Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Properties of Concrete used in Ferronickel Slag Aggregate

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ABSTRACT

Ferronickel slag is an industrial by- product generated during smelting to ferronickel used in the manufacture of stainless steel and nickel alloys. In the late 1980's, it has been studied for more effective use as aggregate for concrete, and the ferronickel slag fine aggregate have been standardized in JIS A 5011- 2 (Japanese Industrial Standard) as slag aggregate for concrete. While in recent years, from the viewpoint of use expansion of ferronickel slag, its coarse aggregate have been developed, and the standardization is investigated in actively research work.

The objective of this study is to investigate some properties of concrete used ferronickel slag as aggregate. This paper include the fundamental properties of slag aggregate, properties of fresh concrete used ferronickel slag aggregate as fine/ coarse aggregate, mechanical properties of concrete used ferronickel slag aggregate and durability of slag concrete.

Keywords. Ferronickel slag, aggregate, concrete, mechanical property, durability

INTRODUCTION

Ferronickel slag is an industrial by- products that produced refining ferronickel from nickel ores. The ferronickel slag production totals approximately 3 million tons per year in Japan. Positive use of the slag is being enhanced from the viewpoint of utilization and recycling of industrial by- products.

On the other hand, in recently, the adoption of good- quality aggregate has been becoming difficult with the depletion of superior natural aggregate resources and the public restrictions of their development for use. Therefore, the utilization of industrial by- products for recycled concrete materials has increased, and it has been also developed from the viewpoint of the effective use of natural resources.

In the late 1980's, it has been studied for more effective use of slag as aggregate for concrete, the various non- ferrous metal slag have been standardized in JIS A 5011 (Japanese Industrial Standard) as slag aggregate for concrete. The ferronickel slag fine aggregate also was standardized in JIS A 5011-2. The recommendation for construction of concrete was published from the subcommittee in JSCE. Especially, the ferronickel slag fine aggregate have applied to the harbour structures, the wave- absorbing concrete block, the concrete pile and so on. Moreover, in recent years, from the viewpoint of use expansion of ferronickel slag as aggregate for concrete, its coarse aggregates have been developed, and investigating in actively research work. However, the slag aggregate for concrete have not yet been fully used.

In general ready- mixed concrete factory, fine aggregate for concrete is adopted blended sand, such as a coarse fine aggregate like a crushed sand and fine sand like a natural sand. The ferronickel slag fine aggregate standardized in JIS A 5011-2 is produced by crushed procedure after air granulated, and as a general rule, these slag fine aggregate is specified that its utilization is single use. From the reason of this, the ferronickel slag fine aggregate is difficult to actively use in general ready- mixed concrete factory. For the reason of above, it is considered that the investigation of utilization of ferronickel slag aggregate as blended sand is important to increase the use of ferronickel slag as aggregate for concrete.

The purpose of this study is to examined the availability of blended the ferronickel slag fine aggregate without crushed processing after the air granulated and natural sand. Moreover, form the viewpoint of expansion availability of FNS and FNG, examination of the fundamental properties of concrete with FNS and FNG was also done in this study. Hereafter, the ferronickel slag fine aggregate and the ferronickel slag coarse aggregate will be denoted as FNS and FNG, respectively.

TEST PROGRAM

Materials and Concrete. Ordinary portland cement (density: 3.16 g/cm^3) was used in this study. Fine aggregates were adopted three types, natural sand for blended sand, crushed lime sand and air granulated ferronickel slag without crushed processing (FNS) for blended. Coarse aggregates were adopted crushed lime stone and two types ferronickel slag coarse aggregates (FNG (1305) for blended and FNG (2005) for single use). Physical properties of these aggregate indicate in Table 1. The air content of the fresh concrete was controlled by an air- entraining admixture.

Ten mixture proportions were planned with the combination of two FNS volume fractions (0 and 40 %), three FNG volume fractions (0, 50 and 100 %) and three water cement ratio (45, 55 and 60 %). The air content of fresh concrete and slump were fixed 5.0 ± 1.0 % and 10.0 ± 1.0 cm, respectively. Table 2 shows the combinational condition of mixture proportions of concrete.

Testing Method. (1) Mechanical Properties Test: Test for compressive strength was done in accordance with JIS A 1108. Compressive strength was tested using cylindrical specimen (ф100 × 200 mm in high) at age of 7, 14, 28 days. Static modulus of elasticity of concrete was measured using cylindrical specimen (ф100 × 200mm in high) with compressometer. Secant modulus was obtained at one third of ultimate compressive strength.

(2) Freezing and Thawing Resistance Test: Freezing and thawing tests were conducted in accordance with JIS A 1148 procedure A (freezing and thawing in water, 1 cycle of about 4 hours). The test was started at an age of 14 days using prisms (100 × 100 × 400mm). Three specimens were tested simultaneously representing each mixture and testing conditions. The change in the relative dynamic modulus of elasticity and the loss in mass were measured

Table 1. Physical properties of aggregates

Test items	for blending		for single application	for blending	for control	
	FNS-B	FNG (1305)	FNG (2005)	natural sand	crushed lime sand	crushed lime stone
Density (oven- dry) [g/cm^3]	2.84	2.90	2.90	2.56	2.65	2.69
Water absorption [%]	1.98	2.10	2.13	1.77	0.69	0.95
Solid content [%]	65.1	59.0	57.6	59.8	61.9	57.3
Mass of unit volume [kg/L]	1.85	1.71	1.67	1.59	1.66	1.49
Fineness modulus	3.87	6.37	6.58	2.39	2.87	6.67
Abrasion loss [%]	-	15.2	16.3	-	-	25.0
BS 40tf cruching value [%]	-	10.2	9.9	-	-	21.7

Table 2. Combinational condition of mixture proportions of concrete

W/C [%]		45		55		60	
FNS volume fraction [%]		0	40	0	40	0	40
FNG volume fraction [%]	0	○	—	○	○	○	—
	50	—	○	○	○	—	○
	100	—	—	○	○	—	—

every 30 cycles up to 300 cycles. The relative dynamic modulus of elasticity P_n was calculated by the following Eq. 1.

$$P_n = \left(\frac{f_n^{\,2}}{f_0^{\,2}} \right) \times 100 \quad (1)$$

where, P_n is the relative dynamic modulus of elasticity after n cycles freezing and thawing, f_0 denotes the fundamental transverse frequency at 0 cycle and f_n denotes the fundamental transverse frequency after n cycles.

(3) Drying Shrinkage Test: Drying shrinkage test was conducted according to JIS A 1129. The test was started at an age of 28 days using prisms (100 × 100 × 400mm) in a controlled room with 60 % in relative humidity and 20 ℃ in temperature. Length change of concrete specimen, where the reference length 100mm was selected, was measured using the contact dial gauge between two brass tips with a small stainless ball for gauge point stuck to the surface of specimen. The loss of moisture was also measured during drying shrinkage test.

EXPERIMENTAL RESULTS AND DISCUSSION

Property of Mixture. Table 3. and Table 4. shows the unit water content and sand aggregate ratio of all mixture, respectively. From these results, it was obtained that the unit water content decreased with the increase of FNS volume fraction. And it was obtained that the sand aggregate ratio of concrete increased with the increase of FNS volume fraction.

Table 3. Unit water content of concrete (unit: kg/m^3)

W/C [%]		45		55		60	
FNS volume fraction [%]		0	40	0	40	0	40
FNG volume fraction [%]	0	163	—	163	153	163	—
	50	—	146	155	150	—	154
	100	—	—	167	150	—	—

Table 4. sand aggregate ratio of concrete (unit: %)

W/C [%]		45		55		60	
FNS volume fraction [%]		0	40	0	40	0	40
FNG volume fraction [%]	0	41.5	—	43.5	47.5	45.5	—
	50	—	43.0	43.5	46.0	—	49.5
	100	—	—	46.5	47.0	—	—

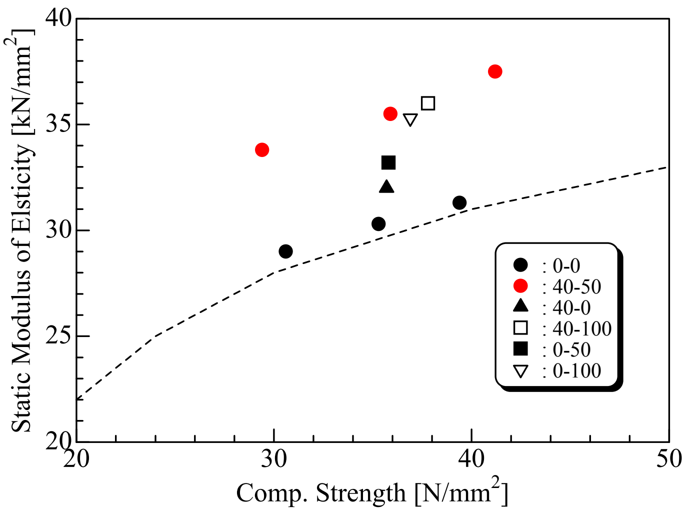

Figure 1. Mechanical properties of concrete at an age of 28 days

From the result of unit water content, the blended use of FNS and FNG will be recommended from viewpoint of reduce of the unit water content.

Mechanical Properties. Fig.1 shows the relationship a static modulus of elasticity and a compressive strength at an age of 28 days. The break line in fig.1 indicates the relationship a static modulus of elasticity and compressive strength that indicated in JSCE Standard. From the result of Fig.1, it was obtained that the static modulus of elasticity of concrete indicated the increase with the increase of compressive strength regardless of whether FNS / FNG were used. Compare with concrete of a same W/C, a static modulus of elasticity of concrete with ferronickel slag aggregate indicates higher value compare with concrete used lime sand and lime stone, although a compressive strength indicates almost same value regardless of whether FNS / FNG were used. This result is considered due to the difference of mechanical properties of aggregate.

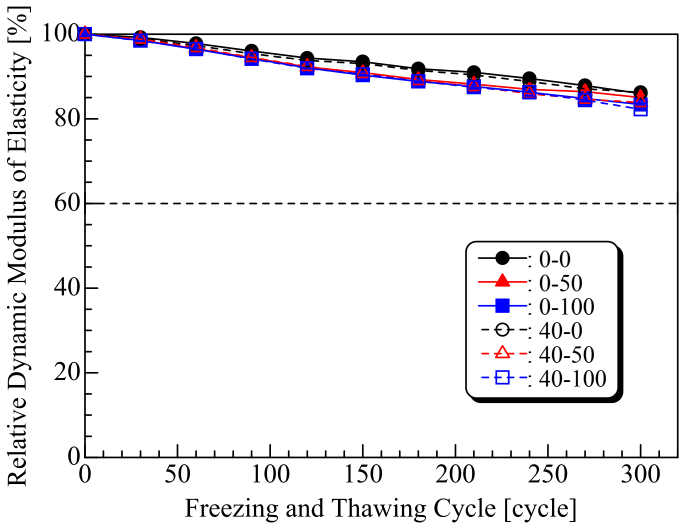

Figure 2. Change of relative dynamic modulus of elasticity (W/C = 55 %)

Freezing and Thawing Resistance. Fig.2 shows the result of freezing and thawing resistance test. The vertical and horizontal lines indicate a relative dynamic modulus of elasticity and cycles of freezing and thawing, respectively. From the result of Fig.2, it was confirmed that the resistance of freezing and thawing of concrete with FNS indicate almost same compare with that of normal concrete. And it was confirmed that the resistance of freezing and thawing of concrete with FNS / FNG also have higher resistance for freezing and thawing action.

Durability indicator for freezing and thawing action indicate more than 80% for all mixture of concrete. From this result, it was considered that the concrete with FNS / FNG has higher resistance for freezing and thawing action.

Drying Shrinkage. Fig.3 indicates the result of drying shrinkage up to 180 days. The vertical and horizontal lines indicate a drying shrinkage and an exposure period, respectively. From the result of Fig.3, it was confirmed that the drying shrinkage of concrete for all mixture indicated about 300 ~ 400 $\times 10^{-6}$. Moreover, the drying shrinkage of concrete with FNS / FNG indicated slightly high value compare with that of normal concrete, and the drying shrinkage of concrete increased with the increase of volume fraction of ferronickel slag aggregate.

CONCLUSIONS

In this study, mechanical property and durability (freezing and thawing resistance and drying shrinkage) of concrete with the air granulated ferronickel slag and natural sand as fine aggregate was experimental examined. And combined using FNS and FNG for concrete was also examined. The test results were summarized as follows.

(1) The water demand of concrete with FNS and natural sand as fine aggregate decreased compared with that of normal concrete.

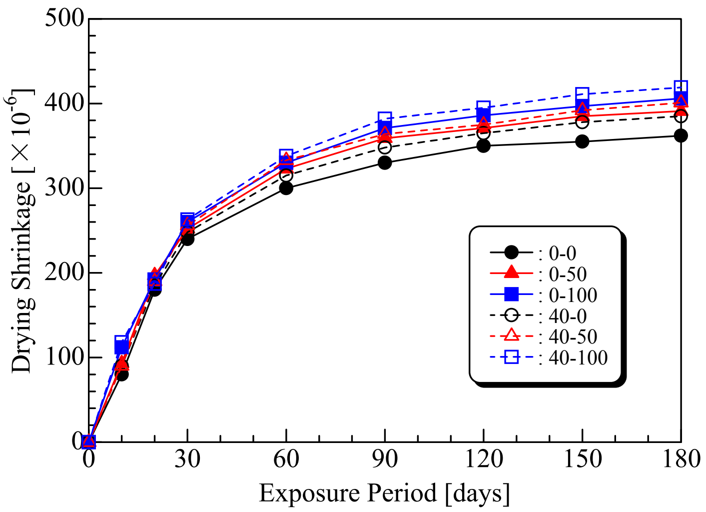

Figure 3. Drying Shrinkage (W/C = 55 %)

(2) The compressive strength of concrete with FNS and FNG indicated almost same value that for normal concrete. And the static modulus of elasticity of concrete with FNS and FNG indicated higher value compared with that of normal concrete.

(3) In the freezing and thawing resistance test, the durability index for freezing and thawing action of concrete showed more than 80% up to 300 cycles of freezing and thawing cycle, and the concrete with FNS and FNG confirmed high resistance for freezing and thawing action regardless of whether FNS and FNG were used.

(4) The drying shrinkage of concrete slightly increased with the increase of volume fraction of ferronickel slag aggregate. However, these value of all mixture indicated about 350 ～ 400 $\times$ 10^{-6}.

From the results of this study, it was judged that the concrete with blended FNS and natural sand has enough mechanical properties and durability compared with that of normal concrete. And it was judged that ferronickel slag aggregate examined in this study was promising as fine/ coarse aggregate for production of concrete.

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