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Recycled Aggregate from C&D Waste Modified by Dry Processing and Used as A Partial Replacement of Coarse Aggregate in Concrete

Abhishek Verma . Krishna Murari . Shivanshu Awasthi . Shivank Kansal . Nitin Okte . Yash Goyal

Department of Civil Engineering, Jaypee University of Engineering and Technology, Guna, India.

ABSTRACT
The issues of sustainability are of great importance these days as we are consuming our natural resources at a very faster rate for producing materials such as concrete. Our country is generating huge amount of construction waste every year. These wastes requires huge amount of land for its disposal and it also creates environmental pollution. Much research is going on to use their construction waste materials used in concrete as a substitute of cement, sand and coarse aggregate without sacrificing the structural health. The present research work is based on the concrete made by using recycled aggregate. The construction demolition waste is collected from nearby place of juet campus where huge volume of building structure is demolished due to four lanning of Agra Bombay road (Guna to Bioara section approx 110Km stretch).In these research work recycled aggregate collected and separated by some mechanical means and used as a partial replacement of coarse aggregate in concrete. The pozzolanic reactivity was evaluated and its suitability as a partial replacement of coarse aggregate using Portland Pozzolana cement 43 grade was analysed. Hence, the recycled coarse aggregate (RCA)of size 20mm were used in concrete as a partial replacement of virgin coarse aggregate(VCA) with 10%, 20%, 30%, 50%, 70% and 100% by weight of aggregate. Concrete mixtures were produced, tested and compared in terms of compressive strength, split tensile strength, sorption, volume of voids, water absorption to the conventional concrete. These tests were carried out to evaluate the mechanical and durability properties for 7 days and 28 days.

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Introduction

Concrete is a composite material, basically consisting of different constituents such as binding materials, water, aggregates and admixtures. Among these ingredients, aggregate plays a very crucial role in concrete which occupy the largest volume of about 60–75% of total concrete volume [1]. Current population of India is 1.34 billons and it is expected by 2050 is 1.66 billion. This will require basic infrastructure for its smooth survival. In India, about 14.5 MT of solid wastes are generated annually from construction industries, which include wasted sand, gravel, bitumen, bricks, and masonry, concrete. However, some quantity of such waste is being recycled and utilized in building materials and share of recycled materials varies from 25% in old buildings to as high as 75% in new buildings [2-3]. Many old buildings, concrete pavements, bridges and other structures have overcome their age and limit of use due to structural deterioration beyond repairs and need to be demolished. The structures, even adequate to use are under demolition because they are not serving the needs in present scenario. Many of Structures are turned into debris resulting from natural disasters like earthquake, cyclone and floods [4].

Figure 1 shows the process of using recycled aggregate from construction and demolition waste in which C&D waste collected to feed in to the crusher for converting the big size demolition waste in to suitable size of aggregate like 40mm, 20mm and 10mm. after that recycled aggregate is used in concrete in which further properties of concrete is tested like workability, hardened properties, microstructure and durability properties.

Recycled Aggregate

Aggregate typically processed by the crushing of parent or old concrete such as demolished waste concrete is regarded as recycled concrete aggregate (RCA). Generally RCAs are mixed with bricks, tiles, metals and other miscellaneous such as glass, wood, paper, plastic and other debris [5].

Figure 2 shows the clear difference between the recycled coarse aggregate and natural virgin coarse aggregate. In recycled coarse aggregate it contain old attached adhered mortar on the surface of aggregate but surface of natural virgin coarse aggregate is free from adhered mortar.

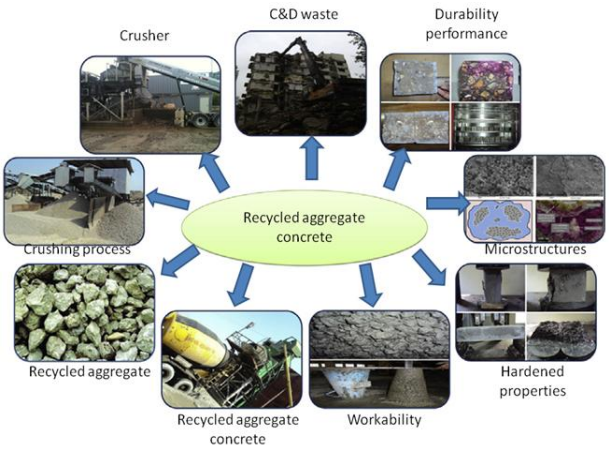

Figure 1: Process of using recycled Aggregate in Concrete [5]

Corresponding Author: Abhishek Verma, Tel: +91 9165363530
Email: verma.abhishek000@gmail.com
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(a) (b)

Figure 2: Recycled aggregate and natural aggregate

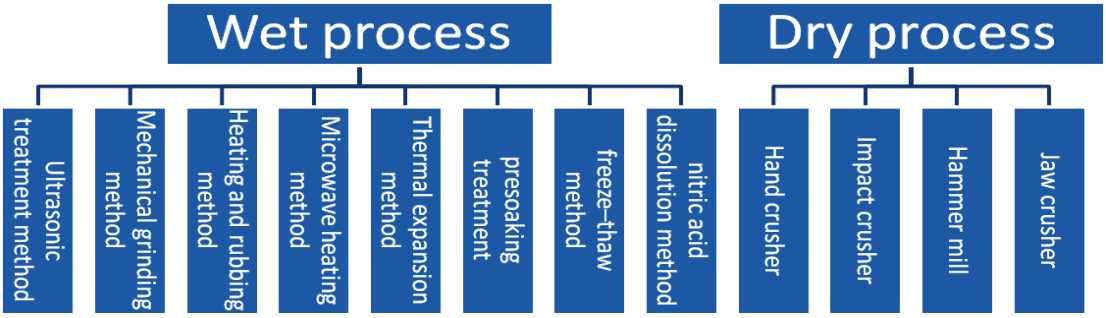

Figure 3: Processing Techniques of Recycled Aggregate

Recycling Process [5-14]

Figure 3 shows the different process for enhancing the quality of recycled coarse aggregate for removing the adhered mortar. The above mentioned dry processes, wet processing technique for RCA provides better quality aggregate with less organic and inorganic impurity. Depending up on the source of aggregate strength of adhered mortar over the aggregate particular method is beneficial otherwise it will results in finer cracks.

Background

Concrete up to 30% of coarse aggregate was replaced by demolished waste which gave strength closer to the strength of plain concrete cubes and strength retention was recorded in the range of 86.84-94.74% for recycled concrete mix. [15]. At high w/c ratio; 60% substitution of dried RCA aggregates results in a suitable amount of superplasticizer and increases the concrete compressive strength at 90 days over 13%. However, at low w/c ratio, the negative effect of excessive super plasticizer dosage reduces the compressive strength about 21% [16].The properties of recycled aggregates were found to be satisfactory for their utilization in road construction activities. The suitability of using recycled fine and coarse aggregates with Portland pozzolanic cement to make a sustainable and environmental friendly concrete mix design was also analyzed. No significant difference was observed in the compressive strength of various concrete mixes prepared by natural and recycled aggregates. However, only the tensile strength of the mix prepared with 25% recycled fine aggregates was comparable to that of the control concrete [17]. The compressive strength achieved at 28 days for FA and RA was 14.6 and 13.4 N/mm2 respectively. Hence a 9% reduction of strength was observed at 100% replacement of FA by the RA. The study shows that fresh aggregates can be replaced by the recycled aggregates. Recycled aggregate concrete can minimize the waste disposal problem and can reduce the cost of concrete [18]. RA is gaining wide spread attention day by day to be used as a construction material both from material and structural point of view. Thus, the use of RA is from C&D waste is contributing towards a sustainable development in construction industry. However, to use RA as a structural material, its quality and properties need to be characterized very precisely as the quality of RA has significant influence on the performance of RAC [19]. Compressive strength of recycled aggregate concrete (RAC) showed a decrease of up to 6% compared to natural aggregate concrete (NAC). RAC water absorption was higher compared to NAC because of remains of mortar on its rough surface [20]. Recycled concrete aggregate leading to reduction in the concrete compressive strength ranged from 37% to 62% depending on the type of the CDW constituents [21]. Recycled concrete aggregate shows inferior physical properties than the natural coarse aggregate. However, treatment of recycled concrete aggregate by acid, thermal and mechanical means improve the physical properties of RCA significantly. The compressive strength of concrete made with untreated RCA is 14% less than NAC. Treatment improves the compressive strength of RAC made with treated aggregates and is more than 95% of NAC, irrespective of the treatment method used. The bond strength of RCA treated with acid, mechanical and thermal treatment methods is 96% and 90% and 79% of the NAC respectively. However, mechanical treatment is found to be less time consuming, eco-friendly and economical compared to acid treatment method [22].

Experimental

Materials and methods

Demolished waste: Demolished waste was collected from two storey 15 years old building near JUET campus along NH-3 Agra Bombay Road. Demolished waste was tested in laboratory after the removal of impurities and removing of adhered mortar with the help of jaw crusher 20 mm for enhancing the pozzolanic properties. Demolished waste used to partially replace coarse aggregate in concrete at different percentage level. Colour of recycled aggregates used in the present investigation was light grayish, specific gravity and water absorption was 2.65 and 3-4% respectively.

Cement: Portland pozzolana cement (43 Grade) brand jaypee cement obtained from a single batches trough out the investigation was used. A pozzolanic material is essentially a siliceous or aluminous material which itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide. The cement satisfies the requirement of IS: 1489-1991 part-1[23].

Fine aggregate: In this research work natural river sand has been used which is conforming to IS: 383 -1970[24] it lies in Zone II. Natural river sand is sieved from 4.75 mm sieve is being used. The fineness modulus of fine aggregate was 2.74 as per IS 460-1978[25] and specific gravity was 2.63.

Coarse aggregate: Coarse aggregate was obtained from locally available crushed stone aggregate about 20 mm maximum of single lot size has been used throughout the experiment, conforming to IS: 383-1970[24]. Specific gravity of the coarse aggregate was 2.77 and the fineness modulus of coarse aggregate was 6.80. The fractions from 20 mm to 10 mm sieve are used as coarse aggregate. The Coarse Aggregates from crushed Basalt rock

Water: Potable water is used for mixing and curing. On addition of higher percentage of demolished waste, the requirement of water increases for the same workability. Thus, a constant slump has been the criteria for water requirement, but the specimens having 0% demolished waste, W/C of 0.45 has been used for the study.

Concrete: The concrete mix design was done in accordance with IS: 10262-2009[26]. The cement content in the mix design was taken as 430 kg/cu m3 which satisfies minimum requirement of 350 kg/cu m^3 in order to avoid the balling effect. Coarse and fine aggregate confirm the zone-II as per IS: 383-1970[24] respectively.

Characterization of Recycled Aggregate

As recycled aggregate is obtained from construction demolition waste which is having different properties from natural aggregate in many respects. The most important is the attached mortar to the recycled aggregate, due to which it shows the variation on most of the properties of recycled aggregate as compared to virgin coarse aggregate. Table 1 shows the various properties of recycled aggregate to be assessed and their limiting values as per Indian standards before using it with the concrete.

Experimental programme

Concrete Mix design- A mix of M25 grade was designed as per Indian Standard method (IS 10262-2009) [26] and the same was used to prepare the test samples. The design mix proportion 1:1.45:2.85 and water cement ratio as 0.45.

Table 1: Various properties of recycled aggregate [27-30]

S. No.	Type of test	Recycled Coarse Aggregate (20mm)	Virgin Coarse Aggregate	Limiting value as per IS code	IS code
1	Aggregate crushing Value	21.55%	13.26%	30%	IS:2386(PART IV)-1963 [27]
2	Aggregate Impact Value	14.08%	12%	30%	IS:2386(PART IV)-1963 [27]
3	Los Angeles Abrasion Test	19.3%	16.22%	30%	IS:2386(PART IV)-1963 [27]
4	Moisture Content	0.5%	0.5 %	-	IS:2386(PART III)-1963 [28]
5	Water Absorption Test	3-4%	2.88	-	IS:2386(PART III)-1963 [28]
6	Specific Gravity Test	2.65	2.77	2.8	IS:2386(PART III)-1963[28]
7	Fineness Modulus	7.13	6.80		IS:2386(PART I)-1963 [29]
8	Flakiness Index Test	18%	-	25%	IRC:111-209 [30]
9.	Elongation Index Test	3%	-	15%	IRC: 111-209 [30]

Table 2: Mix proportioning details of recycled aggregate concrete

S. No	% Replacement	Cement (Kg/m^3)	F. A (Kg/m^3)	C A (Kg/m^3)	Water	Recycled aggregate
1	0%	430 kg	623 kg	1230 kg	186 lit	0 kg
2	10%	430 kg	623 kg	1107 kg	186 lit	123kg
3	20%	430 kg	623 kg	984 kg	186 lit	246 kg
4	30%	430kg	623 kg	861 kg	186 lit	369 kg
5	50%	430kg	623 kg	615kg	186 lit	615 kg
6	70%	430kg	623 kg	369kg	186 lit	861 kg
7	100%	430kg	623 kg	0 kg	186 lit	1230 kg

Table 2 shows the details of mix proportions used to form the different sample of concrete using recycled aggregate at various percentage of replacement with natural coarse aggregate.

Experimental methodology

Natural virgin coarse aggregate is replaced with recycled coarse aggregate with the replacement percentage 0%, 10%, 20%,30%,50%,70%,100% which is denoted by R0, R10, R20, R30, R50, R70, R100.Three cube specimen were cast on the mould of size 150 x 150 x 150 mm for each 1:1.45:2.85 concrete mixes with a w/c ratio as 0.45. After about 24 hrs the specimens were de-molded and water curing was continued till the respective specimens were tested after 7, and 28 days.

Results and Discussion

Compressive strength test [31]

The comparative studies were made on concrete for their characteristics compressive strength for mix ratio of 1:1.45:2.85 with partial replacement of virgin coarse aggregate with recycled coarse aggregate with different replacement percentage like 10%, 20%, 30%, 50%, 70%, and 100%. Based on experimental investigations concern-

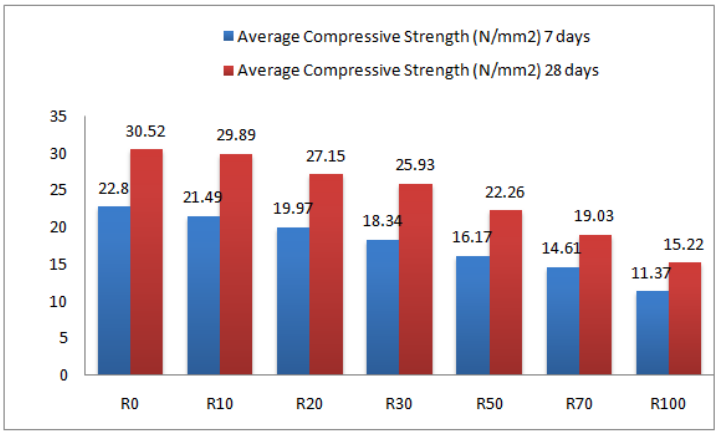

Figure 4: Average compressive strength in N/mm² after 7 and 28 days Vs various percentage replacement of RCA

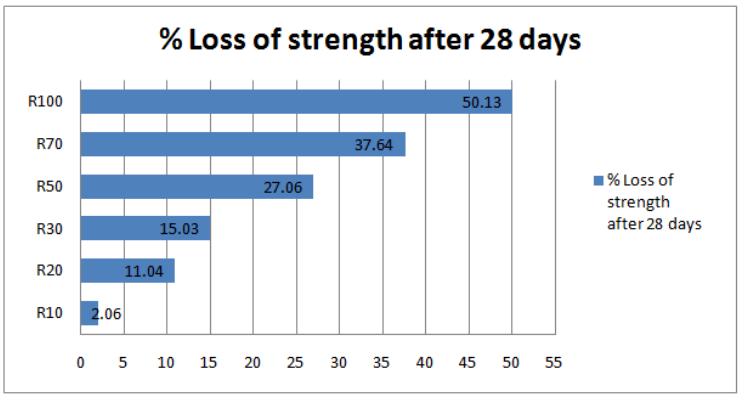

Figure 5: Percentage Replacement Vs loss of compressive strength of concrete after 28 days N/mm²

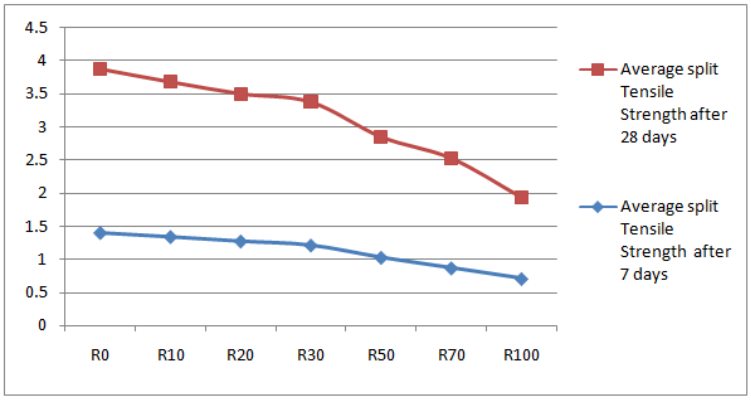

Figure 6: Average split tensile strength in N/mm² after 7 and 28 days Vs various percentage replacement of recycled coarse aggregate

-ing the compressive strength of concrete.

Figure 4 shows the graph between average compressive strength in N/mm² after 7 and 28 days and various percentage replacement of RCA. In this graph the compressive strength is decreasing by increasing the percentage of recycled coarse aggregate. Strength is decreasing due to old adhered mortar attached on the surface of coarse aggregate which weakens the bonding with other ingredients in concrete and also results in more interfacial transition zone (ITZ).

Figure 5 shows the increment in % loss of compressive strength after 28 days as we are increasing the % of RCA in concrete. Up to the 30 % replacement there is little increase in % loss, but after 30% replacement % loss is an increase at higher rate due to large no of capillary voids and weak bonding between old ITZ and new ITZ.

Figure 6 shows the split tensile strength after 7 and 28 days of curing in which the strength is decreasing abruptly after 30% replacement level due to the formation of minor cracks at the surface of aggregate during processing techniques.

Sorptivity test

Sorptivity test is a very simple technique that measures the capillary suction of concrete when it comes in contact with water. This test is used to determine the rate of absorption (Sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water ingress of unsaturated concrete by capillary suction during initial contact with water. Test specimen size (150x150x150).

The rate of sorption is the slope of the best-fit line to the plot of absorption against square root of time.

The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t)

$$I = S.t^{1/2} \quad and \quad S = I/t^{1/2}$$

Where, S= Sorptivity in mm/√min, t= Elapsed time in minute, I= ΔW/A x d, ΔW= Change in weight = W_2-W_1, d= Density of water. W1 = Oven dry weight of cylinder in grams, W2 = Weight of cylinder after30 minutes capillary suction of water in grams, A= surface area of the specimen through which water penetrated.

Figure 7 shows the graph between sorptivity at different level of percentage replacement of RCA with VCA and square root of time t. In this graph the slope of the line is increases as we are increasing the percentage of RCA in concrete. The line with lower slope shows the sorptivity at 0% RCA and highest slope line with 100% RCA. Basically sorptivity is the absorption of water due to capillary voids present in concrete. This will be increase with increase in % of RCA. Figure 8 shows the sorptivity coefficient vs. % Replacement. In this graph the slope of the line for different percentage replacement is increase slightly with increase in % of RCA. Figure 9 shows the water absorption with % of recycled aggregate in concrete. As the % of RCA increases the water absorption is also increase because old mortar contains unhydrated lime which reacts with water to form more C-S-H gel which will results in less porous and dense concrete. Figure 10 shows the graph between volume of voids and % of RCA in concrete. The volume of voids will also be increased due to porous nature of weak adhered mortar attached to the aggregate surface.

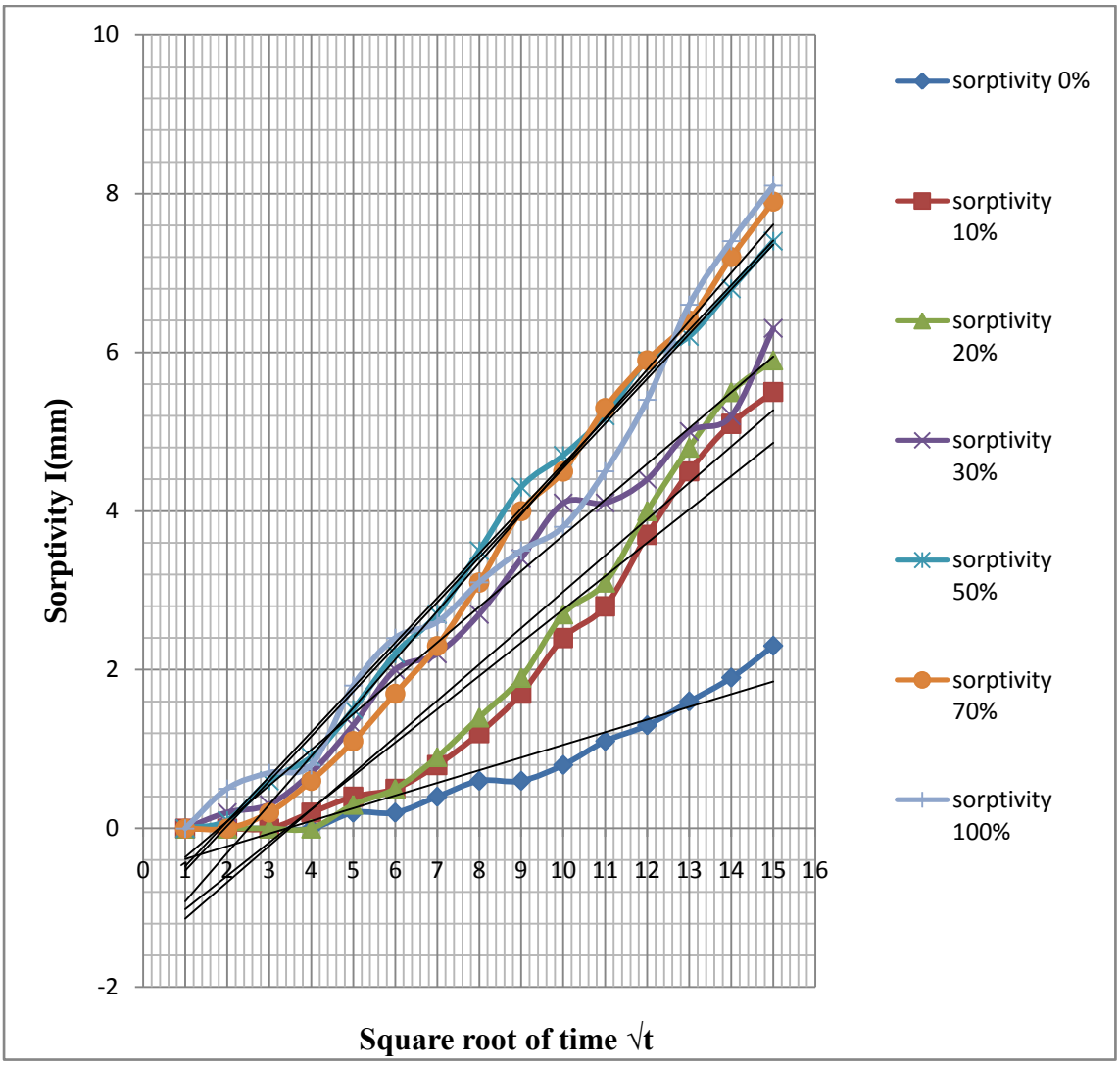

Figure 7: Graph between square root of time Vs sorptivity I (mm)

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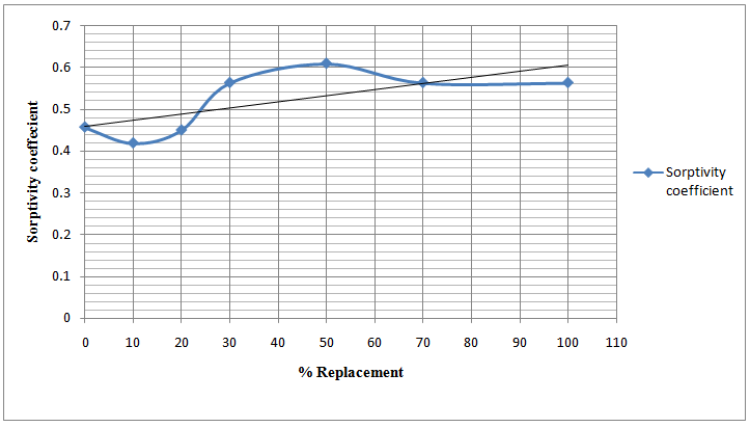

Figure 8: Sorptivity coefficient Vs % replacement

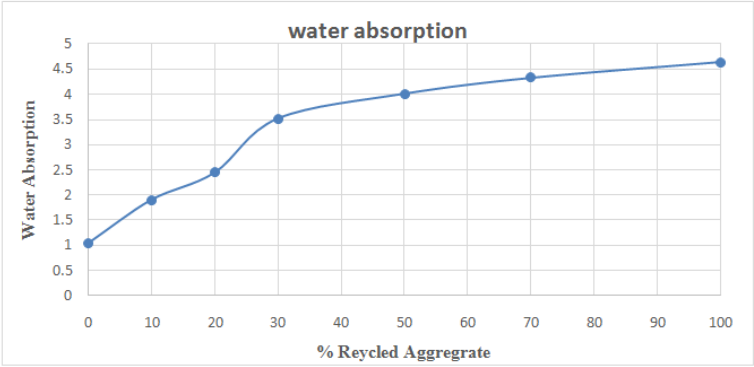

Figure 9: Water absorption Vs % recycled aggregate

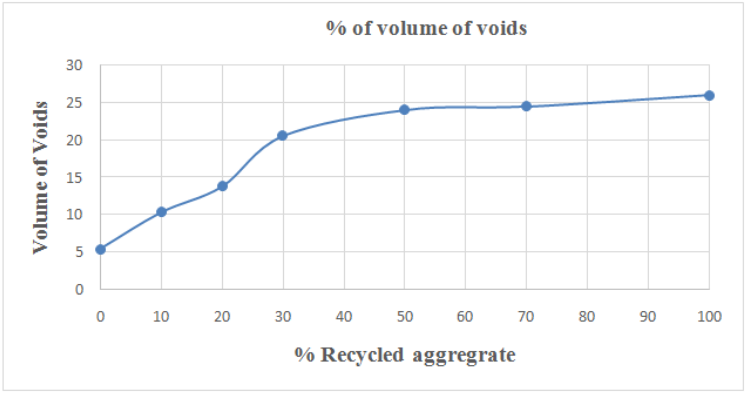

Figure 10: Volume of voids Vs % recycled aggregate

Conclusions

1. As authors had partially replaced the recycled aggregate in concrete, in that replacement we have found a decrement in compressive strength and split tensile strength. Compressive strength comes out to be less than the target mean strength but for 10%, 20%, 30% replacement level the value comes nearer to the characteristic strength. So, it can be applicable to use the aggregate replacement upto 30% and further increase in replacement decreases the compressive strength
2. The aggregate was collected from demolished waste of 2 storey building, which contained adhered mortar on the surface of aggregate which increases the porosity. Due to this adhered mortar the water absorption of aggregate is increases and also result in large volume of voids. Due to this adhered mortar the binding of aggregate with other ingredients also decreases doe to the formation of weak interfacial transition zone in concrete between the old mortar and new mortar.
3. The percentage by which compressive strength decreases for 10%, 20% and 30% replacement is 2.06%, 11.04% and 15.03%. For up 30% replacement the compressive strength decreases at a slower rate, but for 50%,70% and 100% replacement percentage by which compressive strength decreases is 27.06%, 37.64% and 50.13% which says that aggregate replacement will highly decrease the

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compressive strength of concrete after 30% replacement. Hence, there is compromise in concrete strength than the standard concrete and it becomes highly unsafe

4. The percentage decrement in split tensile strength with aggregate replacement by 10%, 20%, 30%, 50%, 70% and 100% is 5.6%, 10%, 13%, 26.5%, 33.6% and 50.9%. So, the aggregate can be replaced up to 30% because for further replacement there is a large percentage decrement in split tensile strength i.e. 26.5%, 33.6% and 50.9%. Hence, there is compromise in concrete strength than the standard concrete and it is highly unsafe. So, aggregate replacement can be done up to 30%.
5. As we see the sorptivity curve, the sorptivity value goes on increasing as we increase the aggregate replacement i.e. from 10% to 100%, the sorptivity value increases as penetration of water increases as the quantity of recycled aggregate is increased in concrete. Penetration increases because of porous structure of recycled aggregate which results in more capillary voids. Upto 30% there is a slight increment in sorptivity value i.e. from 0.45 to 0.56.
6. As we increase the replacement of virgin aggregate with recycled aggregate the water absorption value also increases due to the porous nature and presence of unhydrated lime which react with water to further form secondary C-S-H gel.
7. Recycled aggregate contains more volume of voids as compared to virgin aggregate so as we replace the virgin aggregate with recycled aggregate the % of volume of voids increases. For replacement more than 30% i.e. for 50%, 70% and 100% the volume of voids goes in large increasing trend. Hence the strength goes on decreasing for replacement by 50%, 70% and 100%. Problems like segregation bleeding creep and shrinkage can also be seen due to large no. of voids.
8. As there is a need of huge quantity of aggregate in today's constructing world. It will be economical to use recycled aggregate in fresh concrete because the issues of sustainability are of prime concerns these days as we use large amount of natural resources for producing materials such as concrete. Using recycled aggregate in concrete reduces the CO_2 emission and also reduced the cost of concrete.

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