EVALUATION ON THE MECHANICAL PERFORMANCE OF CONCRETE INCORPORATING STRENGTHENED RECYCLED CONCRETE AGGREGATE

Wafaa Mohamed Shaban, Jian Yang, Haolin Su, Jianhe Xie, Lijuan Li

School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, China
State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai, China
Collaborative Innovation Center for advanced Ship and Deep-Sea Exploration (CISSE), Shanghai, China

ABSTRACT. Recycling of construction and demolition concrete wastes has become an essential issue worldwide due to the depletion of natural resources, the continued increase of construction concrete wastes and the shortage of landfill space. Thus, the use of recycled concrete aggregate (RCA) as a replacement for natural aggregate (NA) to produce new concrete mixes is becoming the most efficient solution. This paper presents an environmental friendly technique for improving the mechanical properties of recycled aggregate concrete (RAC). First, surface treatment by using different types of pozzolanic materials slurries (e.g., fly ash, cement, silica fume, and Nano-silica fume) was applied to RCA. Then, the strengthened RCA by pozzolanic materials was used to produce RAC mixes. Experimental tests were carried out to (i) compare the properties of RCA before and after surface treatment; (ii) evaluate the modification effects of the surface treatment on the mechanical properties of RAC. Test results demonstrated that strengthening RCA by using pozzolanic materials was effective and feasible to improve not only the properties of RCA but also the overall mechanical properties of RAC.

Keywords: Recycled aggregate concrete, pozzolanic materials, surface treatment, mechanical properties

INTRODUCTION

Recently, the use of recycled concrete aggregate (RCA) which retrieved from (C&D) wastes as a replacement for natural aggregate (NA) is becoming the most effective solution to solve the environmental problems [1]. Otherwise, the main drawback of using RCA to produce new concrete mixes is the undesirable properties of the attached adhered mortars, resulting in a poorer quality concrete [2]. Thus, many methods have been developed to overcome the weakness of RCA [3]. For instance, some researchers [4-7] tried to enhance RCA quality by removing the weak adhered mortar through pre-soaking in acid (HCl, H_2SO_4), mechanical treatment (ball milling, ultrasonic water cleaning), and traditional or microwave heating. On the other hand, other researchers [8-11] attempted to strength the adhered mortar by using pozzolanic materials (fly ash, silica fume), water glass (Na_2O-$nSiO_2$), and carbonation. By reducing the water absorption and crushing value, these measures help to produce RCA with better quality. However, might accompany with these treatment methods: Addition of acidic solvents leads to new waste disposal problem; time-consuming; cost-intensive, and inconvenient in practice.

Because of the limitations or negative environmental effects of the previous methods during the treating process, this paper is proposing an economic and environmentally friendly treatment method for improving the mechanical properties of RAC. In the proposed treatment method, RCA is firstly soaked in different types of pozzolanic materials slurries (e.g., fly ash, cement, silica fume, and Nano-silica fume). After that, the strengthened RCA by pozzolanic materials used to produce RAC mixes. During the treating process, pozzolanic materials will penetrate the RCA surface to fill the pores and voids as well as seal the cracks in the attached weak adhered mortar. In order to evaluate the efficiency of the proposed treatment method, this study examined the mechanical properties of RAC including compressive strength, flexural strength, and modulus of elasticity.

SURFACE TREATMENT METHOD FOR RCA

Three different types of pozzolanic materials slurries; (i) fly ash and silica fume (FA&SF), (ii) fly ash and cement (FA&C), and (iii) Nano-silica fume (NSF) as a partial replacement of fly ash and cement slurry were used to strengthen the adhered mortar in RCA. For the first two types of slurries (FA&SF and FA&C), the two strengthening materials of each slurry were used with a percentage of 40% by equal of the total weight of RCA. While for the third slurry, NSF was used with a percentage of 3% as a partial replacement of FA&C slurry to achieve the economic objective of this study. First, the three different slurries were prepared by mixing the corresponding pozzolanic materials with water for 2 min to form the slurries. Then, the RCA was added to the corresponding slurry and soaked for 4 h. After that, The RCA was removed from the slurry and dried at the room temperature for 3 days. Finally, the hardened RCA was sieved to remove the excessive materials before incorporating it into the concrete mix, see Figure 1. Figure 2 shows the RCA before and after surface treatment process.

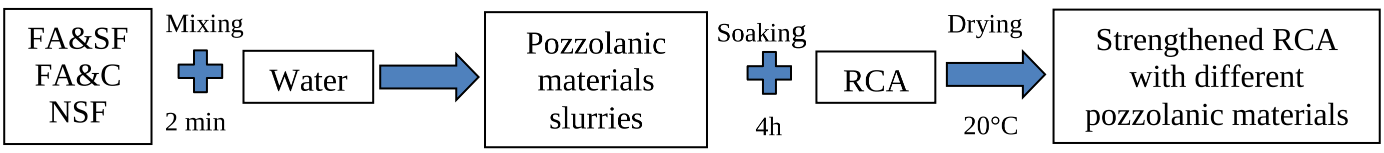

Figure 1   Surface treatment process for RCA

(a) Recycled concrete aggregate

(b) FA&SF treated RCA

(c) FA&C treated RCA

(d) NSF treated RCA

Figure 2 RCA before and after surface treatment process

MATERIALS AND CHARACTERISTICS

The natural aggregate (NA) was supplied by Nantong Golden Sand Construction Technology. Co., Ltd, while the RCA was provided by the Zhongtian Group, Zhegiang province, China. All of the coarse aggregates used in this study had a maximum size of 20.0 mm. Two types of coarse RCA were used; untreated and treated RCA. The treated RCA is prepared by soaking in the different types of pozzolanic material slurries as mentioned before in the previous section. Table 1 summarizes a comparison of the properties of NA, untreated RCA and treated RCA in terms of physical and mechanical strength characteristics. Natural river sand with particles that passed through a sieve size of 5.0 mm was used as a fine aggregate.

Table 1 Properties of coarse aggregate

Properties of aggregate	Natural aggregate	Untreated RCA	Treated RCA by using pozzolanic materials slurries		
			FA&SF	FA&C	NSF
Particle density (OD)	2.88	2.19	2.29	2.44	2.45
Particle density (SSD)	2.89	2.35	2.43	2.52	2.53
Water absorption (%)	0.50	7.26	6.09	3.53	3.21
LA abrasion value (%)	17.33	36.22	25.03	23.51	24.40
Agg. crushing value (%)	20.82	35.81	21.91	20.41	20.12

Ordinary Portland cement grade 42.5 with a density of 3.15 g/cm^3 was used as the main binder and used also as a pozzolanic material for treating the RCA. The used Pulverized fly ash was obtained from the Nantong Golden Sand Construction Technology. Co., Ltd. The used Silica fume was with 100 μm particle size. Nano- silica fume with 30 nm particle size and 2.3 g/cm^3 density was used in this study.

EXPERIMENTAL DETAILS

The designated concrete mixture proportions were based on w/c ratio equal 0.48. All the concrete mixtures were conducted in accordance with the British method [12] to achieve a compressive strength of 30 MPa at the age of 28 days. Five series of mixtures were prepared depending on the type of coarse aggregate content, as follows: (i) specimen type NAC (control concrete) were prepared using only natural coarse aggregate; (ii) specimen type RAC composed of untreated coarse RCA; (iii) specimen type FA&SF consisted of treated coarse RCA by FA&SF slurry. (iv) specimen type FA&C composed of strengthened coarse RCA by FA&C slurry. (v) specimen type NSF consisted of strengthened coarse RCA by NSF slurry. The detailed mix design for all the concrete specimens is shown in Table 2. All concrete mixes were mixed in accordance to the sequence prescribed in BS1881-125 [13].

Table 2 Details of mixing proportion (kg/m^3)

Specimens	Water	Cement	Sand	Coarse NA	Coarse RCA
NAC	210	437	663	1230	-
RAC	210	437	535	-	993
FA&SF	210	437	552	-	1026
FA&C	210	437	577	-	1071
NSF	210	437	579	-	1074

Three 100 mm cube specimens per batch of concrete mixture were prepared to measure the compressive strength according to BS 1881-116 [14]. Development of compressive strength was measured at the age of 3, 7 and 28 days. Three prism specimens of 100 x 100 x 400 mm from each batch of concrete mixture were subjected to flexural strength according to BS 1881-118 [15]. Development of flexural strength was also measured at the age of 3, 7 and 28 days. Three cylinder specimens of 150 x 300 mm were tested for each batch of concrete to measure the elastic modulus at 28 days in accordance with ASTM C469-02 [16].

RESULTS AND DISCUSSION

This section presented the experimental results obtained in the laboratory and discussion for the mechanical properties of strengthened RAC.

Compressive Strength

The concrete compressive strength developments at different ages for the different mixes were presented in Figure 3. It was found that irrespective of the age, the compressive strength of RAC was inferior to NAC. Based on the previous researches it was observed that the presence of attached weak adhered mortar in RCA adversely affects the strength of concrete. The compressive strength of concrete made with untreated RCA was 38% lesser than that of concrete made with NA at the age of 28 days. In treated RCA the weak adhered mortar was strengthened and the aggregate surface characteristics were improved. The contact at the interfacial transition zone (ITZ) between treated RCA and new cement mortar gets improved and thus the compressive strength of treated RAC was improved by 20-35% at the age of 28 days than untreated RAC. The strength development of treated RAC in the later age was found good. Among all the three treated RAC, the strength development was found higher for FA&SF treated RCA and gave better strength improvement in concrete at the age of 28 days than other treated RAC. During silica fume impregnation the pores and voids in the RCA were filled and thus improve the impermeable characteristics of RCA. The presence of silica in the treated RCA react with calcium hydroxide (CH) the main component of adhered mortar and produce additional hydrated calcium silicate (C-S-H) gel which improves the bond between the RCA and the cement mortar. Hence, from the experimental results, it was concluded that the proposed treatment method for RCA effectively provided for increasing the compressive strength of RAC to be closer to that of NAC. As illustrated, it can be explained that the incorporate pozzolanic materials strengthened the old and new cement mortar to create stronger products in RAC.

Flexural Strength

The results of flexural strength were displayed in Figure 4. The flexural strength of treated RAC significantly increased about 22-30% in comparison to the untreated RAC at the age of 28 days. The enhancement of the flexural strength by the proposed method was higher than that of the existing methods which added the pozzolanic materials in the concrete mix [17-18]. Furthermore, incorporation of FA&SF slurry is more prone to achieve a maximum bond between the aggregate and the cement paste, which contributes to the higher flexural strength development of RAC. The increase in the strength of mortar and concretes due to the treatment of RCA by FA&SF slurry can be attributed to the improved aggregate matrix bond associated with the formation of a less porous transition zone and a better interlock between the mortar and the aggregate on the new and old ITZ in comparison with the untreated RAC.

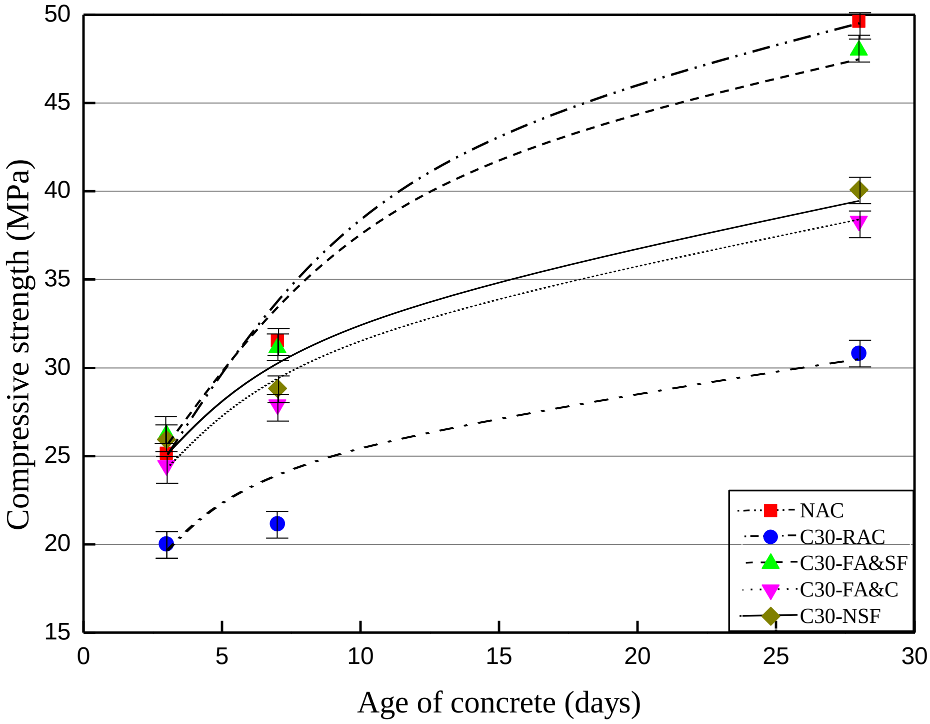

Figure 3 Compressive strength developments of concrete specimens

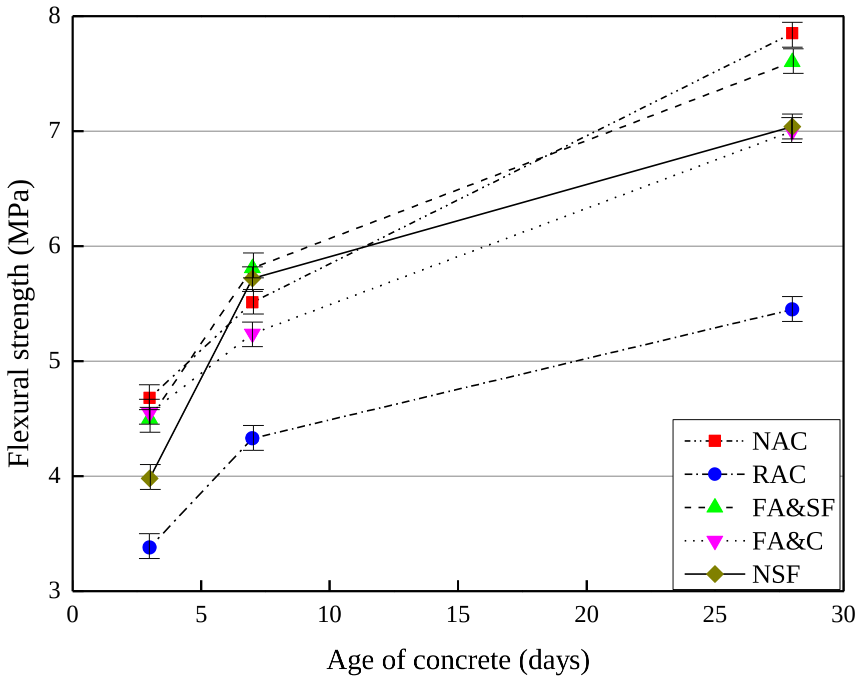

Figure 4 Flexural strength developments of concrete specimens

Modulus of Elasticity

The elastic modulus of concrete mixtures was observed in Figure 5. The elastic modulus of RAC increased substantially after using the proposed method. As can be observed with 0.48 w/c ratio, the elastic modulus of treated RAC increased around 16-30% at the age of 28 days depending on the type of slurry. Therefore, these results confirmed the importance of treating RCA with the proposed method for improving the mechanical properties of RAC.

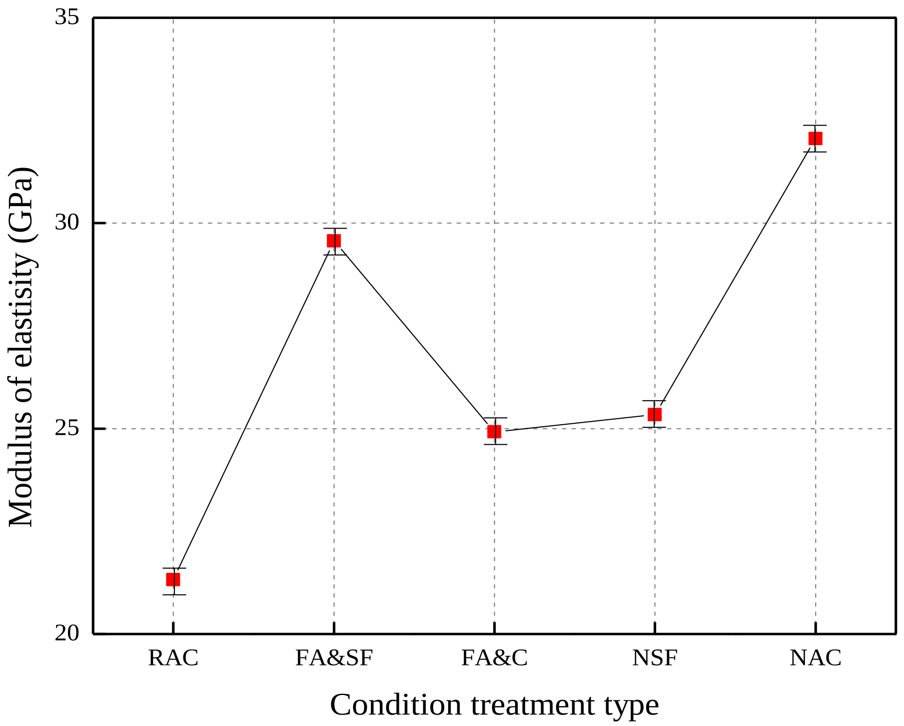

Figure 5 Modulus of elasticity of concrete specimens

CONCLUSIONS

The experimental results obtained in this study observe the feasibility of the proposed method for improving the mechanical properties of RAC. From the results and discussion the remarks conclusions have been summarized as follows:

The economic and environmentally friendly method significantly improved the mechanical properties of RAC at 3, 7, and 28 days. The compressive strength increased 20-35%, the flexural strength increased 22-30%, and modulus of elasticity increased 16-28% at the age of 28 days.

The Treated RCA by the three types of pozzolanic materials affects the mechanical properties of RAC. All the proposed types of slurries accelerated the strength development of RAC at the early age comparable with NAC.

Overall, the surface treatment by soaking the RCA in the pozzolanic materials improves the mechanical properties of RAC and thus this proposed method can be employed in the application on large-scale projects.

REFERENCES

1. TAHAR Z, NGO T-T, KADRI E H, BOUVET A, DEBIEB F, AND AGGOUN S, Effect of cement and admixture on the utilization of recycled aggregates in concrete, Construction and Building Materials, 2017, Vol. 149, pp 91-102.
2. MCGINNIS M J, DAVIS M, DE LA ROSA A, WELDON B D, AND KURAMA Y C, Strength and stiffness of concrete with recycled concrete aggregates, Construction and Building Materials, 2017, Vol. 154, pp 258-269.
3. LI W, LONG C, TAM V W, POON C-S, AND HUI DUAN W, Effects of nano-particles on failure process and microstructural properties of recycled aggregate concrete, Construction and Building Materials, 2017, Vol 142, pp 42-50.
4. KATZ A, Treatments for the improvement of recycled aggregate, Journal of Materials in Civil Engineering, 2004, Vol. 16, No. 6, pp 597-603.
5. AKBARNEZHAD A, ONG K C G, ZHANG M H, TAM C T, AND FOO T W J, Microwaveassisted beneficiation of recycled concrete aggregates, Construction and Building Materials, 2011, Vol. 25, pp 3469-3479.
6. QUATTRONE M, ANGULO S C, AND JOHN V M, Energy and CO2 from high performance recycled aggregate production, Resources, Conservation and Recycling, 2014, Vol. 90, pp 21-33.
7. PANDURANGAN K, DAYANITHY A, AND OM PRAKASH S, Influence of treatment methods on the bond strength of recycled aggregate concrete, Construction and Building Materials, 2016, Vol. 120, pp 212-221.
8. KONG D, LEI T, ZHENG J, MA C, JIANG J, AND JIANG J, Effect and mechanism of surface-coating pozzalanics materials around aggregate on properties and ITZ microstructure of recycled aggregate concrete, Construction and Building Materials, 2010, Vol. 24, pp 701-708.
9. ZHANG H, ZHAO Y, MENG T, AND SHAH S P, The modification effects of a nano-silica slurry on microstructure, strength, and strain development of recycled aggregate concrete applied in an enlarged structural test, Construction and Building Materials, 2015, Vol. 95, pp 721-735.
10. YANG L, QIAN Y, FANG Q, AND HAN Y, Effects of recycled coarse aggregate reinforcing treated by water-glass on the performance of recycled concrete, Advances Engineering Research, 2016, Vol. 103, pp 181-186.
11. ZHANG B J, XUAN D X, AND POON C S, Enhancement of recycled aggregate properties by accelerated CO_2 curing coupled with limewater soaking process, Cement and Concrete Composites, 2018, Vol. 89, pp 230-237.
12. TEYCHENNE D C, FRANKLIN R E, ERNTROY H C, HOBBS D W, AND MARSH B K, Design of normal concrete mixes, Second edition, Building Research Establishment, Watford, UK, 1997, 38p.

13. BRITISH STANDARDS INSTITUTION. BS 1881-125 Testing concrete. Methods for mixing and sampling fresh concrete in the laboratory, BSI London, 1986, 4p.

14. BRITISH STANDARDS INSTITUTION. BS 1881-116 Testing concrete. Methods for determination of compressive strength of concrete cubes, BSI London, 1983, 4p.

15. BRITISH STANDARDS INSTITUTION. BS 1881-118 Testing concrete. Method for determination of flexural strength, BSI London, 1983, 3p.

16. AMERICAN SOCIETY FOR TESTING AND MATERIALS. C 469-02. Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression, United States, 2002, 5p.

17. TAM V W Y AND TAM C M, Diversifying two-stage mixing approach (TSMA) for recycled aggregate concrete: TSMAs and TSMAsc, Construction and Building Materials, 2008, Vol. 22, pp 2068-2077.

18. LI J, XIAO H, AND ZHOU Y, Influence of coating recycled aggregate surface with pozzolanic powder on properties of recycled aggregate concrete, Construction and Building Materials, 2009, Vol. 23, pp 1287-1291.