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Strengthening of Recycled Coarse Aggregate using Different Surface Treatment Techniques

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Abstract

Numerous studies performed on recycled aggregate indicated that recycled aggregate has the undesirable characteristics of porosity, high water absorption, and low crush resistance due to the presence of porous mortar as well as the tiny seams derived from the crushing process. This study involves strengthening of RA using various surface treatment techniques like treatment with pozzolan slurry (fly ash, alccofine and cement slurry), HCl, polyvinyl alcohol and an optimized triple mixing method. The physical and mechanical properties of RA were comprehensively assessed before and after the surface treatment. The optimum percentage of replacement of natural coarse aggregate with treated recycled coarse aggregate is also found out based on compressive strength. It suggests that treatment using fly ash and cement pozzolan slurry is an efficient and feasible method for improving the mechanical properties of recycled coarse aggregate. This treatment of recycled coarse aggregate is not only an efficient way for enhancing the properties of recycled aggregate, but also an environmental friendly approach. Also the optimum percentage replacement of treated recycled aggregate was obtained as 60%.

Keywords: Surface Treatment, recycled coarse aggregate, pozzolan slurry, HCl, Polyvinyl Alcohol, Optimized Triple Mixing Method

1. Introduction

In recent years, it has been recognized that increasing energy consumption from all sources could contribute to the global climate change both directly and indirectly. Not only the global climate change but also another very serious problem faced by the modern society is the depletion of non-renewable resources due to their extensive use. It is generally agreed that current and most often used construction materials as well as building methods are unsustainable, having large environmental impacts such as CO_2 emissions, energy consumption, pollution, dusts, depletion of natural resources, generating considerable amount of solid waste [1].

Among all existing construction materials, concrete is the most used material because of many technical and economic factors. Apart from cement, aggregate accounts for 65-80% of the total volume of concrete and could significantly affect the environmental load of concrete and its level of sustainability. Aggregates for concrete are whether collected as gravel or produced as a result of crushing rocks. In both cases, the excessive use of natural aggregate to respond to the high demand of construction leads to depletion of non-renewable resources. Introducing secondary aggregate from different sources such as aggregates collected from demolished buildings and subjected to crushing and screening and then used in new concrete production has many environmental advantages [1].

It takes many years for a waste management system to develop into a sustainable, reliable, skilful and marketable industry, encouraging the reuse and recycling of components and materials. It is necessary that all parties involved (i.e. clients, contractors, planners and manufactures) play their role in achieving a more sustainable approach. This can be done by extending the life cycle of materials, components and resources. The use of recycled materials in high rather than low-grade applications must also be a priority in the near future. In order to be successful in this approach, the correct choice of materials, recycling procedures and manufacturing processes is fundamental [2].

Over the last decade the concept and development model of Circular Economy has been gaining a growing attention. It aims to provide an alternative to the traditional and dominant model featured at consuming resources and then disposing it. Circular Economy emerges through three main actions, namely reduction, reuse, and recycle. Waste management, as a recovery of resources and environmental impact prevention, has become an important subsector of

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Circular Economy. Around 30% to 40% of the urban solid waste come from construction and demolition (C&D) activities. The overwhelming amount of C&D wastes generated in the forms of concrete, bricks, and tiles are causing pressures on the limited urban landfill space. On the other hand, limited natural resources, such as virgin aggregates, call for the utilization of recycled alternatives to meet the construction industry needs [3].

Many studies have been conducted on recycled aggregate. The results of those works reveal that the quality of recycled aggregate is usually lower than that of natural aggregate due to adhering mortar particles, surface cracks, and higher water absorption and porosity of recycled coarse aggregate (RCA). This will cause negative effects on the mechanical properties, workability, air content and durability of fresh and hardened concrete. To overcome this issue, several studies were conducted on improving the performance of RCA through enhancement treatment methods. These approaches and techniques can be fundamentally classified into two categories. The first category mainly includes removing the adhered mortar on the surface, whereas the second category is extensively focused on modifying and improving the quality of adhered mortar. The adhered mortar can be removed by using different treatments that include ball milling, heating and then rubbing and ultrasonic cleaning method. The modification of the quality of adhered mortar includes surface coating with different materials such as water glass, pozzolanic materials such as fly-ash and silica fume, polyvinyl alcohol emulsion and bio-deposition [4].

The present study aims to evaluate the performance of concrete made with treated recycled coarse aggregate (RCA). In this study, RCA were obtained from crushed concrete structures with an unknown strength and were subjected to treatment. The specific objectives of the study are (1) To determine the physical and mechanical properties of recycled aggregates before and after the surface treatment. (2) To find the optimum percentage of treated recycled concrete aggregates by casting and testing cube specimens. This scheme provides a more industrially-reliable approach that promotes the use of RCA in the construction industry.

2. Treatment techniques

In order to strengthen the weak adhered mortar and improve the RCA surface, four different types of treatment methods were adopted.

2.1 Pre-soaking in Pozzolan Slurry

For the first treatment method using pozzolan slurries ,two different slurries i.e. Fly ash and Cement slurry (FA&C) and Alccofine and Cement slurry (AF&C) were used. The two strengthening materials of each slurry were equally used with 40% of the total weight of RCA. In making slurries, the two different types of strengthening slurries were prepared by blending the strengthening materials with water (twice the weight of RCA taken) for 2 minutes. Then, the RCA was added into each slurry and soaked for a soaking time of 4 hrs. After that, the RCA was removed from the slurry bath and dried at the room temperature for 3 days. Finally, the hardened RCA was sieved again to remove the excessive materials before conducting the different laboratory tests.

This mechanism involves cement reaction together with the pozzolanic reaction forming additional (C-S-H) gel [6], as shown in Eqs. (1) and (2) below

Pozzolanic reaction: $CH + S \rightarrow C\text{-}S\text{-}H$ (1)

Cement reaction: $C_3S + H \rightarrow C\text{-}S\text{-}H + CH$ (2)

2.2 Acid Treatment

For the treatment of aggregates with acid, RCA samples were soaked in 0.1 molar HCl solution for 24 hours at room temperature. Low concentration of acidic solution was chosen to provide a suitable acidic environment for RCA without an influence on its quality. After 1 day pre - soaking, the aggregates were washed in normal water to wash off the adhered mortar and then the treated RCA was dried. Treatment could remove adhered mortar which helps to improve the weak ITZ between the RCA and adhered mortar. The mechanism of this treatment is that the hydration products of cement are dissolved in the acid solution. Acid treatment requires safety precautions while handling the acids and during final washing by fresh water after treatment.

2.3 Pre-soaking in Polyvinyl Alcohol (PVA)

PVA pellets were added into boiled water to prepare the polymer solutions, such that the concentration of PVA solution was 10%. After the PVA pellets were dissolved, the polymer solution was allowed to cool down to room temperature. The aggregates were soaked in the polymer solution for 24 hrs. Then aggregates were removed from solution and air dried. Polymer emulsions have adhesive properties and can solidify in a short period of time. The polymer molecules can fill the pores of the adhered mortar and seal the surfaces of the RCA.

2.4 Optimized Triple Mixing Method

The pretreating process would lead to a higher cost, thus limiting its application in the construction industry [5]. So a special mixing method called optimized triple mixing method (OTM) as shown in Fig.1 was developed to strengthen the ITZ in the RAC by Zhang et al., (2019).

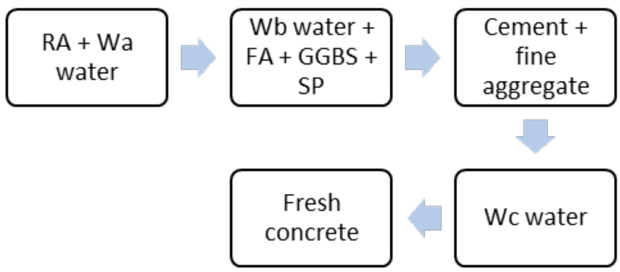

Fig. 1. Schematic diagram of OTM method

'Wa' equals 60–80 percent of the product that the weight of RA multiplied by its water absorption ratio. 'Wb' equals residual water the SCM weight percent in the total cementitious material. 'Wc' equals mixing water-Wb-Wa. 40% of cement was replaced by flyash and GGBS in the ratio 7:3.

3. Experimental investigation

A series of laboratory tests were conducted to investigate the macro properties of RCA before and after using the above mentioned surface treatment methods. In order to assess the effect of the treatment on the physical and mechanical properties of RCA, different tests were conducted according to the following standards:

i) Water absorption (IS: 2386- 1963)
ii) Porosity (IS: 2386 (Part 3) 1963)
iii) Aggregate impact value (IS: 2386 (Part 4)- 1963)
iv) Aggregate crushing value (IS: 2386 (Part 4)- 1963)
v) Specific gravity (IS: 2386- 1963)
vi) Void ratio (IS: 2386- 1963)
vii) Bulk density (IS: 2386- 1963)

Later, cube specimens were cast using treated recycled aggregates in order to find the compressive strength. Apart from using treated recycled aggregates, optimized triple mixing was done using untreated recycled aggregate, which would promote densification of the ITZ in recycled aggregate concrete (RAC). From the results obtained, best treatment method was identified and its optimum replacement percentage in concrete mix was found.

4. Results and discussion

4.1 Water Absorption

The water absorption of RCA increases as the amount of attached mortar increases. The test is done as per (IS 2386-1963) and result is tabulated in Table 1. The results show that aggregate treated with polyvinyl alcohol has shown better results in this regard.

Table 1. Water absorption

Sl. No	Material	Water absorption (%)
1	Coarse aggregate	0.40
2	Untreated recycled aggregate	2.18
3	FA&C treated recycled aggregate	2.14
4	AF&C treated recycled aggregate	2.50
5	0.1 molar HCl treated recycled aggregate	2.13
6	PVA treated recycled aggregate	1.60

Table 2. Porosity

Sl. No	Material	Porosity (%)
1	Coarse aggregate	44.0
2	Untreated recycled aggregate	48.9
3	FA&C treated recycled aggregate	49.0
4	AF&C treated recycled aggregate	49.4
5	0.1 molar HCl treated recycled aggregate	49.6
6	PVA treated recycled aggregate	51.6

4.2 Porosity

Porosity represents the amount of voids present on aggregate surface. The test is done as per (IS: 2386 (Part 3) 1963). The result is tabulated in Table 2. After the treatment of recycled aggregate using various techniques, there is not much comparable difference in porosity.

4.3 Aggregate Impact Value

The impact resistance test for coarse aggregate represents the toughness of aggregate and its ability to resist fracture. The experimental results of the impact resistance test are presented in Table 3, where the better aggregate shows the lower impact value. The PVA treated recycled aggregate has obtained a lower impact value compared to untreated RA.

4.4 Aggregate Crushing Value

The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. Low aggregate crushing value indicates better aggregates. The experimental results of the aggregate crushing value test are presented in Table 4. The PVA treated recycled aggregate has obtained a lower crushing value compared to untreated RA.

Table 3. Aggregate Impact Value

Sl. No	Material	Impact value (%)
1	Coarse aggregate	25.30
2	Untreated recycled aggregate	28.63
3	FA&C treated recycled aggregate	34.00
4	AF&C treated recycled aggregate	33.27
5	0.1 molar HCl treated recycled aggregate	36.20
6	PVA treated recycled aggregate	26.12

Table 4. Aggregate crushing value

Sl. No	Material	Crushing Value (%)
1	Coarse aggregate	27.5
2	Untreated recycled aggregate	31.6
3	FA&C treated recycled aggregate	32.8
4	AF&C treated recycled aggregate	32.0
5	0.1 molar HCl treated recycled aggregate	34.1
6	PVA treated recycled aggregate	30.1

Table 5. Specific gravity

Sl. No	Material	Specific Gravity
1	Coarse aggregate	2.71
2	Untreated recycled aggregate	2.56
3	FA&C treated recycled aggregate	2.54
4	AF&C treated recycled aggregate	2.59
5	0.1 molar HCl treated recycled aggregate	2.46
6	PVA treated recycled aggregate	2.20

4.5 Specific Gravity

Specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregates having low specific gravity are generally weaker than those with higher specific gravity values. The results are shown in Table 5.

4.6 Void Ratio

Void ratio is defined as the ratio of void volume to volume of solids. The test results are shown in Table 6.

4.7 Bulk Density

Bulk density is the weight of material in a given volume. The bulk density of an aggregate is affected by several factors including the amount of moisture present and the amount of effort introduced in filling the measures. The test results are shown in Table 7.

Table 6. Void ratio

Sl. No	Material	Void ratio
1	Coarse aggregate	0.79
2	Untreated recycled aggregate	0.96
3	FA&C treated recycled aggregate	0.97
4	AF&C treated recycled aggregate	0.97
5	0.1 molar HCl treated recycled aggregate	0.98
6	PVA treated recycled aggregate	1.06

Table 7. Bulk density

Sl. No	Material	Bulk Density (g/cc)
1	Coarse aggregate	1.54
2	Untreated recycled aggregate	1.31
3	FA&C treated recycled aggregate	1.28
4	AF&C treated recycled aggregate	1.3
5	0.1 molar HCl treated recycled aggregate	1.24
6	PVA treated recycled aggregate	1.07

4.8 Compressive Strength

Compressive strength was taken as the main parameter in deciding the best treatment method. The results obtained are shown in Table 8. A comparison of the results is shown in Fig. 2. The result shows that the concrete prepared using recycled aggregate treated with fly ash and cement slurry has higher compressive strength.

The strengthening technique by using pozzolanic materials works to fill the pores and voids in the weak adhered mortar. The pozzolanic materials react with the hydrous compounds (CH) in the adhered mortar that leads to the formation of new hydrated compounds such as C-S-H formation by the pozzolanic reaction. Also comparing to other methods of treatment, treatment with fly ash and cement slurry is both economical and effective.

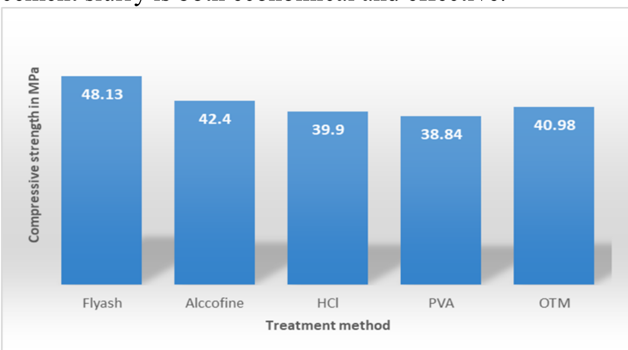

Fig. 2. Comparison of compressive strength

Table 8. Compressive strength

Sl. No	Treatment Method	28 days compressive strength in MPa
1	Control specimen (NA)	46.7
2	Untreated RCA	39.2
3	Flyash + Cement	48.13
4	Alccofine + Cement	42.4
5	HCl	39.9
6	Polyvinyl alcohol (PVA)	38.84
7	Optimum triple mixing method (OTM)	40.98

Table 9. Optimum percentage replacement of treated recycled aggregate

Sl. No	Mix	Compressive strength (N/mm^2)
1	RAC0	46.7
2	RAC20	48.24
3	RAC40	49.56
4	RAC60	50.63
5	RAC100	48.13

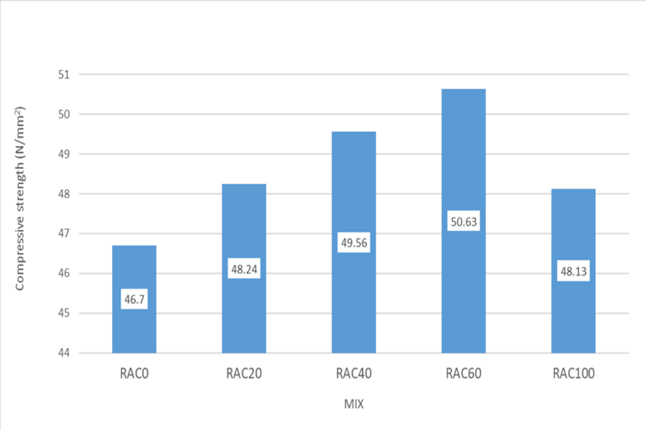

Fig. 3. Comparison of compressive strength to find optimum percentage replacement

In general, polymer treatment can improve the quality of RCA and reduce water absorption, impact value etc. However, they cannot enhance the compressive strength of the concrete. The reason for reduction of compressive strength may be attributed to the process by which the positive polymer groups permeate into the cement paste and make it hydrophobic, which hinders the hydration of the unhydrated cement in the paste. At the same time, the formation of water-repellent film weakens the bonding strength between the aggregate and cement matrix [6].

4.9 Optimum percentage replacement of RCA treated with fly ash and cement slurry

Optimum percentage replacement of treated recycled aggregate was found out. Cubes were cast with 0%, 20%, 40%, 60% and 100% replacement of natural coarse aggregate with recycled aggregate treated using fly ash and cement slurry. The results obtained are shown in Table 9. A comparison of the results is shown in Fig. 3.

5. Conclusions

Treated recycled aggregate can perform better than untreated recycled aggregate and contribute to significant improvement in compressive strength of concrete. Among the treatment methods adopted in the present study, treatment of recycled aggregate with fly ash and cement slurry soaking is found to be an effective technique, with advantages in terms of both low cost and the enhancement effects on recycled aggregate. The optimum percentage replacement of treated recycled aggregate was found out to be 60% based on compressive strength. Thus, a sustainable and environment friendly concrete with adequate structural capacity can be proposed which can also address the issues of disposal of construction and demolition waste.

Disclosures

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