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MECHANICAL PROPERTIES AND SHRINKAGE PROPERTIES OF THE CONCRETE WITH RECYCLED FINE AGGREGATE AND ADMIXTURE

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In Japan, it is forecasted that massive amounts of concrete waste material will be generated in the future as a result of demolition of many buildings, and expansion of the use of recycled aggregate is expected. In this study, it was verified the effect when relatively large amount of admixture is mixed, a combination of recycled fine aggregate of different quality and various admixtures, combination of each admixture in order to realize high strength and high durability by using recycled aggregate. The increase in the drying shrinkage ratio due to the deterioration of the recycled fine aggregate quality was larger than the fluctuation due to the admixture mixing ratio and the drying shrinkage ratio was distributed by forming a group for each quality of recycled fine aggregate. In the relationship between the pore volume and the compressive strength, when evaluated with pore volume of 2 μm or less in both cases, a good linear relationship could be confirmed. The relationship between the pore volume and the drying shrinkage rate was similar. Therefore, it was suggested that compressive strength and drying shrinkage ratio of mortar contained composite recycled fine aggregate and admixture could be predicted by evaluating with the pore volume of 2 μm or less.

Keywords: Demolition wastes, Fly ash, Ground granulated blast furnace slag, Compressive strength, Drying shrinkage, Pore volume.

1 INTRODUCTION

In Japan, it is forecasted that massive amounts of concrete waste material will be generated in the future as a result of demolition of many buildings, and expansion of the use of recycled aggregate is expected. It is necessary to actively use unused resources in resources recycling society. The construction industry in Japan is working on the recycling of construction waste in this situation. In 2000, there were 85 million tons of construction waste from wood, dirt, asphalt concrete mass, concrete mass and others; 72 million tons (81%) was recycled. The concrete mass waste was 49% and 96% of that was recycled (JCI 2005). However, considering the fact of recycling, most of the recycling of concrete masses is used for the road board material. It is necessary to take out the aggregate from concrete masses and use it for concrete again as a recycled aggregate. The research of the recycled aggregate is being studied by researchers, and the recycled aggregate was standardized by JIS now. In this study, the effects were studied when a relatively large amount of admixture is mixed using a combination of recycled fine aggregate of different quality and various admixtures, and combinations of each admixture, in order to realize high strength and high durability by using recycled aggregate.

Table 1. Materials.

Item	Type	Physical properties	Symbol
Cement	Ordinary portland cement	Density 3.16g/cm³	C
Water	Top water		W
Fine aggregate	standard sand	Density 2.57g/cm³	NS
		Water absorption rate 1.26%	
		Solid content rate 62.4%	
		Fineness modulus 2.60	
	M class recycled fine aggregate [JIS] A 5022	Density 2.21g/cm³	MS
		Water absorption rate 6.55%	
		Solid content rate 63.8%	
		Fineness modulus 3.21	
	L class recycled fine aggregate [JIS] A 5023	Density 1.96g/cm³	LS
		Water absorption rate 11.1%	
		Solid content rate 73.7%	
		Fineness modulus 3.21	
Admixture	Ground granulated blast furnace slag	Density 2.96g/cm³	BS
		Specific surface area 3970cm²/g	
	Fly ash（JIS class Ⅱ）	Density 2.25g/cm³	FA
		loss on Ignition 2.25%	
		Specific surface area 3770cm²/g	
AE agent	AE Water reducing agent	Alkyl ether type anionic surfactant	AE

2 SUMMARY OF THE EXPERIMENT

Table 1 shows the materials. We used ordinary Portland cement, and standard sand, M class recycled fine aggregate, or L class recycled fine aggregate as fine aggregate. Fly ash for concrete class II was used as fly ash. We used ground granulated blast furnace slag (GGBS) for concrete conforming to the 4000 class. Table 2 shows the mixture proportions, and N indicates standard sand, M indicates M class recycled fine aggregate, and L indicates L class recycled fine aggregate depending on the quality of the fine aggregate. Hereafter, we refer to samples made with standard sand as N series, those made with M class recycled fine aggregate as M series, and those made with L class recycled fine aggregate as L series. The replacement of cement with 10%, 20%, and 30% fly ash is indicated by FA10, FA20, and FA30, respectively. The replacement of the cement with 10%, 20%, and 30% GGBS is indicated by BS10, BS20, and BS30, respectively. We prepared a total of 21 samples. The water content per unit volume of concrete was 170 kg/m³ and the cement content was 567 kg/m^3 without admixture. The mortar did not contain coarse aggregate. The target mortar flow was 18 ± 2 cm and the target air content was 6.2 ± 1.5%. The compressive strength, drying shrinkage rate, and pore volume were measured. We used cylindrical specimens ϕ50 × 100 mm in size to measure compressive strength. The specimens were demolded after 1 day of aging and cured in water at 20 ± 1 °C. The compressive strength test was conducted after 28 and 91 days of aging. We used 40 × 40 × 160 mm prism specimens 5021 for the drying shrinkage test. We measured the specimens after up to 91 days of aging. The specimens were demolded after 1 day of aging and cured in water at 20 ± 1.0 °C for 7 days. We sealed both ends and measured the original length. The samples were then cured in a thermostatic chamber at 20 ± 1.0 °C and relative humidity of 60 ± 5.0%, and the drying shrinkage rate was measured at a predetermined material age. For the pore volume measurements, after the compressive test at 28 days, the specimen was crushed and the hydration was stopped with acetone. Thereafter, D-dry drying was performed and the pore volume from 6 nm to 90 μm was measured by a mercury intrusion porosimeter.

Table 2. Mix proportions.

Symbol	W/C	W/B	Unit content (kg/m³)					
	(%)	(%)	W	C	FA	BS	S	G
N							700	
M	30.0			567	0		643	(945)*
L							630	
N+FA10							692	
M+FA10	33.3			510	57		623	(934)*
L+FA10							580	
N+FA20						0	683	
M+FA20	37.5			453	113		628	(923)*
L+FA20							615	
N+FA30							675	
M+FA30	42.9	30	170	397	170		621	(912)*
L+FA30							608	
N+BS10							698	
M+BS10	33.3			510		57	628	(943)*
L+BS10							585	
N+BS20							696	
M+BS20	37.5			453	0	113	640	(940)*
L+BS20							627	
N+BS30							694	
M+BS30	42.9			397		170	638	(938)*
L+BS30							625	

※Estimated amount of coarse aggregate

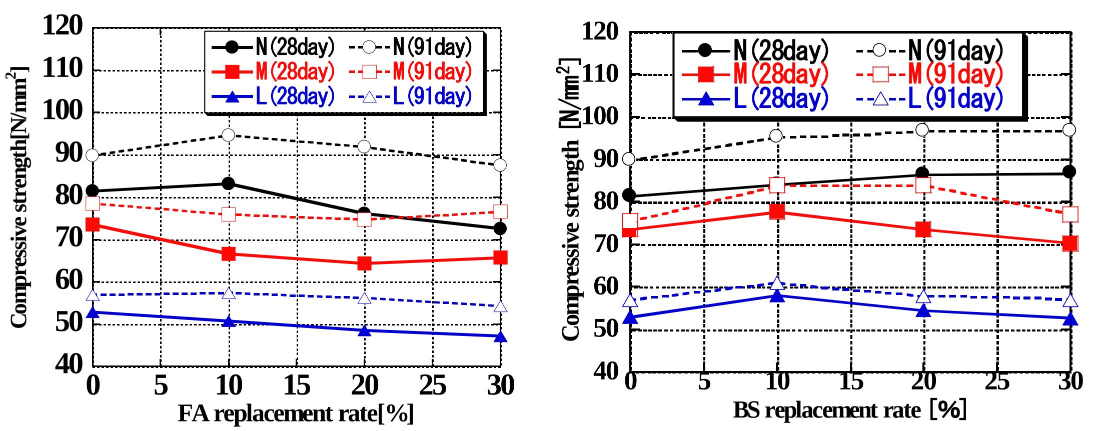

Figure 1. The relationship between the replacement rate of admixture and compressive strength.

3 RESULT AND DISCUSSION

3.1 Compressive Strength

Figure 1 shows the relationship between the replacement rate of admixture and compressive strength after 28 and 91 days of aging. When standard sand was used in the FA series, the strength increased at a replacement rate of 10% after 28 and 91 days of aging. Subsequently, the compressive strength decreased as the replacement rate increased. The rate of decrease was smaller at 91 days than at 28 days. The strengths of the specimens containing fly ash at 28 days were lower than those containing recycled aggregate, whereas at 91 days, the specimens showed the same strength. This increased strength was explained by the pozzolanic reaction with the fly ash. Therefore, when the water/cement ratio was 42.9 or less, even if the specimen contained fly ash, the amount of cement necessary for the pozzolanic reaction was present and the compressive strength increased. For the BS series, the compressive strength also increased with the replacement rate of GGBS at 28 and 91 days. For mortar using recycled aggregate M, the compressive strength increased at the replacement rates of 10% and 20% and decreased at 30%. However, all these specimens had higher compressive strengths than the specimens without fly ash. In the FA and BS series specimens, the compressive strength was reduced by the difference in the quality of the fine aggregate rather than the effect of increasing the replacement rate from 0 to 30%. In particular, the difference in the compressive strengths of M class and L class aggregates was large.

3.2 Drying Shrinkage

Figure 2 shows the drying shrinkage rate for FA series and BS series. When standard sand was used in the FA series, specimen N + FA 10 had a drying shrinkage rate similar to specimen N. However, the shrinkage rate increased as the replacement rate increased. Compared with the specimens containing M class recycled fine aggregate, the shrinkage rate was equivalent to the specimens without fly ash at a replacement rate of 10%. However, in the M + FA 30 specimen, the shrinkage rate was lower than that without fly ash. In the L series, the shrinkage rate was increased L + FA 10 more than without FA. Moreover, the shrinkage rate was smaller L + FA 30 than without FA. In the BS series, compared with the specimens containing standard sand, the shrinkage rate was equal to that without fly ash, regardless of the GGBS replacement rate. However, in the M and L series, the dry shrinkage rate was reduced by GGBS. Therefore, in mortar containing recycled fine aggregate, the drying shrinkage rate was decreased by replacing cement with 30% fly ash or up to 30% GGBS. In both the FA series and the BS series, the shrinkage rate fluctuation due to the deterioration of the quality of the regenerated fine aggregate was larger than that due to the replacement rate of the admixture. Although the shrinkage rate was smaller in the BS series than in the FA series, there was no decrease in the shrinkage ratio compared N indicates standard sand and without admixture.

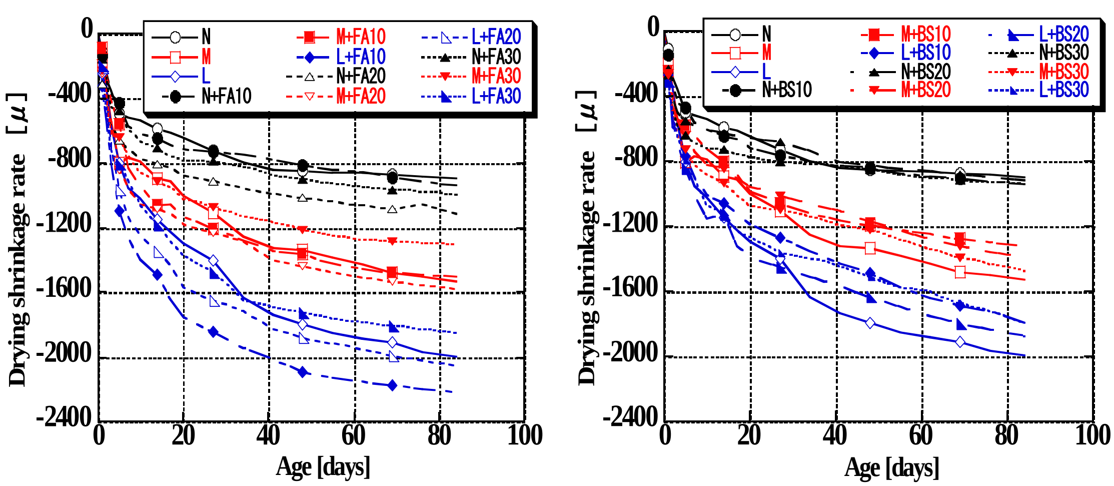

Figure 2. The drying shrinkage rate for FA series and BS series.

3.3 Relation Between Pore Volume, Compressive Strength and Drying Shrinkage

Figure 3 shows the relationship between the pore volume from 50 nm to 2 µm at 28 days aging and the compressive strength. Uchikawa *et al.* (1990) reported that a capillary void volume of 50 nm or more affected the compressive strength in normal concrete. However, in the present experiment, the coefficient of determination between the pore volume from 50 nm to 2 µm and the compressive strength was 0.28 and we did not observe a good correspondence. Figure 4 shows the relationship between the pore volume from 4nm to 2 µm at 28 days and the compressive strength. Hanehara *et al.* (1993) reported that when the water to cement ratio was 40% or less, almost no transition zone was formed, so the correlation between the pore void volume, including the small diameter, and the compressive strength was high. In the present experiment, the compressive strength decreased as pore volumes increased below 2 µm. The relationship was linear, and the coefficient of determination was 0.94. Therefore, the compressive strength of samples with a pore volume from 4nm to 2 µm could be evaluated regardless of the quality of the recycled fine aggregate, the kind of admixture, and the replacement rate.

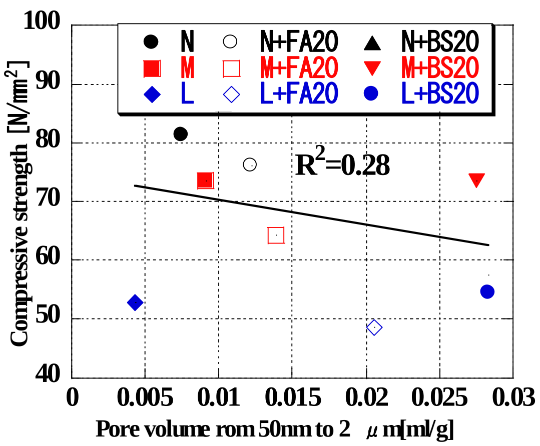

Figure 3. The relationship between
the pore volume from 50 nm to 2 µm at 28 days
aging and the compressive strength.

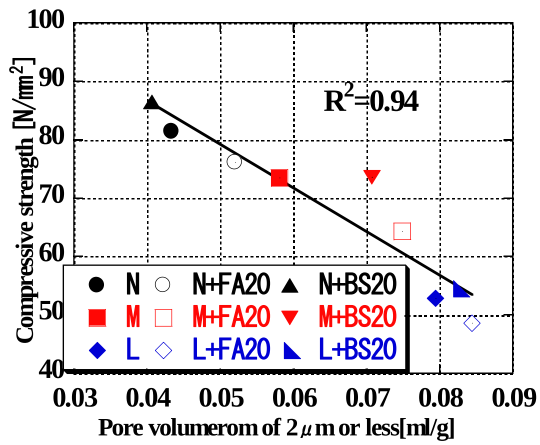

Figure 4. The relationship between
the pore volume from 4nm to 2 µm at 28 days
and the compressive strength.

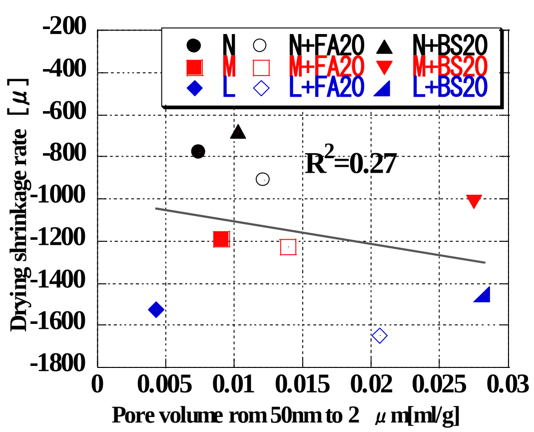

Figure 5. The relationship between
the pore volume from 50 nm to 2 µm at 28 days aging
and the drying shrinkage rate.

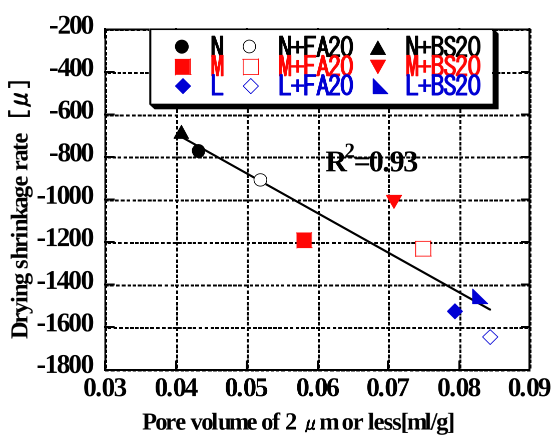

Figure 6. The relationship between
the pore volume from 4nm to 2 µm at 28 days
and the drying shrinkage rate.

Figure 5 shows the relationship between the pore volume from 50 nm to 2 μm at 28 days aging and the drying shrinkage rate. Similar to the compressive strength, the coefficient of determination between the drying shrinkage rate and the pore volume from 50 nm to 2 μm was 0.27, and we did not observe a good correspondence.

Figure 6 shows the relationship between the pore volume from 4nm to 2 μm at 28 days and the drying shrinkage rate. The shrinkage rate increased linearly with the pore volume and the coefficient of determination was 0.93. Therefore, the drying shrinkage rate of specimens with a pore volume from 4nm to 2 μm could be evaluated for mortar containing recycled fine aggregate and admixture for high compressive strength.

4 CONCLUSION

In the FA and BS series specimens, the compressive strength was reduced by the difference in the quality of the fine aggregate rather than the effect of increasing the replacement rate from 0 to 30%. In particular, the difference in the compressive strengths of M class and L class aggregates was large. The shrinkage rate fluctuation due to the deterioration of the quality of the regenerated fine aggregate was larger than that due to the replacement rate of the admixture. Although the shrinkage rate was smaller in the BS series than in the FA series, there was no decrease in the shrinkage ratio compared N indicates standard sand and without admixture.

In relation to the variation of pore volumes, from 50 nm to 2 μm, the results did not show a good correlation between the compressive strength and the drying shrinkage. The compressive strength and drying shrinkage of samples with a pore volume from 4nm to 2 μm could be evaluated regardless of the quality of the recycled fine aggregate, the kind of admixture, and the replacement rate.

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