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Research Paper

Effect of surface treatment of recycled concrete aggregate by cement - silica fume slurry on compressive strength of concrete

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ABSTRACT

Recycled concrete aggregate (RCA) used as an alternative to natural aggregate contains weak adhered mortar. The adhered mortar adversely affects the properties of RCA, and compressive strength of concrete with RCA. Therefore, a treatment method by coating surface of RCA with cement-silica fume slurry (CSS) at concentrations of 20, 40, and 60% was done to evaluate its effects on crushing value and water absorption of RCA, and compressive strength of concrete with treated RCA. The replacements of natural coarse aggregate by RCA for concrete production were 0, 25, and 50% by volume. Compressive strength of the concrete having a constant water-to-cement ratio of 0.35 was tested at ages of 3, 7, 28, and 56 days. Results showed that crushing value and water absorption of the treated RCA were more improved when compared with those of the untreated RCA due to new products formed from cement hydration and pozzolanic reactions on its surface detected by using scanning electron microscope. The surface treatment with CSS at concentration of 60% was the most effective method when compared with that with CSS at concentrations of 20 and 40%. The higher the concentration of CSS, the higher the compressive strength of concrete with the treated RCA. The treatment of RCA led to a significant improvement of compressive strength of the concrete at later ages (i.e., at 28 and 56 days) when compared with the concrete using untreated RCA.

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1 Introduction

With economic development and population growth, waste from construction and demolition (C&D) has been increasing in industrialized societies. As the landfill site becomes scarce and demand of natural resources for aggregate in construction

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industry is ever-increasing, the use of recycled concrete aggregate (RCA) from C&D waste to replace natural aggregate (NA) has become common in the world. Several countries such as China, Singapore, Thailand, Mexico ... have focused on the utilization of RCA for construction [1].

The RCA is generally weaker than the NA because it consists of original aggregates and the adhered cement mortar with more pores [2]. The workability of fresh concrete with RCA in dry condition greatly decreased because of its high water absorption [2]. For the same water-to-cement ratio, the compressive strength of concrete with more 25% RCA replacement is lower than that of conventional concrete without RCA [3]. Moreover, the other mechanical properties (i.e., the tensile and shear strengths, and modulus of elasticity) of the concretes with RCA strongly decrease while their shrinkage tends to increase [3].

To enhance the RCA properties and RCA concrete performance, various treatment methods have been widely suggested such as acid treatment, thermal treatment, mechanical treatment, pre-soaking in water glass, and so on [4]. However, the mechanical and thermal treatments not only consume a huge amount of energy but also produce additional carbon dioxide emission. The acid treatment can lead to a new pollution causing a threat to the safety of workers and introducing some detrimental ions such as Cl^- or SO_4^{2-} ion into the concretes. The pre-soaking with water glass can increase a risk of alkali-silica reaction in the concretes [5].

To overcome the drawbacks of these techniques, there are few researches that used pozzolanic slurries to treat RCA [6]. Therefore, this study proposed using cement-silica fume slurry to enhance properties of RCA and improve compressive strength of concrete with treated RCA. This method was expected to have several advantages such as safer, cleaner, and more environmentally friendly treatment when compared with the other treatments.

2 Experimental Program

2.1 Materials

Type I Portland Cement supplied by Nghi Son company was used as an ingredient of slurry and main binder conforming to TCVN 2682:2009 [7] in this study. Silica fume with percentage retained on 45- μm sieve of 3.0% by mass was used as a pozzolanic material for the slurry. The physical properties of the cement and silica fume are shown in Table 1.

Table 1 - Physical properties of cement and silica fume

	Density (g/cm^3)	Setting time (<i>min</i>)		Compressive strength (<i>MPa</i>)	
		Initial	Final	3 days	28 days
Cement	3.10	140	175	37.0	58.3
Silica fume	2.2	-	-	-	-

-: not measured

Natural river sand (RS) with fineness modulus of 1.53 was used as fine aggregate whereas crushed stone and RCA with a maximum particle size of 20 mm were used as coarse aggregates. The RCA was obtained from original concrete waste having compressive strength of approximate 30 MPa. The physical properties of all aggregates are shown in Table 2. In addition, tap water conforming to TCVN 4506:2012 [8] was employed for mixing concrete while water-reducing agent was used to adjust slump of fresh concrete.

Table 2 - Physical properties of aggregates

	Density (g/cm^3)	Bulk density (kg/m^3)	Crushing value (%)	Water absorption (%)
RS	2.70	1430	-	0.92
RCA	2.50	1290	18.00	5.27
NA	2.70	1500	5.93	0.20

RS: river sand; RCA: recycled concrete aggregate; NA: natural aggregate; -: not measured

2.2 Treatment of RCA

In order to strengthen and improve RCA surface, cement-silica fume slurry was used with three different concentrations of 20, 40, and 60% by mass of RCA. The proportions of the slurry presented in Table 3 was referred to a previous study [6] in which cement and fly ash was used for the slurry. For making the slurry, silica fume and cement was mixed with tap water for 2 min. Then, RCA was soaked in the slurry for various soaking times (i.e., for 4, 12, 24, and 48 hours). After drying at room temperature for 6 hours, water absorptions and crushing values of RCA were tested to compare with those of the untreated RCA.

Table 3 – Concentrations of the cement-silica fume slurry for 1000 kg of RCA

Concentration (%)	Slurry			RCA (kg)
	Cement (kg)	Silica fume (kg)	Water (kg)	
20	100	100	2000	1000
40	200	200	2000	1000
60	300	300	2000	1000

2.3 Concrete mixture proportions

The mixture proportions of concretes with a constant water-to-cement ratio of 0.35 are shown in Table 4. The control proportion (CC) using 100% NA was designed at slump of 8±2 cm and compressive strength at 28 days of 70 MPa as per TCVN 10306:2014 [9]. The other concrete mixture proportions were made with 25% and 50% replacements of NA by RCA as coarse aggregate as shown in Table 4.

Table 4 – Concrete mixture proportions

Mixture proportions	Unit: kg					Water-reducing agent (% by mass of cement)
	Cement	River sand	NA	RCA	Water	
CC	480	835	990	0	168	0.9
RCA25	480	835	743	235	168	0.9
RCA50	480	835	495	469	168	0.9

2.4 Test procedures

Water absorptions and crushing values of coarse aggregates were tested as per TCVN 7572-4:2006 [10], and TCVN 7572-11:2006 [11], respectively. In addition, the microstructure of RCA surface before and after the treatments was analysed through scanning electron microscope (SEM).

After mixing the components of each mixture proportion as shown in Table 4, slump of fresh concrete and compressive strength of hardened concretes were determined as per TCVN 3106:1993 [12] and TCVN 3118:1993 [13], respectively. The compressive strength test was performed at 3, 7, 28, and 56 days on cubic specimens with a size of 100 mm. The compressive strength value of each mixture proportion at each age was an average value obtained from three corresponding specimens.

3 Results and Discussion

3.1 Effects of surface treatment on properties of RCA

3.1.1 Water absorption and crushing value

Due to the presence of weak adhered mortar, the water absorption of RCA is higher than NA [2]. Fig. 1(a) illustrates the effects of slurry concentration and soaking time on water absorption of the treated RCA. The results indicated that the cement-silica fume slurry effectively reduced the water absorption of the treated RCA. The water absorption of untreated RCA was 5.37% while that of RCA treated by the slurry at concentration of 60% for 48 hours was 2.89%. Furthermore, the higher the

concentration of the slurry, the lower the water absorption of RCA. The longer the time of RCA soaked in the slurry, the lower the water absorption of RCA. It confirms that soaking RCA in the slurry at concentration of 60% for 48 hours was the most effectively method. This might be due to silica fume filling pores and reacting with portlandite in the old mortar, and thereby improving the water absorption of RCA [6].

Figure 1(b) illustrates the effect of concentration and soaking time on crushing value of RCA. The higher the concentration of slurry, the lower the crushing value of RCA. Similar to water absorption, the most effective method was the soaking RCA in the cement-silica fume slurry at concentration of 60% for 48 hours. The longer soaking time may be better approach to reduce the water absorption and crushing value of RCA. The reason may be due to the further formations of C–S–H and ettringite in RCA soaked in the slurry for 48 hours when compared with that soaked in the slurry for 4, 12, and 24 hours. The similar result could be observed in a previous study [6].

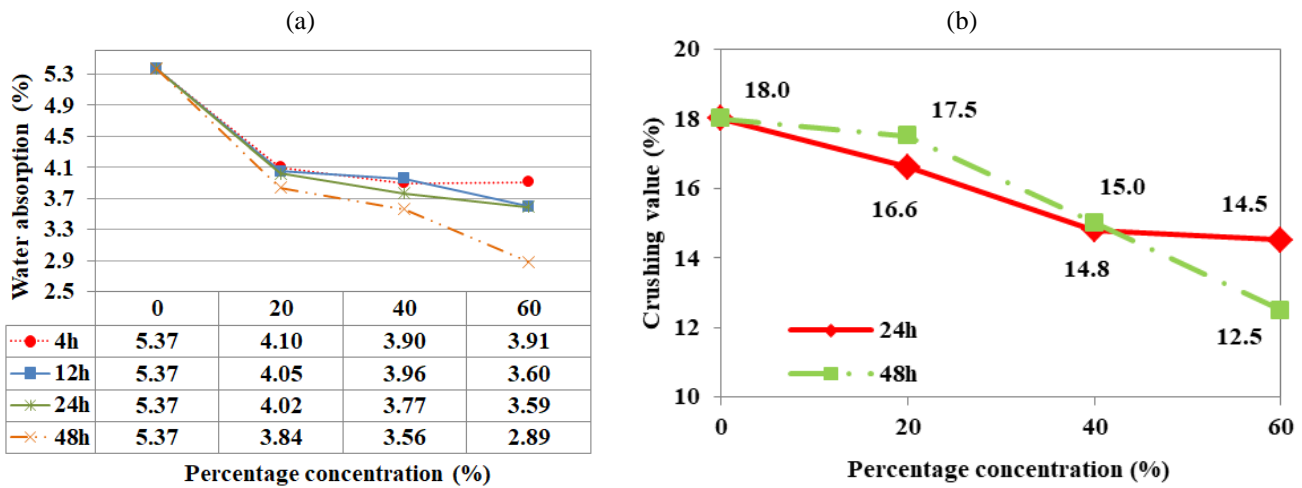


Fig. 1 – Effect of concentration and soaking time of RCA treatment by cement-silica fume slurry on water absorption (a) and crushing value (b) of RCA

3.1.2 SEM analysis

The microstructures of untreated and treated RCA by the slurry at concentration of 60% for 48 hours via SEM images are shown in Fig. 2. Fig. 2(a) indicates that there was considerably more porous and loose cement paste in the untreated RCA. Similar results were observed in an existing study [2]. Meanwhile, the microstructure of the treated RCA consisted of ettringite and C–S–H generated from pozzolanic reaction and cement hydration as seen in Fig. 2(b). The additional hydration products filled pores in the cement paste, leading to an improvement of water absorption and crushing value of RCA as seen in Figs. 1(a) and (b), respectively.

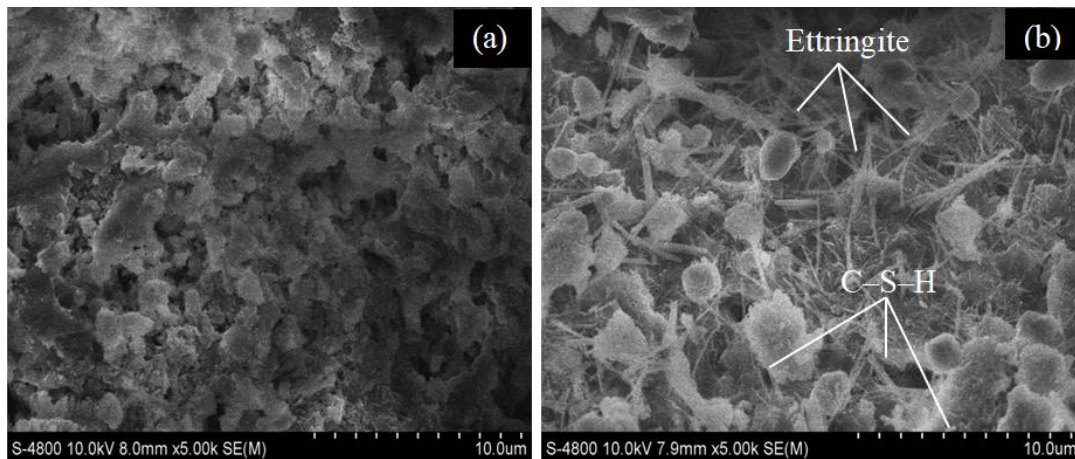


Fig. 2– SEM images of untreated (a) and treated (b) RCA

3.2 Effect of treatment of RCA by cement-silica fume slurry on compressive strength of concrete

Figure 3(a) shows compressive strength of all the concretes with 0 and 25% RCA replacements. The compressive strengths at 3 and 7 days of concretes containing treated RCA slightly decreased by 12.19 – 7.67% when compared with that of concrete containing untreated RCA (CSS0) and that of control concrete (CC). It might be due to the presence of the ultrafine particles (i.e., silica fume and anhydrous cement particles) on the treated RCA surface which may negatively affect the interfacial transition zone between aggregate and cement matrix. The negative effect should be studied in future works. At 28 and 56 days, the compressive strength of the concretes containing RCA treated by the slurry at concentration of 20% (CSS20) was almost the same or slightly lower than that of the concrete containing untreated RCA (CSS0) and that of control concrete (CC). Meanwhile, the compressive strength of the concrete containing RCA treated by the slurry at concentrations of 40% (CSS40) and 60% (CSS60) was significantly higher. In addition, the higher the concentration of the slurry, the higher the compressive strength of concrete regardless of curing age. This was due to the further formations of ettringite and C–S–H in the treated RCA as seen in Fig. 2(b). The other reason could be the contribution of cement-silica fume slurry coating the surface of RCA to the matrix of the concrete which should be investigated in future works.

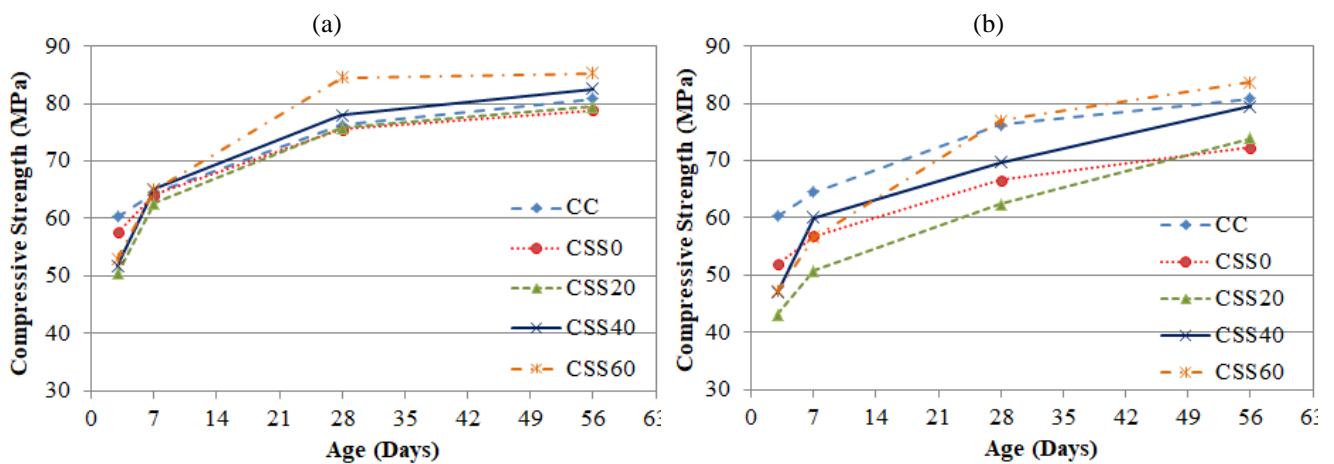


Fig. 3 – Effects of RCA treatment by cement-silica fume slurry on compressive strength of concrete made with 25% (a) and 50% (b) RCA replacements

Similarly, Fig. 3(b) shows compressive strength of all the concretes with 0 and 50% RCA replacements. It can be said that the effects of surface treatment can be observed more clearly due to the higher amount of RCA. The compressive strength of concrete made with 50% treated RCA decreased by 9.07 – 16.79% at 3 days and 0.04 – 10.78% at 7 days as compared with that of concrete made with untreated RCA (CSS0) and that of control concrete (CC), except the concrete made with 50% RCA treated by the slurry at concentration of 40% (CSS40) at 7 days. At the ages of 28 and 56 days, the compressive strength of concrete made with 50% RCA treated by the slurry at concentration of 60% (CSS60) was higher than that of concrete made with untreated RCA (CSS0) and that of control concrete (CC). Briefly, using RCA treated by cement-silica fume slurry decreased compressive strength of the concrete at early ages (i.e., at 3 and 7 days). However, the use of treated RCA increased compressive strength of the concretes at later ages due to the further formations of ettringite and C–S–H in the treated RCA in long term. This treatment for RCA should be applied for the concrete mixtures with a high RCA replacement.

4 Conclusion

From the experimental results, the conclusions can be summarized as follows:

The higher the concentration of the cement-silica fume slurry, the lower the water absorption and the crushing value of recycled concrete aggregate (RCA). The longer time of treatment resulted in the lower water absorption and crushing value of RCA. The most potential concentration of the slurry was 60% and the time of the treatment was 48 hours.

Although the treatment of RCA reduced the compressive strength of the concretes at early ages (i.e., at 3 and 7 days), it significantly improved compressive strength of the concretes at later ages (i.e., at 28 and 56 days) when compared with the

concrete using untreated RCA. The higher the concentration of cement-silica fume slurry, the higher the compressive strength of concrete with the treated RCA.

Consequently, the treatment of RCA by using cement-silica fume slurry improved the water absorption, crushing value, and microstructure of RCA. As a result, the compressive strength of the concretes with the treated RCA was enhanced at later ages.

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