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Influence of Coarse Aggregate on the Shrinkage of Normal and High-Strength Concretes

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Inclusion of aggregates leads to a reduction in the drying shrinkage of cement paste. This is due to the elastic deformation of the aggregates that partly restrains the shrinkage deformation of cement paste. Hence, concrete with higher aggregate content exhibits smaller shrinkage. In addition, concrete with aggregates of higher modulus of elasticity or of rougher surfaces is more resistant to shrinkage process. In this paper the effects of the type of coarse aggregate on the shrinkage of normal and high-strength concretes are investigated. Two different types of crushed stone were used as coarse aggregates to produce the concrete mixtures used in this study. For each coarse aggregate type, two normal-strength concrete (NSC) mixtures and two high-strength concrete (HSC) mixtures were prepared. The 28-day compressive strength values of NSC mixtures were about 35 and 50 MPa, while those of HSC mixtures were 70 and 100 MPa, respectively. All shrinkage specimens were cured in water for 14 days after casting, then exposed to drying under the conditions of constant temperature (20°C) and relative humidity (60%). It has been shown that the type of the coarse aggregate influences the shrinkage behaviour of both normal and high-strength concretes.

Key words: *Shrinkage, Coarse aggregate, High-Strength Concrete, Silica Fume*

1 INTRODUCTION

Elastic strain, shrinkage and creep present themselves from time to time as being important issues in structural performance. There are cases where structural stability and/or serviceability and safety are critically dependent on time-dependent deformations. Aggregates may exert a profound and important influence on the properties of hardened concrete. In particular, the deformation properties of concrete are affected by aggregates through a combination of the effects of water demand, aggregate stiffness and volume concentration, and paste/aggregate interaction (Alexander, 1996). In NSC, the hydrated cement paste and the transition zone around the coarse aggregate are relatively weak, since it is the (w/c) that predominantly controls the elastic modulus of concrete. Unlike normal concrete, HSC behaves as a true composite material with an efficient transfer of stresses between mortar and coarse aggregate even at low loads, thereby, demonstrating the early involvement of the coarse aggregate in the mechanical behaviour of HSC (Baalbaki, et al. 1991). Shrinkage is a function of the paste, but is significantly influenced by the stiffness of the coarse aggregate (Zia and Ahmed, 1991). Troxell et. al. (1958), investigated the effect of mineralogical character of coarse aggregate on shrinkage of concrete. One-cement type and six different types of coarse aggregates were used in concretes having a constant aggregate/cement ratio and water/cement ratio. The results show that the shrinkage for sandstone aggregate concrete was more than double that for quartz aggregate concrete. The published literature contains little information on the influence of the coarse aggregate characteristics, especially mineralogy, on the shrinkage behaviour of HSC mixtures. Previous publications (Adam, et al. 2000, 2001) have shown that the type of the coarse aggregate significantly influences the mechanical properties and creep behaviour of HSC. This paper reports the results of a study undertaken to investigate the effect of the coarse aggregate type on the shrinkage of NSC and HSC. The results of concretes containing clay slate and basaltic aggregates are compared.

2 MATERIALS AND MIXTURE PROPORTIONS

The cementitious materials used for making the concrete mixtures were a Type I portland cement meeting JIS R 5202-95 standard specifications, and a condensed silica fume with 92 percent SiO_2 content and 22,880 m^2/kg specific surface area. Superplasticizer was a naphthalene-based type. Natural river sand with maximum size of 5.0 mm was used as fine aggregate. Two types of coarse aggregate with different properties were used to realize the concrete mixtures. According to the information given by the supplier, one aggregate was crushed clay slate while the other was crushed basalt. The nominal maximum size of both coarse aggregate types was 20 mm. The grading curves and physical properties of both fine and coarse aggregates were measured according to the relevant Japanese Industrial Standard and are given in **Fig. 1** and **Table 1**, respectively. All

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aggregates were used wet in all mixes and corrections were made to take into account the water on the surface of the aggregate particles.

Table 1 Physical properties of fine and coarse aggregates

Aggregate	Specific gravity	Water absorption, %	Fineness modulus
Sand	2.62	1.69	2.36
Clay slate	2.69	1.12	6.67
Basalt	2.75	0.52	6.77

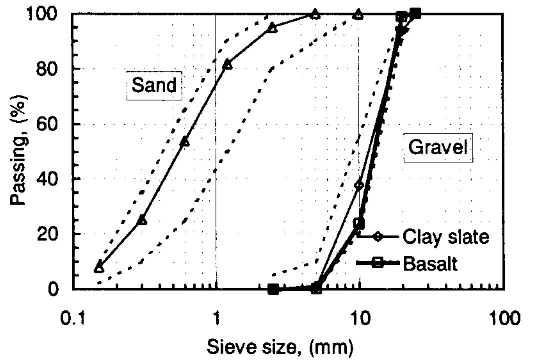

Fig. 1 Grading curves for fine and coarse aggregates

For each coarse aggregate type, mainly two grades of concrete were prepared for research purpose. These are: normal-strength concrete (NSC) and high-strength concrete (HSC). For each concrete grade, two series with different 28-day compressive strength values were prepared. For NSC the targeted 28-day strength values were 35 and 50 MPa, while those for HSC were 70 and 100 MPa. This was achieved by decreasing the (w/c) ratio and partial replacement of cement with silica fume. Superplasticizer admixture was used as 1.5% (of the cement content) in non-silica fume concrete, while its percentage was 3.5% (of the total cementitious materials content) in silica fume concrete. All the concretes tested, within each series, had the same composition, except that the mass of the coarse aggregate per m^3 was adjusted as according to the specific gravity of the coarse aggregate to maintain a constant volumetric content (Baalbaki, et al. 1991). All mixture proportions are summarized in **Table 2**. The first letters of the series name indicates the grade of concrete (NSC= normal-strength concrete, HSC = high-strength concrete), and the number indicates the water/cementitious ratio.

3 SPECIMENS AND TEST PROCEDURES

Compressive strength and elastic modulus tests were done on 100x200-mm cylinders at different ages. Specimens were fully water-cured, and at least three specimens were tested at any given age. Shrinkage tests were done on 100x100x400-mm prisms in a controlled 20 °C and 60 percent relative humidity environment. All specimens were stored in water at 20°C prior to commencement of drying. Shrinkage tests were commenced after 14 days of water curing. Strains on shrinkage prisms were measured longitudinally with a Whittemore strain gauge (with an accuracy of 4 microstrains) on two opposite faces on a 250-mm gauge length. Shrinkage observations were made for about 5 months, in which measurements were carried out at 1, 3, 7, 10, 14 days, and every 7 days thereafter, after the starting of drying.

4 RESULTS AND DISCUSSION

The influence of the coarse aggregate type on the compressive strength and modulus of elasticity of both NSC and HSC is presented and discussed in details elsewhere (Adam, et al. 2001), and are briefly summarized herein. As shown in Reference (Adam, et al. 2001) and **Table 3**, compressive strength of concrete depends to some degree on the type of coarse aggregate in the mix. The influence of the aggregate type on the compressive strength increases in HSC. The influence of the coarse aggregate type on the elastic modulus is much more pronounced than its influence on the compressive strength, especially in the case of NSC. Generally, concrete containing basalt aggregate tends to have higher strength and elastic modulus values than those of concrete prepared with clay slate aggregate.

Shrinkage, as described in this work, is the increase in strain with time due to changes in the moisture content of the concrete, which occurs under constant conditions of temperature and relative humidity without applying external stress to the concrete. Each curve plotted in the following figures represents the result of the average

Table 2 Mixture proportions of concrete

Series Name	Gravel Type	w/c	s/a	Weight per unit volume (kg/m^3)					
				W	C	SF	S	G	SP
NSC-0.60	Clay slate	0.60	0.50	137	233	0	994	1039	3.5
	Basalt							1063	
NSC-0.50	Clay slate	0.50	0.49	136	280	0	955	1039	4.2
	Basalt							1063	
HSC-0.33	Clay slate	0.33	0.45	134	420	0	839	1039	6.3
	Basalt							1063	
HSC-0.20	Clay slate	0.20	0.36	116	595	105	568	1039	24.5
	Basalt							1063	

Table 3 Compressive strengths and elastic modului of concrete mixtures containing different aggregate types

Aggregate Type	Age, days	f_c, MPa			
		NSC-0.60	NSC-0.50	HSC-0.33	HSC-0.20
Clay slate	7	28.045	36.665	52.274	78.233
	28	32.221	50.307	74.409	93.505
	91	42.819	56.324	77.419	99.122
Basalt	7	29.559	40.550	67.334	86.447
	28	37.627	48.874	71.925	106.966
	91	44.450	55.529	92.000	120.174
Aggregate Type	Age, days	E_c, GPa			
		NSC-0.60	NSC-0.50	HSC-0.33	HSC-0.20
Clay slate	7	29.000	32.612	39.834	40.041
	28	32.223	36.006	40.753	44.079
	91	34.263	34.683	40.276	45.249
Basalt	7	32.407	37.269	41.047	41.837
	28	35.200	38.907	44.712	47.150
	91	36.000	41.300	45.364	48.439

shrinkage strain measured for two identical shrinkage specimens dried together under the same curing conditions. Shrinkage strain values of the two NSC series (NSC-0.60 and NSC-0.50) prepared with clay slate and basalt aggregates are presented in **Fig. 2** and **Fig. 3**, respectively. It is clear from these figures that shrinkage strain for concrete containing basalt aggregate is smaller than that for concrete containing clay slate aggregate. This is valid for the two NSC series all ages after drying. At the end of the test period, shrinkage strain of clay slate aggregate concrete was about 1.25 times higher than that of basalt aggregate concrete. Shrinkage strain data for the two HSC series (HSC-0.33 and HSC-0.20) are shown in **Fig. 4** and **Fig. 5**, respectively. Just as in the case of NSC, basalt aggregate concrete produced a smaller shrinkage strain than that of clay slate aggregate concrete at all ages after drying. Moreover, HSC prepared with clay slate aggregate experienced as high shrinkage as 1.25 times of that of concrete containing basalt aggregate. Hence, coarse aggregate type has a marked influence on the shrinkage strain of both NSC and HSC. This influence could be explained in terms of the porosity and water absorption of the coarse aggregate, which play a direct role in the transfer of moisture within concrete; this transfer is associated with shrinkage. Aggregates can act as tiny water reservoirs distributed throughout the concrete (ACI Committee 363, 1984). It is possible that water absorbed by aggregate during mixing is transferred, during the drying process, to the surrounding paste. This moisture movement affects the extent of shrinkage and the internal relative humidity of the concrete; this would lead to more shrinkage (Neville, et al. 1983). Therefore, concrete made with basalt aggregate, which has the lower value of water absorption (see **Table 1**), imparted smaller shrinkage strain values, as shown in **Fig. 2** through **Fig. 5**. Thus, shrinkage strain is directly proportional to the value of water absorption of the coarse aggregate. This agrees with the findings of Alexander (1996) who stated that aggregates with lower water demand would tend to produce concretes with lower creep and shrinkage properties.

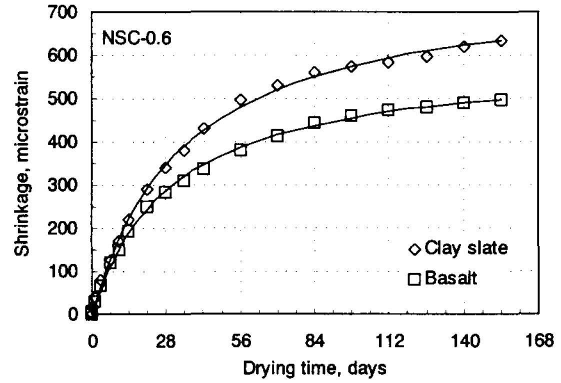

Fig. 2 Shrinkage-time curve for NSC Series NSC-0.60

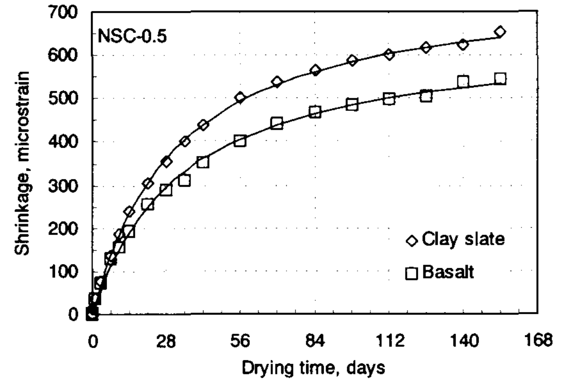

Fig. 3 Shrinkage-time curve for NSC Series NSC-0.50

It is well established, in literature, that drying shrinkage strain of concrete is closely related to water loss and a linear straight line can express the relation for both NSC and HSC (Sakata, 1983, El-Hindy, et al. 1994, and Bissonnette, et al. 1999). Weight changes (water loss) for all shrinkage specimens were also measured using a balance with an accuracy of 1 g. **Fig. 6** shows the results of the loss in weight (water loss) with time for Series

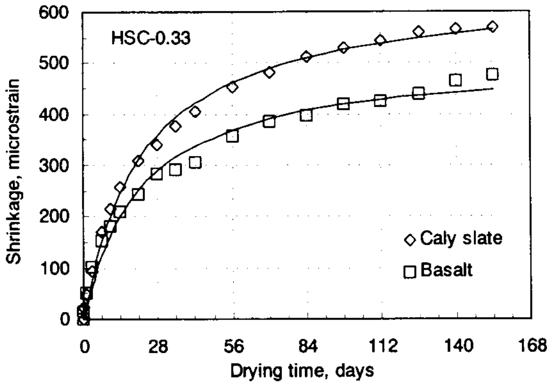

Fig. 4 Shrinkage-time curve for HSC Series HSC-0.33

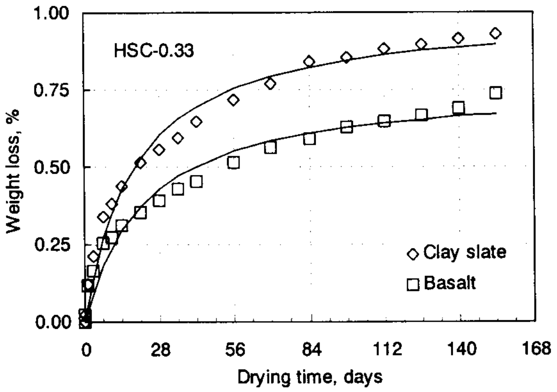

Fig. 6 Weight loss-time curve for HSC Series HSC-0.33

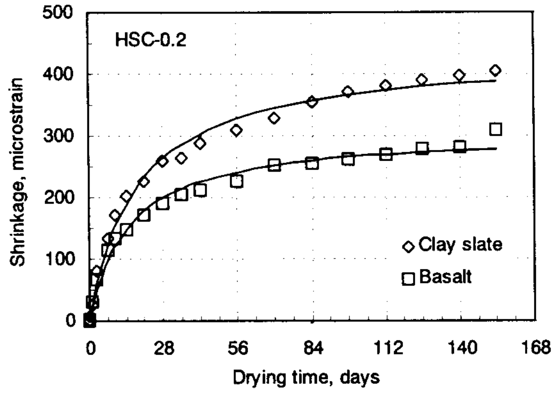

Fig. 5 Shrinkage-time curve for HSC Series HSC-0.20

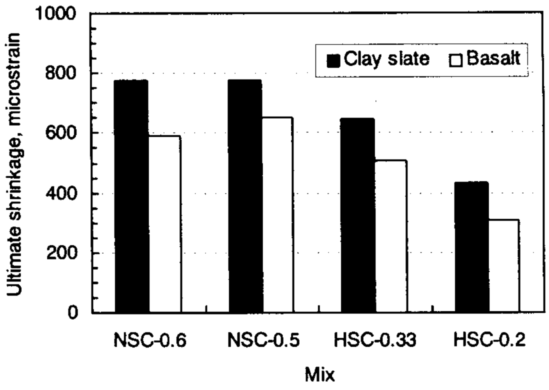

Fig. 7 Ultimate shrinkage strain for NSC and HSC

HSC-0.33 as an example. It is clear from this figure that the shape of the water loss-time curves is similar to that of shrinkage-time curves. The results show that the water loss for basalt aggregate concrete is less than that for clay slate aggregate concrete, this is valid for all concrete series at all ages after drying.

The type of the coarse aggregate significantly influences not only the magnitude of shrinkage but also the ultimate shrinkage strain value of concrete. **Fig. 7** presents the ultimate shrinkage strain for all concrete mixtures made with different coarse aggregates. For both NSC and HSC, the ultimate value of shrinkage strain is lower for concrete made with basalt aggregate than that for concrete made with clay slate aggregate.

Examining **Fig. 2** to **Fig. 7**, it could be easily noticed that, in spite of the coarse aggregate type, the shrinkage strains of HSC particularly that contains silica fume, were remarkably less than shrinkage strains of NSC. For instance, at the end of the test period, the shrinkage strain values of the two HSC series (HSC-0.33 and HSC-0.20) prepared with basalt aggregate were 475 and 308 microstrain respectively. While the corresponding values of the two NSC series (NSC-0.60 and NSC-0.50) prepared with the same aggregate type were 500 and 540 microstrain respectively. Moreover, the ultimate values of shrinkage strain of HSC mixtures were noticeably lower those than of NSC mixtures. Zia and Ahmed (1991) concluded that shrinkage of HSC containing high range water reducers is less than for lower strength concrete, probably due to the increase in stiffness of the stronger mixtures.

5 CONCLUSIONS

Concretes with 28-day compressive strengths in excess of 90 MPa are possible using different types of commercially available coarse aggregates in Japan. In this study it has been shown that the shrinkage properties vary significantly depending on the type and properties of the coarse aggregate used. Concrete made with basalt aggregate, which has the lower value of water absorption, imparted smaller shrinkage strain values. Thus, shrinkage strain is directly proportional to the value of water absorption of the coarse aggregate. Moreover, the weight (water) loss for basalt concrete is less than that for clay slate concrete. The type of the coarse aggregate significantly influences not only the magnitude of shrinkage but also the ultimate value of shrinkage strain of both NSC and HSC. In spite of the coarse aggregate type, the shrinkage strains of HSC particularly that contains silica fume, were remarkably less than shrinkage strains of NSC.

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