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Characterization of recycled concrete aggregates and their effects on fresh and hardened properties of normal concrete strength

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Abstract

In today's modern world, the significance of maintaining a clean environment and the conservation of natural resources are super important globally. This goal emphasizes the need to reduce waste generation, promote recycling and sustainable waste management practices, and minimize the environmental impact of consumption and production activities.

Concrete demolished waste presents both environmental and economic challenges. Improper disposal of concrete waste can lead to land degradation, contamination of soil and water bodies, and contribute to greenhouse gas emissions. By minimizing the need for new materials, the carbon emissions associated with their extraction and transportation are reduced. Moreover, the accumulation of concrete waste in landfills occupies valuable space that could be used for other purposes.

This paper studies the effects of replacement of natural aggregates with recycled aggregates on fresh and hardened properties of normal strength concretes. The study focuses on determining the appropriate percentage of recycled aggregate to achieve desired concrete workability and strength. The percentage of recycled aggregate that partially and fully replaced natural aggregate by weight was (0%, 50%, 75%, and 100%). Concrete cubes, cylinders and beam were casted and tested in Kabul Polytechnic University's laboratory and the comparison between recycled coarse and fine aggregate with natural aggregate has been made in terms of various fresh and hardened properties, including absorption, air content, slump/workability, specific gravity, compression strength, tensile strength, and flexural strength. Based on the empirical findings obtained in this study, it can be inferred that the incorporation of recycled concrete aggregates (RCAs) at varying replacement percentages (0%, 50%, 75%, and 100%) yields corresponding compressive strength values of 30.54 MPa, 24.37 MPa, 19.37 MPa, and 18.27 MPa, respectively. These results demonstrate the feasibility of utilizing RCAs in practical construction ventures, highlighting their favorable performance characteristics and overall viability as a sustainable alternative within the industry.

Keywords: Recycled Concrete Aggregate (RCA), Natural Concrete Aggregate (NCA), Recycled Aggregate (RA).

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1. Introduction

Recycled Aggregate in Concrete is a recent development in the use of various types of waste materials in concrete production. The information that is scattered in various journals and conference proceedings published up to the end of 2022 has been taken into consideration. Construction & demolition (C & D) waste is generated when new infrastructure is built and/or older structures are demolished or renovated. Hundreds of millions of tons of such waste are generated worldwide annually, making it one of the most significant waste generating activities in the world.

Buck cites, the inception of recycled concrete aggregate (RCA) utilization back to the post-World War II era, characterized by the extensive demolition of buildings and road infrastructure. This period witnessed a pressing demand to manage the surplus waste material effectively while simultaneously facilitating the reconstruction efforts across Europe [1]. Shortly after the initial need to recycle concrete arose, the use of recycled concrete aggregate (RCA) diminished. However, in the 1970s, the United States began to reintroduce RCA for non-load bearing uses like fill material, foundations, and base courses[15]. Since that time, some studies have explored the feasibility of employing RCA instead of unused natural aggregate (NA) in load bearing concrete structures. Research has evaluated how viable an option RCA presents as a substitute for natural aggregate in structural concrete applications.

The global demand for construction aggregates, which are used extensively in the construction industry, is increasing at an approximate rate of 5.2% annually. In 2019, the total worldwide demand for construction aggregates reached 51.79 billion metric tons according to available data sources. This reflects the rising need for aggregate materials to support ongoing construction activities across various sectors worldwide[2]. This increasing demand has led to growing concerns around diminishing natural resources and environmental degradation. Approximately 850 million tons of solid waste generated in Europe each year stems from demolition activities, accounting for roughly 31% of total waste. However, only 3% of this demolition waste is currently being utilized as aggregate derived from recycled aggregates (RA). The large volumes of demolition waste highlight the potential of recycled aggregates to help address sustainable development challenges by better utilizing material streams that would otherwise be landfilled or incinerated as non-recycled demolition waste[3].

For this reason, the disposal of construction and demolition (C&D) waste has become a concern for environmentalists. As discussed above, it is clear that natural resources are being depleted rapidly. In addition, cement and concrete production is contributing to environmental degradation. With diminishing natural aggregates and the large quantities of C&D waste generated, recycled concrete aggregates provide an option to help address both the shortage of natural resources as well as sustainable waste management challenges associated with disposal of demolition materials[4].

In the current decade, the Asia/Pacific region, Russia, and South America have emerged as some of the largest producers and consumers of aggregates globally. This is due to

rapidly rising construction activity in countries such as China, India, Indonesia, Malaysia, Thailand, Gulf states, Turkey, Russia, Brazil, and Mexico. China alone accounted for half of all new aggregate demand worldwide during the 2010-2015 period. The construction booms in many developing nations within these regions have made them dominant in aggregate production and consumption to supply the massive demand from growing infrastructure and building construction[5].

One way to take care of a significant fraction of this waste is recycled aggregates (RA), wherein the waste is crushed to the dimensions of coarse and fine aggregates and is used for various activities, most notably in manufacturing of concrete. Other uses may include landfilling, manufacturing of tiles, bricks, pavement blocks, etc. This paper deals with the various technical and mechanical, impact related to the application of various replacement percentage of Natural Aggregates by recycled aggregates.

In the research, the properties of the aggregate and their effect on various concrete properties are presented separately. It has been considered to describe a quantitative procedure to estimate the properties of concrete containing construction and demolition waste as aggregates. Moreover, the comprehensive information presented in this research will be helpful to graduate students, researchers, and concrete technologists. It is also expected that the data presented in this paper will be an essential reference for practicing engineers who face several problems concerning the use of these materials in concrete production.

1.1. Objectives

This research aims to utilize Recycled Concrete as an Aggregate in fresh concrete to replace with Natural Aggregate mixture in order to preserve the environment from building demolition waste. And to analyze the quality and suitability of recycled concrete as an aggregate (RCA) for reusing.

By preparing the Recycled Concrete aggregate, testing, analyzing, and evaluating the following two objectives will be followed:

1. To determine the optimum proportion of recycled concrete as an aggregate replacing with Natural aggregate in concrete mixture to positively affect mechanical properties of concrete like compression strength, workability durability and density.
2. To compare mechanical properties of concrete consisting of an optimum proportion of RCA replacing NA, with the conventional concrete mixture.

2. Literature review

The use of recycled concrete aggregate (RCA) is gaining more attention from the civil engineering sector as a greener replacement for natural aggregates. RCA offers a lower carbon material and reduces demolition waste. It also addresses concerns about depleting high quality natural resources. With global challenges of waste and resource scarcity, RCA proves a suitable solution if research establishes its properties and concrete performance match those of natural aggregate.

This has spurred studies comparing RCA and natural aggregate concrete[6]. Growing dumping fees[19] and increasing hauling costs provide additional incentive to utilize RCA materials. Estimates suggest using RCA could reduce hauling distances for aggregates by as much as 80%, since demolition sites can supply materials locally rather than transporting from farther aggregate sources. This is beneficial from both environmental and financial perspectives as it decreases transportation impacts and costs associated with hauling virgin aggregates over long distances[7].

Use of demolished concrete as aggregate for new concrete began in Europe after World War II [7]. However, recycling was largely abandoned at that time [18] as soon as the demand for aggregates could be met by available natural sources. Once supplies of natural aggregate were sufficient again, the practice of concrete recycling declined since it was not economically necessary at that point. This shows how demand and availability of natural aggregates have historically influenced whether recycling of concrete was utilized or not.

Recently, some countries have established standards and guidelines specifically related to RCA aggregates, although not yet for its use in RCA concrete. In the United States, the ASTM Standard Specification for Concrete Aggregates, C33-82, included "crushed hydraulic cement concrete" within its definition of coarse aggregate as early as 1982 (ASTM 33-82 (1982)) [8]. This demonstrated growing recognition and acceptance of recycled concrete as a potential aggregate source in the US standards.

In addition, "hydraulic-cement concrete" could also be classified as a type of manufactured sand according to (ASTM 125-93) [13]. The standard definitions of terms relating to concrete and concrete aggregates[11], further acknowledged concrete as a potential aggregate source by broadening aggregate definitions. This expanding acceptance of recycled concrete in standards reflected its evaluation as a viable aggregate material.

The Building Contractors' Society of Japan (BCSJ) published a "Proposed standard for the use of recycled aggregate and recycled aggregate concrete" as early as 1977 [21]. Additionally, Japan established recycling laws in 1991 aimed at controlling the rise of waste and promoting more recycling [9]. By developing standards and laws supporting recycling, Japan showed early leadership in recognizing the role standards and policies play in enabling increased use of recycled aggregates.

The Netherlands also demonstrated an early effort to support increased use of RCA. The CUR (Commissie voor Uitvoering van Research ingesteli de Betonvereniging) in the Netherlands developed a standard allowing the use of RCA in concrete at up to 20% by weight of the total coarse or fine aggregates [20]. This standard provided guidelines enabling a limited contribution of RCA to new concrete mixes.

The UK permits RCA use in both road construction and buildings per New British Standard Guide 6543 on using industrial byproducts and waste in construction. Russia allows coarse RCA in low-strength concrete up to 20 MPa, including reinforced concrete but not prestressed[20]. Similarly, Denmark allows RCA concrete for some

structural uses under mild exposure conditions. These examples demonstrate standards in multiple European countries beginning to support limited RCA applications by the late 20th century[11].

While the use of RCA has increased over time, issues related to its structural performance, durability, and long-term behavior have limited more widespread application for structural elements, especially when variable source materials are used presenting different properties. Despite the environmental benefits of utilizing RCA in construction [10], its application has remained quite limited for structural purposes due to material uncertainties. Further understanding of RCA concrete behavior is still needed to enable greater confidence and acceptance for structural applications on a larger scale.

In North America, recycled concrete aggregate (RCA) is primarily utilized in non-structural applications such as backfill, base or fill for drainage systems, pavement base and sub-base, lean-concrete bases, concrete blocks, sound barrier walls along highways, partition walls, embankments, and the like [11]. Similarly, in Canada, RCA is permitted for use in road or parking lot base and sub-base, as well as sewer bedding and backfills [12].

Despite the limited use of RCA in structural grade concrete, its successful application in road construction has been demonstrated in numerous countries, including Canada, the United States, France, Netherlands, Denmark, Germany, Japan, Belgium, and the United Kingdom (Fathifazl et al. 2008)[11]. However, the adoption of RCA concrete for structural grade applications faces several challenges, as identified by Fathifazl et al. (2008):

(1) Designers and owners are hesitant to use RCA due to concerns related to quality control, clear specifications, and lack of technical data or guidelines for both RCA materials and the production and proportioning of concrete mixes made with RCA. This necessitates further investigation.

(2) The inadequate market demand and absence of economic incentives hinder the utilization of recycled concrete aggregates (RCA). Consequently, there arises a necessity for the development of novel technical standards, quality control measures, and quality assurance methodologies to facilitate the production of structural-grade concrete incorporating RCA.

In several countries, the incorporation of recycled concrete aggregates (RCA) into structural concrete is driven by the objective of promoting environmentally friendly and sustainable construction practices. This approach aims to address significant environmental challenges associated with the construction industry, as highlighted by Oikonomou (2005)[13]. These challenges include the extraction of 50% of raw materials from natural resources, the consumption of 40% of total energy, and the generation of 50% of total waste. By extensively utilizing RCA, it becomes possible to mitigate the impact of construction activities on these factors by reusing waste materials and reducing the need for further extraction of natural aggregates.

Exteberria et al. (2007) conducted tests that demonstrated similar performance between concrete mixes containing 25% RCA and conventional concrete with the same water-to-cement (w/c) ratio. Their study involved testing concrete mixes with varying proportions of RCA (0%, 25%, 50%, and 100%) and concluded that up to 25% RCA could be used as a replacement without significant changes in compressive strength or requiring a different w/c ratio. However, when aiming for the same strength using 50-100% RCA, a lower w/c ratio of 4-10% was necessary. Without this adjustment, the compressive strength of 100% RCA mixes decreased by 20-25% [14]. Similarly, Kang et al. (2012)[15] conducted recent tests that revealed a reduction in compressive strength of approximately 25% for mixes containing 50% RCA and a reduction of up to 18% for mixes containing 15-30% RCA (Table 1).

Table 1 Compressive strength of concrete with partial and full replacement of NCA by RCA.

Concrete	f'_c (MPa)	Reduction in f'_c (%)	f_{ct} (MPa)	Reduction in f_{ct} (%)	f_r (MPa)	Reduction in f_r (%)
RCA 0 %	38.6	–	3.3	–	10.2	–
RCA 15 %	32.7	15	3	9	9.7	5
RCA 30 %	31.7	18	2.7	18	9.0	12
RCA 50 %	29.0	25	2.7	18	8.9	13

f'c compressive strength; fct splitting tensile strength; fr modulus of rupture.

3. Material and Method

During this investigation, Ghori Afghani Cement was employed. In Afghanistan, the annual consumption of cement is estimated to exceed 300 million tons, with a significant portion being imported from neighboring countries. Afghanistan currently hosts four cement factories, namely Pul-e-khumri, Jabal-e Saraj, Herat, and Samangan cement plants. These existing facilities have suffered damage over the course of decades of war and necessitate restoration and machinery renewal to sustain their competitiveness in the market.

The physical properties of cement vary due to a change in the amount of chemical composition of the cement. The chemical compositions such as CaO, SiO2, Al2O3, Fe2O3, MgO, SO3 and LOI for Ghori Afghani cement is indicated in the chart below [16].

Table 2 Chemical composition of Ghori Afghani cement by weight percent. [16].

Cement Type	Compounds Weight (%)						
	CaO	**SiO2**	**Al2O3**	**Fe2O3**	**MgO**	**SO3**	**LOI**
Ghori Afghani cement	61.67	21.08	6.15	2.28	1.23	3.51	2.45
ASTM C150	60-67	17-25	≤6	≤6	<6	<3	<3

3.1. Natural Fine Aggregate

Fine aggregates derived from Paghman washed sand sources were utilized to formulate experimental concrete mixtures, meeting the compositional specifications for fine aggregate set forth by ASTM C-33 standard. Prior to inclusion within test mixes, the fine aggregate material underwent washing and drying procedures. To validate suitability, a battery of preliminary quality assessment tests were conducted on samples of the processed fine aggregate. The quantitative outcomes from these preliminary characterization experiments are encapsulated within Table 3, documenting the results from the fine aggregate quality tests.

Table 3 Results of fine aggregate preliminary quality tests

Test Type	Result	Standard Used
Specific Gravity- Oven Dry	2.653	ASTM C128-15
Specific Gravity- S.S.D.	2.650	ASTM C128-15
Unit weight – Loose	1.885 gr/cm3	ASTM C29
Unit weight - Rodded	2.200gr/cm3	ASTM C29
Fineness Modulus	2.49	ASTM C33

- Sieve Analysis: The sieve analysis test is conducted to determine the particle size distribution of both fine and coarse aggregates. This test method follows the guidelines outlined in ASTM C136, which provides the standardized procedure for conducting the test. It involves sieving the aggregate samples to separate them into different size fractions, allowing for the evaluation of the distribution of particle sizes within the material.

Table 4 The below table presents the results of a sieve analysis test conducted on natural fine aggregates.

Sieve Size (mm)	Passing %	Retained%	Average Passing %	Standard Used

9.5	100	00.00	100	ASTM C136
4.75	95.33	4.67	95-100	ASTM C136
2.36	90.65	9.35	80-100	ASTM C136
1.18	73.12	26.88	50-85	ASTM C136
0.6	55.44	44.56	25-60	ASTM C136
0.3	25.13	74.87	5-30	ASTM C136
0.15	10.88	89.12	0-10	ASTM C136

Obtained results show that selected sand is satisfactory according to the ASTM requirements so that it can be used for further processes.

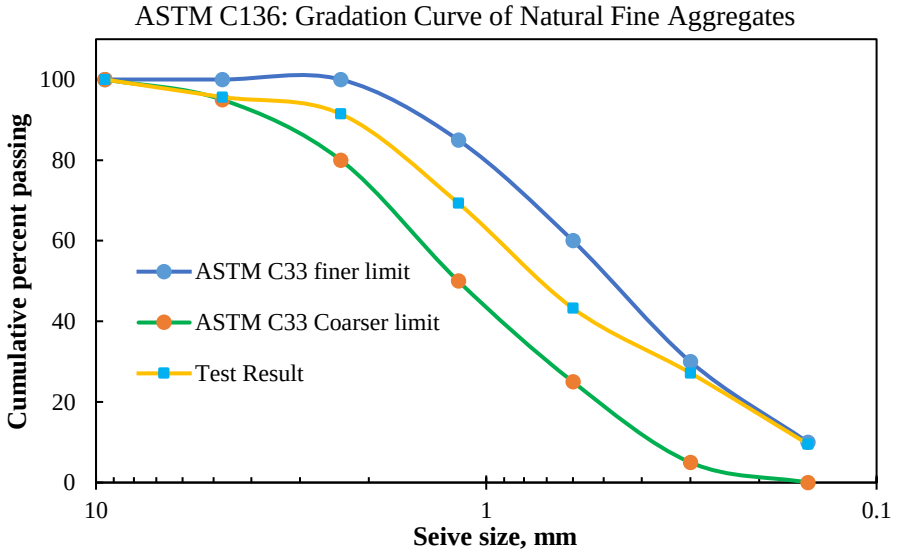


Figure 1. Natural fine aggregate gradation curve

3.2. Natural Coarse Aggregate

Paghman crushed aggregate is used as coarse aggregate for preparation of concrete mix, conforming to ASTM C-33 requirement for coarse aggregate, in the size range of (5-20) mm. The preliminary test results tabulated bellow.

Table 5 Results of 5-20 mm aggregate quality tests

Test Type	Result	Standard Used
Specific Gravity- Oven Dry	2.68	ASTM C128-15

Specific Gravity- S.S.D.	2.67	ASTM C128-15
Water Absorption	3.2 %	ASTM C128-15
Unit weight – Loose	1.558 gr/cm3	ASTM C29
Unit weight - Rodded	1.782 gr/cm3	ASTM C29
Fineness Modulus	2.804	ASTM C33
Flakiness index	0.186	BS 812-105.1
Elongation index	0.251	BS 812-105.2
Los Angeles Test- Abrasion	31 %	ASTM C535

Table 6

Sieve Analysis test result for Natural Coarse Aggregates is provided in the table below.

Sieve Size (mm)	Passing %	Retained%	Average Passing %	Standard Used
25.00	100	00.00	100	ASTM C136
19.00	91.35	8.65	90-100	ASTM C136
12.50	41.5	80.77	35-80	ASTM C136
9.50	22.3	93.56	20-55	ASTM C136
4.75	2.50	97.5	0-10	ASTM C136

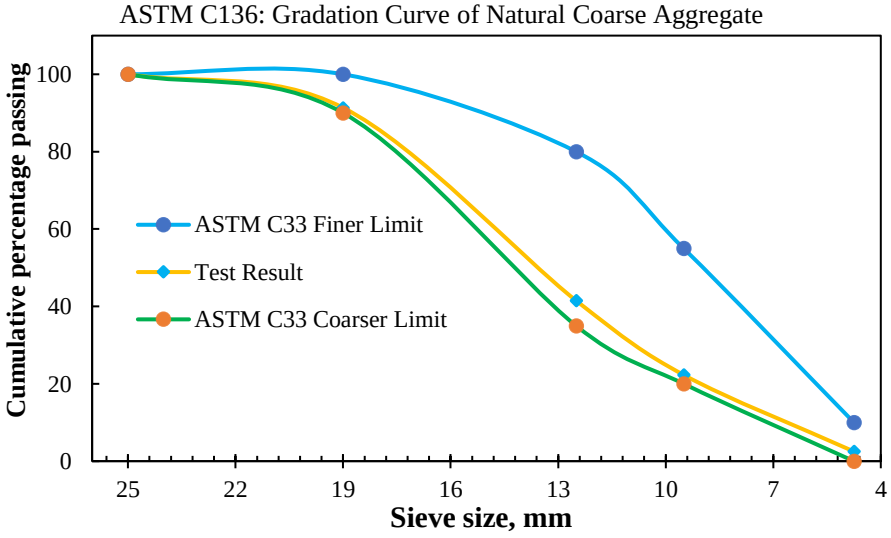


Figure 2. Natural coarse aggregate gradation curve



Figure 3. Sieve analysis of reference aggregates.

3.3. Recycled Fine Aggregate

The recycled aggregates used in this research were obtained from the waste generated during the demolition of a building in the 5th district of Kabul city. The collection process took place during the reconstruction of the Charahi-e-Qamber blocks road, which was carried out by Kabul Municipality. To recycle the concrete masses, industrial crushing equipment equipped with jaws and large impactors was utilized. This equipment was instrumental in breaking down and processing the recycled concrete materials for reuse in the project. After the concrete is broken up it is usually run through a secondary impactor and is then screened to remove dirt and particles and to separate the large and small aggregates. For preparation of concrete mix, the recycled fine aggregates were conforming to ASTM C-33 requirement. After washing and oven drying of the fine aggregate several quality tests, for the purpose of validity, are carried out on the samples.

Some preliminary tests were carried out on recycled fine aggregate and the results of the tests are tabulated here:

Table 7 Results of recycled fine aggregate quality tests

Test Type	Result	Standard Used
Specific Gravity- Oven Dry	2.32	ASTM C128-15

Specific Gravity- S.S.D.	2.35	ASTM C128-15
Unit weight – Loose	1.870 gr/cm3	ASTM C29
Unit weight - Rodded	2.100 gr/cm3	ASTM C29
Fineness Modulus	2.635	ASTM C33

Table 8 Sieve Analysis test result for Recycled Fine Aggregates is provided in the table below:

Sieve Size (mm)	Pass %	Retained%	Average Pass %	Standard Used
9.5	100	00.0	100	ASTM C136
4.75	95.65	4.35	95-100	ASTM C136
2.36	91.45	8.55	80-100	ASTM C136
1.18	69.33	30.67	50-85	ASTM C136
0.6	43.25	56.75	25-60	ASTM C136
0.3	27.18	72.82	5-30	ASTM C136
0.15	9.55	90.45	0-10	ASTM C136

Obtained results show that selected sand is satisfactory according to the ACI requirements so that it can be used for further processes.

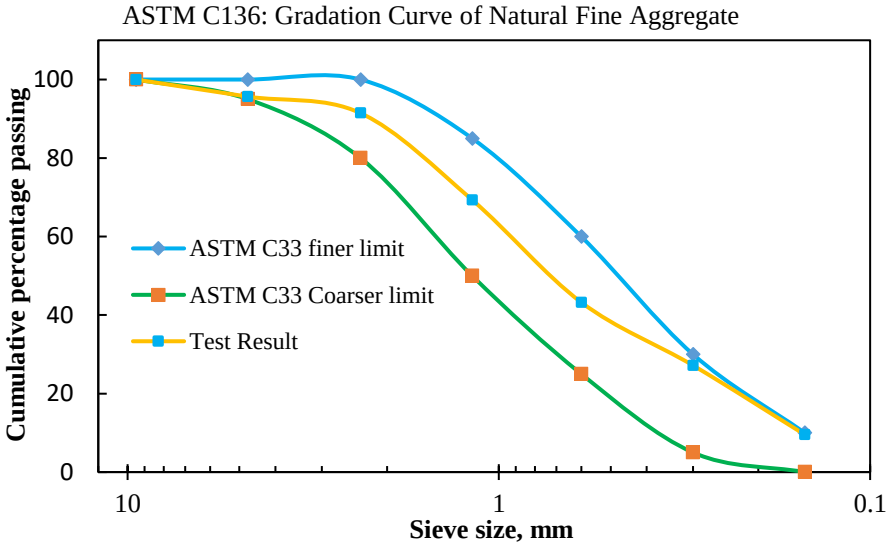


Figure 3. Recycled fine aggregate gradation curve.

3.4. Recycled Coarse Aggregate

The waste of recycled aggregates was collected from a demolished building in 5th district of Kabul city while the Charahi-e-Qamber blocks road was reconstructing. The recycled concrete masses have been recycled by using industrial crushing equipment with jaws and large impactors. After the concrete is broken up it is usually run through a secondary impactor and is then screened to remove dirt and particles and to separate the large and small aggregates. For preparation of concrete mix, the recycled coarse aggregates were conforming to ASTM C-33 requirement for coarse aggregate, sizes: 5-20 mm aggregate. After washing and oven drying of the coarse aggregate several quality tests, for the purpose of validity, are carried out on the samples.

Table 9 Results of 5-20 mm aggregate quality tests

Test Type	Result	Standard Used
Specific Gravity- Oven Dry	2.50	ASTM C128-15
Specific Gravity- S.S.D.	2.53	ASTM C128-15
Water Absorption	6.50 %	ASTM C128-15
Unit weight – Loose	1.532gr/cm3	ASTM C29
Unit weight - Rodded	1.741gr/cm3	ASTM C29
Fineness Modulus	2.776	ASTM C33
Flakiness index	0.178	BS 812-105.1
Elongation index	0.225	BS 812-105.2
Los Angeles Test- Abrasion	36.20 %	ASTM C535

Table 10 Sieve Analysis test result for Recycled Coarse Aggregates is provided in the table below:

Sieve Size (mm)	Passing %	Retained%	Average Passing %	Standard Used
25.00	100	00.0	100	ASTM C136
19.00	89.50	10.5	90-100	ASTM C136
12.50	25.20	74.8	35-80	ASTM C136
9.50	6.33	93.67	20-55	ASTM C136
4.75	1.30	98.7	0-10	ASTM C136

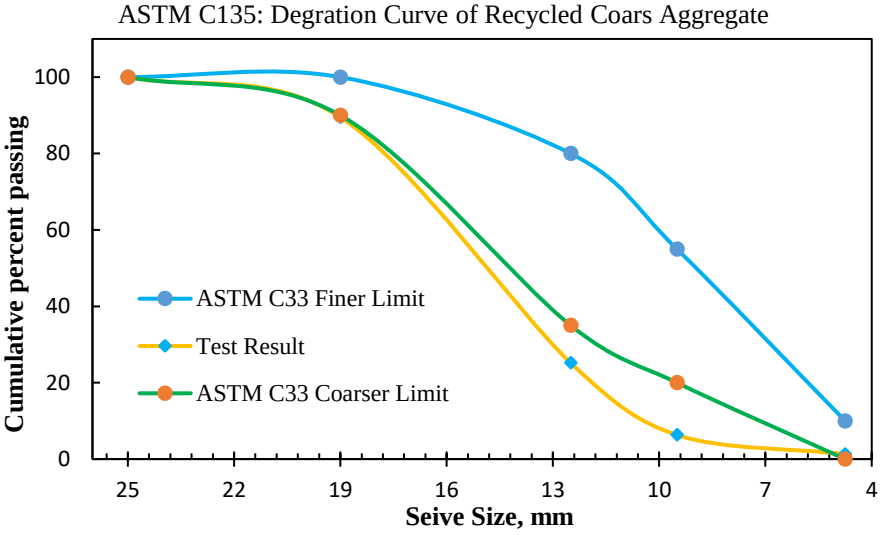


Figure 4. Recycled coarse aggregate gradation curve.



Figure 6. Sieve Analysis of Recycled Concrete Aggregates.

3.5. Water

Drinking water with Ph. (7.5) was used for the experimental study.

3.6. Admixtures

Water reducing admixtures play a crucial role in RCA (Recycled Concrete Aggregate) concrete as it tends to have higher water absorption properties compared to NCA (Natural Coarse Aggregate) concrete. The addition of water reducing admixtures is necessary to preserve similar properties to NCA concrete. Our study has shown that various properties such as compressive strength, split tensile strength, flexural strength, density, workability (in terms of slump), and compaction factor of RCA concrete are influenced. Based on our understanding, we have chosen to incorporate a superplasticizer at a dosage of 1.0% in all four mixtures, including the control mix,

which involves different percentages of recycled aggregates replacement. This decision aims to optimize the performance of the RCA concrete and maintain its desired properties.

4. Experimental Procedure

4.1. RCA & NCA Mix-Design and Testing

The study involved the fabrication of four 28 MPa RCA concrete mixtures, utilizing different sources of RCA aggregates (0%, 50%, 75%, and 100% replacement). The ACI 211.1-91 method was used for mix design. Workability was assessed through slump tests, and all aggregates used in the RCA mixtures were obtained from concrete waste in the crush plant. Natural aggregates consisted of river sand and limestone aggregates. The study aimed to evaluate the impact of RCA source on the properties of fresh and hardened RCA concrete mixtures.

Table 11. gives the detailed RCA and Natural Aggregates concrete mixture proportions.

Mix proportion	Cement Content KG/M3	Natural Fine Aggregate KG/M3	Natural Coarse Aggregate KG/M3	Recycled Fine Aggregate KG/M3	Recycled Coarse Aggregate KG/M3	W/C	Super Plasticizer %
*Ratio for 0%RCA	1	2.01	2.16	0	0	0.47	-
Control specimen	414.98	833.171	896.31	0	0	0.47	1
RCA 75% NA 25%	414.98	208.29	224.07	624.878	672.23	0.47	1
RCA 50% NA 50%	414.98	416.58	248.155	416.58	248.155	0.47	1
RCA100% NA 0%	414.98	0.00	0.00	833.171	896.31	0.47	1
Ratio for 100% RCA	1	0	0	2.01	2.16	0.47	-

*: The mix- design is presented in ratios here, i.e. all the ingredients of each mix are divided by the cement content of the respective mixture.

A total of 64 samples were prepared in the laboratory of Kabul Polytechnic University, Afghanistan, from the four RCA concrete mixtures with varying levels of recycled concrete aggregates (0%, 50%, 75%, and 100%) replacement. The samples included 24 cylinders (100 by 200 mm), 24 cubic prisms (100 x 100 x 100 mm), and 16 beams (500 x 100 x 100 mm).

After casting, the specimens were demolded 48 hours later and subjected to a moist curing environment at 28 ºC for a period of 28 days. Mechanical testing, including compressive strength, bending flexure, split tensile strength, and modulus of elasticity, was conducted on the RCA samples following the guidelines outlined in Table 12. These tests aimed to assess the mechanical properties and performance of the RCA concrete samples

Table 12 Testing matrix developed for this study.

Test methods (number of samples)	Time (days)				
	Fresh state	3	7	14	28
1) Compressive strength	x	x	3	x	3
2) Bending flexure (3-point test)	x	x	2	x	2
4) Slump test	√	x	x	x	x
5) Split tensile	x	x	3	x	3

The compressive strength test was performed according to ASTM C C39 / C39M and the flexural test through the third point test as per ASTM C78 / C78M - 16.

4.2. Los Angeles Abrasion

The LA abrasion test was performed on both the RCA and NA aggregates used in the research project. Results showed that all RCA samples experienced higher mass loss compared to NA, as expected. However, different levels of mass loss were observed within the RCA materials (33% to 36%) and NA (25% to 31%). Nonetheless, all RCA mixtures met the criteria set by AASHTO T 96 or ASTM C 131, indicating that the aggregates are suitable for use in concrete as their losses were below the 40% threshold.



Figure 5. Los Angeles abrasion test for recycled and reference aggregates.

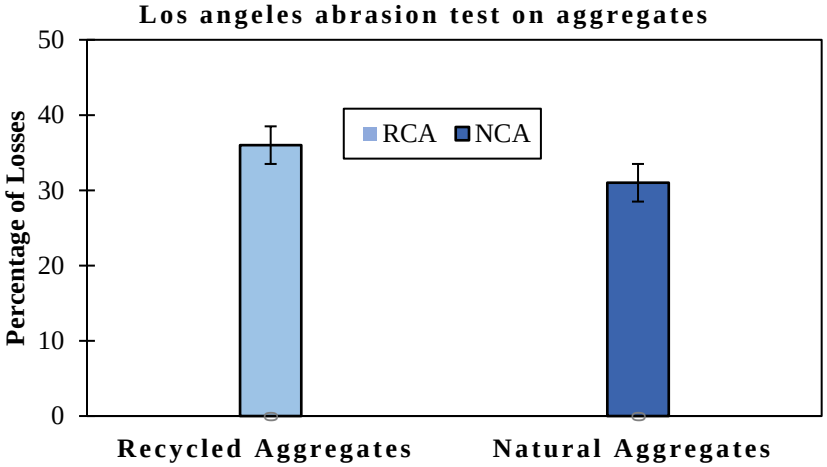


Figure 6. Percent loss of Los Angeles abrasion test for recycled and reference aggregates.

5. Result and Discussion

5.1. In the Laboratory of Kabul Polytechnic University, Afghanistan, the 7-day and 28-day compressive strength, tensile strength, and flexural strength values were determined for each mixture with varying percentages of recycled concrete aggregate (RCA) replacement: 0.0%, 50%, 75%, and 100%. Relevant specimens such as cylinders and beams were tested to obtain these strength values. This testing aimed to assess the mechanical performance and durability of the concrete mixtures with different levels of RCA replacement.

5.2. Compressive Strengths

Axial compression tests were conducted in accordance with ASTM C39/C39M-16b (ASTM 2016) to determine the compressive strengths (fcm) of the concrete samples. The results of these tests are presented in Table 13 and Table 14, which provide the measured values for the compressive strengths of the tested specimens.

Table 13 7-day compressive strength test results

Samples	**S_1**	**S_2**	**S_3**	**S_4**
Replacement	0%	50%	75%	100%
Compressive Strength (MPa)	19.91	17.3	15.5	14.23
Percent reduction in strength	100	86.89	77.85	71.47

Table 14 28-day compressive strength test results

Samples	**S_1**	**S_2**	**S_3**	**S_4**
Replacement	0%	50%	75%	100%

Compressive Strength (MPa)	30.54	24.37	19.37	18.27
Percent reduction in strength	100	79.80	63.42	59.82

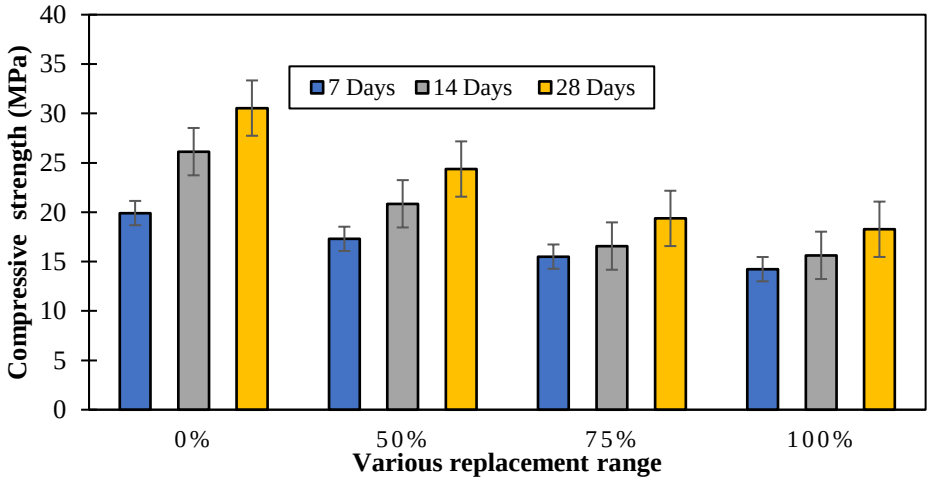


Figure 7. Compressive strength result at different age.



Figure 8. 7-Day & 28-day compressive strength test

5.3. Flexure test

The flexural strength (fr) of each concrete series was evaluated through three-point bending tests carried out in accordance with ASTM C293/C293M-10 (ASTM 2010) standards. These tests provided measurements of the flexural strength for the respective concrete series, allowing for an assessment of their structural performance under bending forces.

Table 15 7-day flexure strength test results

Samples	**S_1**	**S_2**	**S_3**	**S_4**
Replacement	0%	50%	75%	100%
Flexure Strength (MPa)	3.65	2.875	2.6	2.33
Percent reduction in strength	100	78.76	71.23	63.83

Table 16 28-day flexure strength test results

Samples	**S_1**	**S_2**	**S_3**	**S_4**
Replacement	0%	50%	75%	100%
Flexure Strength (MPa)	4.45	3.35	3.23	2.98
Percent reduction in strength	100	75.28	72.58	66.96

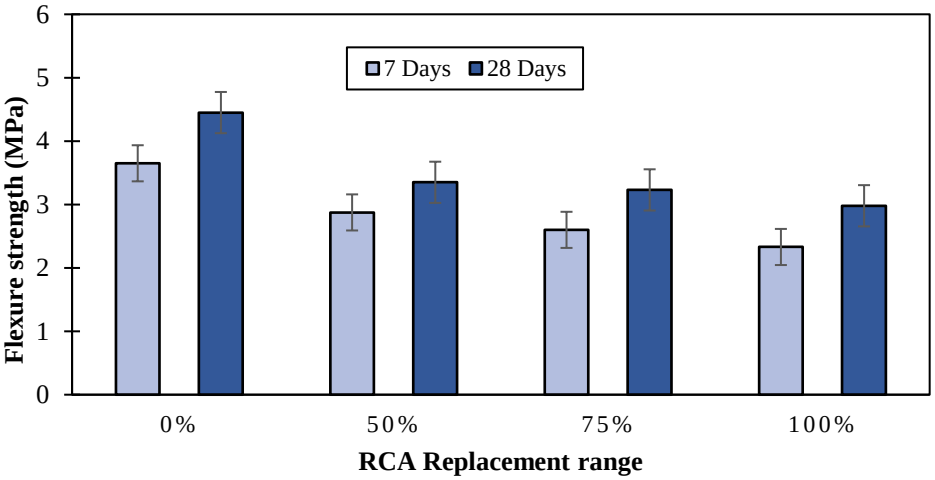


Figure 9. flexure strength test results at different age.





Figure 10. 7-day & 28-day flexure strength test

5.4. Tensile strength

The splitting tensile strength (fst) of each concrete series was determined by conducting tests in accordance with ASTM standard C496/C496M-04 (ASTM 2004). These tests provided measurements of the splitting tensile strength for each concrete series, which is an important parameter for assessing the resistance of concrete to tensile forces perpendicular to its axis.

Table 17 7-day tensile strength test results:

Samples	**S_1**	**S_2**	**S_3**	**S_4**
Replacement	0%	50%	75%	100%
Tensile Strength (MPa)	2.5	2	1.82	1.72
Percent reduction in strength	100	80	72.8	68.8

Table 18 28-day split tensile test results

Samples	**S_1**	**S_2**	**S_3**	**S_4**
Replacement	0%	50%	75%	100%
Tensile Strength (MPa)	3.6	3.17	2.43	2.33
Percent reduction in strength	100	88.05	67.50	64.72

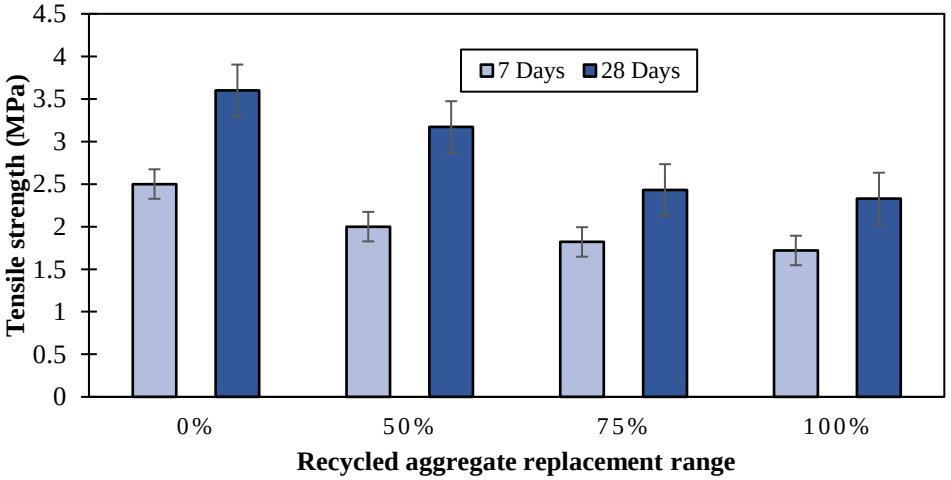


Figure 11. Split tensile test results chart at different age.

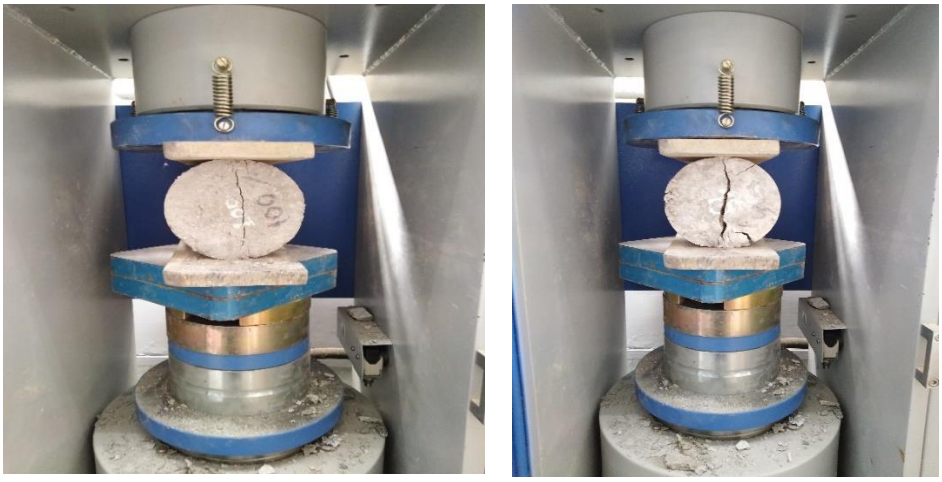


Figure 12. 7-day & 28-day split tensile strength test

5.1- Slump test

The slump was carried out as per procedures mentioned in ASTM C143.

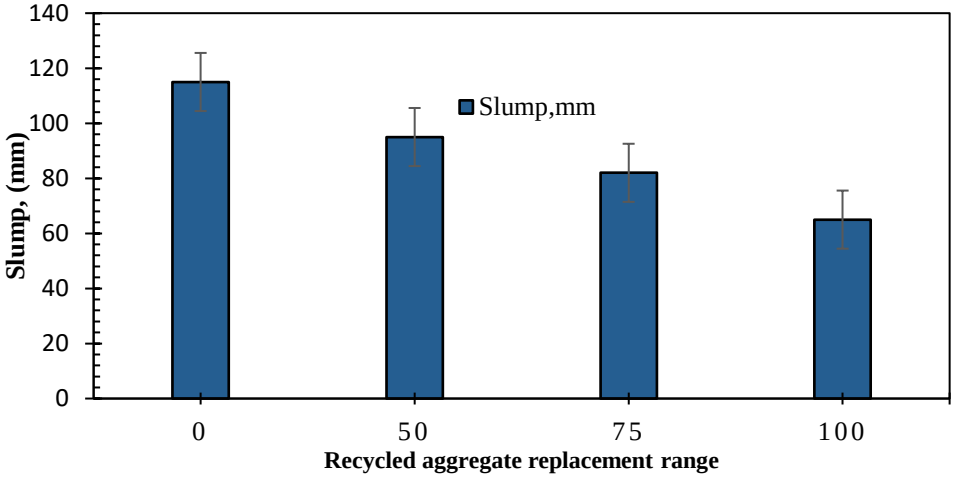


Figure 13. Illustrates slump test level for different replacement of NA by RCA

5.5. Air Content Test

The air content of the freshly mixed concrete was determined using the ASTM C231 standard, "Air Content of Freshly Mixed Concrete by the Pressure Method." An air meter type B, conforming to ASTM C231, was used to measure and record the air content percentage of the concrete mixture.



Figure 14. Air content test for different replacement of NA by RCA

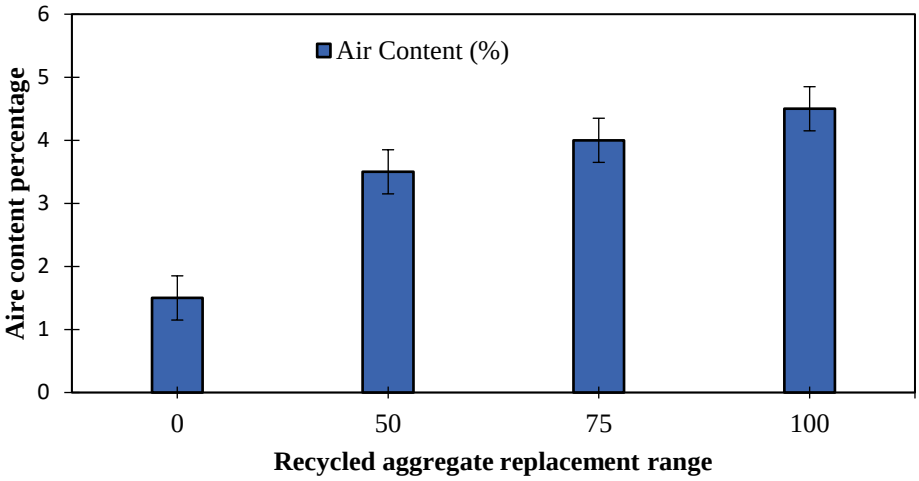


Figure 15. Air content test level for different replacement of NA by RCA

5.6. Temperature Test

The temperature of the fresh concrete mix was tested immediately after the mixing of each batch for all four mixtures. This temperature measurement was conducted in accordance with the ASTM C1064 standard, which provides guidelines for measuring the temperature of freshly mixed concrete to ensure compliance with specifications. The recorded temperatures were documented to monitor and verify the temperature of the concrete mixes.

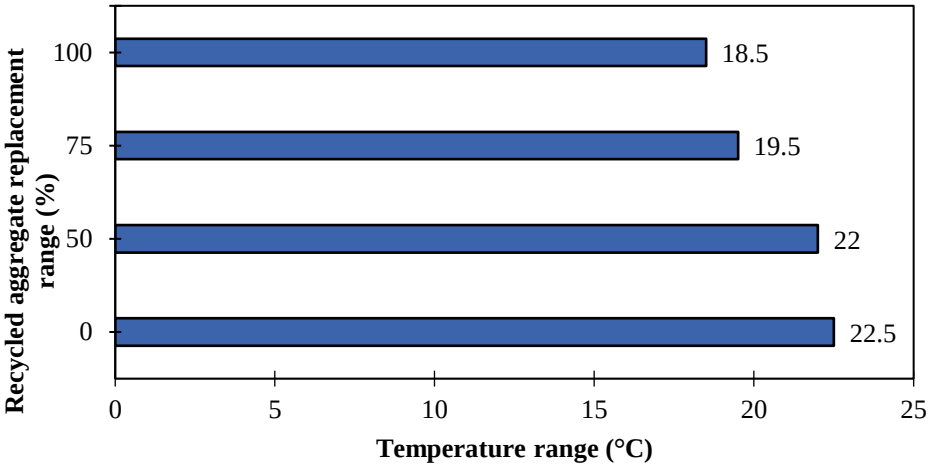


Figure 16. Temperature test for different replacement of NA by RCA

5.7. Curing

The concrete specimens were cured in a water storage tank located inside the KPU laboratory, following the specifications outlined in ASTM C511. The specimens remained submerged in the tank until the day of testing. The water temperature was maintained at 28 degrees Celsius, and potable water with a pH value of 7 was utilized throughout the study for curing purposes.



Figure 17. Concrete specimens curing in 28°C water.

6. Conclusion

This research focused on the production of RCA concrete specimens using recycled aggregates with diverse mechanical properties. The objective was to investigate how the quality and source of the RCA influence the properties of the resulting concrete mixtures. The study employed a combination of chemical and mechanical techniques for evaluation. The key findings of this research are summarized below.

- In general, increasing the quantity of recycled concrete aggregate (RCA) in the concrete mixture leads to a decrease in compressive and flexural strength. As the percentage of RCA increases, it requires a higher amount of water in the mixture, resulting in a decrease in the slump size or workability of the concrete. Additionally, a higher ratio of recycled aggregate can negatively impact the overall properties and strength of the concrete mix. It is important to carefully consider the optimal amount of RCA to be used in order to maintain the desired concrete performance and strength.

6.1. Effect of RCA on Fresh Concrete Workability

Incorporating recycled concrete aggregate (RCA) in concrete mixes reduces the workability and results in a decrease in slump, making the concrete less fluid and more challenging to handle and place.

6.2. Effect of RCA on Fresh Concrete Air Content

Increasing the level of recycled concrete aggregate (RCA) in fresh concrete results in higher air content in the mix due to the higher absorption capacity of RCA.

6.3. Effect of RCA on Concrete Compressive Strength

6.4. When natural aggregate is fully replaced with recycled concrete aggregate (RCA), it has a significant effect on the compressive strength of hardened concrete. The compressive strength tends to decrease significantly when using 100% RCA as a replacement for natural aggregate.

6.5. Effect of RCA on Concrete Flexure Strength

The flexural strength of hardened concrete is significantly affected by the use of recycled concrete aggregate (RCA) as a 100% replacement for natural aggregate. The flexural strength tends to decrease notably when natural aggregate is completely replaced with RCA.

- The LA (Los Angeles) abrasion test may not be suitable for distinguishing different qualities of RCA (recycled concrete aggregate) unless the results are compared to their specific original natural aggregates (NAs). However, the relative increase in mass loss compared to a reference aggregate could potentially serve as an indicator of RCA quality. By comparing the mass loss of RCA to that of a reference aggregate, it may be possible to assess the quality of the recycled aggregate in terms of its resistance to abrasion.
- The utilization of recycled aggregate in the construction industry can contribute to reducing the environmental impact of waste. By incorporating recycled aggregate into construction projects, it helps divert waste materials from landfills and promotes their reuse. This recycling practice reduces the consumption of natural resources, such as virgin aggregates, and conserves energy that would otherwise be required for their extraction and processing.
- The flexural capacity of concrete is influenced by the source of recycled concrete aggregate (RCA), particularly in terms of angularity and surface roughness. These factors can enhance the bond between the cement paste and aggregate at the interfacial transition zone (ITZ). However, it is worth noting that the test being referred to (not specified) may not be capable of effectively distinguishing different qualities of RCA. Other testing methods or parameters might be required to accurately assess and differentiate the quality of RCA in terms of its flexural capacity and performance in concrete applications.

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