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A review of coarse recycled aggregate in concrete applications.

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ABSTRACT: *A necessary byproduct of industrialized civilizations' functioning has been solid waste. One effect of economic growth is an increase in the generation of solid waste, which was previously disposed of in landfills and contaminated the land, water, and air with hazardous materials like asbestos, construction chemicals, and heavy metals. However, due to the lack of land for planting areas, industrial growth, and stringent environmental regulations in developed and developing nations, the methods used to recycle and use construction and demolition (C&D) waste as recycled aggregate for civil engineering projects in construction and infrastructure development have been revaluated globally. Recycled aggregate made from C&D waste can be used in a variety of civil engineering projects, depending on their quality. The quality of recycled aggregate derived from construction and demolition debris determines its suitability for use in different civil engineering projects, so contributing significantly to the economic and environmental sustainability of the corresponding nations. Natural crushed stone aggregates can be substituted with recycled concrete aggregate (RCA), which is a sustainable option. This study examines the literature on the qualities of recycled aggregate concrete and the variables that affect it, such as the ratio of cement to water, the amount of cement, and the replacement % of new aggregates. The study covered resistance and strength attributes such as modulus of elasticity, flexural strength, split tensile strength, fractional tensile strength, and compressive strength. Reviewing the durability attributes includes water absorption, resistance, and permeability to chlorides.*

Research results to date indicate that the characteristics of natural aggregate concrete (NAC) can be substantially maintained when using recycled concrete aggregate (RCA) to replace up to 25% of the original stone aggregates.

KEYWORDS: *Recycled concrete aggregates (RCA), natural concrete aggregates (NCA) coarse aggregates, recycling demolition waste, physical and mechanical properties.*

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I. INTRODUCTION

In today's world, sustainable development is essential for both the increase of the human population and the health of the planet. The most common material utilized in contemporary construction projects is concrete. After a structure is demolished, a lot of waste is created that is challenging to manage. Concrete waste accounts for 30 to 40 percent of the estimated 2-3 billion tons of building waste produced annually worldwide. Many CO2 emissions occur throughout the cement production process, which pollutes the environment. We must regulate CO2 emissions in the atmosphere in order prevent environmental risks. According to the US Environmental Protection Agency, construction and demolition waste (C&D) is made up of undesired materials that are produced during the construction, renovation, and demolition of antiquated buildings, roads, bridges, and other infrastructure. Recycled aggregate is the leftover aggregate from demolished building concrete that is utilized in construction projects instead of natural cement aggregate (NCA). Natural aggregates may become rare in developing nations due to their rapid growth and urbanization. Developing nations should create RCA to meet their local construction needs rather of relying on imports. Unrestricted mining extraction results in landslides and massive dirt releases that contaminate the land, water, and air. The only way to solve this issue is to build landfills using more environmentally friendly construction methods. As a result, using RCA derivative derived from concrete waste could show to be a valid alternative and a strategy for adding value. When it comes to grade M25 and below reinforced concrete construction (RCC), IS: 383 allows for RCA replacement up to a maximum of 20%.[1] When producing concrete, RCAs are a useful substitute for aggregates in the mix. In order to obtain RCA which may be used to produce primary crushed concrete of the appropriate grade or combined with secondary crushed concrete waste concrete material from destruction sites must be ragged. The content and durability of the original concrete, from which the RCA is recycled, determine the properties of the concrete containing RCA. advised that the water/cement (w/c) ratio of the parent concrete and the crushing technique determine how much mortar should be applied to the RCA. [2] Over 500 million tons of leftover concrete were produced annually in China's mainland during the previous three years. In the US, demolition and construction activities produced roughly 136 million tons of garbage, only about 28 percent of which were recycled. [3] About 110 million tons of construction waste are produced annually in Britain as a result of building destruction; this makes up more than 60% of all rubbish produced in the country. [4] Ordinary size recycled coarse aggregate (RCA) concrete has been thoroughly studied and contrasted with natural coarse aggregate (NCA) concrete. [5-10]

II. CLASSIFICATION OF AGGREGATES [11-13]

Natural Aggregate:
Construction aggregates made from natural materials such as gravel and sand, as well as extractive products like crushed rock.

- Crushed rock
- Sand and gravel
- Crushed river gravel

Manufactured Aggregate:
Aggregates made from natural materials, industrial byproducts, or a combination of the two.

- Foamed Blast Furnace Slag (FBS)
- Fly Ash Aggregate- Manufactured Sand
- Polystyrene Aggregate (PSA)
- Expanded Clays, Shales and Slates

Recycled Aggregate:
Aggregates created from the processing of materials previously utilized in a product or in construction.

- Recycled Concrete Aggregate (RCA)
- Recycled Concrete and Masonry (RCM)
- Reclaimed Aggregates (RA)
- Reclaimed Asphalt Pavement (RAP)
- Reclaimed Asphalt Aggregate (RAA)
- Scrap Tyres- Polystyrene Aggregate (PSA)
- Used Foundry Sand

Reused by-product:
Aggregates created as byproducts of industrial processes.

- Air-cooled BF Slag (BFS)
- Granulated BF Slag (GBS)
- Electric Arc Furnace Slag (EAF)
- Steel Furnace Slag (BOS)
- Fly Ash (FA)
- Furnace Bottom Ash (FBA)
- Incinerator Bottom Ash (IBA)
- Coal Washery Reject (CWR)
- Organic Materials

III.COMPARISON BETWEEN RECYCLED COARSE AGGREGATES WITH NATURAL AGGREGATES. [11-13]

Strength
Recycled coarse aggregate has less strength than natural aggregate. Compared to natural aggregate, recycled coarse aggregate weighs less. This is the overall effect that reduces the strength of reinforced concrete.

Texture

Recycled coarse aggregate contains rough-textured, angular, and elongated particles, whereas natural aggregate is smooth and rounded compact aggregate. The particle form and surface roughness of the aggregate will have an effect on the characteristics of freshly mixed concrete. When forming workable concrete, rough-textured, angular, and elongated particles require significantly more water than smooth and rounded compact aggregate. The void content increases with angular aggregate, while larger well sizes and superior grading aggregate reduce void content.

Quality

The quality varies between recycled coarse aggregate and recycled coarse aggregate. Natural aggregate quality is determined by the physical and chemical qualities of the source locations, whereas recycled coarse aggregate is affected by debris pollution. It further said that natural resources are suited for many products and have a bigger marketing area, whereas recycled aggregate has limited product mixes, and lower product mixes may limit the market.

Density

The recycled coarse aggregate has a smaller density than the natural aggregate. When compared to natural aggregate, recycled coarse aggregates have a lower density due to the porous and less dense residual mortar lumps that adhere to the surfaces. When the particle size is increased, the volume percentage of remaining mortar also increases.

Location

Natural aggregate comes from a range of rock sources. Natural aggregate processing plants are resource-dependent. It usually occurs on the mining site or outside the city. Recycled coarse aggregate is obtained from construction and road detritus. The locations of recycling factories vary depending on where the constructions are demolished. Recycling is frequently carried out in cities.

IV.SUMMARY OF PROPERTIES OF NCA AND RCA [14]

Basic physical properties of NCA and RCA		
Physical property	NCA	RCA
Shape and texture	Well rounded, smooth (gravels) to angular and rough (crushed rock)	Angular with rough surface
Specific gravity (saturated surface-dry based)	2.4-2.9	2.1-2.5
Bulk density (compacted) (kg/m3)	1450-1750	1200-1425
Absorption (wt. %)	0.5-4	3--12
Pore volume (vol. %)	0.5-2	5.0-16.5

Table 1 - Basic physical properties of NCA and RCA

Key mechanical properties of NCA and RCA		
Mechanical property (wt. %)	NCA	RCA
Aggregate abrasion value	15-30	20-45
Aggregate impact value	15-20	20-25
Aggregate crushing value	14-22	20-30

Table 2 - Key mechanical properties of NCA and RCA

Fresh properties of NCA and RCA concretes		
Fresh property	NCA (concrete)	RCA (concrete)
Workability		
Slump (mm)	90–275	70–255
Slump flow (mm)	600–735	380–725
Slump loss for normal concrete (after 45 min) (%)	50	75
Slump loss for self-consolidating concrete (after 1 h) (%)	2.4–2.6	7.4–10.4
Stability (segregation resistance)		
Visual stability index, VSI (based on bleeding, mortar halo, and aggregate piling)	VSINCA ≤ 1	VSIRCA << 1
Sieve segregation (%)	8.9–10.4	8.3–12.3

Wet density (kg/m3)	2325–2455	2250–2370
Air content (%)	1.3–6.3	1.5–6.9

Table 3 - Fresh properties of NCA and RCA

IV.1 RELATIVE COMPRESSIVE STRENGTH

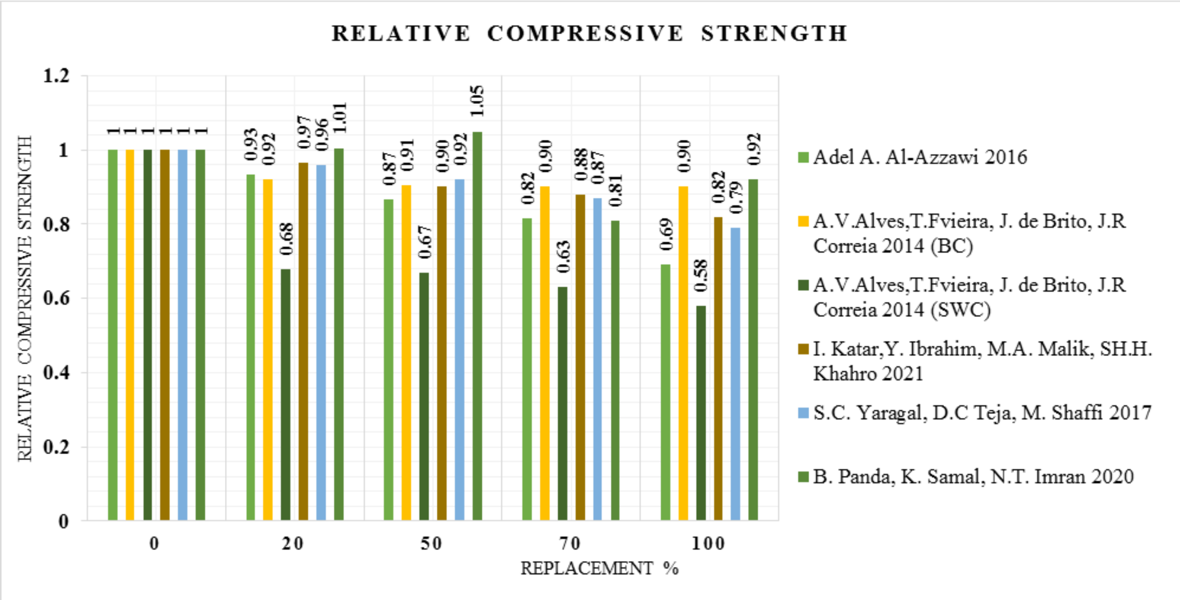

Chart 1 - Relative Compressive Strength

According to the experimental results of:
1. Adel A. Al-Azzawi 2016

The universal testing machine is used for testing the compressive strength of concrete according to ASTM C39M/2003 [15] for cylinders (f'c) measuring 150mm x 300mm and BS1881-116, 1997.Testing was conducted at 28 days, with three cylinders and three cubes evaluated each time. Chart 1 displays the results of compression tests conducted on concrete cubes and cylinders. This chart shows that as the percentage of recycled aggregate increases, compressive strength decreases. Using 100% recycled aggregate reduced concrete's compressive strength by approximately 30.9%. ACI 318/2014 [15] specifies that recycled aggregate concrete mixes can be utilized for structural concrete. The ratio of cylinder strength to cube strength declined by 11% as the recycled aggregate content increased from 0 to 100%. [5]

2. A.V.Alves, T.Fvieira, J. de Brito, J.R Correia 2014

The compressive strength test results (mean values – fcm – and standard deviations) for all the mixes and replacement ratios are given in Chart 1 for the experiments conducted from A.V.Alves,T.Fvieira, J. de Brito, J.R Correia 2014 , together with the relative percentage
difference compared to the reference concrete. Incorporating fine brick particles does not significantly alter compressive compared to conventional concrete. Using recycled sanitary ware aggregates reduces the attribute significantly. [6]

3. I. Katar,Y.Ibrahim, M.A. Malik, SH.H. Khahro 2021

Increased replacement ratio leads to reduced compressive strength. The drop in 28-day compressive strength was 21%, 24%, and 25% at the 25%, 50%, and 75% replacement levels, respectively. The minimum 28-day strength with 75% RCA replacement was 41.8 MPa, which is adequate for structural applications. [7]

4. S.C. Yaragal, D.C Teja, M. Shaffi 2017

It has been shown that when the percentage of RCA replacement increases, compressive strength falls. The compressive strength of the control mix without RCA was 32.7 MPa, which was lowered to 25.9 MPa with 100% RCA based concrete. 100% RCA-based concrete has a strength loss of about 20%. [8]

5. B. Panda, K. Samal, N.T. Imran 2020

According to the results, the compressive strength increased slightly with the addition of RCA, resulting in maximum compressive strength of 24 and 35 Mpa for concrete cubes created with 50% substitution of RCA for

7 days and 28 days curing periods, respectively. Furthermore, the compressive strength of concrete with 50% RCA replacement was comparable to that of control concrete (0% replacement), which was formed entirely of natural coarse particles.[9]

Fig 1. Concrete compression test.[17]

IV.2 RELATIVE SPLIT TENSILE STRENGTH

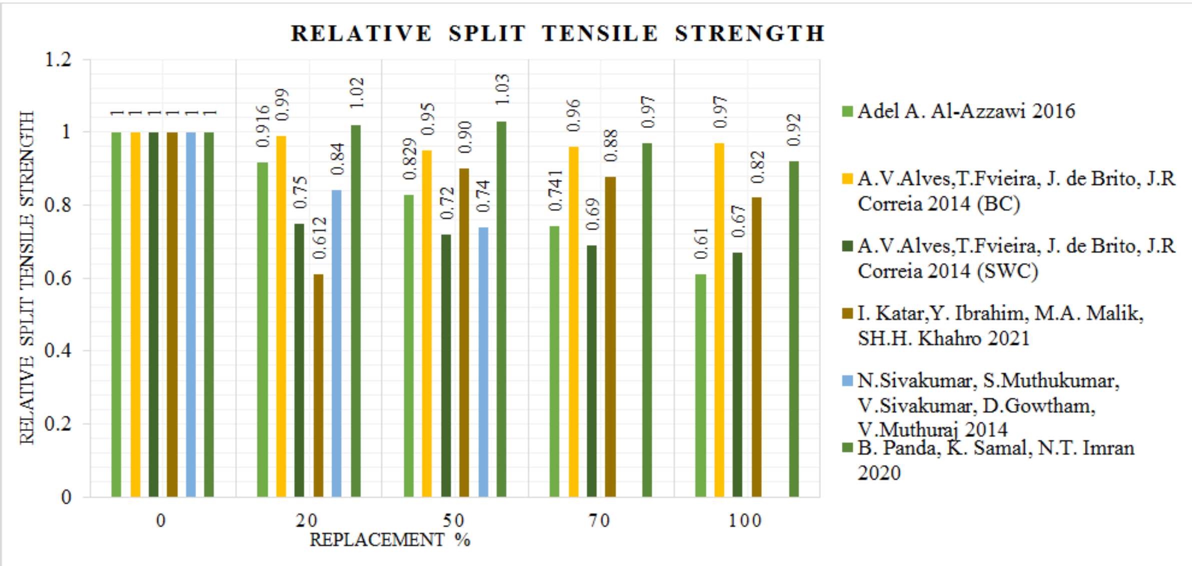

Chart 2 - Relative Split Tensile Strength
According to the experimental results of:

1. Adel A. Al-Azzawi 2016

The splitting tensile strength tests were carried out on concrete specimens in accordance with ASTMC496/ 2006 [13]. The results of tensile testing on concrete cylinders are displayed in Chart 2. This chart shows that as the percentage of recycled aggregate increases, tensile strength declines. When 100% recycled aggregate was employed, the tensile strength of concrete decreased by approximately 38.91%. The ACI 318/2014 [15] split cylinder strength equation (fct= $0.56\sqrt{f'c}$) underestimate the value of tensile strength for normal aggregate concrete by 6.55% and overestimate the value by 23.14 for 100% recycled aggregate concrete. It is not recommended to apply this calculation for recycled aggregate concrete with a percentage more than 50%. [5]

2. A.V.Alves, T.Fvieira, J. de Brito, J.R Correia 2014

As seen in the Chart 2 for the experiment performed A.V.Alves, T.Fvieira, J. de Brito, J.R Correia 2014, similar to the compressive strength trend, increasing the use of recycled ceramic aggregates leads to a decrease in performance. The reasons behind this Strength decreases are similar to compressive strength loss, resulting from increased porosity in the paste with higher replacement ratios. [6]

3. I. Katar,Y.Ibrahim, M.A. Malik, SH.H. Khahro 2021

Split tensile strength ranged from 1.9 to 3.3 MPa, with SCC-RCA25% having the lowest value of 1.9 MPa. Higher superplasticizer dosage in SCC-RCA25% caused a decrease in split tensile strength. A very flowable mixture. SCC-NCA, SCC-RCA50%, and SCC-RCA75% measured 3.1, 3.3, and 3 MPa, respectively. Split tensile strength readings are marginally lower compared to concrete mixtures with similar compressive strength. [7]

4. N.Sivakumar, S.Muthukumar, V.Sivakumar, D.Gowtham, V.Muthuraj 2014

The concrete specimen with 50% recycled aggregate and 0.4w/c ratio exhibited the lowest tensile strength (76%).The concrete specimen with 50% recycled aggregate (0.4 water/cement ratio) had a 24% loss in tensile strength, but still maintained 76% strength compared to 0% recycled. Aggregate concrete specimen. The concrete specimen with 50% recycled aggregate (0.34 water/cement ratio) had the highest tensile strength remaining. Although it lowers by 7%, it still remains 93% when compared to 0% recycled aggregate concrete samples. The reason is the decreased water cement ratio compared to other batches of concrete sample. [10]

5. B. Panda, K. Samal, N.T. Imran 2020

The aforementioned data clearly show that the concrete cylinder tensile strength followed the same trend as the compressive strength, reaching a maximum of 3.91 Mpa with 50% replacement of RCA. Furthermore, the tensile strength of concrete with 50% RCA replacement of RCA was close to that of the control concrete (0%). [9]

Figure 2 - Split Tensile Test [18]

V. CONCLUSIONS

-Recycling demolished concrete has substantial economic and environmental benefits.

-RCA can be converted into valuable resources for producing new concrete. This study evaluated the characteristics of RCA and RCA concrete. This study's conclusions are as follows:

-RCA is a viable alternative to NCA for producing durable and acceptable concrete. The biggest issue with using RCA in new concrete is its uneven quality, especially when obtained through demolition of old structures. However, RCA can be successfully used provided it meets conventional standards for natural aggregate. New specifications and recommendations are needed for RCA.

The physical qualities of RCA greatly impact the fresh and hardened properties of concrete.

-Aggregate abrasion, impact and the strength of concrete is affected by the crushing values of RCA. RCA's chemical characteristics can negatively impact its durability and performance in service situations. 100% RCA can generate acceptable quality concrete. RCA concrete typically has 80-90% the strength of equivalent NCA

concrete. RCA concrete's strength decreases due to its poor physical qualities and insufficiently dense transition zone with bulk cement paste.
- The use of recycled aggregate as a partial replacement for coarse aggregate affects tensile strength, compressive strength, and elastic modulus, with values varying according to the proportion of partial replacement. It is evident that the influence is basically minor for low substitution rates (25%). For higher percentages of aggregate replacement, all mechanical parameters fall as recycled aggregate content increases. The best value or proportion of recycled aggregates that can be used to replace standard coarse aggregates is 25%.
-Using RCA in a fresh concrete mix requires careful consideration since the recycled aggregates can lower concrete strength. The use of concrete with recycled aggregates should always take into consideration that it has, in most cases, a lower performance than conventional concrete.
-Up to 20% of virgin natural coarse aggregate can be replaced with recycled aggregate. To improve the performance of RCA concrete, adjust the water-to-cement ratio, add pozzolanic materials, use new mixing techniques, and allow for extended curing. RCA can also be used in high-quality concretes like high-strength, high-performance, and self-consolidating concretes with proper material selection and mix design.
-RCA emphasizes its fresh and toughened characteristics, as well as its durability.
-Additionally, RCA's chemical pollutants should be reduced to promote its use in the concrete sector.

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