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Properties of treated recycled aggregates and its influence on concrete strength characteristics

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HIGHLIGHTS

- The surface treatment by presoaking the recycled aggregates in acids significantly improves the properties of RA.
- Acid treated and silica fume impregnated recycled aggregate gave better concrete strength in the later age.
- The strength development of recycled aggregate concrete with treated RA was better than untreated RA.

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ABSTRACT

Utilization of recycled aggregate (RA) from crushed concrete wastes as alternative to natural aggregate in construction industry solve the construction and demolition waste (C&DW) disposal problems and reduces the gap between the demand and supply. The adhered mortar affects the properties of RA to significant level. This paper has studied the characteristics of recycled aggregates retrieved from crushed old concrete obtained from demolished structures, and five different presoaking surface treatment method and silica fume impregnating method to improve the properties of the recycled aggregates and its effect on recycled aggregate concrete (RAC). From experimental results it was observed that after treatment there was a significant improvement in the physical and mechanical properties of RA because of adhered mortar removal. The compressive strength was also significantly improved by using treated RA in RAC. Hence it is concluded that these treatment methods can be effectively used for the recycled aggregates to improve its characteristics.

1. Introduction

For environmental reasons and availability of increased volumes of C&DW, the use of recycled aggregates as a supplement to natural aggregate in construction industry and producing good quality concrete having similar performance characteristics of NAC is considered very valuable, from different prospects. Many attempts were made by researchers to develop a structural concrete with RA [1–14]. The properties of recycled aggregates were generally inferior to NA mainly because of the existence of mortar and impurities [15]. Most of the knowledge and experience with RAC showed a decrease in strength properties when compared with natural aggregate concrete and NA with RA replacements also limited to 20% as per RILEM TC 121 DRG [16] report for all strength classes. It was observed that, the major reason for the strength reduction of RAC was because of its adhered mortar which forms weak interfacial transition zone leads to cracks in the concrete. Many attempts were made by researchers to improve the characteristics of RAC by varying w/c ratios, adding mineral and chemical admixtures like silica fume, slag etc., and blending recycled and natural aggregate with various replacement percentages.

Similarly the properties of RA also enhance by giving beneficiation treatment to RA. Recycled aggregates treatment mainly involves the reduction of adhered mortar present on the surface of the aggregate. To remove the adhered mortar, mechanical treatment (ultrasonic cleaning, ball milling), chemical treatment (presoaking RA in an acidic environment) and thermal treatment

Abbreviations: NA, natural aggregate; NAC, natural aggregate concrete; RA, recycled aggregate; RAC, recycled aggregate concrete; $RA_{H_2SO_4}$, H_2SO_4 treated recycled aggregate; RA_{HNO_3}, HNO_3 treated recycled aggregate; RA_{HCl}, HCl treated recycled aggregate; $RAC_{HCl\&SF}$, HCl and silica fume treated recycled aggregate; $RAC_{H_2SO_4}$, H_2SO_4 treated recycled aggregate concrete; RAC_{HNO_3}, HNO_3treated recycled aggregate concrete; RAC_{HCl}, HCl treated recycled aggregate concrete.

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(aggregate heating through micro wave etc.,) were reported in literatures [4,17].

Amnon [4] studied the microstructure of RA and found that the presence of loose particles in RA affects significantly the bonding capacity of the RAC. Treatment of RA by impregnation of silica fume solution and by ultrasonic cleaning improves the compressive strength of RAC by 15% and 7% respectively. Purushothaman et al. [18] studied the influence of mechanical and chemical treatment methods such as acid scrubbing treatment, heating and scrubbing treatment and acidic treatment (HCl and H_2SO_4) on RA. They found that the aggregates treated with H_2SO_4 and heating and scrubbing gave better quality RA than other acid and mechanical treatments.

Surface modification by aggregate coating results better bonding characteristics of RA. Polymers and pozzalanic materials were tried for surface coating by many researchers. Ismail and Ramli [19] attempted to improve the physical and mechanical strength of RA by soaking the RA in hydrochloric (HCl) acid at 0.5 mol (M) concentrations and impregnated with calcium metasilicate (CM) solution to coat their surface with CM particles. They found that combination of these two surface treatment methods modify the surface and improve RA properties. Li et al. [20] reported that surface coating with pozzalanic materials (silica fume and fly ash) improved the strength of RAC. The silicon-based polymer impregnation treatments were carried out on RA and reported that these treatment methods significantly reduce the rate of water absorption [21].

In the present study, the characteristics of recycled aggregates retrieved from crushed old concrete obtained from demolished structures were studied, and several presoaking surface treatment methods to improve the properties of the recycled aggregate were evaluated. The influence of treated recycled aggregates on concrete strength characteristics also studied.

2. Experimental investigations

2.1. Materials and methods

Crushed granite recycled concrete aggregates were obtained from 20-year-old demolished structure. The reinforcements and aggregates were separated from the demolished concrete by crushing and cleaning. The required size of the recycled aggregate was attained by further crushing and the loose particles were removed through water washing. Physical and mechanical properties for RA such as specific gravity and water absorption, bulk density, aggregate crushing, impact and abrasion value were measured by the methods proposed by ASTM C127, ASTM C29 and ASTM C131 [22–24] respectively. The microstructure of RA was studied through Scanning electron microscope (SEM) analysis and its chemical composition was evaluated by XRF spectrometer. The XRF results were shown in Table 1.

The recycled aggregates were subjected to various presoaking surface treatment methods and the performance of each treatment methods on physical and mechanical properties were estimated. For presoaking surface treatment, the recycled aggregates were presoaked in three different acidic solutions namely, hydrochloric acid (HCl), nitric acid (HNO_3) and sulfuric acid (H_2SO_4) in room temperature (27–30 °C) for 24 h. To provide suitable acidic environment and to improve the quality by means of removal of adhered mortar from recycled aggregates, 10% normality was chosen for the acidic solutions. After presoaking the aggregates were thoroughly washed with distilled water to remove the acid solvents and loose particles. The HCl treated RA was again treated with silica fume by soaking the HCl treated RA into the silica fume solution for 24 h at room temperature. After that it was allowed to dry for 24 h. Fig. 1 shows the aggregates before and after treatment.

Table 1
Chemical composition of coarse aggregates found by XRF analysis.

Description	NA (%)	RA (%)	$RA_{H_2SO_4}$ (%)	RA_{HNO_3} (%)	RA_{HCl} (%)	$RA_{HCl\&SF}$ (%)
SiO_2	56.54	53.44	53.41	52.46	52.44	56.90
Al_2O_3	17.81	11.9	12.99	15.19	16.78	14.77
CaO	6.17	18.84	13.12	14.80	11.70	11.55
Fe_2O_3	6.07	5.9	7.18	7.80	8.19	7.15
MgO	2.91	0.94	2.78	2.94	4.45	3.35
Na_2O	4.20	2.19	2.66	2.93	3.91	3.56
K_2O	2.65	3.89	1.86	1.44	0.70	0.93
TiO_2	0.66	1.00	0.69	0.63	0.64	0.54
SO_3	0.14	1.03	1.57	0.84	0.36	0.51

2.2. Experimental procedure

2.2.1. Aggregate crushing value

In this test a cylindrical measure was filled with specified quantity of aggregate in three layers and compacted by tamping of 25 strokes using tamping rod for each layer. Using compression testing machine a uniform rate of 40 kN load was applying to the aggregate sample in a steel cylinder for 10 min. The crushing value of the aggregate sample was estimated by finding the passing percentage of resulting crushed aggregate through a No. 12 sieve.

2.2.2. Aggregate impact value

In this test a steel cup shall be fixed firmly in position on the base of the impact test machine and the test sample will be placed in it and compacted by a single tamping of 25 strokes. The hammer shall be raised until its lower face is 375 mm above from the upper surface of the aggregate in the cup, and allowed to fall freely on the aggregate. The test sample shall be subjected to a total 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate shall then be removed from the cup and the whole of it sieved on No. 7 B.S. sieve until no further significant amount passes in one minute. The percentage of aggregate passing through the sieve gives the impact strength of the aggregate.

2.2.3. Aggregate abrasion value

In this test a specified quantity of aggregate is placed in the steel drum along with 6–12 steels spheres weighing approximately 420 g each. The drum is rotated for 500 revolutions with a shelf inside the drum causing a tumbling and dropping of the aggregate and balls. The percentage of the aggregate worn away is determined by sieving the resulting sample over a No. 12 sieve. As per ASTM C 33, "Concrete Aggregates," specifies a maximum mass loss of 50% for gravel, crushed gravel, or crushed stone.

2.3. Concrete specimen preparation and testing

Concrete mix design was done as per ACI method and 1:1.4:2.3 mix proportions was arrived with 0.45 water cement ratio. Ordinary Portland cement ASTM type 1 with a specific surface area 3960 cm^2/g and specific gravity of 3.15 was used throughout this work. Treated and untreated recycled aggregates, natural crushed granite aggregates and locally available river sand were used for the specimen preparation. The maximum size of coarse aggregate used for this work was less than 20 mm and all aggregates were used in saturated surface dry state. Hence there was not much difference found in the slump value. The mix proportion of each concrete and its slump value was detailed in a Table 2. The particle size distribution for coarse and fine aggregates were carried out based on BS EN 933-1 [25] and the results were shown in Table 3. To increase the workability of concrete and to reduce the water content, super plasticizer Conplast SP-40 was used at 2% by mass of cement content. Concrete specimens made from the natural coarse aggregates, untreated and treated recycled aggregates in the forms of 100 mm sized cube according to British Standard (BS 1881: Part 116, 1983) were prepared to assess their compressive strength. The specimens were demolded after 24 h and further water cured in a curing tank at 27 ± 1 °C until the ages of 90 days were reached. The crystalline phases present in the concrete were found through XRD analysis. The pH values are also examined to find the alkalinity of the concrete. The properties of the concrete specimen were found at the age of 7, 28, 56 and 90 days and the average of three specimen values were taken for result comparison.

3. Results and discussion

3.1. Properties of recycled aggregate

3.1.1. Specific gravity and mass loss

The specific gravity of natural aggregate and recycled aggregate were found as 2.71 and 2.47 respectively. The major factor for getting lower specific gravity in recycled aggregate was its source, mix proportion and age of the concrete [11]. For this work the recycled aggregates were collected from a single source and before demolition the compressive strength of the concrete was estimated by taking concrete cube samples and NDT (Rebound Hammer test) technique. From that it was confirmed that the existing concrete has a compressive strength of 25 MPa. Since the RA having adhered mortar, it affects its specific gravity very much. The specific gravity