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Effect of Sulfuric Acid Treated Recycled Aggregates on Properties of Concrete

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Abstract: The major factor affecting the utilization of recycled aggregates (RA) in concrete was its ill quality. The adhered cement mortar that remains on the surface of the recycled aggregate affects the quality of recycled aggregate. This paper attempts to study the efficiency of sulfuric acid soaking treatment method for recycled aggregates and the effectiveness of using these treated recycled aggregates in concrete strength and durability. Three concrete mixes were prepared using natural coarse aggregate, untreated recycled aggregate and sulfuric acid treated recycled aggregate. The properties of aggregates and the effect of replacement of natural coarse aggregate (NA) with treated and untreated recycled aggregates in concrete were examined. The test results show that the behaviour of recycled aggregate has improved after treatment. The strength and durability characteristics of recycled aggregate concrete can be improved in a much better way by using the treated recycled aggregates in concrete.
Keywords: Natural coarse aggregate, Untreated recycled aggregate, Treated recycled aggregate, Sulfuric acid soaking treatment method.

Introduction

Concrete is the second most consumed material in the world after water. It is estimated that the current consumption of concrete is about 25 billion tonnes every year in the world[1]. Concrete is a very strong and flexible building material. The main basic materials used in concrete are cement, aggregate and water. The use of Cement is to bind the ingredients together, water affords the concrete viscosity and initiates the hydration process when mix with the ingredients, and the aggregates occupies 60-75 percent of the total portion of concrete which adds bulk to the concrete, but aggregates are not involved in the chemical processes. Danish Environmental Protection Agency (DEPA) reported that 5-10% waste was generated from new building constructions, 20-25% was from renovation of structures and the rest 70-75% was generated from the demolition activity. In India Construction industry generated 10-12 million tons of Construction debris in the year of 2000 and it emitted over 626 million tons of construction waste in 2013[2]. Reuse and recycling of the waste materials are one of the construction sector's main contributions to the protection of the Environment. When structures constructed with concrete are demolished, recycling of concrete is one of the common method in which the reuse of the aggregate was the main focus and it was widely discussed by many researchers[3,4,5]. The main aim of Recycling is to keep construction project costs down, reduces the usage of landfill required for debris and protects the natural resources which ultimately benefit the environment. Heavy crushing equipment is necessary to crumble the rubbles into aggregate[6]. Now-a-days the equipment used for recycling is portable and can arrange on site for immediate function. From the literatures it was observed that the use of recycled aggregate in concrete mix instead of natural aggregates usually increases the porosity, shrinkage and creep. It also decreases the strength of concrete[7]. A reduction in the compressive strength was mostly observed in all literatures in which maximum was found in full replacement of natural coarse aggregate with recycled coarse aggregates[8,9,10]. The reduction in the strength is mainly due to the mortar which is attached to coarse aggregates. Several investigations were made by researchers for improving the mechanical and durability properties of recycled aggregate concrete by the treating of recycled aggregates and by adding mineral admixtures[11- 17]. Some studies were also made by replacing some portion of natural aggregate with recycled aggregate for improving the concrete properties[18,19]. The interrelationship between the mechanical properties of recycled aggregate concrete were estimated by the researchers and reported that it was different from natural aggregate concrete [20]. All these literatures mentioned that mechanical properties are dependent on the recycled aggregate properties.

The present study aims to investigate the feasibility of using Sulfuric acid to enhance the properties of recycled aggregate and ultimately improves the mechanical and durability characteristics of recycled aggregate concrete.

Materials and Methods

ASTM Type 1 Ordinary Portland cement with a specific gravity of 3.15 and specific surface area of 3540 cm^2/g was used for this experimental study. The chemical composition of the cement was found through XRF analysis and it was given in Table 1. For concrete preparation crushed granite available from a local quarry was used as the natural coarse aggregate and two types of recycled aggregates were used. Uncrushed locally available natural river sand with a fineness modulus of 3.35 was used as fine aggregate.

The first type of coarse recycled aggregates was obtained through the crushed concrete wastes of a demolished building in the university campus. The concrete rubbles were crushed through impact crusher and the unwanted wastes such as reinforcements and aggregates were separated. Further crushing, water washing and screening were done to attain the required size of the recycled aggregates. The second type of recycled aggregates was obtained by treating the sized recycled aggregate with sulfuric acid. The nominal size of recycled aggregate used for this work was less than 20 mm. The physical and mechanical properties of the natural coarse aggregates and recycled coarse aggregates were shown in Table 2.

Conplast SP430(NE1) complies with IS:9103 [21] and BS:5075 Part 3 [22] and ASTM-C-494[23] Type 'F' as a high range water reducing admixture was used to improve the workability and reduce the water content.

Table 1: Physical and chemical composition of ordinary Portland cement (OPC)

Description	Composition
Physical Properties	
Color	Grey
Specific gravity	3.15
Specific surface area (cm^2/g)	3540
Chemical Composition	
CaO (%)	62.8
SiO_2 (%)	20.3
Al_2O_3 (%)	5.4
Fe_2O_3 (%)	3.9
MgO (%)	2.7
Na_2O (%)	0.14
K_2O (%)	62.8

Table 2: Aggregate properties

S. N.	Property	Fine Aggregate	Natural Coarse Aggregate	Recycled Coarse Aggregate	Treated Recycled Coarse Aggregate
1	Specific Gravity	2.56	2.67	2.47	2.37
2	Water Absorption in %	0.8	1.56	6.48	4.43
3	Density (Kg/m3)	1655	1635.5	1392.59	1457.77

Acid Soaking Treatment for Recycled Aggregate

The crushed and sized recycled aggregates were further treated by soaking the aggregates in sulfuric acid with 0.1 M for 24 h in room temperature. The acid container was periodically stirred with wooded stick to ensure a more efficient acid reaction which results in turn of debonding of mortar adhered in the crushed recycled aggregate.

Fig.1 Recycled aggregates before and after treatment

Then the treated recycled aggregates were taken out from the solution and washed thoroughly with distilled water and sundried. After that the treated recycled aggregates were sieved through 4.75 mm sieve and the retained aggregates were used for concreting. The recycled aggregates before and after treated were shown in Fig.1

Mix Proportions

In this study, IS 10262 [24] method was adopted for mix design and three different concrete mixes using natural coarse aggregate, untreated recycled aggregate and sulfuric acid treated recycled aggregate were prepared to evaluate the properties of concrete. A two-stage mixing approach suggested was followed during concrete mixing [25]. Table 3 shows the mix proportion for concrete mixes.

Table 3: Concrete mix proportion

Type of concrete	w/c	Cement	FA	NA	RA
Natural aggregate concrete (NAC)	0.4	425	693	1172	-
Recycled aggregate concrete (RAC)	0.4	425	693	-	1172
Treated Recycled aggregate concrete (RAC_{H2SO4})	0.4	425	693	-	1172
FA – Fine Aggregate NA – Natural coarse aggregate RA – Recycled coarse aggregate					

Experimental Procedure

Compressive and Split tensile strength

Compressive and Split tensile strength were evaluated through the cube specimens of size 100 x 100 mm and the cylinders of size 100 mm diameter and 200 mm height respectively at the ages of 7, 14 and 28 days. The tests were conducted in accordance to the requirements of IS 516 [26]. In each test three specimens were tested and the mean values were reported as strength of the specimens.

Water Absorption Test

The Volumetric water absorption of concrete specimen was found as per the guide lines of ASTM C 642 [27]. After 28 days curing the concrete specimen was taken out from the curing tank and oven drying at 105°C temperature for 24h. The dried specimen was cooled in room temperature and the weight of the specimen was noted. To evaluate the water absorption of concrete the dried specimens were immersed in a water container and the difference in weight of the specimen before and after immersion were measured at periodic interval of one hour till a same successive observations obtained. The amount of water absorbed by the concrete was computed as the change in the weight of specimen from saturated surface dry condition to dry condition and the values were represented as percent by the volume of specimen.

Alkalinity measurement test

To measure the alkalinity of the concrete powdered concrete samples were obtained by crushing and grinding the broken pieces of tested specimen. The powdered samples of 20gm was put into100ml distilled water and the solution was allowed to stand for 72 hours. The solution was agitated often, to enable more of free lime of hydrated cement paste to get dissolved in water .The pH of the aqueous solution were measured by pH meter.

Results and Discussions

Properties of aggregates

From the earlier research it was observed that all the physical properties of the recycled aggregates are inferior to the natural aggregate. This is because of the adhered mortar attached to the aggregate [28]. The physical properties of recycled aggregates, treated recycled aggregates are compared with natural aggregate which was given in the Table 2. The physical properties of the treated recycled aggregates also inferior to natural aggregate but better than the recycled aggregate. This was mainly due to the removal of adhered mortar content from the recycled aggregate after treatment.

When the recycled aggregates were immersed in sulfuric acid, it reacts with the existing adhered mortar and form gypsum and ettringite. Initially these reaction products occupy the voids in the adhered mortar and increase the weight of the aggregate. Finally the continued expansion of adhered mortar leads to peeling off of the surface layer of adhered mortar. The experimental results clearly indicated that considerable amount of mortar content was removed by the acid soaking treatment and the properties of recycled aggregates were improved after treatment.

Compressive and Tensile Strength

Compressive and Split tensile strength of natural aggregate concrete and recycled aggregate concrete mixes at the age of 7, 14 and 28 days were shown in Fig.2 and Fig.3 respectively. The compressive strength of concrete made with recycled coarse aggregates (RAC) was 25% lesser than that of concrete made with normal coarse aggregates (NAC) at the age of 28 days. Based on previous research reports it was observed that the presence of adhered mortar in recycled aggregate affects the strength characteristics of the concrete. It weakens the bond between the aggregate and the cement mortar. Using treated RA in concrete improves the strength characteristics by 12.5% than untreated RAC. But still 14% lesser strength was observed in concrete made with treated recycled aggregates (RAC_{H2SO4}). This is because of presence of adhered mortar in recycled aggregate even after cleaning.

Similar trend was also observed for tensile strength. The tensile strength of RAC was found to be decreased by 5%, 9%, 13.5% at the age of 7, 14 and 28 days respectively whereas the concrete with treated aggregate showed only 3%, 6.5% and 7% tensile strength drop at the same above respective ages. After treatment the adhered mortar and loose mortar particles were removed to a greater extent from recycled aggregates which improve the formation of strong ITZ between the aggregate and mortar. This results in turn of strength improvement of RAC. Similar trend was also observed in the earlier research reports [29,30,31].

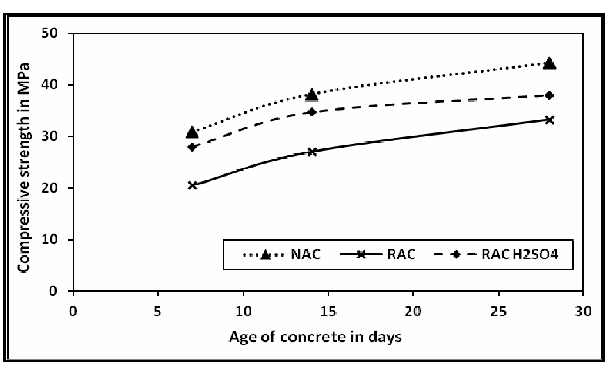

Fig.2 Influence of Recycled Aggregate in Compressive strength of concrete

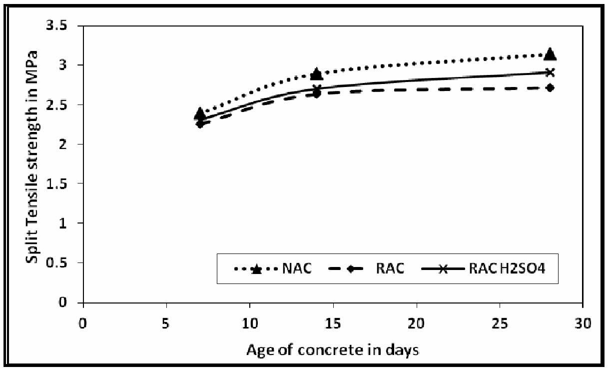

Fig.3 Influence of Recycled Aggregate in Split tensile strength of concrete

Water Absorption Test

The rate of water absorption with respect to time was presented in Fig.4. From the results it was observed that the water absorption of concrete in the first two hours is high irrespective of aggregate and after that it gets reduced. After six hour duration the concrete attained the saturated condition in all concrete mixtures. Highest absorptions were found in concrete containing untreated recycled aggregates and the difference in absorption was 3.79% with respect to NAC. Concrete made with treated recycled aggregate showed only 0.53% differences in water absorption after six hour duration when compared with NAC. There was a remarkable improvement in water absorption capacity in concrete made with treated recycled aggregate. This was because of the removal of adhered mortar from recycled aggregate concrete. This will improve the surface characteristics of the aggregates which in turn increase the bond between the aggregate and the cement paste.

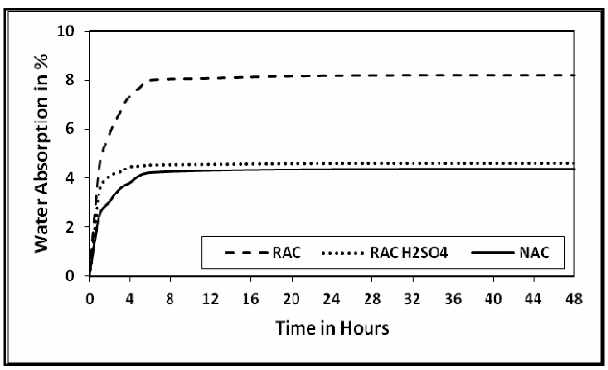

Fig.4 Influence of Recycled Aggregate in water absorption of concrete

Alkalinity

Alkalinity test is one of the important tests to find the degradation level of the concrete. For a good concrete the pH value should be 12 to 13 and if it is between 9 and 11 it is pretty good shape. If pH value is between 7 and 9 it indicates the failure stage of the concrete. The concrete pH value below 6 indicated the severe deteriorated stage of the concrete. As the pH is lowered, the bonding capability of cement gets lowered and the corrosion gets initiated. The pH values of the all concrete specimens were found after 28 days and are represented in the Table 5. From the experimental results it was clear that all the concrete mixtures have low possibility of corrosion and using treated recycled aggregates in concrete increase the resistance against corrosion.

Table 5: pH values for different coarse aggregates

Mix	pH
NAC	12.62
RAC	12.08
RAC_{H2SO4}	12.24

Conclusions

Based on the results obtained in this experimental study the following conclusions were made:

1. Considerable amount of mortar content was removed from recycled aggregate after acid soaking treatment and there by the physical and mechanical properties of recycled aggregates were improved.
2. The test results show that the compressive and tensile strength of RAC was lower than that of NAC at all ages. The adhered mortar presence in recycled aggregate may affect the bond between RA and cement paste.
3. The experimental results indicated that the concrete containing treated RA attained 12.5% better compressive strength than the concrete with untreated RA. However after treatment also there was 14% reduction in concrete strength compared with NAC.
4. The durability characteristics of RAC were evaluated in terms of water absorption and alkalinity test. The water absorption of RAC was almost double the amount of NAC. However there was a remarkable improvement was found in water absorption capacity of concrete made with treated recycled aggregate.
5. The Alkalinity test results indicated that all the concrete mixtures have low possibility of corrosion and using treated recycled aggregates in concrete increase the resistance against corrosion.
6. Overall, the concrete made with sulfuric acid treated RA significantly improves the recycled aggregate concrete properties. Hence this method can be considered and employed in the application on large scale RAC projects.

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