Study on Effect of Heat, Abrasioned and Ground Granulated Blast Slag (GGBS) Slurry Treated Recycled Concrete Aggregates (RCA) on Fresh and Hardened Properties of Recycled Aggregate Concrete (RAC)

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Abstract. Recycled concrete aggregate (RCA) is obtained from construction and demolition waste. However, due to cement mortar attached to its surface, RCA has high water absorption and poor engineering properties compared to natural aggregates. To remove this cement mortar, paste, various treatment methods have been proposed by researchers which includes thermal, mechanical and chemical treatment. In this study, the effect of heated, abrasioned and ground granulated blast slag (GGBS) slurry treated RCA on the workability and compressive strength of recycled aggregate concrete (RAC) has been studied. An improvement in compressive strength and workability of heated, abrasioned and GGBS slurry treated RAC was observed compared to concrete with untreated aggregate.

Keywords: Recycled Concrete Aggregates · Heat Treatment · Abrasion Treatment · Ground Granulated Blast Slag (GGBS) slurry Treatment

1 Introduction

The last couple of years have witnessed tremendous increase in construction activities due to growing urbanization and higher demand for better infrastructural facilities in various cities across globe. This increase in construction activities has in turn raised demand for construction materials such as cement, aggregates and sand. Since aggregates constitute almost 70–75% volume of concrete, it has major part in influencing engineering properties of finished concrete. Traditionally, natural aggregates including gravel, crushed stone and shale have been used in concrete production due to their abundant supply. However, the ever-increasing demand for natural aggregates [8] is generating high pressure on naturally available resources leading to ecologically harmful practices such as stone quarrying and river dredging. Further, disposal of large quantities of construction waste in open landfills is also putting significant pressure on available spaces [35]. Hence, researchers and environmentalists have been advocating usage of

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recycled concrete aggregates as more sustainable substitute to natural aggregates in concrete manufacturing. Traditionally RCA have been used in low strength structural applications such as sub-base course for road surface, reclamation, roadside kerbs, architectural finishes and drainages [8]. But, with the development of newer surface treatment methods over last few decades, many research studies have recommended use of RCA as core structural element [2]. The limitations of RCA as structural material have been documented in numerous research studies conducted in past. Higher replacement rate of natural aggregate (NA) with RCA leads to high porosity [11], high permeability [8] and decrease in density and specific gravity of RCA. The inferior proprties of RCA are primarily due to attached mortar on the RCA surface. This attached mortar is highly porous in nature because of which RCA have high water absorption rate [36] and weaker interfacial transition zone. The water absorption rate of RCA is influenced by various factors such as larger size aggregates [12], quality of recycling procedure and strength of original concrete [8]. In order to enhance RCA properties, the interfacial transition zone needs to be strrengthened [32].

2 Literature Review

A review of various treatment methods proposed by researchers to enhance engineering properties of RCA is presented in below section. The treatment methods have been classified into 3 categories viz thermal, mechanical and chemical.

2.1 Thermal Treatment

The traditional heating method includes heating RCA at temperature between 100–500 °C for 1–2 hours in either microwave oven or electric shaft rotor. When aggregates are heated at temperature greater than 300 °C, thermal stresses are generated which results in gradual loosening and removal of attached mortar interface due to dehydration [25]. Koga demonstrated there is no significant deterioration in density and water absorption when RCA are heated at temperature up to 500 °C [6]. However, heat treatment of RCA above 900 °C may cause damage to structure of aggregate and reduction in compressive strength by 17% [3].

2.2 Mechanical Treatment

2.2.1 Microwave Heating Treatment

This method consists of heating the RCA in a microwave equipment leading to generation of thermal stresses at the interfacial transition zone. The RCA are placed into Los Angles abrasion machine in which the drum is rotated at various rotations like 100,200,300,400and 500rpm for duration between 2–15 min. The scrubbing action of ball leads to gradual removal of adhered mortar from the aggregate surface. However, treating aggregates in abrasion device for higher duration may lead to microcracking of surface [7] An improvement of 25.79% in compressive strength, 30.05% in crushing strength, 26.45% in impact strength and 30.74% in abrasion resistance was observed after implementing mechanical scrubbing method [45].

2.2.2 Water Cleaning Treatment

In this method, RCA are placed in ultrasonic water for 10 min which leads to removal of residual slurry and loose surface particles and strengthen the bond between new cement paste and RCA. Katz et al. observed during cleaning process that RCA from low grade concrete requires more surface cleaning as compared to higher grade concrete. Ultrasonic treatment method results in 3% improvement in compressive strength of RCA at 7 days and 7% increase at 28 days. The limitation of this treatment is that strong adhered mortar cannot be easily removed by this method [22].

2.3 Chemical Method

2.3.1 Polymer Treatment

Spaeth and Tegguer observed reduction of almost 90% in water absorption and 20–22% in LA coefficient value of RCA by treating aggregate surface with different polymers such as alkyl alkoxy silane (Silane), polydiorganosiloxanes (Siloxane) and combination of both silane and siloxane [46]. The application of polymer treatment such as polyvinyl alcohol helps in filling up the surface pores of RCA which leads to better adherence between cement paste and aggregates [26, 29]. Surface modification of RCA using 1:20 alkaline organosilicone was also proposed by Cui et al. to reduce slump loss of fresh concrete and improve mechanical and durability properties [15]. However, polymer treatment is time consuming treatment and disposal of waste solution after treatment becomes challenge [30].

2.3.2 Acid Treatment Methods

Acid treatment is considered to be an effective treatment for removing the attached mortar and improving RCA performance. When RCA are submerged in acid solution, the acid reacts with RCA constituents such as calcium oxide (CaO), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) due to which different products such as (Ca2+, Al3+, Fe3+) are generated which weakens the mortar and gradually removes the same. Previous research studies have shown that RCA treated with acid solution exhibits low water absorption [2]. A linear co-relationship between higher degree of HCL concentration treatment (10–12.8 mol) and subsequent improvement in aggregate crushing value, impact value and water absorption was demonstrated by Alodaini et al. [2].

2.3.3 Carbonation Treatment

Carbonation treatment consists of penetrating CO_2 into concrete surface through diffusion mechanism. CO_2 reacts with calcium hydroxide ($Ca\,(OH)_2$) in moist conditions to form calcium carbonate (CaCO3) which results in high compressive strength and low permeability of RCA [29]. Gombosuren et al. observed reduction in water-absorption rate and improvement in mechanical properties of RAC containing carbonated recycled fine aggregates. However, they also recommended that maximum replacement of recycled fine aggregates should be limited to 30% in concrete. The application of carbonation treatment does not lead to any significant improvement in durability characteristics of RAC such as shrinkage and creep [8].

2.3.4 Calcium Carbonate Bio Deposition

Bio-deposition is an innovative and eco- friendly treatment for reducing water absorption and enhancing the quality of RCA. This method involves using bacteria to expedite formation of calcium carbonate (CaCO3) to fill or bind micro cracks of RCA which reduces porosity and wettability of RCA [15]. Bio deposition has been considered as natural method by researchers, because the components used for producing substrates naturally occurs in the environment. Singh et al. concluded that treatment of RCA with ureolytic bacteria (B Pasteruii and B. sphaericus) shows better results as compared to non ureolytic bacteria (B.Cohnii). Some research studies have also advocated soaking RCA into the bacterial solution compared to mixing process to improve the surface properties of RCA [15].

2.3.5 Addition of Pozzolanic Material

Surface treatment of RCA with Pozzolanic material such as fly ash (FA), silica fume (SF), GGBS, slag, and Metakaolin helps to fill the pores and micro cracks present on the RCA surface. Pozzolanic material reacts with calcium hydroxide Ca (OH)2 to develop hydrated calcium silicate (C-S-H) gel which ultimately helps to decrease the porosity of RCA and make ITZ's dense and stronger [21]. The surface coating of RCA with flyash using triple mixing method led to improvement in mechanical and durability properties of RAC due to pozzolanic effect of flyash [39]. Bui et al. demonstrated decrease in water absorption rate and increase in compressive strength, elastic modulus and split tensile strength of RAC by treating surface of RCA with solution of silica fume and sodium silicate and concluded that high percentage of amorphous silica contribute to the strength development in RAC [5].

2.4 Combination of Thermal-Mechanical-Chemical Treatment

Wang et al. proposed combination of chemical and mechanical treatment to enhance the surface quality of RCA. The combination method includes immersion of RCAs in low concentration acetic acid solution (1–5%). During this phase, Acetic acid react with calcium hydroxide, calcium carbonate and calcium silicate hydrate thereby forming calcium ion ($Ca2+$) which helps to weaken the attached mortar. In the second phase RCA are treated in ball and milling machine so that most of the adhered mortar can be removed. The test results indicated 9.3%, 27.9% and 38.7% decrease in water absorption for RCA treated with 1%, 3% and 5% acetic acid solution followed by mechanical rubbing [49]. Similar recommendations were made by Perumal et al. who proposed combination of carbonation and pozzolanic coating as more effective pre-treatment method as compared to applying only pozzolanic coating (47). Surface treatment of RCA by heating the aggregates at 100 °C followed by Los Angeles abrasion along with Acid treatment can lead to better mechanical performance and improved water absorption as compared to only thermal and mechanical treatment (26).

3 Study Objectives

The proposed study has below two objectives:

3.1. To compare effectiveness of treatment methods with water absorption as performance parameter
3.2. To study the effect of treated aggregates on the workability and compressive strength of concrete

4 Experimental Program

4.1 Cement

The cement conforming to Bureau of Indian Standard Specification (BIS) 12269 having below mentioned characteristics was used for the experimentation work.

Type	Ordinary Portland Cement (O.P.C)
Grade	53
Consistency	31%
Specific gravity	3.15
Initial setting time	165 min
Final setting time	600 min
Compressive strength	Mpa

4.2 Sand

Zone 1 Tapi sand conforming to IS 383-1970 with below characteristics was used for the experimentation program.

Specific gravity	2.6
Moisture content	2.1%
Water absorption	1%
Silt content	9%
Fineness modulus	3.885

4.3 Recycled Concrete Aggregates

The RCA were collected from demolition concrete waste of 2 story building. The concrete blocks were crushed at crusher plant into combined various sizes and later on separated into 20mm, 10mm and 6mm size aggregates. The sieve analysis of 10mm and 20mm size aggregates was carried out in accordance with guidelines of IS 2386:1963 and grading percentage for both 10mm and 20mm was finalized according to IS 383:1970. The physical properties of natural aggregates and RCA including specific gravity and water absorption were obtained in accordance with IS 2386-1 1963 as shown in Table 1. The untreated RCA are shown in Fig. 1.

Table 1. Physical properties of NA and RCA

	Specific Gravity	Water Absorption (%)	Bulk density	Abrasion value (%)	Crushing value (%)	Impact value (%)
NA						
10mm	2.90	1.42	1.50	10	14	15
20mm	2.94	1.2	1.55	15	12	12
RCA						
10mm	2.54	4.5	1.31	14	29.32	32
20mm	2.53	4.72	1.38	9.48	16.62	24.3

4.4 Treatment Methods of RCA

The treatment method employed to improve the surface properties of RCA consisted of heated, abrasioned and GGBS slurry treatment.

4.4.1 Heat Treatment

In the heat treatment method, the RCA were heated in Microwave oven at 350 °C for 2 hours. After 2 hours, the aggregates were removed from the oven and immediately immersed in water. These aggregates were later dried at lab temperature. The objective of heat treatment was to produce thermal stresses in microstructure surface of RCA so that attached mortar can be loosened and gradually removed. The heat-treated 10mm and 20mm aggregates have been shown in Fig. 2.

4.4.2 Abrasion Treatment

The heat-treated aggregates were abrasioned in Los Angeles abrasion machine according to guidelines of IS 2386 part 4. The aggregates were placed in LA abrasion machine containing 12 steel balls having 60 mm diameter and they were offered 300 revolutions for 10 minutes. The objective of abrasion treatment was to remove attached mortar through peeling and friction action of steel balls. The heat treated and abrasioned 10mm and 20mm aggregates are shown in Fig. 3.

4.4.3 GGBS Slurry Treatment

The volume of slurrry containing cement, GGBS and water was taken as 15% of total volume of dry loose weght of aggregates. The percentage of GGBS and cement was taken as 70%: 30% of slurry volume so that the effect of GGBS becomes more visible compared to cement. The slurry treatment was applied to RCA in batches with each batch consisting of 27 kg of aggregates. For 1m^3 of concrete, the water content was taken as 629kg, fine aggregate was taken as 629 kg and cement voliume was taken as 270 kg. The slurry treated aggregates are shown in Figs. 4 and 5.

Fig. 1. Untreated 10 mm and 20 mm aggregates

Fig. 2. Heat treated 10 mm and 20 mm aggregates

Fig. 3. Heat and abrasioned 10 mm aggregates

Fig. 4. Heat and abrasioned 20 mm aggregates

The water absorption of both untreated as well as treated aggregates was calculated, the results of which are presented in results and discussion section.

Fig. 5. Heat, abrasioned and GGBS slurry treated aggregates

Table 2. Mix design proportions with various ratios of Fine Aggregate:RCA

% of FA: RCA	45:55	40:60	35:65	30:70
W/C	0.4	0.4	0.4	0.4
Water (Kg)	170	170	170	170
Calculated Cement (Kg)	425	425	425	425
Flyash (10%)	43	43	43	43
Actual cement	383	383	383	383
Air (%)	1	1	1	1
Superplasticizer (ml)	0	0	0	0
10mm RCA (kg/m3)	866	940	1024	1102
20mm RCA	96	105	114	122
Fine aggregates (kg/m3)	790	703	615	527

4.5 Concrete Mixture Proportions

The concrete mixes were prepared with various ratios of fine aggregate and coarse aggregates under laboratory controlled environment in accordance with the guidelines of IS 10262-2019 with proportions tabulated in Table 2. The objective was to understand influence of variations in fine and coarse aggregates on slump and compressive strength of RAC. Overall 12 number of trial mixes were prepared for the experimental work for treated and untreated aggregates.

4.6 Specimen and Testing

Standard concrete cube specimen of size 150mmx150mmx150mm were prepared using the treated RCA and placed in moulds for 24 hours. After 24 hours, the cubes were removed from the mould, labelled and cured in curing pond for 28 days at 95% relative humidity. The concrete cubes were divided into untreated and treated group. The aggregate testing performed in this study includes water absorption, specific gravity and bulk density. The fresh and hardened properties obtained in this study includes slump and compressive strength for both untreated and treated coarse aggregates of size 10 mm and 20m.

Table 3. Water absorption results for treated and untreated aggregates

Type	20mm	10mm
Untreated Aggregates	4.72	4.5
Heat and Abrasioned aggregates	3.39	3.4
Heat, Abrasioned and GGBS treated aggregates	2.9	3.1

5 Results and Discussion

5.1 RCA Characteristics

The characteristics of untreated RCA such as specific gravity, water absorption and bulk density are summarized in Table 1. RCA had low specific gravity, low bulk density and high water absorption compared to NCA which was mainly due to presence of adhered mortar in RCA surface.

5.2 Water Absorption

The results of water absorption are presneted in Table 3 for untreated as well as treated RCA. The % reduction in water absorption for 20mm heated and abrasioned aggregates was 28% compared to 20mm untreated aggregates and 24% for 10mm heated and abrasioned aggregate compared to 10mm untreated aggregate. Further reduction in water absorption was observed for for heated, abrasioned and GGBS treated aggregate which was 38% for 20mm aggregates and 31% for 10mm aggregates. The % decrease in water absorption for 20mm and 10mm heated, abrasioned and GGBS treated aggregate compared to 20mm and 10mm untreated aggregate was 14% and 8%. The higher reduction in water absorption as result of heat and abrasion treatment was mainly due to removal of adhered mortar from RCA surface.

5.3 Fresh Concrete Properties

The workability of concrete mixes were determined in accordance with guidelines of IS 1199-1959. The values are illustrated in Table 4. Reduction in slump was observed for decrease in fine aggregate: RCA proportions and finally collpase slump was observed for highest replacement of fine aggregate at 70% with RCA. For treated RCA mixes, higher slump value was observed compared to untreated mixes maintaining same proportions. However, similar trend was also observed in case of treated mixes with slump value decreasing with decrease in FA:RCA ratio.

5.4 Compressive Strength

The compressive strength of concrete was calculated in accordance with IS 516-1959 guidelines. The compressive strength of concrete containing heat treated and abrasioned aggregates did not show any improvement, however increase in compressive strength

Table 4. Slump test results for treated and untreated mixes

Concrete mix	Proportion fo Fine Aggregate: RCA			
	45:55	40:60	35:65	30:70
Untreated RCA(mm)	70	50	26	Collapse slump
Heat+Abrasion treated RCA (mm)	68	50	24	Collapse slump
Heat+Abrasioned+GGBS treated RCA (mm)	85	70	60	25

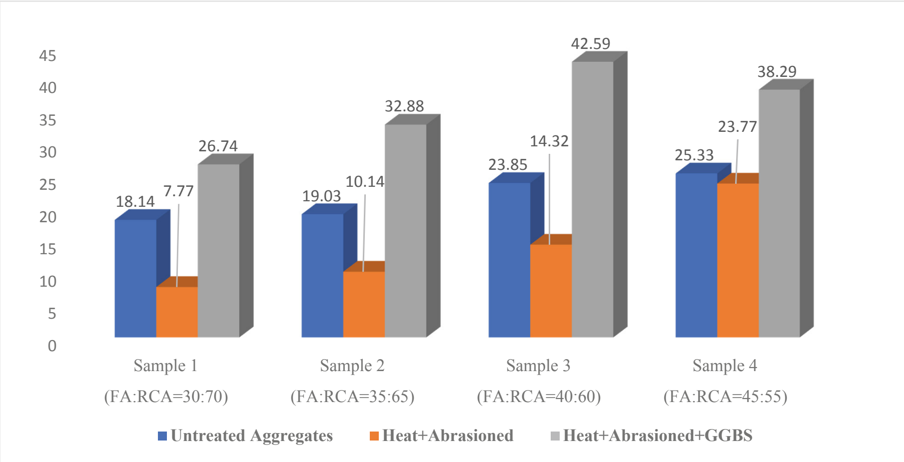

Fig. 6. Compressive strength values for untreated and treated mixes(Mpa)

was observed for heated, abrasioned and GGBS slurry treated aggregates. The highest strength was observed for heat treated, abrasioned and GGBS treated RAC at FA: RCA ratio of 40:60. The increase in compressive strength due to heated, abrasioned and GGBS treatment can be attributed to both densification of RCA surface due to better packing and removal of adhered mortar from RCA surface. The compressive strength results for treated and untreated aggregates are shown in Fig. 6.

6 Conclusion

The effect of heat, abrasion and GGBS slurry treated RCA on the fresh and hardened properties of recycled aggregate concrete (RAC) was determined. The characterization of untreated RCA was done based on physical properties post which 2 different types of treatments were applied which includes (1) heat and abrasion (2) heat, abrasion and GGBS treatment. The performance parameter identified for this study was reduction in water absorption and improvement in slump and compressive strength of RCA Based on experimental test results, following conclusions can be drawn.

1. The water absorption for 10mm and 20mm RCA was 68% and 74% higher than 10mm and 20mm NA due to attached cement mortar. The specific gravity of 10mm and 20mm NA was higher than 10mm and 20mm RCA by 12% and 13.9%. The bulk denisty of 10mm and 20mm NA was higher than 10mm and 20mm RCA by 12.5% and 10.9% respectively
2. A gradual reduction was observed for slump value of both untreated and treated RCA mixes with decrease in fine aggregate and increase in RCA proportions which shows that slump value is negatively influenced by increase in volume of RCA. At maximum RCA volume of 70%, collapse slump was observed for untreadted RCA mixes. However, an improvement in slump value was observed for treated RCA mixes with highest slump value at 45: 55 proportions. This improvement in slump value could be could be attributed to surface densification of RCA surface due to GGBS penetration which helped in better binding of constituent materials.
3. Both RCA treatments resulted in increase in compressive strength of RAC, however highest improvement in compressive strength was observed for heat, abrasioned and GGBS treated RCA at FA:RCA ratio of 40:60, which indicates that out of all 4 proportions, FA:RCA of 40:60 is the most optimum proportion.
4. There was decrease in water absorption for both the RCA treatment mainly due to higher rate of mortar removal due to thermal stresses generated during heat treatment and peeling and friction action during abrasion treatment which led to breaking of RCA microstructure and gradual removal of adhered mortar from RCA surface. The reduction in water absorption was more noticeable for 20mm aggregate compared to 10mm.
5. The feasibility of utilization of GGBS and RCA in concrete manufacturing needs to be explored rather than simply disposing them as waste material. A concrete prepared with GGBS and RCA would not only facilitate in effective utilization of these materials but also helps to reduce the dependence on cement and natural aggregates thereby lessening environmental impact of concrete

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