare the compressive strength after 7 & 28 days of curing.

VI. RESULTS AND DISCUSSION

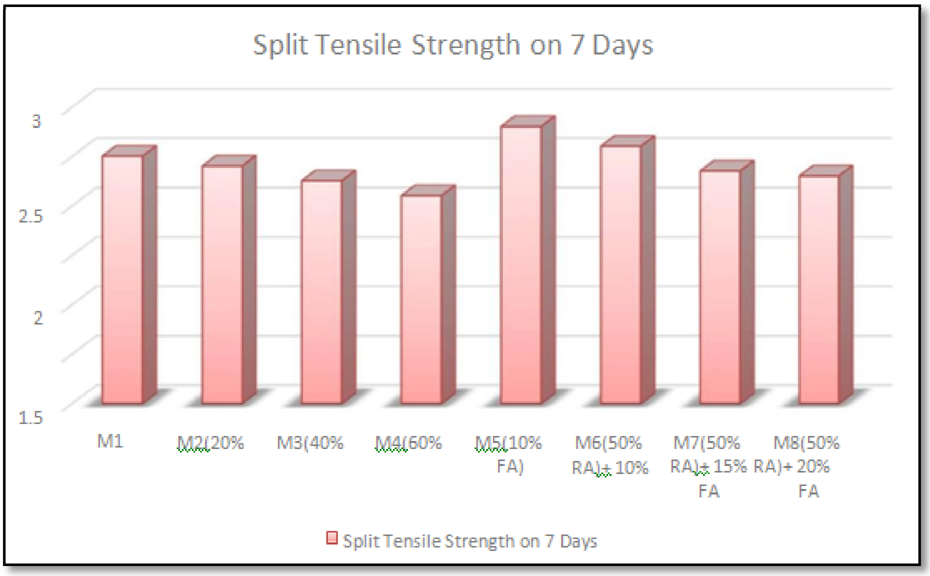
Mix	Comp. Strength KN/mm2- 7 DAYS	Comp. Strength KN/mm2 - 28DAYS
M1	25.90	36.85
M2 (20% RA)	24.12	34.15
M3 (40 % RA)	23.22	32.65
M4 (60% RA)	19.45	28.65
M5 10% FA	26.70	38.27
M6 (50% RA) + 10% FA	24.10	31.25
M7 (50 % RA) + 15 % FA	25.10	31.75
M8 (50% RA) + 20 % FA	25.20	32.45

Mix		SPLIT TENSILE STRENGTH -7 DAYS	SPLIT TENSILE STRENGTH -28 DAYS
M1		2.5	3.85
M2	(20% RA)	2.4	3.65
M3	(40 % RA)	2.25	3.40
M4	(60% RA)	2.1	3.25
M5	10% FA	2.8	4.15
M6	(50% RA) + 10% FA	2.6	3.40
M7	(50 % RA) + 15 % FA	2.35	3.55
M8	(50% RA) + 20 % FA	2.3	3.60

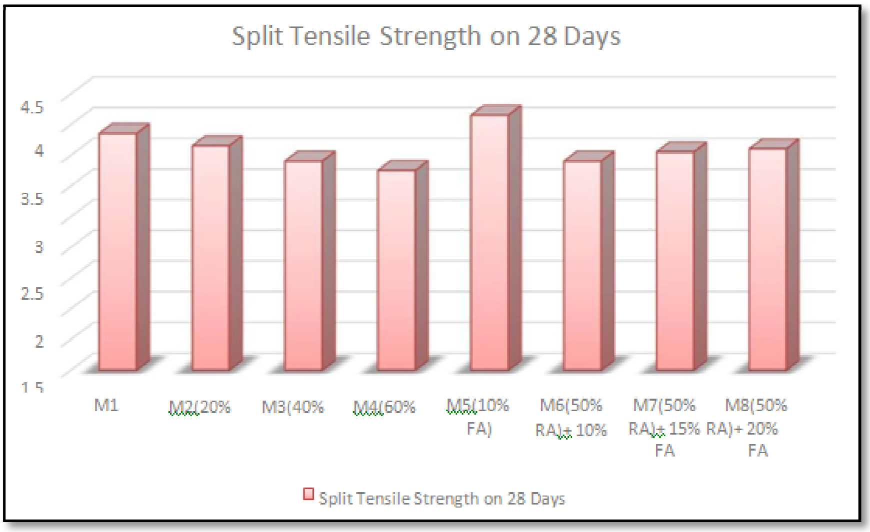
Graph 1: Comp Strength on 7 Days

Graph 2: Comp Strength on 28 Days

Graph 3: Split Tensile Strength on 7 Days



Graph 4: Split Tensile Strength on 28 Days



VII. CONCLUSION

1. In comparison to the control mix, the workability of the concrete decreases as the proportion of RCA to natural aggregates in the mix grows.
2. Maintaining workability necessitates the use of superplasticizer anytime workability drops below a certain threshold.
3. Compressive strength decreases by as much as 40% when 60% RCA is substituted into a concrete mixture.
4. Split tensile strength of concrete mixes containing 60% replacement RCA was found to be lower than those containing no RCA.
5. Compressive strength was shown to decrease when 60% RCA was used to replace natural aggregate in the concrete mix; however, when 50% RCA was used to replace natural

aggregate, the strength increased to above the Target mean strength when 20% flyash was also added.
6. The split tensile strength of concrete mixes including RCA was shown to diminish at 60% replacement, but to exceed the Target mean strength when combined with 20% flyash at 50% replacement.

VIII. SCOPE FOR FUTURE RESEARCH WORK

The following topics of study become plausible when one considers the current trend of employing recycled aggregates in concrete.

1. How recycled aggregate affects the durability of concrete constructions throughout time.
2. Analysis of recycled aggregates' characteristics and performance in a wide range of contexts
3. Analysis of benefits and costs of employing recycled vs virgin aggregates from an environmental and financial perspective
4. Recycled aggregates in high-performance concrete and other specialized applications including bridge and precast structure building are the focus of this study.
5. Properties as well as performance of recycled aggregate concrete with and without mineral admixtures and other additions

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