Structural behavior of Reinforced Concrete Beams using stainless slag as fine aggregate

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1. Introduction

Stainless slag is by-product on the production of stainless steel. In Japan, stainless slag is generated approximately 30,000 tons every year. The effects utilize on the concrete production consider as an important thing, on the previous research investigated basic physical properties of concrete used stainless slag as fine aggregate and derived that stainless slag can be used as fine aggregate of concrete up to 60% in mix proportion without any caution [(2)(3)]. This study aims at using stainless slag effectively as a material of structural concrete. In order to promote stainless slag as fine aggregate on the structural purpose, behavior and performance of Reinforced concrete (RC) simple beam used stainless slag were investigated experimentally. In the experiment of loading tests, the result of mechanical responses such as crack width, deflection and strengths were discussed among the behavior of those of RC beams without using stainless slag and discussed.

2. Experimental Procedures

2.1 Material and mix proportions

Table 1 shows the properties of concrete materials. The ordinary Portland cement with density 3.15 g/cm^3 was used. Sea sand as fine aggregate is produced from the Sea of Genkain located in Fukuoka prefecture, and with dry density 2.57 g/cm^3, water absorption 1.62% and fineness modulus 2.85. Stainless steel slag which is a by-product stainless steel production, with physical properties oven-dry density 3.04 g/cm^3, surface dry density 3.08 g/cm^3, water absorption1.53%, and fineness modulus 2.96, including 1.96% amount of finer material. Reinforcement consists Deformed bar D16 mm as main reinforcement and plain bar Ø6mm as stirrups, as shown in table 2.

Table 3 shows the mix proportions and fresh properties of the concrete used in this experiment. The two cases of replacement of sea sand with stainless slag are designed as 0 % and 60 %. Every concrete has w/c ratio 50 %, slump design 12± 2 and air content 4.5 ± 1.5. In additional AE water reducing agent (Frolich SV) in admixture is 0.1 % total amount of cement.

Table 1. Description concrete material

Material	Density (g/cm^3)	Water absorption (%)	FM	G max (mm)
Sea Sand (S)	2.57	1.62	2.85	
Crushed Gravel (G)	2.70	1.00		20
Ordinary Cement (C)	3.15	-		
Stainless Slag	3.08	1.53	2.95	
Water (W)	1.00			
AE				

Table 2. Description of reinforcement

Type	Elastic Modulus (kN/mm^2)	Yielding strength (N/mm^2)	Area (mm^2)	Remark
Ø6	120	388	63.67	stirrup
D 16	200	350	397.2	tendon

Table 3. Mix proportion of concrete

Type	W/C	Material (kg/m^3)						Slump Design (cm)	Slump Measured (cm)	Air content Design (%)	Air content Measured (%)
		W	C	NSS	S	G	AE				
Slag 0 % 28 days	50	170	340	0	696	1097	3.40	12±2	12	4.5±1.5	3.5
Slag 60 % 28 days	50	170	340	500	278	1097	3.40		10.5		3.8
Slag 0 % 91 days	50	170	340	0	696	1097	3.40		10		3.5
Slag 60 % 91 days	50	170	340	500	278	1097	3.40		10		3.5

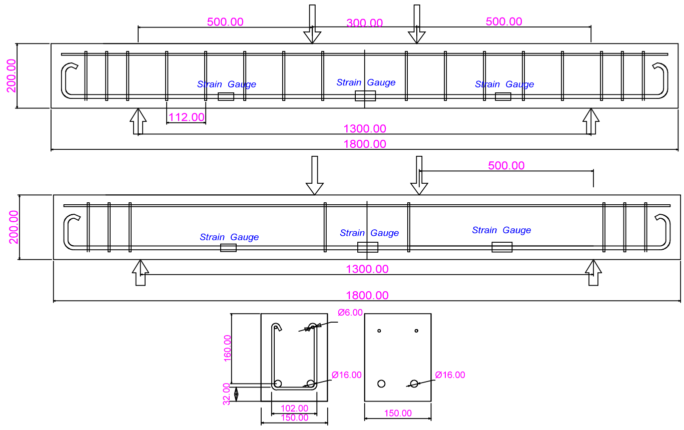


Figure 1. Dimension and loading of RC beams

2.2 Concrete specimens

The cylindrical specimens were prepared for the compressive strength, split testing (tensile strength) and elastic modulus test. The specimens were cured in the water pool, with temperature and moisture control until the testing day. The testing methods are based on Japanese industrial standard (JIS), namely JIS A 1108 for compressive strength test, JIS A 1113 for Split tensile testing and JIS A 1149 for elastic modulus at the age 28 and 91 days.

2.3 Reinforced Concrete (RC) beams

Two types used stirrups and without using a stirrup of beams shown in Figure 1 were designed, fabricated and loaded up to failure condition. To investigate the structural behavior of beams using stirrups and without stirrup, two specimens corresponded to each stainless slag composition were prepared. RC beams with a similarity of dimension (200mmx150mm), effective depth (160mm), and reinforcement ratio (0.016) were fabricated. Then, after casting, pouring with water, placing and covering outside building, thus temperature depended on the weather condition. The method used to cure RC beams was by the sealed and spray with water every day until the loading age of 28 days and 91 days. The measurement and loading position of RC beams specimen are shown in Fig. 1, correspondingly. The strain gauge attached to the main reinforcement in center of beam and other strain gauge attached at center between loading point and support point. The crack location, crack width, and crack length were measured after cracks appeared. Crack widths were measured at every load interval at the tension steel level and the crack formations were marked on the beam.

3. Result and Discussion

3.1 The property of concrete specimens

Table 4 shows the compressive strength, the tensile strength and the elastic modulus at 28 and 91 days. The compressive and tensile strength of concrete containing stainless slag were slightly higher than those without using stainless slag, including development of mechanical property of concrete during curing showing the condition of compressive strength and tensile strength concrete increasing. However, the elastic modulus of concrete no shows significant differences.

Table 4. Mechanical property of concrete

Slag (%)	28 days			91 days		
	Fc (N/mm^2)	Ft (N/mm^2)	E (kN/mm^2)	Fc (N/mm^2)	Ft (N/mm^2)	E (kN/mm^2)
0	32.3	2.70	37	45.4	3.17	40
60	34.3	2.56	40	46.3	3.72	41

Table 5. Ultimate strength of RC beams

Slag (%)	Calculation						Experiment						Note
	28 day			91 days			28 day			91 days			
	Mu (kNm)	Vc (kN)	Vu (kN)	Mu (kNm)	Vc (kN)	Vu (kN)	Mu (kNm)	Vc (kN)	Vu (kN)	Mu (kN.m)	Vc (kN)	Vu (kN)	
0	19.9	32.5		20.6	36.4		19.9	39.7		21.8	43.6		Without Stirrup
			50.4			53.7	20.0		40.0	20.7		41.4	With Stirrups
60	20.1	33.2		20.6	36.6		21.6	43.1					Without Stirrup
			51.0			53.9	21.9		43.3	22.1		44.1	With Stirrups

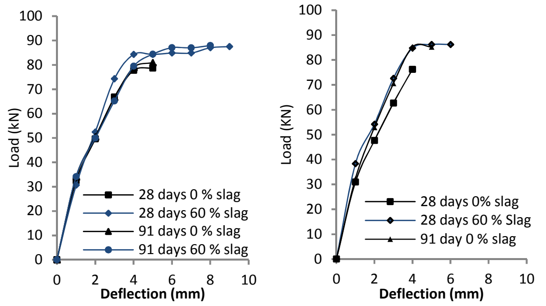
3.2 Reinforced concrete beams.

3.2.1 Load deflection relationship

Figure 2 shows the experimental result of the load and deflection relationships of the specimens at the center of the total span of beams. There was a considerable effect of replacement of the stainless slag as fine aggregate on deflection when the maximum loads applied at yield point of reinforcement. RC beams containing 60 % of the stainless slag deflection higher than those RC beams without using stainless slag (0 %).

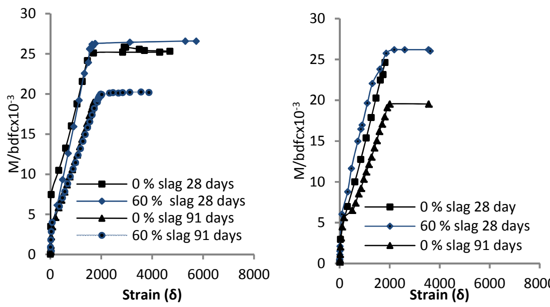
Table 5 shows the ultimate strength of RC beams, that table indicates the ultimate shear force on calculation higher than the result of experiment, however ultimate moment design and experiment almost similar, even the calculation used the result of compressive strength of concrete.

Figure 3 shows the relationship average strain of reinforcement bar at the center of loading point. This figure shows that average strain in the reinforcement of RC beams containing stainless slag a slight higher than RC beams without use stainless slag. However, this figure shows a distance at the age 28 days higher than in the 91 days. This is due to increasing compressive strength of concrete cylinder compared to the experimental result of ultimate strength of RC beams slightly similar.



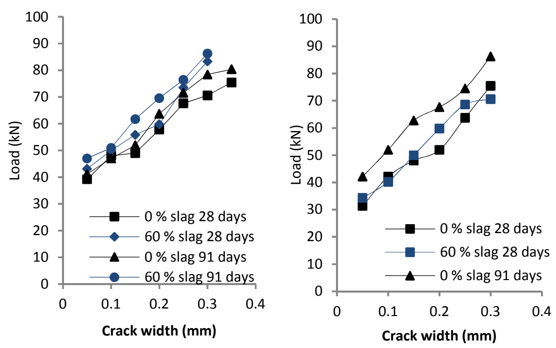
a) With Stirrups b) Without Stirrup

Figure 2. load and deflection relationship



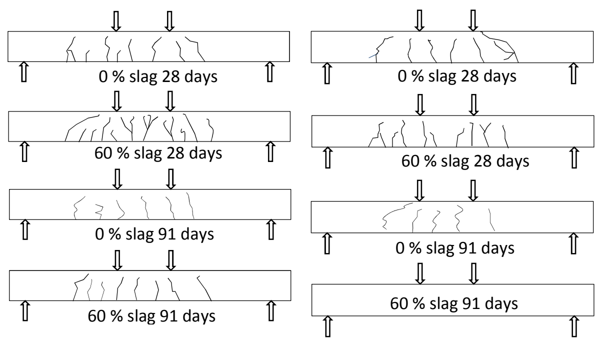
a) With Stirrups b) Without Stirrup

Figure 3. Average of strain of reinforcement



a) With Stirrups b) Without Stirrup

Figure 4. load and crack width relationship



a). With Stirrups b). Without Stirrup

Figure 5. Crack pattern

3.2.2 Crack of RC beams

Crack formation refers to the occurrences of any narrow, irregular opening of indefinite dimensions resulting from shrinkage, flexural or direct tension stresses, or internal expansion resulting from the products of corrosion or deleterious aggregates. However, in this study focused on the measurement of crack at RC beams when cracks occurred in loading step.

Figure 4 shows the relationship between load and crack width, that figure show a crack occurs in earlier loading step to the beams without stirrup compared to the beams with stirrups. Also, RC beams containing stainless slag (60%) show crack width slightly narrower than those of RC beams without use stainless slag (0%) according to loading age.

Figure 5 shows the crack pattern and the numbers of cracks. Those figures show the total amount number of cracks for RC beams at 28 days is more than those of RC beams in the 91 days of testing age.

4. Conclusion

In this study, behavior of RC beams using stirrups and without stirrups, which containing stainless slag (60 %) were investigated by comparing to the RC beams without using stainless slag (0%). Then, the following conclusions were shown.

(1) Concrete containing stainless slags shown slightly higher the compressive strengths, tensile strength and elastic modulus compared to concrete without using stainless slag. Thus, the result of ultimate moment strength and ultimate shear strength of RC beams indicates slight differences in two RC beams containing each composition of stainless slag.

(2) The deflection of beams shows RC beams containing stainless slag larger than those RC beams without using stainless slag at yielding point (maximum load) for beam with stirrups. However, for beams without stirrup RC beams containing stainless slag slight similar to those of RC beams without using stainless slag.

(3) Crack occurs at earlier loading step to the RC beams without stirrup compared to the beams with stirrups. Also on the RC beams with stirrups, crack width of RC beams containing stainless slag shows slightly narrower than those of RC beams without stainless slag. However, for RC beams without stirrup the crack width is almost same between RC beams containing stainless slag and RC beams without using stainless slag.

5. Reference

(1) JSCE Guideline for Concrete no. 15 (2007) Standard Specification for concrete structure-2007 “design” English version.

(2) 浦木 大資, 高海 克彦, 松尾 栄治 , ステンレススラグコンクリートの基礎物性に関する研究，平成 25 年度土木学会中国支部研究発表会概要集，2013.5.

(3) 徳重裕平, 松尾栄治, 高海克彦, 王 亮, ステンレススラグ細骨材を用いたコンクリートの諸物性に関する研究，平成 24 年度土木学会中国支部研究発表会概要集，2013.3.