Properties of Concretes with Natural and Recycled Coarse Aggregates

Rattapon Somna[1], Apiruk Martnok[1] and Suksun Horpibulsuk[2,*]

[1] Department of Civil Engineering, Faculty of Engineering and Architecture, Rajamangala University
of Technology Isan, THAILAND
[2] School of Civil Engineering, and Center of Excellence in Innovation for sustainable Infrastructure Development,
Suranaree University of Technology, THAILAND

rattapon.so@rmuti.ac.th, apiruk.2011@gmail.com and suksun@g.sut.ac.th[*]

Abstract. *This research studied effects of moisture and absorption of natural and recycled coarse aggregates on properties of concretes. The effects of two moisture states, air-dried state (AD) and saturated surface dry state (SSD), of both aggregates were investigated. Recycled coarse aggregate was used to replace crushed limestone at 25 and 100 percent by volume. The compressive strength, ultrasonic pulse velocity (UPV), and modulus of elasticity of concretes were determined. The results revealed that the coarse aggregates in SSD state gave higher compressive strength than those in AD state. The moisture states of aggregate did not affect the UPV of concrete but the replacement of crushed limestone by recycled aggregate reduced the UPV. The cracks on cement paste of the recycled coarse aggregate increases the distance for wave travel passing through concrete. The modulus of elasticity of concrete is independent of the moisture states of recycled coarse aggregate but dependent on the strength of concrete.*

Keywords:

concrete, recycled aggregate, moisture, UPV

1. Introduction

Recently, wastes have been promoted to be reused and recycled. One of wastes which can be recycled and used as aggregates in concrete is the demolition concrete. The properties of recycled aggregate obtained from crushing the concrete waste has been studied for reuse as aggregates in concrete. Attached mortar on the surface of recycled aggregates caused the low specific gravity, high water absorption, and weakness of recycled aggregates [1-2]. Moreover, the properties of recycled aggregate concrete, such as the compressive strength and modulus of elasticity, were lower than those of concrete using natural aggregate [3-5].

It has been known that the amount of mixing water affects the strength of concrete. The factors related to the amount of mixing water are water absorption and moisture of aggregate. They are important not only for the mix design but also for mixing concrete. If the moisture state of aggregate used for the mixing concrete is different from the designed state, the strength of concrete may be unsatisfied. Therefore, this research investigates the effect of moisture and absorption of natural and recycled coarse aggregates on the compressive strength, UPV, and modulus of elasticity of concrete.

2. Experimental Investigation

2.1 Materials

2.1.1 Portland Cement

Ordinary Portland cement type I (OPC) was used in this study. Its specific gravity of OPC was 3.15 and median particle size (d50) was 15 micron.

2.1.2 Fine aggregate

River sand was used as fine aggregate in this study, which had fineness modulus and specific gravity of 2.01 and 2.67, respectively. The water absorption and unit weight of the river sand were 1.11% and 1643 kg/m^3, respectively.

2.1.3 Coarse aggregates

Crushed limestone and recycled coarse aggregate (RCA), the maximum size of 19 mm, were used as coarse aggregate. Fineness modulus and specific gravity values were 7.05 and 2.74 for crushed limestone, respectively and were 6.40 and 2.70, respectively for RCA. The unit weight of crushed limestone and RCA were 1,542 and 1,432 kg/m^3, respectively. The water absorption of RCA (4.77%) was higher than that of crushed limestone (0.85%) by about 5.6 times. The water absorption of RCA was within a range

of 4.7 to 4.81%, which is in the range reported by the previous research [2, 6, 7]. The high water absorption is due to higher absorption of the attached mortar on the surface of RCA [8].

2.2 Mix Proportion and Test Specimens

Table 1 shows the mix proportions of concretes. Mix proportion of concrete using natural aggregates (crushed limestone and sand) in the saturated surface dry state (SSC concrete) was designed by ACI method [9]. Two moisture states of coarse aggregates, AD and SSD, were controlled before mixing. Recycled aggregate was used to replace crushed limestone at 25 and 100% by volume. Concrete using crushed limestone in air-dried and state was defined as AC concrete. The AR and SSR concretes are concretes using recycled aggregate as coarse aggregate and the number 25 and 100 are the percentage of the replacement of RCA. To control the same amount of effective water without using water reducing admixture, the trial mixes were performed for the AR25 concrete to obtain the amount of effective water at the slump of about 100 mm. The effective water was 0.85.

The 150-mm cube concretes were cast and used for the compressive strength and UPV tests. The cylindrical concretes with 150 mm in diameter and 300 mm in height were cast and used to investigate the modulus of elasticity.

3. Results and Discussions

3.1 Fresh Concrete

The mixing water of AC concrete was higher than that of SSC concrete. For example, the mixing water of AC and SSC concretes was 231.3 and 221.3 kg/m^3, respectively. When the recycled aggregate in AD state was used to replace crushed limestone in the same moisture state, the absorption water was added to the mixing water in order to keep the same water quantity in SSD state. Therefore, the mixing water of AC25 and AC100 concretes was higher than that of SSC25 and SSC100 concretes. It was found that an increase of replacement of recycled aggregate in AD state in concrete resulted in an increase of the mixing water.

Table 1 shows that the initial slump values of concretes containing coarse aggregates in AD state (AR25, and AR100 concretes) were higher than those of concretes containing coarse aggregates in SSD state (SSR25, and SSR100 concretes) at the same replacement of RCA. This is because the addition of absorption water to the effective water causes the increase of mixing water of AC, AR25 and AR100 concretes. The slump values of AR25 and AR100 concretes rapidly decreased in the first hour after mixing and then slightly decreased. This is a fact that aggregates highly absorb the water in the early time of the water immersion. Thus, in the concrete mixture using recycled

aggregate in AD state, the recycled aggregates absorbed more water than the crushed limestone at the same moisture state. For the concretes containing the aggregates in SSD state, the slump values gradually decreased over the time.
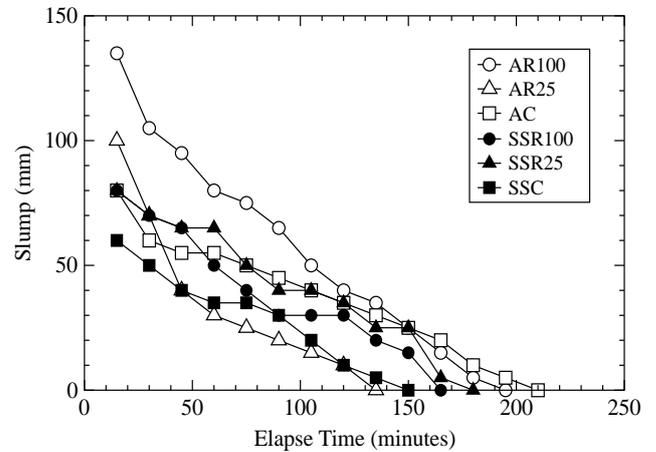

Fig. 1 Slump of concretes

Table 1 Mix proportions of concretes

Mix	Mix Proportion (kg/m³)										
					Absorption Water						
	Cement	Sand	Crushed Limestone	RCA	Sand	Crushed Limestone	RCA	Total	Effective Water	Mixing Water	Slump (mm)
AC	250	845	1180	-	9.4	10.0	-	19.3	212	231.3	80
AR25	250	845	885	263	9.4	7.5	12.5	29.3	212	241.3	100
AR100	250	845	-	1052	9.4	-	49.9	59.3	212	271.3	135
SSC	250	845	1190	-	9.4	-	-	9.3	212	221.3	60
SSR25	250	845	895	276	9.4	-	-	9.3	212	221.3	80
SSR100	250	845	-	1103	9.4	-	-	9.3	212	221.3	80

Note: Effective water to cement ratio of 0.85.
    Sand is in air-dried state with moisture content of 0.22%.
    Crushed limestone is in air-dried state with moisture content of 0.18%.
    RCA is in air-dried state with moisture content of 0.62%.

3.2 Compressive Strength

The compressive strengths of concretes are shown in Fig.2. For the AD state, the AR25 concrete had the highest compressive strengths. Some of mixing water of AR25 concrete was highly absorbed by recycled aggregate in the early time (vide Fig.1) and thus causes the decrease of water in the mix. Consequently, the strength of concrete increased as reported by Abrams [10]. Moreover, the slump of AR25 was about 100 mm for the same effective water for all tested concretes. Therefore, the AR25 concrete mixture had the best consistency as compared to another mixture in this study. Moreover, the recycled aggregates affect insignificantly the compressive strength of concrete when its quantity did not exceed 30% by weight [11].

The compressive strength of AR100 concrete was lower than that of AR25 concrete because the high volume of recycled aggregate increases weak points in the concrete. Recycled aggregate was weaker than crushed limestone because of the weak paste or mortar attaching on its surface. The water used for mixing the AR100 concrete was

more than that of AR25 concrete by about 12 percent. Therefore, the AR100 concrete mixture had higher water to cement ratio, resulting in a decrease of compressive strength.

The effective water for the AC concrete was the amount of water used to mix the AR25 concrete for a slump value of about 100 mm. Consequently, the amount of water for mixing the AC concrete was higher than the amount of water required from the design mix obtained from ACI by about 0.20. This resulted in the lowest compressive strength of AC concrete.
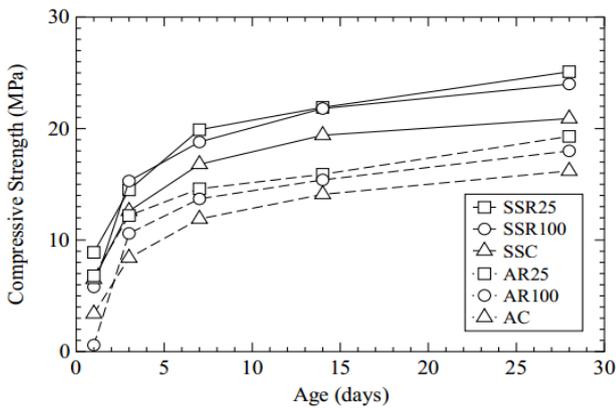
Fig. 2 Compressive strength of concretes

All concretes using coarse aggregates in SSD state had compressive strengths higher than those using coarse aggregates in AD state because the mixing water in SSD state was lower than that in AD state. Therefore, the concretes using coarse aggregates in SSD state was denser than the concretes using coarse aggregates in AD state with the same mixture. This resulted in higher strength. The compressive strength development with time of concretes using coarse aggregates in SSD state had a similar trend to that of concretes using coarse aggregates in AD state. The SSR25 concrete had the highest compressive strengths, followed by the SSR100 concrete. The lowest compressive strengths were found for the SSC concrete.

Figure 3 was plotted in order to find out the effect of moisture states of coarse aggregates on the compressive strengths of concretes. The results showed that compressive strengths of concretes using coarse aggregates in AD state were in a range of 71 to 78% of 28-day compressive strength concrete using coarse aggregate in SSD state (SSC, SSR25, and SSR100 concretes). It was indicated that the use of coarse aggregates in different moisture states affected the compressive strength of concrete with the same mixture proportion.
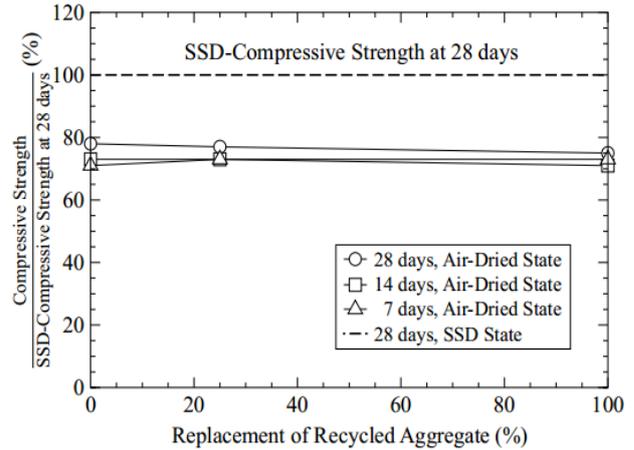

Fig. 3 Percentage of compressive strength of concrete compared with 28-day compressive strength of the concrete using coarse aggregates in SSD state

3.3 Ultrasonic pulse velocity of concretes

Fig. 4 shows the relationship between ultrasonic pulse velocity (UPV) and compressive strength of concretes at the ages of 7, 14, and 28 days. It was found that the UPV of concretes increased when the compressive strength of concretes increased. The results in Fig. 4 could be separated into 2 groups: concrete using 100% recycled aggregate and the rest concretes.
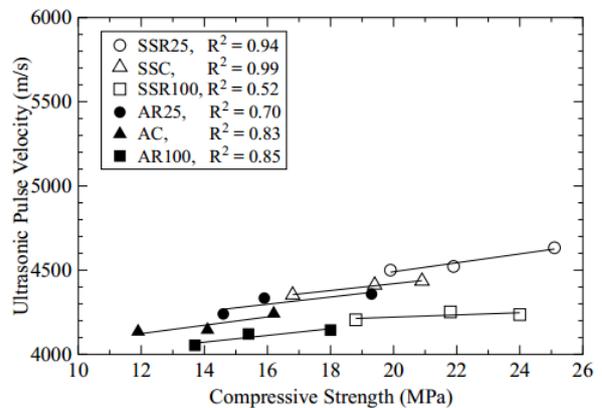

Fig. 4 Relationship between ultrasonic pulse velocity and compressive strength of concretes at the ages of 7, 14, and 28 days

After separating the concretes into 2 groups, the relationship between UPV and compressive strength of concretes was plotted to illustrate clearly as shown in Fig. 5. It was indicated that concretes using recycled aggregate to fully replace crushed limestone had lower UPV than that of concrete using crushed limestone and using 25% recycled aggregate. Because the attached mortars on the surface of recycled aggregates had voids and cracks at the interface between the old aggregate and attached mortar,

the ultrasonic wave took a long time when it passed through the recycled aggregates; hence, the decrease of UPV.
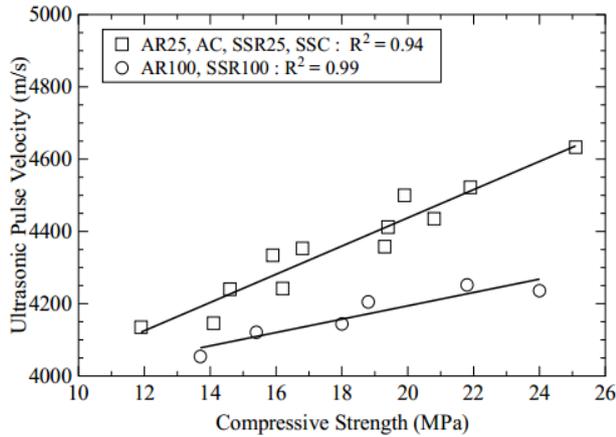

Fig. 5 Relationship between ultrasonic pulse velocity and compressive strength of concretes at the ages of 7, 14, and 28 days after separating into 2 groups

It is noted that there was no effect of moisture and absorption of coarse aggregates on UPV. The replacement of crushed limestone by recycled aggregate in concrete causes the decrease of the UPV of concrete.
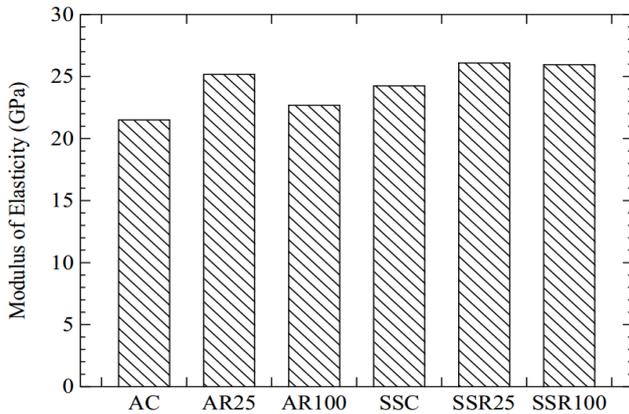

Fig.6 Modulus of elasticity of concretes

3.4 Modulus of elasticity of concretes

The modulus of elasticity of concretes at 28 days is shown in Fig. 6. At the same mix proportion, the modulus of elasticity of concretes using coarse aggregates in the AD state was lower than that in the SSD state. For example, the AC concretes had the modulus of elasticity of about 21.5 GPa with the compressive strength of 16.2 MPa while the SSC concrete had modulus of elasticity by about 24.3 GPa with compressive strength of 20.9 MPa. This indicated that the modulus of elasticity is directly related to the strength of concrete. It was clear that the moisture and absorption of coarse aggregates insignificantly affects the modulus of elasticity of concrete directly.

4. Conclusions

Based on this research, following conclusions can be drawn.

4.1 Initial slump of concretes using coarse aggregates in the AD state was higher than that in the SSD state. The more water was required for the concrete using coarse aggregates in the AD state for the same amount of water used in concrete using coarse aggregates in the SSD state. This higher mixing water causes the higher initial slump.

4.2 The compressive strengths of concretes using coarse aggregates in the SSD state were higher than those of concretes using coarse aggregates in the AD state. This is because the mixing water used in the mix proportion of concrete using coarse aggregates in the SSD state was lower than that in the AD state. The higher compressive strength was due to lower mixing water.

4.3 The moisture states of coarse aggregates used in concrete insignificantly affect the UPV of concretes. The replacement of crushed limestone by recycled aggregate significantly causes the reduction of UPV of concrete. The cracks and voids in the recycled aggregates increase the ultrasonic wave time.

4.4 The modulus of elasticity of concretes is directly related to the compressive strength of concrete, which is governed by the moisture states.

5. Acknowledgements

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Bibliography

Rattapon Somna was born in Chainat, Thailand. He received his Ph.D. in Civil Engineering from King Mongkut's university of technology Thonburi in 2012. He is a lecturer in Department of Civil Engineering, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand. His research interests include recycled aggregates, durability of concrete, and pozzolanic materials.

Apiruk Martnok was born in Nakhon Ratchasima, Thailand. He received his M.Eng. in Construction and Infrastructure Management from Suranaree University of Technology in 2013. He is a technician in Department of Civil Engineering, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand. His research interests include cement, concrete, and recycled aggregates.

Suksun Horpibilsuk joined Suranaree University of Technology (SUT) as a lecturer in 2002. His outstanding research, teaching and service for the university, community and profession over the years was duly recognized when he was promoted to the level of full professor in 2010. He is a chair of School of Civil Engineering and a founder director of Center of Excellence in Innovation for Sustainable Infrastructure Development at Suranaree University of Technology. He is a Registered Professional Civil Engineer in Thailand. His most significant contributions to the profession have been in the field of ground improvement techniques; specifically issues associated with compaction, earth reinforcement, prefabricated drains and chemical stabilization. He has published extensively with over 300 technical publications, including more than 150 technical papers in internationally reputed Geotechnical Engineering and Civil Engineering journals. Due to his outstanding contributions for the profession and community as well as his national and international recognition, he was nominated as a TRF Senior Scholar in 2013 and 2016 by the Thailand Research Fund.