Mechanical properties of molten slag by itself and in concrete mixes

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1. Abstract

The purpose of this study is to compare the performance of the molten slag produced in 2009 with those produced in 2008 and 2007 in Shiga prefecture in Japan. Some experiments were done which were not included in previous studies. Additionally, the volume change test in aggregates show results which may be directly related to the drying shrinkage in concrete.

2. Introduction

Lake Biwa is the largest lake in Japan, at the moment the extraction of natural aggregates is prohibited by law. However, the production of concrete continues in the region and consequently the consumption of aggregates. The solutions to supply the aggregates demand near Lake Biwa, is either to purchase natural aggregates from far places or to produce artificial aggregates in factories near to the lake. The production of molten slag in Shiga (Prefecture where the lake is located) has been a good solution to accomplish the demand of aggregates. This paper is based on previous studies performed to these artificial aggregates from this region and its results were compared to those results obtained by Takeda [1] in 2007 and Inoue [2] in 2008. Furthermore, this paper includes new experiments done to these artificial aggregates. Additionally, the volume change test preformed to the aggregates show results which are clearly related with the drying shrinkage test in concrete and it is thought that the shrinkage in any common concrete is occasioned by the volume change of the aggregate itself and the paste.

3. Experiments

3.1 Materials: The cement used was Ordinary Portland Cement (C), complying with JIS R 5201, with a density of 3.16g/cm^3 and Blaine of 3260 cm^2/g. The fine aggregate was crushed sand (S) from Osaka Prefecture complying with JIS A 5005 with density of 2.60g/cm^3, water absorption; 2.00%, F.M.; 2.75 and M.S.; 5mm. The additives were High performance water reducer (Ad1) with a density of 1.10g/cm^3 and Air reducer, Polycarboxylic Acid Polymer, (Ad2) with density of 1.19g/cm^3, both admixtures complying with JIS A 6204. The coarse aggregates properties are listed in Table 1. The molten slags MG and MG2 are from the same facility in the northern part of Shiga Prefecture but MG was produced in 2009 and MG2 in 2008. The molten slag MG3 was produced in a facility located in the southern part of Shiga Prefecture in 2007. The Gravel is from Osaka Prefecture and all the materials are from Japan.

3.2 Methods, specimen sizes and nomenclature: The standard methods followed were according to the Japanese Industrial Standard (JIS), except only for the crushing value (BS 812). However there was 1 special experiment for the volume change in aggregates with no standard method. Description: Five rocks were sampled for every coarse aggregate (including MG2 and MG3). The samples were totally dried (1 day at 105^{o}C). One of the rock faces was polish with regular sandpaper to attach a double 2 mm gauge and be connected to a data logger equipment. The samples were immersed in tap water for 7 days and 7 days drying (while the data logger was measuring the volume change). This test was performed in the same controlled room as the drying shrinkage test (20±1^{o}C, 60±5 RH). The nomenclature of the specimens is shown in Table 2. The water/cement ratio was 55%, slump target of 7.5±1 cm and entrapped air target of 4.5±1%.

Table 1. Physical properties of the coarse aggregates

Property	MG*1	MG2*2	MG3*3	JIS A 5031	Gravel*4	JIS A 5005
Specific gravity (g/cm^3)	2.64	2.48	2.65	--	2.65	--
Dry density (g/cm^3)	2.60	2.44	2.60	Above 2.0	2.64	Above 2.50
Water absorption (%)	0.90	0.69	2.16	Below 3.00	1.32	Below 3.00
Unit of mass per volume (kg/l)	1.45	1.41	1.52	--	1.59	--
Absolute volume (%)	57.0	57.4	58.5	--	59.1	Above 55.0
Resistance to abrasion (%)	23.6	28.2	43.6	--	9.8	Below 40.0
Crushing value (%)	21.5	22.7	41.1	--	8.96	--

1)MG=Molten slag 2009, 2)MG2=Molten slag 2008, 3)MG3=Molten slag 2007 and 4)G=Gravel

Table 2. Nomenclature of the specimens

Nomenclature	Materials			
	Cement	Coarse Aggregate	Fine Aggregate	Additives
55,0,100	Ordinary Portland	100% G	Crushed Sand	Ad1 & Ad2
55,25,75		25% MG, 75% G		
55,50,50		50% MG, 50% G		
55,100,0		100%MG		

MG=Molten slag 2009, Ad1=Air reducer and Ad2=Water reducer

Keywords: molten slag, sewage, coarse aggregate, drying shrinkage.

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4. Results and discussions

4.1 Strength and elasticity: Fig.1 shows the strength and modulus of elasticity. The experiments done by Takeda [1] and Inoue [2] had a W/C ratio of 50% while the experiments done for this MG had a W/C ratio of 55%. Fig. 1 shows MG with lower results than MG2 and MG3 in most of the strength test. However, the importance of these tests is the tendency, according its percentage of molten slag in the specimen. MG and MG2 incremented the strength and elasticity in concrete according its percentage in the mixes increased.

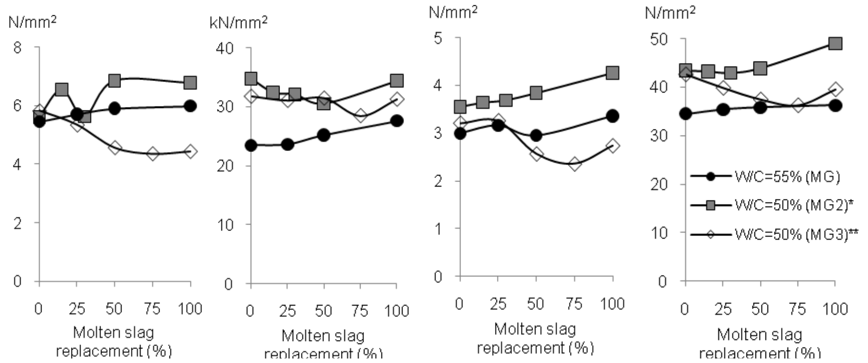

Fig. 1. Strength and modulus of elasticity
(*Inoue [2] specimens, ** Takeda [1] specimens)

4.2 Freezing and thawing (F&T): The specimens were tested to freezing and thawing conditions for 300 cycles and its durability and weight were measured after every 30 cycles of F&T. Fig. 2 and Fig. 3 shows the results for this test. The specimen who was more affected by these cycles was the specimen produced of 100% molten slag (55-100), its durability was lower and its weight was reduced to 90% of its original weight. Based on the results obtained in this test, the concrete made of 100% molten slag may have damage on its appearance. Molten slag concretes are not the most suitable option for places where the weather is extremely changing.

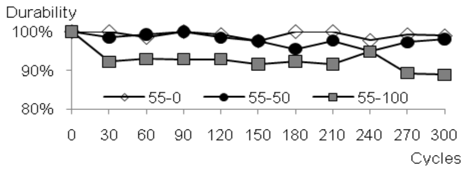

Fig. 2. Durability of the specimens after the F&T test.

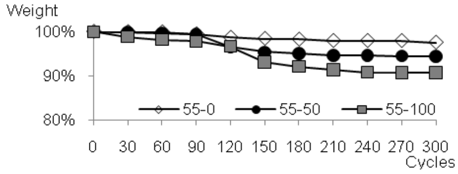

Fig. 3. Weight of the specimens after the F&T test.

4.3 Drying shrinkage in concrete: Fig. 4 shows the results of the drying shrinkage. The results obtained in this test were compared with those obtained by Inoue [2]. The specimens made by Inoue [2] had a 50% of W/C ratio (first 2 figures in its nomenclature) and 0%,50% and 100% of molten slag. (e.g. 50-0, W/C=50% with 0% MG2). The effect of the water is very clear, all the specimens made with 50% of W/C shrunk lesser than those made with 55% of W/C. However, in both experiments (this paper and Inoue's [2]), the specimens which included molten slag tended to reduce the shrinkage in concrete. The specimens made of 100% gravel were the highest results in both experiments.

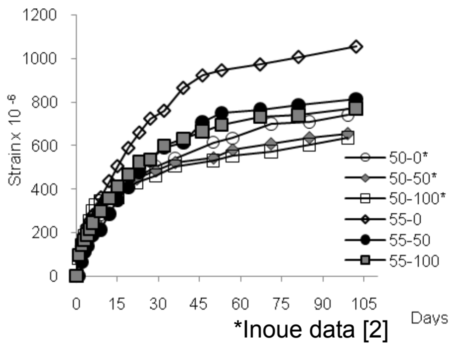

Fig. 4. Drying shrinkage in concrete

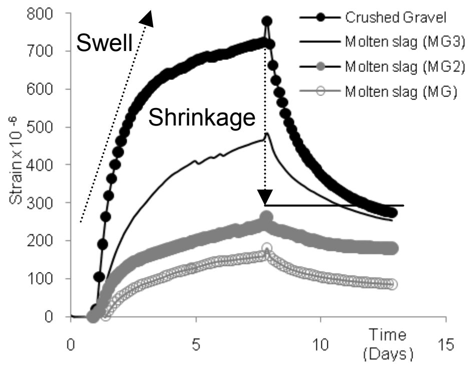

Fig. 5. Volume change in aggregates

4.4 Volume change in aggregates: It is possible that the drying shrinkage in concrete is directly related with the volume change of the aggregates, if the cement paste is the same. The gravel swells faster and larger than the molten slags. The shrinkage of the gravel was about 400μ while the MG and MG2 had only about 50μ (see Fig. 5). It is possible that a similar effect occurs while the concrete is fresh. The gravel may swell during the addition of water during mixing and the fresh concrete, occupying a determinate volume. After that, the complete concrete structure will dry and consequently the gravel will shrink, but now the paste is added to it, making the paste to follow the shrinking movement of the gravel making a larger shrinkage. A same effect could occur to the molten slag, but lower than the effect in gravel.

5. Conclusions

Even the molten slag is an artificial aggregate not completely accepted, this paper demonstrate the consistent quality of MG and MG2 from one year to another. In most of the tests, the molten slag shows better results than the ordinary gravel. However, this molten slag (under the experiments conditions) could have deterioration in its appearance under several cycles of freezing and thawing. Regarding the volume change in aggregates, the molten slag shows smaller changes than the gravel. Also, the drying shrinkage test in molten slag concrete was smaller than the gravel concrete. Possibly, the restriction of every aggregate type to the volume change influence greatly in the drying shrinkage on concrete.

References

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