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Properties of Recycled Aggregate Concrete Containing Hydrochloric Acid Treated Recycled Aggregates

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Abstract: The suitability of replacement of natural aggregate (NA) with recycled aggregate (RA) mainly depend on the properties of recycled aggregates. The presence of loose mortar particles and surface cracks result in inferior aggregate properties. This experimental study presents a surface treatment method which enhances the properties of coarse recycled aggregate. In this study, recycled aggregates were treated by soaking in hydrochloric (HCl) acid at 0.1 M concentration. The basic properties of RA before and after treatment and its effect on concrete were examined. The results show that the behaviour of RA has improved after treatment. Usually there will be 10-30% decrease in the strength value of recycled aggregate concrete when compared with natural aggregate concrete. The strength improvement can be achieved in a much better way by using the treated recycled aggregates in concrete than untreated recycled aggregates.
Keywords: Natural Aggregate, Recycled Aggregate, surface treatment method, hydrochloric acid, Compressive strength.

Introduction

Construction industry which is one of the major industries consumes large amounts of cement, aggregate and sand. The cement concrete is the major material used in construction. The concrete debris which comes from demolished old structures and damaged buildings is huge. About 1.183 billion tons of concrete debris is generated worldwide annually[1]. This concrete debris has become a major problem in every country. For its appropriateness and compliance to the present urbanized environment, it must be such that it should be capable of preserving natural assets, save the environment, lead to proper consumption of energy. So the re-use of this debris helps in decreasing the area of land required for its disposal. This concrete debris should undergo crushing and screening processes in order to get required aggregate within the limits of mixing gradation. As the construction waste is progressively growing with the development of urban localities, study on the usage of discarded material from demolished buildings is very significant. Many researchers have made an attempt to study the strength variation of concrete when recycled aggregate is used [2,3,4,5,6,7,8,9,10,11,12,13]. As the recycled aggregate is much easier to obtain and comparatively less in cost than natural aggregate many investigations had been made on its properties. A decrease in the strength value was the most important factor which was noticed from the recent studies when recycled aggregates were used and this reduction of strength is due to the adherence of mortar particles to stone particles. A weak porous and crack layer is formed due to the adhered mortar particles which have a substantial effect on the strength property of recycled aggregate concrete. Some researchers have made investigations on the workability of concrete and reported that the required workability can be gained by using mineral admixtures[14,15,16]. To reduce the amount of mortar attached to the aggregate many investigations have been made and some treatment methods are proposed. The treatment methods which were proposed were either single or a group of mechanical, thermal and chemical approaches[17,18,19,20,21,22]. They were used to decrease the amount of loose particles adhered to the aggregates and to improve the properties of recycled aggregate.

So in the same context, an attempt was made to enhance the recycled aggregate concrete properties by treating the recycled aggregates with Hydrochloric acid and to study the strength and durability properties of the same.

Materials Used

ASTM type 1 ordinary Portland cement with a specific gravity, specific surface area and 28 days compressive strength of 3.15, 3960 cm^2/g and 43 MPa respectively was used in all concrete mixtures. The elemental configurations of the cement are indicated in Table 1. Locally available river sand was used as fine aggregate throughout this experimental work and sieve analysis was carried out based on BS EN 933-1:2012 [23]. The outcome of this experiment showed that the fine aggregate used fall under medium size fine aggregate. Natural crushed granite aggregates were used for control specimens in this investigation. The recycled coarse aggregates were obtained from an old demolished building in the university campus. The age of the building was about 15 years. The demolished beams were crushed through impact crusher. The reinforcements and aggregates were separated and cleaned. The required size of the recycled aggregate was attained by further crushing and the loose particles were removed through water washing. The nominal size of recycled aggregate used for this work was less than 20 mm and its particle size distribution were shown in Table 2. To enhance the workability of the concrete, a Type-F naphthalene sulphonate formaldehyde condensate based superplasticizer (SP) in aqueous form conforming to ASTM C 494 [24] was used.

Table 1 Chemical Compositions of the Cement

Description	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_{2O}	MgO	K_2O	SO_3	Cl
Cement (%)	24.5	7	63	0.55	0.4	2	0.6	1.5	0.05

Table 2 Sieve analysis of aggregates

Aggregate	Aggregate passing (%) according to sieve size (mm)										Fineness modulus
	0.15	0.3	0.6	1.18	2.36	4.75	10	12	16	20	
Sand	0.8	7.9	24.6	44.8	76.9	100	100	100	100	100	3.45
Natural Coarse Aggregate	0.0	0.0	0.0	0.0	0.4	1	23	49.2	74.5	100	7.52
Recycled Coarse Aggregate	0.0	0.0	0.0	0.0	0.5	0.9	34	58.4	85.3	100	7.21

Experimental Program

Surface treatment for recycled aggregate

To remove the loosely adhered mortars from the recycled aggregates, the aggregates were treated with hydrochloric acid (HCl) with low concentration of molarities of 0.1 M. HCl is one of the least harmful sturdy acids to handle regardless of its acidity and it has the non-volatile and harmless chloride ion. Hence, it is considered suitable for removing mortar from recycled aggregates. The recycled aggregates were treated by soaking the aggregates in 0.1M HCl solution for 24 hours. The vessel was intermittently shaken to confirm a much proficient reaction of acid in the removal of loose particles attached to the original aggregate. Then the recycled aggregates were taken out and washed thoroughly with sanitized water. The treated aggregates were then sieved using a 4.75 mm sieve and the aggregates which were retained were only used. The recycled aggregates before and after surface treatment by pre-soaking of recycled aggregates in HCl solution was shown in Fig.1. There was a remarkable improvement found in the recycled aggregate concrete due to the effectiveness of using HCl treated recycled aggregate [25]. The properties of the natural aggregates and recycled aggregates were shown in Table 3.

Fig. 1. Recycled aggregates before and after treatment

Table 3 Coarse Aggregate properties

S.NO.	Property	NA	RA	RA_{HCl}
1	Specific Gravity	2.67	2.47	2.49
2	Water Absorption	1.56	6.48	5.08
3	Density (kg/m^3)	1635.5	1392.59	1422.22

Concrete Specimen preparation and curing

Three groups of concrete mixtures that contain natural, recycled and treated recycled aggregates were cast in the laboratory. Indian standard mix design method (IS 10262 - 2009)[26] was employed to design the mix proportions and the mix ratio obtained was 1:1.4:2.27 (cement: fine aggregate: coarse aggregate). In all mixtures, the water/cement ratio (w/b) is fixed as 0.45 and the quantity of the cement is 377 kg/m^3. To increase the workability of concrete and to reduce the water content, high range water reducing admixture was used at 2% by mass of cement content and thus a reduction in 19.81% of water content was obtained. To avoid high water captivation by recycled aggregates and maintain the uniform slump, all aggregates were pre soaked in water for 24 hrs before casting. The recycled aggregate used in saturated surface dry conditions improved the concrete workability [27]. Each mix was prepared using a pan mixer for the above mix design. The concrete mix prepared from natural aggregate was designated as NAC and the concrete mix prepared from recycled aggregate and treated recycled aggregate were designated as RAC and RAC_{HCl} respectively. Concrete was cast in accordance with ‘‘Methods of Tests for Strength of Concrete (IS: 516 - 2004)’’ [28].There is no observation made of any bleeding or segregation for any of the concrete mixtures tested. For each concrete mix, 100 mm cubes and cylinder with 100 mm Ø x 200 mm length were cast. Steel molds were used to cast all the specimens required in laboratory conditions. The specimens were detached from the mold after 24hrs, and were cured in water at 27 ± 2°C for 28 days.

Testing of Specimens

Compressive and Split tensile test

As per IS 516-2004 [28], the compressive strength and split tensile strength were experimentally found using concrete cubes and cylinders respectively. It was done with the help of a compression testing machine with a maximum loading capacity of 3,000 kN. The results of the compressive strength test and split tensile strength were shown in Fig. 2 and Fig.3 respectively for different concrete mixes.

Density and water absorption ratio

Volumetric water absorption test was conducted as per the guide lines of ASTM C 642- 2013 [29]. The dry weight of the cube specimen was taken by oven drying it at 105°C for 24h with 28 days cured specimen. After that they were taken out and cooled to room temperature and their weights were taken. The dried specimens were placed in a water tub and the weight of the specimen was measured at periodic interval of one hour till a constant value was arrived. 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.

Results and Discussions

Properties of Aggregates

The properties of the natural aggregate and recycled aggregate before and after treatment were presented in Table 3. It was found that there was a reasonable improvement in the properties of RA after treatment. The bulk density of RA was 15% lesser than that of NA (1635.55 kg/m^3) and only 13% density variation was observed in HCl treated recycled aggregates. Similarly the water absorption was also reduced from 6.5% to 5% after treatment. This improvement in the RA properties indicates the removal of adhered mortar from the recycled aggregates.

Properties of Hardened Concrete

Compressive and Tensile strength

The compressive strength of concrete mixture prepared with 100% natural aggregate (NAC) and 100% recycled aggregate before (RAC) and after (RAC_{HCl}) treatment were found at the age of 3, 7, 14 and 28 days as per IS:516-2004 and presented in Fig. 2. It was found that after 28 days the compressive strength of RAC was 30% lesser than NAC. This indicates that the replacement of NA with RA results lower compressive strength. This was due to the presence of loose mortar on RA which results weak interfacial transition zone and higher water absorption due to adhered mortar. Similar trend was observed by the author in his earlier research [7,8,9,10]. The experimental results showed that the increase in the strength of concrete with treated aggregate was better than that of untreated RA concrete. However in the initial age (3days) it was almost same. The rate of strength gain of treated RAC was 6% higher than that of untreated RAC. The compressive strength at the age of 28 days of treated RAC was found to be 19% lesser than NAC.

The split tensile strength of concrete was presented in Fig. 3. Similar trend was observed in split tensile strength as observed in compressive strength. Irrespective of the type of aggregates, the tensile strength increases as the age increases. However there was a drop in tensile was observed in concrete when NA was replaced with RA. The split tensile strength value of the recycled aggregate concrete was found to be decreased by 9%, 16%, and 14% at the age of 7, 14 and 28 days respectively whereas the concrete with treated aggregate showed only 6%, 4% and 9% tensile strength drop.

A strong bond between mortar and aggregates was developed because of the removal of loose mortar particles from recycled aggregate by acid treatment. It also helps in the formation of strong ITZ which in turn resulted in much better strength than untreated recycled aggregate concrete. The key factor which regulates the strength development of concrete is the interfacial bond between cement paste and aggregate [30]. Even after treatment the RAC did not attain the strength of NAC. This is due to the fact that the adhered particles were not fully removed from the aggregates as the treatment was done with a low concentrated acid. Therefore, the existing adhered particles hindered the improvement of RAC.

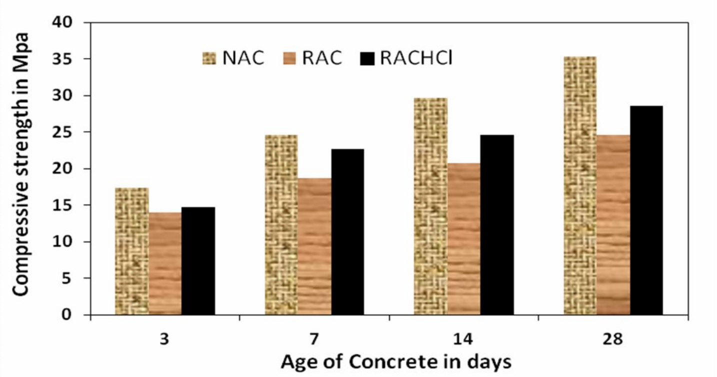

Fig. 2 Compressive Strength of Concrete

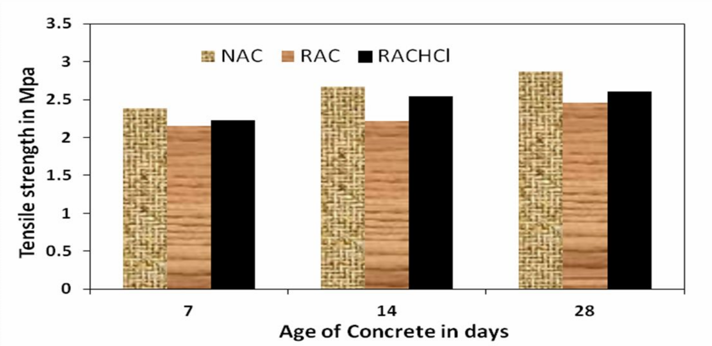

Fig. 3 SplitTensile Strength of Concrete

Density and water absorption ratio

The bulk density of various mixes of concrete with regard to age of concrete was shown in Fig.4. The bulk density of concrete gets reduced when NA was replaced with RA in concrete. From results it was observed that for all concrete mixes there was an increase in the density with respect to age. The lower density was observed in RAC due to the lower particle density of RA compared with that of the NA. A density variation of 6% was observed in RAC with respect to NAC. However, the concrete containing treated RA have a density variation of 4% with respect to NAC. Similar trend was observed by other researchers [2]. This improvement in concrete properties may be due to the increasing C-S-H gel formation between cement mortar particles with new cement paste and thus makes the treated RAC denser than that of RAC.

The water absorption of NA, RA and treated RA concrete mixtures were illustrated in Fig. 5. The durability of concrete can be assessed by using the values of water absorption which is directly associated to the perviousness of concrete. As expected the RAC absorb more water than NA. This was due the presence of adhered mortar on RA. The water absorption characteristic of RAC was improved by incorporating treated RA in concrete. Because of adhered mortar removal from RA the concrete containing treated RA showed lesser water absorption percentage (5.57%) than the concrete containing untreated RA (8.76%).

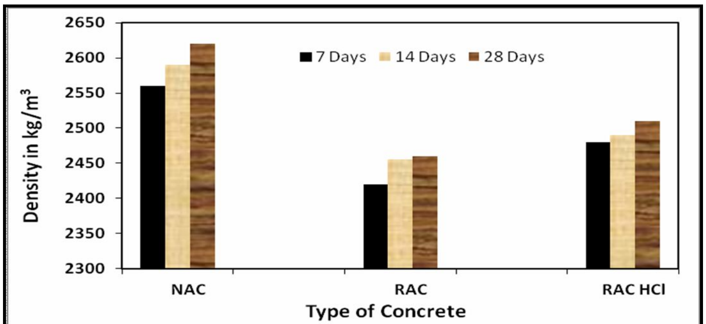

Fig. 4 Concrete Density

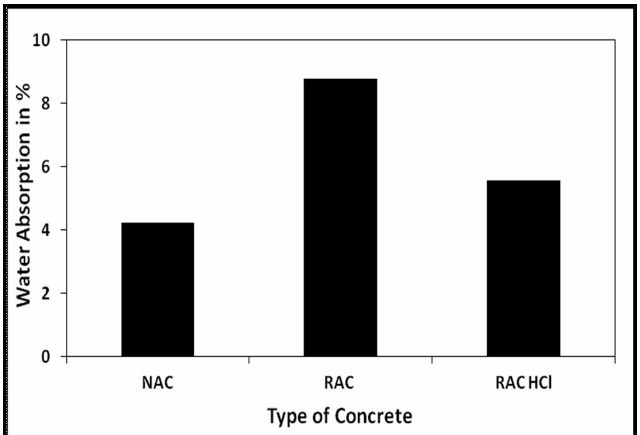

Fig. 5 Percentage of Water Absorption

Conclusions

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

1. The surface treatment method effectively removed the loose mortar particles and thereby significantly improves the properties of RA.
2. The compressive and tensile strength of RAC was lower than that of NAC at all ages. However, the development of concrete strength with treated RA was better than untreated RA.
3. The durability of RAC evaluated in terms of water absorption was improved by incorporating treated RA in concrete.
4. Overall, the surface treatment by presoaking the RA in HCl significantly improves the properties of RA. Hence this method is considered as a beneficial method and can be employed in the application on large scale RAC projects.

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