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Partial Replacement of Coarse Aggregate by Demolished Concrete Aggregate

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Abstract:

Growing awareness of the substantial ecological changes calls for sustainable advancements in every sector. Since natural fine and coarse aggregates make up 70% to 80% of the volume of concrete, the manufacturing of concrete is one of the biggest users of natural resources. It is obvious that the enormous volume of concrete produced by the expanding building sector has a substantial influence on the environment and the usage of natural resources. As a result, it became clear that researchers should look into using recycled materials to replace the limited natural resources. This study looked at replacing some of the fine and coarse particles in concrete using trash from destroyed concrete structures and used for concreting for a mix proportions of M30 as a replacement for natural coarse aggregate in proportions of 0%, 20%, 40%, 60%, 80%, and 100% by weight of coarse aggregates, six concrete mixes containing 42 cube specimens and 12-cylinder specimens were casted and the various tests to be conducted on concrete such as compressive strength, split tensile strength at ages of 7, 14, and28 days. The results showed that the concrete's strength increased up to 60% replacement, but then it began to decrease beyond 60% replacement. The 60% replacement concrete was found to have the best strength. However, more research is required to ascertain the impact on durability and enhancement on workability.

Keywords — **Recycled Concrete Aggregate, Silica Fume, Durability test**

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I. INTRODUCTION

Concrete was discovered by the Minoan culture, which flourished around 2000 B.C. During the early days of the Roman Empire, in approximately 300 BC, the inhabitants of Rome discovered that they could make concrete, a hard, waterproof substance, by mixing lime mortar with volcanic ash. The most common building material on this planet is concrete. In fact, concrete is used in virtually everything and there is still no substitute available for huge of its applications.

Concrete is the prime construction material used in practice. Constituents of concrete are binding material (cement), fine aggregate and coarse aggregate and water. Because they are overused for building purposes, aggregates are a naturally occurring resource that is becoming less and less accessible every day.

Wastes from construction and demolition are among the most significant types of garbage produced globally. A staggering amount of aggregates are utilized in construction and the production of concrete. The structure will be dismantled after its useful life is ended, and all of the debris from the demolition process will end up in landfills.

In the last decade, amount of construction waste has considerably increased due to the demolition of old structures. Disposal of C&D waste is not only an environmental concern but also has a major influence on the conservation of natural resources by avoiding the excavation of raw material. Most of this waste goes into landfills. Some noninert waste materials in C&D waste (such as lead, tar, asbestos, paint, and preservative residues) may introduce environmental hazards over time.

Environmental advocacy groups are advocating for the utilization of RCA and solid wastes, including fly ash, slag, and silica fume, in building projects. By 2023, it is anticipated that the world's aggregate needs for construction would total 47 billion metric tons annually. The demand for concrete is continuously rising. In order to not only give a coarse aggregate substitute but also a waste management solution for concrete that has been removed. By using destroyed debris, we attempt to lower building costs concurrently.

Recycling is the process that takes waste items and turns them into raw materials that can be made into new products. The recycling process begins with the collection of recyclable items, which are sent to a plant where they can be sorted and prepared for reuse. 60%–70% of RA's volume is made up of natural aggregates, while 30%–40% is mortar made of leftover cement. Workability, mix percentage, parent concrete qualities, and other factors influence the compressive strength and other attributes of RCA. When compared to concrete with natural aggregates, the mechanical and durability performance of RCA is extremely poor. Natural coarse aggregates (NCA) are substituted, either whole or partially, with recycled coarse aggregates to create recycled aggregate concrete (RAC).

According to investigation made by Rakesh et al. (2023) of replacing varying percentage of coarse aggregate by recycled concrete aggregate with varying percentage of 25%, 50%, 75% & 100%. The test result shows that the compressive strength of 25% & 50% of demolished concrete aggregates are near to the value of standard concrete. The optimum replacement is in b/w 25% to 50%. Up to 50% replacement good compressive strength can be achieved. 100% replacement of course aggregates the workability of decrease.

The present research focused on the use of partial replacement of coarse aggregate by demolished concrete waste at various proportions with addition of silica fume as a replacement of cement as constant and also use SP-430 as chemical admixture as constant to increase workability of the concrete. The effect of using different percentages recycled concrete aggregate as replacement for the coarse aggregate in the concrete mix was experimentally investigated and the optimum percentage of replacement that results in the best possible mechanical properties of produced concrete was proposed.

II. MATERIALS

Different materials were used in the present experimental program:

- Cement
- Natural coarse aggregates (NCA)
- Recycled concrete aggregate (RCA)
- Fine aggregate
- Silica fume
- Water.

A. Cement:

The cement utilized in this experiment is Ultratech Ordinary Portland Cement, which is classified as Grade 53 and its other properties in accordance with the requirements of IS 12269-1987.

TABLE I
PROPERTIES OF CEMENT

Sl.no	Physical properties of cement OPC 53 grade	Result
1.	Standard consistent value	31 percentage
2.	Initial setting time	42 minutes
3.	Final setting time	510 minutes
4.	Specific gravity	3.15
5.	Fineness (<90 microns)	2 percentage
6.	Soundness (Le Chatliers Apparatus)	1.6mm expansion

B. Natural coarse aggregates (NCA):

For the project, coarse material with a 20mm size is obtained locally in the form of crushed stone aggregate. Below is a table with coarse aggregate's characteristics.

C. Recycled concrete aggregate (RCA):

Crushed concrete made out of aggregate pieces covered in cement mortar or paste is known as recycled concrete. When compared to a normal aggregate, the destroyed aggregate exhibits more abrasion loss, lower bulk density, decreased specific gravity, and pozzolanic properties in the test results. Below is a table with recycled concrete aggregate characteristics compared with normal coarse aggregate.

TABLE II
PROPERTIES OF NCA AND RCA

Sl.no	Physical Properties	Natural coarse aggregate	Recycled Concrete aggregate
1.	Specific gravity	2.87	2.68
2.	Impact value	13.23	24.26
3.	Water absorption	1.00	3.52
4.	Bulk density	0.72	1.39
5.	Abrasion test	13.4	14.6
6.	Size	20mm	20mm

D. Fine aggregate:

The code IS 383:1970 should be consulted in order to comprehend the fine aggregate definition. Natural sand or broken stone make up the majority of fine aggregates, which are typically screened using a 9.5 mm screen. Natural sand or broken stone make up the majority of fine aggregates, which are typically screened through a 3/8-inch screen. Natural sand that has been cleaned and sieved to eliminate particles bigger than 4.75 mm is known as fine aggregate.

TABLE III
PROPERTIES OF FINE AGGREGATE

Sl.no	Characteristics	Fine aggregate
1.	Specific Gravity	2.65
2.	Fineness Modulus	2.74
3.	Water Absorption	0.55%
4.	Density	1765kg/m3

E. Silica Fume (SF):

Silica fume is one of the most significant types of supplementary cementitious material used in the concrete as a partial replacement of cement, which was used to improve the strength and durability of the concrete. Industry waste is utilized to improve the properties of concrete as well as to minimize the environmental pollution.

F. Water:

A water-to-cement ratio (W/C) of 0.43 was utilized in the preparation of the concrete, and portable water was utilized for both mixing and curing.

III. METHODOLOGY

Designing the concrete mix was carried out in compliance with IS:10262-2019. The mix ratio utilized in this project is 1:1.42:2.677. The volume of cement, fine aggregate, and coarse aggregate are approximated using this proportion value. For the coarse and fine aggregate, Ordinary Portland Cement (OPC-53GRADE), decent stone aggregate, and natural sand were utilized. In this study, cubes measuring 150 x 150 x 150 mm and cylinders measuring 150 mm in diameter and 300 mm in height were cast using Demolished Concrete Aggregate (DCA) in place of coarse aggregate at weights of 20%, 40%, 60%, 80%, and 100%. Additionally, 13% silica fume was used in place of cement to increase the strength before additional tests, such as workability, were carried out before casting.

IV. MIX DESIGN

Concrete mix design for M30 grade is done as per code IS: 10262-2019. The results obtained from the concrete mix design are tabulated.

TABLE IV
MIX PROPORTIONS

Weight	W/C	Cement	Fine aggregate	Coarse aggregate
Kg/m3	192	447	637	1196
Ratio	0.43	1	1.42	2.677

V. TEST ON CONCRETE

G. Compressive strength test:

A compressive strength test can be used to determine the quality of concreting work. Typically, cube test sizes of 150 x 150 x 150 mm are utilized. To ensure there are no voids, this concrete is carefully poured into the mould and adjusted. These moulds disappear within a day. Test specimens are cured by submerging them in water. This specimen has to have a nice, even top surface. The entire surface of the specimen is covered with cement paste, which is applied smoothly. After 7 days, 14 days, and 28 days of curing, these specimens are put through a compression testing equipment. The compressive strength of concrete is calculated by dividing the load at failure by the specimen's cross section area. Every value displayed is the mean of two measurements.

Compressive strength = P/A (N/mm2)

Where,

P - Load (N)
A - Area (mm^2)

H. Split tensile strength:

A measurement of a material's resistance to a force that would normally cause it to break. It is stated as the least force per unit area, or tensile stress, required to cause the material to split. The cylinders' split tensile strength was evaluated using a CTM (Compressive Testing Machine), which applies a load to the specimen until it breaks under tension. The load at which the failure occurs is known as the split tensile strength. Concrete cylinders with nominal dimensions of 150 mm in diameter and 300 mm in height were cast for this investigation. The concrete cylinder was cast in this investigation using seven different mix proportions, and the split tensile strength for seven, fourteen, and twenty-eight days was measured. The test results are tabulated below.

Split tensile strength = $\mathbf{2P/\pi dl}$ (N/mm2)

Where,

P - Load (N)
D - Diameter of specimen (mm)
L - Length of the specimen (mm)

I. Saturated water absorption (SWA):

Concrete durability can be determined, among other things, by measuring its absorption capacity. 100 mm cubes were used for the SWA test in accordance with ASTM C642-13. The test specimen underwent a 24-hour curing period at 110ºC in an oven after 28 days. After being in the oven for a full day, the specimen was removed and allowed to cool in dry air. W1 was determined by measuring the specimen's dry mass. Next, water was added to completely submerge the concrete sample. Periodically, the sample was removed, its surface dampness was removed with a fresh cloth, and it was weighed. The weights were kept constant (completely saturated) by repeating this process, at which point W2 was determined. Then the SWA of the specimen is calculated using the equation.

SWA after immersion (%) = $\mathbf{W_2 – W_1 / W_1 \times 100}$

where,

W_1- mass of oven dried sample in air, g
W_2 - mass of saturated surface dry sample in air after immersion, g

J. Porosity:

The amount of pores occupied in the entire volume of a concrete specimen is known as porosity, and it is measured in percentage. It may be computed using the following equation. When oven dried at 105°C, the volume of water lost represents the volume of voids. Below graph is used to represent both SWA and porosity results.

Porosity = $\mathbf{(W_2 – W_1 / V) \times 100}$

Where

W_1- mass of oven dried sample in air, g
W_2 - mass of saturated surface dry sample in air after immersion
V – Volume of sample

K. Acid Resistance:

Cubes of size 100 mm, containing the following proportions: FA, NCA, RCA, silica fume, cement, and water (may be added) were cast and cured in water for 28 days. Following a 28-day water curing period, the specimens were let to dry in the open for one day before their dry weight was determined. To counteract acid assault, distilled water with a pH of 2 was mixed with 3% sulfuric acid by volume. After that, the cubes were placed in the acid solution and left for a full 28 days. By routinely replacing the acid solution, the concentration and pH of the solution were maintained during this time. The specimens were dried, weighed, and recorded after 28 days of curing.

VI. RESULTS AND DISCUSSION

L. Compressive Strength

TABLE V
COMPRESSIVE STRENGTH RESULTS

Sl.no	Replacement percentage	7-days (N/mm2)	14-days (N/mm2)	28-days (N/mm2)
1.	RCA 0%	19.04	24.97	31.58
2.	RCA 20%	19.80	25.02	33.57
3.	RCA 40%	20.66	27.05	34.44
4.	RCA 60%	22.24	28.168	36.19
5.	RCA 80%	21.04	26.14	32.7
6.	RCA 100%	15.91	17.89	25.07

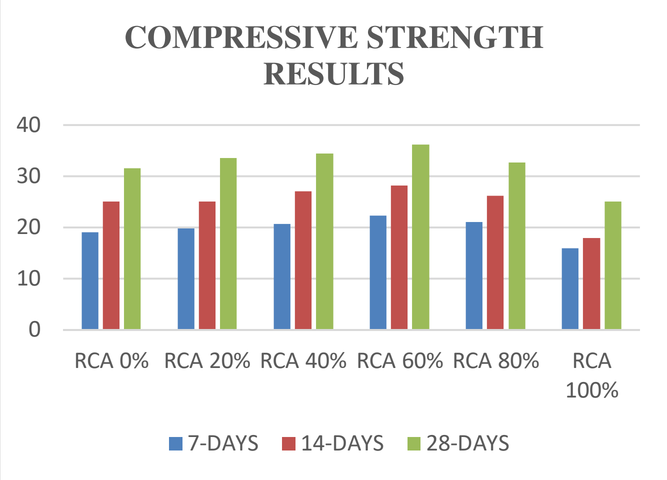

Fig 1 The compressive strength results of 7, 14, 28 days of different proportions of M30 grade are shown in chart.

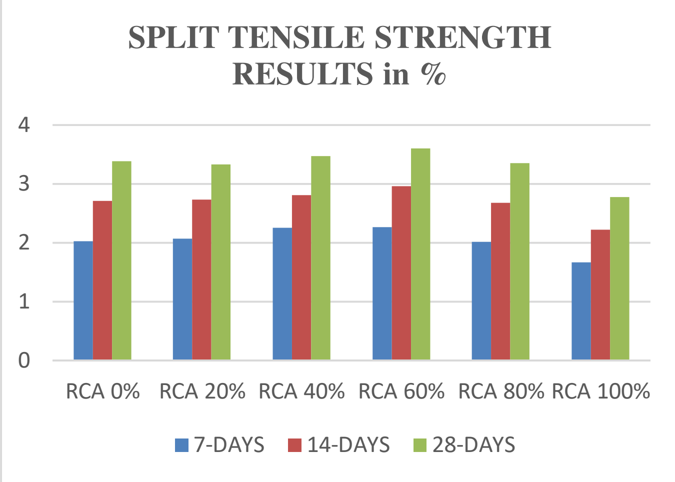

Fig 2 This graph shows the split tensile strength test of different proportions of M30 grade concrete.

Comparing RCA replacement to regular concrete, the results indicate that up to 60% replacement can be advantageous and even enhance compressive strength. Strength declines and advantages become less beyond this stage. The substantial strength loss after 100% RCA substitution emphasizes how crucial recycled aggregate quality is. The overall performance of the concrete may be impacted by the RCA's potential inferior mechanical and physical qualities as compared to natural aggregate. It is permitted to replace an RCA up to 60%.

M. Split tensile strength:

TABLE VI
SPLIT TENSILE STRENGTH RESULTS

Sl.no	Replacement percentage	7-days (N/mm2)	14-days (N/mm2)	28-days (N/mm2)
1.	RCA 0%	2.028	2.704	3.38
2.	RCA 20%	2.065	2.731	3.33
3.	RCA 40%	2.254	2.81	3.469
4.	RCA 60%	2.26	2.953	3.602
5.	RCA 80%	2.01	2.68	3.350
6.	RCA 100%	1.662	2.216	2.77

The data shows that compressive strength generally improves with RCA up to 60% replacement, peaking at 2.26 N/mm² at 7 days, 2.953 N/mm² at 14 days, and 3.602 N/mm² at 28 days. Beyond this, strength decreases, particularly at 100% RCA replacement, where strengths are notably lower (1.662 N/mm² at 7 days, 2.216 N/mm² at 14 days, and 2.77 N/mm² at 28 days). This suggests RCA's positive impact is optimal up to 60%, with diminishing returns beyond that.

N. Saturated water absorption (SWA):

TABLE VII
SATURATED WATER ABSORPTION (SWA) RESULTS

Replacement percentage	0%	20%	40%	60%	80%	100%
Saturated water absorption (%)	2.67	1.764	1.70	1.74	1.40	1.20

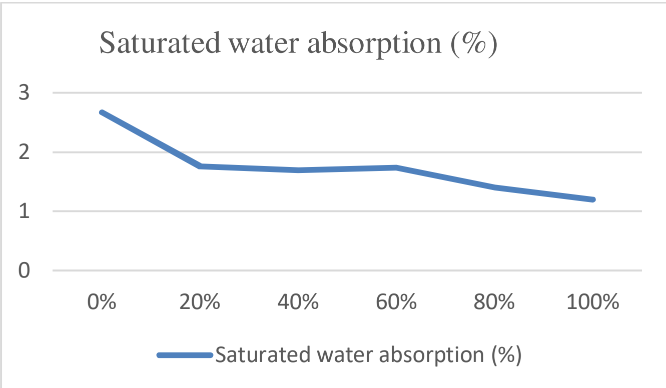

Fig 3 Graph represents the Saturated Water Absorption

The data indicates that saturated water absorption of aggregates decreases with increasing RCA replacement. Starting at 2.67% for 0% RCA, it drops to 1.20% at 100% RCA. This reduction suggests that recycled aggregates absorb less water as the replacement percentage increases. Lower water absorption in RCA at higher replacement levels might be due to the reduced porosity or better quality of the recycled material, which could influence the concrete's overall performance.

O. Porosity:

TABLE VIII
POROSITY RESULTS

Replacement percentage	0%	20%	40%	60%	80%	100%
Porosity	6	4.2	4	4.1	3.2	4.5

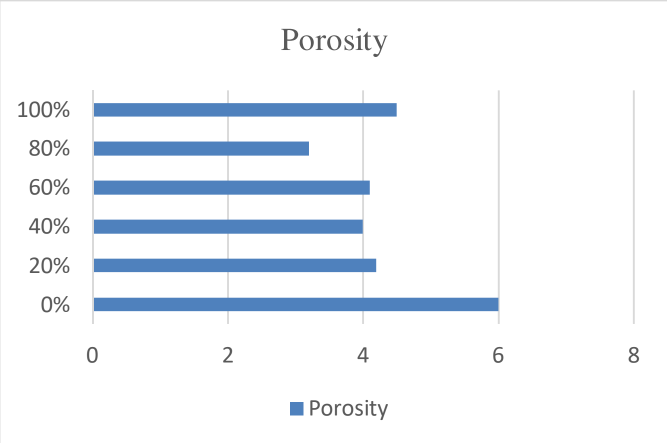

Fig 4 This chart represents the percentage of porosity

The data shows that porosity decreases from 6% at 0% RCA to 3.2% at 80% RCA, suggesting improved aggregate density with higher RCA percentages. However, it increases to 4.5% at 100% RCA, indicating that excessive RCA replacement may negatively impact the aggregate's structural integrity. The optimal porosity appears to be between 40% and 80% RCA, balancing improved density and structural performance.

K. Acid Resistance:

TABLE IX
TEST RESULTS OF ACID RESISTANCE

Sl. No	Percentage loss in weight of conventional concrete at 28 days	Percentage loss in weight of optimum replacement concrete at 28 days
1.	12.5%	7.2%
2.	14%	8.84%
3.	15.6%	6.75%

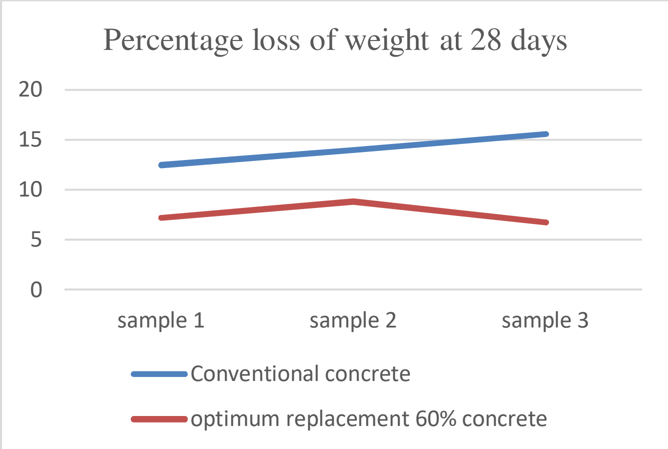

Fig 5 This graph shows the percentage loss of weight due to acid.

The data shows that concrete with optimum RCA replacement of 60% replacement exhibits a lower percentage loss in weight at 28 days compared to conventional concrete. Specifically, conventional concrete loses between 12.5% and 15.6% of its weight, while the optimum replacement concrete loses between 6.75% and 8.84%. This indicates that the optimized RCA mix performs better in terms of weight retention, likely due to improved aggregate properties and reduced porosity.

VII. CONCLUSION

The study mentioned above led to the results listed below.

- A further method of converting waste into useful resources is to replace part of the coarse aggregates with recycled concrete.
- The amount of waste that ends up in landfills and the pollution it produces can be reduced by removing the trash from destroyed buildings and utilizing it as coarse aggregate.
- An experimental study was carried out using different ratios of mixtures to replace coarse aggregate in demolition trash. The compressive and split tensile strengths of this

mixture are contrasted with those of traditional M30 concrete.

- The major goal is to determine the proportion of material substituted in concrete that increases its strength by examining the effects of replacing coarse aggregates, both partially and completely, with demolition trash.
- We may infer from the previously mentioned graph and flow chart analysis that replacing coarse aggregate with 60%–80% more demolition trash will boost compressive strength. These two replacement percentages provide good strength in comparison to alternative replacement when compared to traditional concrete. A replacement ratio of 60% is ideal.
- Our analysis of the flow chart and the preceding graph leads us to the conclusion that replacing coarse aggregate with 60%–80% more demolition trash will boost split tensile strength. These two replacement percentages, when compared to normal concrete, provide considerable strength in comparison to other alternatives. 60% is the ideal replacement ratio.
- From the above investigations states that the saturated water absorption (SWA) and porosity tend to decrease. This trend suggests that incorporating RCA can potentially improve the resistance of concrete to water penetration and reduce its porosity, which are favourable characteristics for enhancing durability and performance of concrete structures.

- RCA helps reduce the environmental impact of concrete production. By recycling concrete from demolished structures, you decrease the need for virgin materials and minimize the waste sent to landfills.
- Reusing RCA conserves natural resources such as gravel and crushed stone, which are finite and require energy-intensive processes to extract and process.
- The production of conventional aggregates often involves significant carbon emissions. RCA can lower the overall carbon footprint of concrete production, contributing to more sustainable construction practices.
- In some cases, RCA can be less expensive than natural aggregates, particularly if it is locally available and the infrastructure for processing and transporting it is already in place.
- The processing of recycled concrete can be less energy-intensive compared to the extraction and processing of virgin aggregates, leading to lower energy consumption.

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