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Physical and mechanical properties of construction and demolition waste

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Abstract: Construction and demolition waste is produced every day around the world posing a great disposal problem. Thus, the idea of using wastes in different forms appears to be an effective approach to waste disposal. The various materials that can be reclaimed from construction and demolition waste include recycled concrete aggregates (RCA), crushed brick (CB), reclaimed asphalt pavement (RAP), waste excavation rock (WR), fine recycled glass (FRG). The assessment of the recycled concrete aggregates is identified by performing various tests, which indicate physical, chemical and mechanical properties of the materials. The physical properties test results indicated that the recycled aggregates showed good performance in comparison with the natural ones. The results of the test assessing mechanical performance of concrete with recycled aggregates also indicated better performance when required measures are taken, such as (i) The aggregates to be used are obtained from recycled materials the sizes of the fine aggregates can be controlled as per the requirement during demolition process and by sieving. (ii) The water absorption capacity of the recycled fine aggregates is higher than the natural fine aggregates and this water absorption capacity can be reduced by wetting and drying the aggregates. (iii) The performance of recycled coarse aggregates can be enhanced by removal and separation of the old hardened mortar which adhered to the aggregates obtained post-demolition. (iv) The performance can also be enhanced by the usage of suitable commercially-available plasticiser to reduce the higher water absorption ratio of the recycled aggregates to attain the required strength.

1. Introduction

The study deals with the identification of reusable material salvaged from construction and demolition waste which supports to reduce the usage of natural materials. Previous research has evaluated the sustainability of C&D waste materials in various civil engineering applications such as pavements, ground improvement, pipe backfilling and concrete applications.

The compressive strength of various concrete mixes by using RCA in different replacements with natural aggregates [1] was evaluated and observed loss in compressive strength of concrete is in between 18 % to 39 %. The requirement of cement is more [2] when concrete is produced using recycled aggregates than conventional concrete to obtain the same compressive strength. The loss in strength was evaluated for concrete produced with recycled aggregates [3] and it is found that the negative influence of the use of RCA partially fades over time. The modulus of elasticity of concrete produced from RCA was less than the modulus of elasticity of conventional concrete [4] and a decrease in the elastic modulus was observed. The complete replacement of natural aggregates with RCA keeping the water/cement ratio and cement content constant, a loss in 28-day compressive strength was observed [5]. The compressive strength of various concrete mixes produced using fine aggregate from recycled concrete [5] was found to be similar to the conventional concrete. The use of fine aggregate from recycled concrete was found to be viable [6] since it does not lead to a significant loss in mechanical and durability properties. The performance of construction waste as material for the base of pavement layers [7] was found to be satisfactory and is possible to produce

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the same effect as that of the natural aggregate when the waste material is free from impurities. The influence of superplasticizers on the compressive strength of concrete with fine recycled aggregate was evaluated [8] and it was found that there is an increase in the compressive strength due to the incorporation of superplasticizers. The use of recycled concrete aggregates in pavement applications [9] as a subbase material was found to be satisfactory whereas the usage of crushed brick, recycled asphalt and fine recycled glass requires to be blended with additives for better performance. The usage of recycled materials from C&D waste in embankment fills [10] resulted that the recycled material can be used in the production of mortar and does require washing as long as the recycled material exhibits similar properties to that of natural materials. The performance of concrete produced from recycled aggregates [11, 12] was found to reduce when the ratio of recycled aggregates to the natural aggregates increases and the influencing factors are identified as the source of material and its composition. The mechanical performance of concrete produced using recycled fine aggregate [13] was found to be workable enough to be used in construction and can be used in the construction of members which do not carry much load like walls, hollow bricks etc. The behaviour of recycled aggregates in soil improvement [14] was found to depend on the addition rates of material and needs extensive research to make it a cost effective and sustainable approach. The performance of recycled concrete aggregates and recycled brick aggregates in concrete production [14] was evaluated and found that the performance of recycled concrete aggregates was satisfactory and the performance of recycled brick aggregate can be improved by controlling the particle size distribution.

Recent generation of large amounts of waste produced all over the world has imposed significant pressure on the environment. Waste is being produced from different sources like households, industries, hospitals, construction and demolition of structures which can be categorized into the following:

- Domestic/Municipal waste
- Industrial waste
- Hospital waste
- E-waste
- Construction and demolition (C&D) waste

Construction waste is defined as the waste from the construction, remodeling and repairs of structures i.e., buildings, transport infrastructure and other civil engineering structures.

Demolition wastes are defined as the wastes obtained from the demolition of buildings and roads. The amount of C&D waste being generated all over the world is now gaining concern regarding its production and management.

In India, on an average 28 million tons of C&D waste was produced (as per 2016 estimates), with 11 million tons in the best case and 43 million tons in the worst case scenario. The C&D waste being produced is contributed more from the rural areas ranging between 50 – 80%. The estimates of C&D waste generation in India is shown in the below Table 1.

Table 1. Estimates of C&D waste generation in India [15].

	Estimated volume (million tons)
Metro city demolition	15.0
Industrial demolition	4.0
Demolition waste in Urban locations	3.0
Roads, old highways, old bridges	2.5
Repairs and modifications	1.0
Construction debris	2.0
Miscellaneous unaccounted debris	0.5
Total	**28.0**

The traditional method of managing C&D waste is to dispose it off in landfills. However, the need to recycle and reuse the C&D waste is a global concern due to the following reasons:

- Environmental pollution being caused due to its disposal.
- Scarcity in the availability of natural materials.

- The increasing proportion of waste materials in landfills and its disposal cost in many countries.

Granite polishing waste (GPW) was used as sand replacement [16] and the results showed that adding a suitable amount of GPW as sand replacement would, apart from reducing waste disposal and sand consumption, also improved mortar performance by filling the voids between sand particles to decrease the voids ratio and porosity and increase the packing density and water film thickness and improve the rheology and impermeability. The physical characteristics of three types of commercially crushed concrete and brick materials [17] were presented two of them being similarly based crushed concrete materials with different degrees of processing and one being crushed brick. Their results showed that there are similarities and differences between the two concrete-based materials and the characteristics of the brick-based materials are significantly different from the crushed concrete materials. The effect of different concentrations of C&D waste (0%, 10%, 20%, 30%, and 50%) as coarse aggregates in concrete as substitute to virgin aggregates on workability, compressive, tensile, and flexural strengths was investigated [18] at the water-to-cement (W/C) ratios of 0.40, 0.45 and 0.50. The strengths were measured at the ages of 7 and 28 days. The results proved that C&D waste has no significant effect on compressive strength, while its negative impact on workability was palpable. With respect to tensile and flexural strength, just 50% of C&D waste led to significant reduction.

The feasibility of using aggregate from recycled C&D waste for urban road embankment applications based on the Sanhuan road construction project in eastern Xi’an (China) was evaluated [19]. The effect of curing on the strength of the C&D waste was investigated using unconfined compression strength (UCS), California bearing ratio (CBR), and deflection tests. The results showed that the C&D waste has the characteristics of high strength and significant stability after simple treatment and further suggest that the use of these materials for paving urban road embankments is feasible.

The feasibility of using aggregate from Recycled Construction and Demolition Waste (RCDW) in pavement applications was evaluated [20] with the help of laboratory experiments. The results revealed that the composition and the compactive effort influenced the physical characteristics of the RCDW aggregates. The compaction process promoted a partial crushing and breakage of RCDW aggregates changing the grain-size distribution and increasing the percentage of cubic grains and this physical change contributed to a better densification of the RCDW aggregates and consequently an improvement in bearing capacity, resilient modulus and resistance to permanent deformation was observed. It was concluded that the RCDW aggregates may be utilized as coarse base and sub-base layer for low-volume roads.

The main difficulties observed with recycled aggregates (RA) in concrete, such as high levels of water demand, porous structure, and low mechanical strength, occur in RA alkali-activated concretes [21]. These are associated with the highly porous nature and defects of RA. It was observed that the high calcium concentration of RA affects the binder gel products, accelerates the hardening rate of the concrete, and reduces the flowability of alkali-activated concretes.

Mortars produced with recycled fine aggregates achieved a compressive strength of 5.20MPa after 28 days [22] which is the minimum requirement for a Type III mortar, consequently they could be used in the manufacturing of masonry mortar. The recycled coarse aggregate originating from pre-cast floor elements could possibly be used in the production of structural concrete for medium and low aggressive environments when concretes were made with 50% and 100% of recycled coarse aggregates in substitution of the natural aggregates. respectively.

The possibility of construction of concrete pavements with a high rate of recycled concrete aggregate [23] was explored. A series of fatigue tests were conducted on concrete. In the first case the coarse natural aggregates were replaced with recycled aggregates, while in the second case all the granular skeleton (sand and coarse particles) were replaced. The tests carried out confirmed that high recycling rates lead only to a slight deterioration in the fatigue behaviour of pavement concretes.

The different applications that are presently [24] practiced to optimize the recovery and/or application of CDW for reuse were summarized, and various measures and strategies to improve the processing of CDW were proposed. It was suggested that to enhance environmental effectiveness, a conscious and comprehensive C&DW management plan should be implemented in each jurisdiction.

Using supplementary cementitious materials and recycled aggregates (from 30 to 50 %) a strength equivalent to natural aggregate concrete was achieved [25].

The core principles were synthesized and the best practices were linked for the management of construction and demolition waste across the entire construction value chain, and it was observed that a systematic implementation of the best practices could dramatically improve resource efficiency [26] and reduce environmental impact by: reducing waste generation, minimizing transport impacts, maximizing re-use and recycling by improving the quality of secondary materials and optimizing the environmental performance of treatment methods.

The economic viability is likely to occur when the cost of landfilling of CDW exceeds the cost of bringing the waste to the recycling centre [27] and the cost of using primary aggregates exceeds the cost of using recycled aggregates. It was demonstrated that recycling centres benefit from economies of scale implying that an increase in the scale of a centre, in turn results in a decrease in recycling costs.

Results of research designed to characterize the physical and chemical properties of fine recycled aggregates for concrete production and their relationship with mineralogical composition and pre-processing were discussed [28]. The constraints of the incorporation of fine aggregates in reinforced concrete were also discussed. It was shown that, unless a developed processing diagram is used, this application is not feasible.

The chemical–mineralogical appraisal of construction and demolition waste indicated that the recycled grain-size fraction 0.60–0.125mm could be directly re-employed [29] in the preparation of new mortar and concrete, while finer fractions could be considered as components for industrial processing in the preparation of cements and bricks/tiles. A study [30] indicated that the use of construction and demolition waste aggregates in percentages of up to 20 % for paving urban roads is feasible.

The analysis of the durability performance of CDW concluded that the use of RA is highly detrimental. This is mostly true when fine RA (recycled aggregates) are used [31]. The carbonation resistance is the property most affected by the use of RA, leading to increase in the carbonation depth between 22.2% and 182.4% for the various RA types. However, the most influencing factor is by far the RA’s composition.

A range of case studies undertaken in several countries worldwide were used [32] to highlight the technical viability and appropriateness of using recycled aggregates in a broad range of construction applications.

As approximately 13.71million tons of C&D waste was generated in 2012 in Shanghai, of which more than 80% of this C&D waste was concrete, bricks and blocks [33], it was suggested to implement proper recycling technologies and measures. And researchers should take it up as an important responsibility of formulating precise policies and specifications to this effect.

A vertical impact crusher was used for the production of high quality recycled sand [34] which resulted in the production of low-porosity sand from construction and demolition waste.

Normalized laboratory tests to assess the performance of standard mortars were used to demonstrate the technical feasibility of recycling the waste produced by the ceramics industry and from the demolition of red-clay bricks or tiles to produce mortars with less/no consumption of natural aggregates [35]. Up to a replacement ratio of sand with ceramic waste of at least 20% the results were encouraging. It is widely accepted that the recycling and reuse of C&D materials will reduce the demand for scarce virgin natural resources and simultaneously reduce the quantity of waste material that is being disposed [36].

The primary aim of this research paper is the identification of gainful utilization of materials which are reclaimed from the waste obtained from construction and demolition sector. It also aims at finding various alternative methods to use the recycled materials to the full extent and what methods can be adopted to meet the expected results.

2. Methods

The performance of the materials reclaimed from construction and demolition waste is found by performing various tests. The test results obtained suggest the application of materials in various fields. During the execution of work, the following phases are adopted which are presented in Fig.1 below.

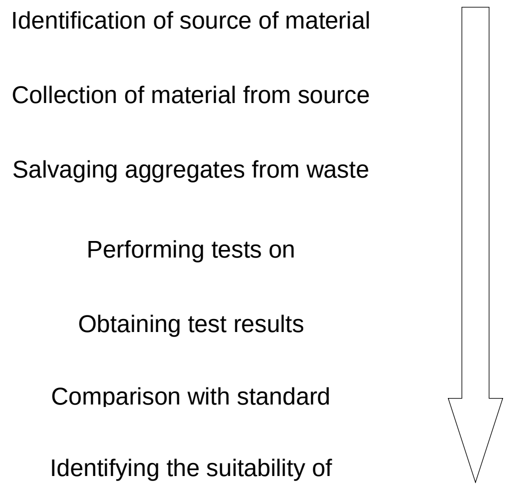

Figure 1. Phases of work

The source of materials was identified and large chunks of concrete from demolished waste was obtained. The concrete chunks were further broken into smaller fragments to reclaim aggregates, both fine and coarse aggregates.

The different tests that were conducted on the aggregates reclaimed are as follows:

- Sieve Analysis
- Specific Gravity
- Water Absorption
- Angularity Number
- Aggregate Impact Value test
- Aggregate Crushing Value test

The results from the above tests performed determine the suitability of materials in transportation and geotechnical perspectives. The suitability of materials in construction field is assessed by studying the behaviour of concrete which include compressive strength, splitting tensile strength and flexural strength of concrete.

The Compressive strength of concrete is found by testing cubes of size 150 mm x 150 mm x 150 mm which are cast and cured for 7 and 28 days. The test on cylinders of size 150 mm in diameter and 300 mm in height reveal the performance of concrete in tension. The behaviour of concrete in flexure can be understood by testing prisms of size 500 mm x 100 mm x 100 mm [37-39]. Review of earlier works indicated that in the study of recycled aggregates from waste, the aggregates used in concrete mix were either coarse aggregates or fine aggregates.

The present study aims at maximum utilization of aggregates reclaimed from waste and adopted the usage of both coarse and fine aggregates in concrete mix which also paves way for the behavioural assessment when both fine and coarse aggregates are used. In this study the concrete behaviour is studied by adopting five different proportions of coarse aggregates. The recycled coarse aggregates are replaced in the following ratios:

- 0 % – all natural coarse aggregates
- 25 %
- 50 %
- 75 %
- 100 %

The recycled concrete sand i.e. the fine aggregate is used at full level i.e. 100 %.

The mix design opted for study is M20 in which the coarse aggregates (CA) are replaced in the above stated percentages and fine aggregate (FA) is replaced completely. As the fine aggregate has a higher water absorption ratio, the water–binder ratio is fixed as 0.62 with the usage of 1 % superplasticizer Conplast 430.

The different proportions of recycled coarse aggregates (RCA) used are presented in the table below:

Table 2. Representations of different proportions of RCA.

% of RCA	Representation
0	C_0
25	$C_{0.25}$
50	$C_{0.5}$
75	$C_{0.75}$
100	C_1

The representation of recycled fine aggregate (RFA) used in the mix is represented as follows:

Table 3. Proportion and representation of RFA.

% of RFA	Representation
0	S_0
100	S_1

The representation of the mixes which constitute the various proportions of aggregates specified above are as follows:

Table 4. Composition and representations of different mixes.

% of RCA	% of RFA	Representation
0	0	C_0S_0
0	100	C_0S_1
25	100	$C_{0.25}S_1$
50	100	$C_{0.5}S_1$
75	100	$C_{0.75}S_1$
100	100	C_1S_1

3. Results and Discussion

The results obtained from different tests performed on the materials reclaimed from the construction and demolition waste indicate their behavior and their further usage in various fields. The results also bring a contrast with the standard results so as to identify the effect of re-using the reclaimed material and develop suitable measures to increase their applications.

The results of various tests on aggregates are presented in the Table 5 below:

The values presented in the Table 5 are in close agreement with similar work done by past researchers [11, 36, 40-43].

Table 5. Test Results of aggregates (Natural and Recycled).

Test Conducted	Result
Fineness modulus of NFA	2.68
Fineness modulus of RFA	2.65
Specific Gravity of NCA	2.81
Specific Gravity of RCA	2.70
Specific Gravity of NFA	2.81
Specific Gravity of RFA	2.67
Water Absorption of NCA	0.5%
Water Absorption of RCA	3.15%

Test Conducted	Result
Water Absorption of NFA	1.2%
Water Absorption of RFA	13%
Angularity Number of NCA	7
Angularity Number of RCA	8
Aggregate Impact Value of NCA	14%
Aggregate Impact Value of RCA	18.75%
Aggregate Crushing Value of NCA	18%
Aggregate Crushing Value of RCA	21.86%

3.1. Physical properties

A sample of fine aggregates obtained from crushing of concrete chunks is taken, sieved and grain size distribution curve is plotted which indicated that the material is well graded. On comparison with standards specified by IS 383-1970, the material is categorized under Zone 2.

The figure below shows the grain size distribution curve plotted between grain size (in mm) and % finer.

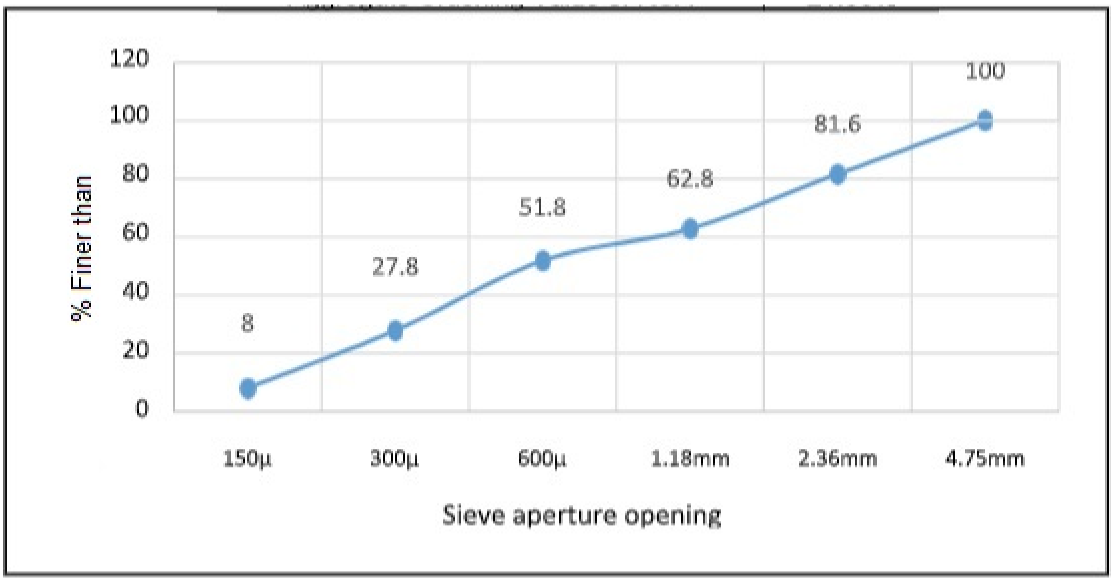

Figure 2. Particle size distribution curve.

The results obtained from specific gravity and water absorption test revealed that the water absorption of recycled aggregates is high [44] and it indicates that the amount of water to be added to the concrete mix to attain suitable workability and strength is more which increases the water–binder ratio than specified by the design code IS 456:2000. And the values of water absorption being high has also been confirmed by many researchers [6,12, 40].

The Aggregate Impact Value Test result indicates that the resistance offered by the reclaimed aggregates from waste is good and the aggregates can be reused in concrete for wearing surface of the pavements. These values are in agreement with the work of past researchers [44] and the code (IS 383:1970).

The Aggregate Crushing Value Test result also indicates that the reclaimed aggregates are resistant to compressive load applied gradually and as the value is less than 30 %, it can be used in road construction. These values are in agreement with the work of past researchers [44] and the code (IS 383:1970).

3.2. Mechanical properties

The mechanical behaviour of the aggregates reclaimed from the construction and demolition waste is studied by incorporating the aggregates in concrete mix in various proportions. The strength parameters are observed in compression, tension and flexure. The table below shows the compressive strength of cubes at 7 and 28 days for various replacements of aggregate.

Table 6. Compressive strength of concrete.

Representation	Compressive Strength (MPa)	
	7 days	28 days
C_0S_0	22.5	28.66
C_0S_1	19.11	28.14
$C_{0.25}S_1$	18.74	27.99
$C_{0.5}S_1$	18.66	27.85
$C_{0.75}S_1$	18.52	25.92
C_1S_1	18.11	24.29

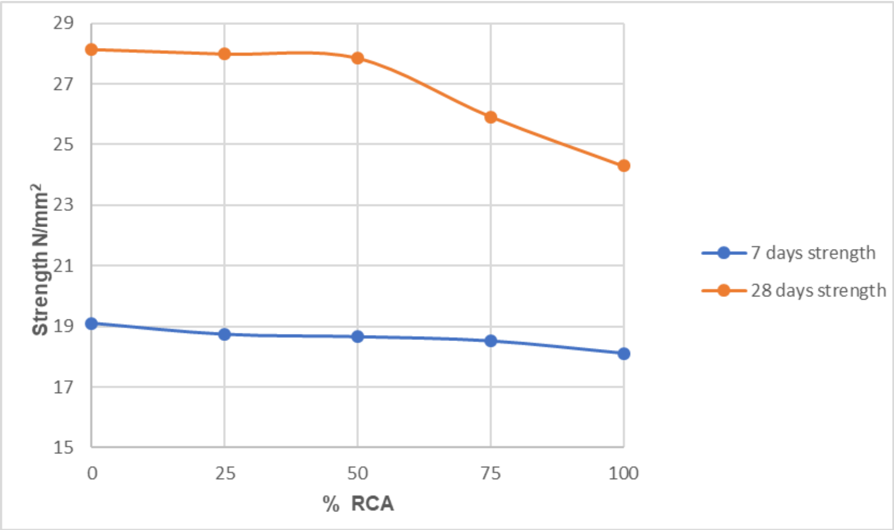

Figure 3. Compressive strength of concrete.

From Table 6 it is evident that the behaviour of reclaimed aggregates from demolition waste is satisfactory and it is also clear that 3 out of 5 replacements in concrete mix are resulting in the required strength for the design mix opted i.e. M20 and 2 replacements are resulting in strengths which are very close to the required values.

The selection of replacements can be decided based on the results acquired and the replacement of both coarse and fine aggregate can be suggested based on the strength obtained. As concrete is strong in compression and weak in tension, the concrete behavior is also observed in tension by testing cylinders which are cured for 7 and 28 days and the results are compared with that of the conventional cylinders cast using all the natural aggregates. The results are found to be satisfactory. The table below shows the tensile strength of concrete and the values are close to the ones reported by [40, 44].

Table 7. Tensile strength of concrete.

Representation	Tensile Strength(MPa)	
	7 days	28 days
C_0S_0	1.3	3.2
C_0S_1	1.87	2.83
$C_{0.25}S_1$	1.85	2.80
$C_{0.5}S_1$	2.27	2.73
$C_{0.75}S_1$	1.87	2.59
C_1S_1	1.91	2.43

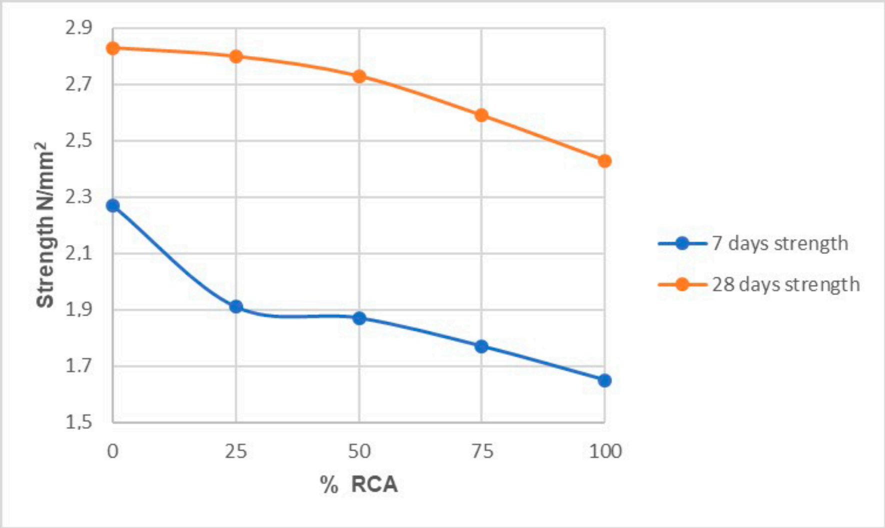

Figure 4. Splitting tensile strength of concrete.

The flexural strength of concrete is found by testing the prisms and the results are satisfactory which are presented in the Table 8 and the values are closer to the values reported by [44].

Table 8. Flexural strength of concrete.

Representation	Flexural Strength (MPa)	
	7 days	28 days
C_0S_0	2.8	3.68
C_0S_1	2.49	3.36
$C_{0.25}S_1$	2.29	3.24
$C_{0.5}S_1$	2.22	3.09
$C_{0.75}S_1$	2.06	2.85
C_1S_1	2.05	2.67

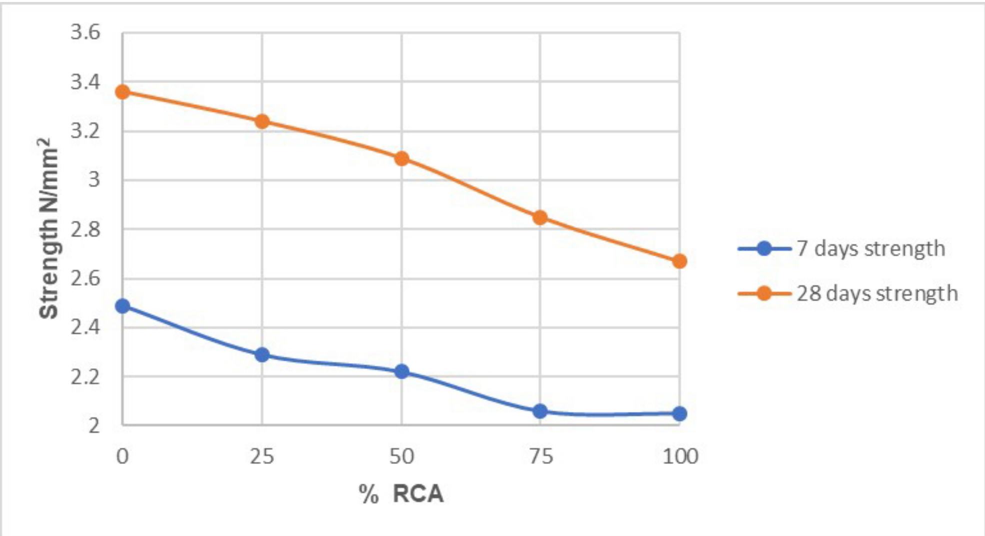

Figure 5. Flexural strength of concrete.

4. Conclusions

1. The behaviour of recycled coarse aggregates is similar to that of natural coarse aggregates.

2. The recycled fine aggregate exhibits a higher water absorption (13%) than natural fine aggregate (1.2%) as it is a by-product of demolition waste which contains cement mortar. The water absorption of recycled fine aggregates is 10 times of water absorption of natural fine aggregate.

3. The water – binder ratio when recycled fine aggregate is used, can be controlled by using plasticizer. The usage of 1% plasticizer to the mix controlled the water – binder ratio by 22.5% (from 0.80 to 0.62).

4. The strength of concrete produced from partial replacement of aggregates i.e. natural coarse aggregates with recycled coarse aggregates and complete replacement of natural fine aggregate with recycled fine aggregate, is high for 0%, 25% and 50% replacements which exhibit 98%, 97% and 96% of strength of concrete produced with natural aggregates.

5. From the above study, it is evident that the usage of recycled aggregates from construction and demolition waste can help in the reduction of usage of virgin materials up to 50% which preserve the virgin materials for future generations.

From the results obtained, it can be concluded that the behaviour of reclaimed coarse aggregates from construction and demolition waste does not show a huge difference in comparison with the natural coarse aggregates and the usage of recycled fine aggregates in comparison with the natural fine aggregate is a bit challenging and proper measures are to be taken to obtain the required result.

Hence the recycled materials when properly brought to reuse they serve various purposes:

- Reduce the usage of natural resources which take a lot of time to replenish.
- Protect the environmental degradation.
- Avoid the inconvenience caused due to its disposal.

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