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Effect of Aging Process to Use Steel Slag for Concrete Aggregate

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Compared with the blast furnace slag, steel slag has the expansibility due to the reaction with water and free CaO. Therefore it is specified in Standard Specification for Concrete in Korea that steel slag aggregate must not be used in concrete. So it is unusual to use steel slag aggregate in concrete. In this study steel slag aggregate processed by several aging process was comparatively satisfied with fundamental properties as concrete aggregate, which are specific gravity, absorption, unit weight, percentage of solids and abrasion value etc. And chemical analysis is observed to understand the effect of aging process in steel slag aggregate. When the strength is measured, it is found that the concrete replacing crushed stone with steel slag aggregate had a little problem without sufficient aging process

1. Introduction

As the use of concrete for large-scale constructions, such as the Inchun International Airport, the Yungjong Bridge and etc., increases rapidly, the demand aggregate for concrete outnumbers the supply in Korea. Since natural aggregates with good quality, such as river sands and gravels, are almost used up and the use of crushed stone may cause environmental problems, studies to develop substitute aggregates showing advantages for both economical and environmental aspects are urgently demanded.

Blast furnace slag and steel slag(divided into electric arc furnace slag and converter slag) are being produced at millions of tons per every year in many industrial countries. About 6 million tons of steel slag is produced yearly as an industrial by-product in Korea.

Dumping away these by-products represents a waste of the material and causes serious environmental pollution problems. Blast furnace slag is a high-value use which utilize the cementitious materials and aggregate for concrete. But disposal of steel slag is a low-value use which can utilize only the roadbase construction, because the reaction with water and free CaO in slag causes volume instability, expansion of it.

In this paper, we would make a comparative study of the suitability of steel slag as concrete aggregate with several aging methods. First of all, we used several aging(stabilization) methods in order to decrease the volume expansion of steel slag. Then the chemical compositions and physical properties of steel slag aggregates were researched. The strength of the concrete mixed with the steel slag aggregate were measured. As a result, expansion of the steel slag processed by aging satisfies the KS (Korean Industrial Standard) while the non aging converter slag aggregate didn't meet the KS. Therefore we came to the conclusion that EAF slag processed by optimal aging methods in this study can be used as concrete aggregate.

2. Materials and Test Methods

2.1 Materials

2.1.1 Cement

Ordinary portland cement has the chemical compositions and physical properties as shown in Table 1.

Table 1. Chemical Compositions and Physical Properties of Cement

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig. loss (%)	Specific Gravity	Specific Surface Area (cm^2/g)
20.30	6.20	3.20	62.40	3.00	2.00	1.90	3.14	3,265

2.1.2 Aggregates

Seashore sand washed with water as fine aggregate and converter slag aggregate(CSA), electric arc furnace slag aggregate(EAFSA) and crushed stone as coarse aggregate were used. These aggregates have the physical properties as shown in Table 2. and the chemical compositions as shown in Table 3.

2.2 Test Methods

2.2.1 Aging Methods of Steel Slag Aggregate

In order to reduce the expansibility of steel slag aggregate, several aging methods were selected. Aging methods used in the experiment were air aging, hotwater aging and steam aging; one is the method that is left out in the open for 1 months weathered in air(air aging), another that immerses steel slag aggregate in hot water of 80±3℃ for 1 day or 3 days(hotwater aging) and the other that exposes steel slag aggregate in 100℃ steam for over 3 days under 1atm(steam aging).

Table 2. Physical Properties of Aggregates

Types \ Items	Specific Gravity	Absorption (%)	F.M.	Unit Weight (kg/㎥)	Percentage of Solids(%)	Abrasion Value(%)
Fine Aggregate	2.59	0.80	2.80	1,633	63.1	-
Coarse Aggregate	2.63	0.78	6.75	1,741	65.4	28.9
EAF Slag Aggregate	3.30	1.64	6.75	2,006	60.8	25.9
Converter Slag Aggregate	3.39	1.96	6.75	1,922	55.2	16.8

Table 3. Chemical Compositions of Steel Slag Aggregate (%)

Types \ Items	SiO_2	Al_2O_3	Total Fe	CaO	MgO
EAF Slag	22.26	10.65	17.94	21.35	12.35
Converter Slag	14.41	5.30	15.97	36.31	8.60

Table 4. Mix Proportion of Concrete

Types \ Items	Gmax (mm)	Slump (㎝)	Air (%)	W/C (%)	S/a (%)	Unit Weight (kg/m^3)					Types of Aging
						W	C	S	G	G_{slag}	
Crushed Stone	20	8	4	55	40	193	350	682	1,031	-	-
EAF Slag Aggregate	20	8	4	55	40	193	350	682	-	1,287	Air 1 month
	20	8	4	55	40	193	350	682	-	1,263	Hotwater 1 day
	20	8	4	55	40	193	350	682	-	1,260	Hotwater 3 days
	20	8	4	55	40	193	350	682	-	1,252	Steam 3 days
Converter Slag Aggregate	20	8	4	55	40	193	350	682	-	1,334	Air 1 month
	20	8	4	55	40	193	350	682	-	1,370	Hotwater 1 day
	20	8	4	55	40	193	350	682	-	1,346	Hotwater 3 days
	20	8	4	55	40	193	350	682	-	1,338	Steam 3 days

2.2.2 Chemical Compositions, pH and $Ca(OH)_2$ of Steel Slag Aggregate

In order to analyze the chemical compositions of steel slag aggregate, XRF was used and the result is shown in Table 3.

The pH value of steel slag aggregate was measured with modified KS M 0011.

$Ca(OH)_2$ altered from free CaO in steel slag aggregate can be taken with loss of ignition at 550℃(maximum dehydration temperature of $Ca(OH)_2$ to CaO and H_2O)modified CAJS methods.

2.2.3 Mechanical Properties of Steel Slag Aggregate

The specific gravity, absorption, unit weight, percentage of solids, abrasion value and immersion expansion ratio depending on the presence of aging and the methods of aging were measured within the KS.

2.3. Concrete Mixture

In concrete mixture, design strength was 28.57Mpa and target slump was 8cm. The compressive strength was measured at the age 7, 28 and 91 days. Table 4 shows the mix proportion of crushed stone and steel slag aggregate concrete.

3. Results and Discussion

3.1 Expansion of Steel Slag Aggregate

Generally aggregate is relatively stable and does not enter into complex chemical reactions with water. Unfortunately, however, steel slag contain residual iron, free lime(CaO) or free magnesia(MgO). If present, the hydration of lime and magnesia makes steel slag unstable and liable to expand like this.

free CaO + H_2O o $Ca(OH)_2$

free MgO + H_2O o $Mg(OH)_2$

The hydration of free lime is rapid but it may be locked up within the slag particles and the rate of reaction is much reduced, while the hydration of free magnesia is slow even under favourable conditions. The hydration of free lime in steel slag can be accelerated by several aging methods.

Figure 1 and 2 show the expansion results obtained after the immersion expansion test of steel slag aggregate.

In figure 1 and 2, non aging steel slag aggregate shows maximum volume expansion. Any aging methods decrease the expansion of steel slag aggregate. Especially steel slag aggregate processed by accelerated hydration in 80°C hot water during immersed age(hotwater aging) and 100°C steam(steam aging) and weathered in air during 1 month(air aging) decrease the expansion.

Expansion of non aging converter slag aggregate(figure 2) is 10 times higher than that of EAF slag aggregate(figure 1). This is because free CaO in EAF slag aggregate, about 0.3% is much lower than it in converter slag, about 3.3%.

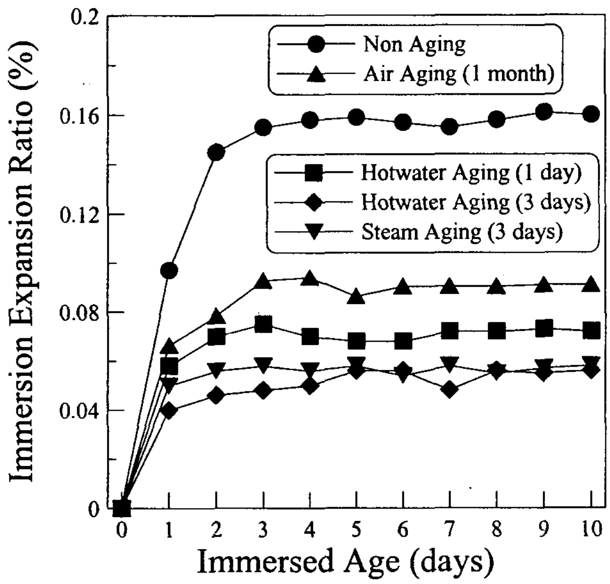


Fig. 1. Immersion Expansion Ratio of EAF Slag Aggregate

In figure 2, expansion of converter slag aggregates by hotwater, steam or air aging satisfy the restriction in the KS F 2535 Iron and Steel Slag for Road Construction, but non aging does not. The reason is because of the fact that the unstable free CaO is expanding while in reaction with water. The immersion expansion ratio of the converter slag aggregate by steam aging is approximately 20 times lower than that of non aging on the 10th day. The immersion expansion ratio of converter slag aggregate by non aging doesn't even have proper value for road construction.

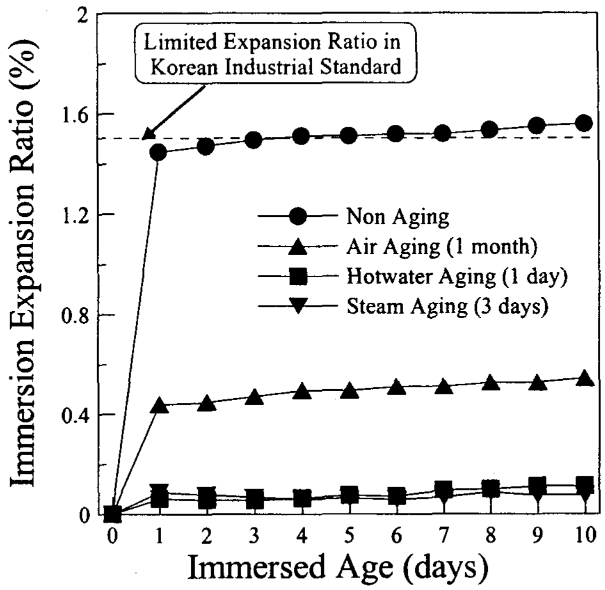


Fig. 2. Immersion Expansion Ratio of Converter Slag Aggregate

3.2 pH Value and $Ca(OH)_2$ of Steel Slag Aggregate

Figure 3. shows the pH value of steel slag aggregate immersed for 21 days in distilled water over an elapsing time period.

Free CaO in EAF slag is different from it in converter slag. The pH of EAF slag aggregate therefore is lower than that of converter slag aggregate.

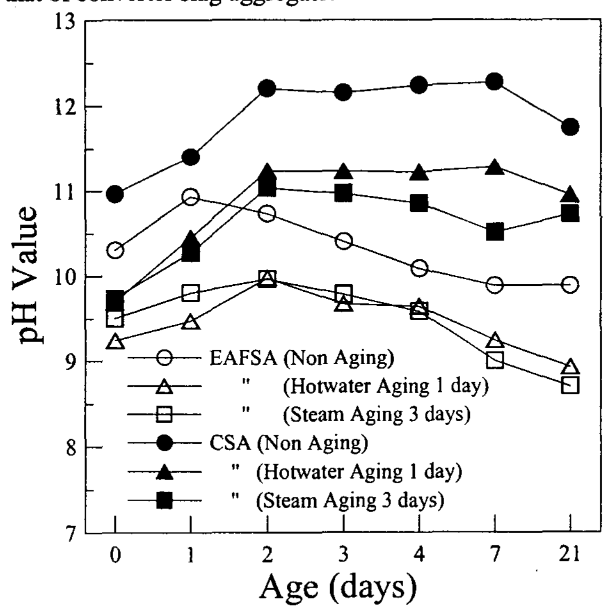
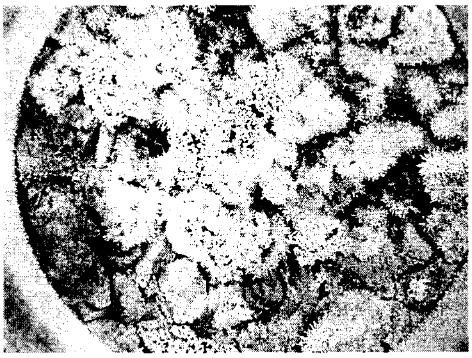


Fig. 3. pH Value of Steel Slag Aggregate

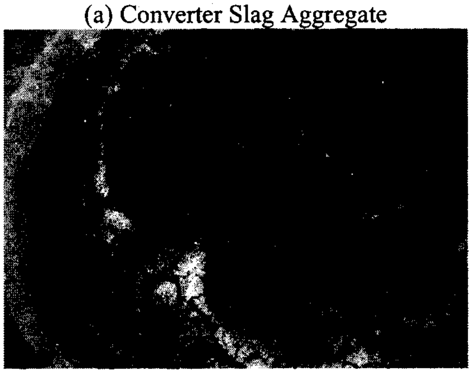
In this figure, the difference between non aging and aging steel slag aggregate can be seen. Free CaO in steel slag aggregate is altered to $Ca(OH)_2$ in distilled water. So non aging steel slag aggregate has free CaO much better than hotwater or steam aging steel slag aggregate.

The pH value of non aging steel slag aggregate is 1 value higher than that processed by aging. It is thought that free CaO subsisting inside steel slag aggregate altered into $Ca(OH)_2$, which came out of it during process.

The reason the pH value of steel slag aggregate increases until the second or first day but rather decreases after few days, aged or not, is because of a further change from $Ca(OH)_2$ and CO_2(in air) to $CaCO_3$



(a) Converter Slag Aggregate



(b) EAF Slag Aggregate

Photo 1. Steel Slag Aggregate after aging

Photo 1. is taken from steel slag aggregate after aging. There are white grains those are abundant in converter slag better than EAF slag. Those of steel slag aggregate are thought $Ca(OH)_2$ from free CaO and a little of $CaCO_3$ from $Ca(OH)_2$.

So we must know the capacity of $Ca(OH)_2$ from steel slag aggregate. We know all $Ca(OH)_2$ dehydrate to CaO and H_2O at max. 550°C. But first of all we want to know the velocity of dehydration time. Time of dehydration is measured from reagent $Ca(OH)_2$ in electric arc furnace at 550°C. There are the results in table 5. Dehydration of $Ca(OH)_2$ increase at 550°C until 60 minutes, but it doesn't do after 60 minutes. So we can determine the time of dehydration is 60 minute at 550°C.

The weight of $Ca(OH)_2$ is

$$Ca(OH)_2 = \frac{\frac{C}{H}\times(A - B)}{A}\times 100 \text{ (wt. \%)}$$

where A : the weight of steel slag aggregate for 10 minute at 350°C

B : the weight of steel slag aggregate for 60 minute at 550°C

C : the molecular weight of $Ca(OH)_2$

B : the molecular weight of H_2O

Table 5. Ignition Loss of Reagent $Ca(OH)_2$ at 550 °C (wt. %)

20min.	40 min.	60 min.	80 min.	100 min.	120 min.
45.91	65.59	91.35	92.18	91.70	91.57

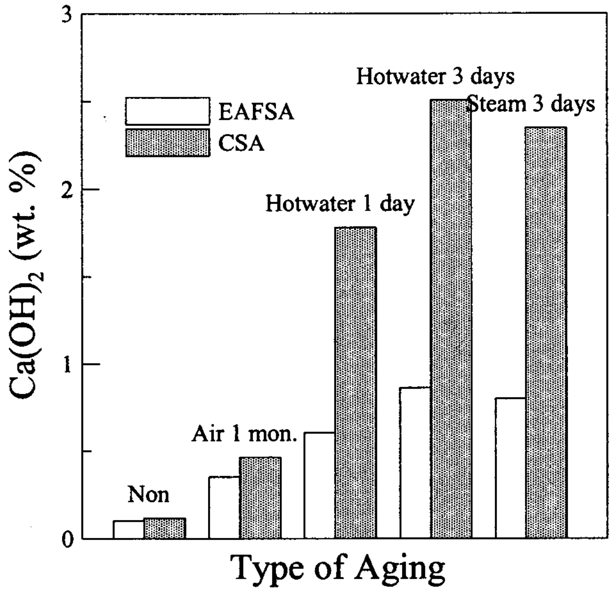


Fig. 4. $Ca(OH)_2$ of steel slag aggregate

In figure 4, $Ca(OH)_2$ in steel slag aggregate is arranged in aging methods. $Ca(OH)_2$ was decreased with aging methods, 3 days hotwater aging, 3 days steam aging, 1 day hotwater, 1 month air aging and non aging in orders.

As steel slag aggregate is treated with aging, free CaO in it is changed to $Ca(OH)_2$ reacting with H_2O, but non aging isn't done. In the scope of this study 3 days hotwater aging of 4 aging types is good in $Ca(OH)_2$

3.3 Mechanical Properties of Steel Slag Aggregate

3.3.1 Specific Gravity, Absorption and Abrasion of Steel Slag Aggregate

As can be known in figure 5, the specific gravity of steel slag aggregate shows values of 3~3.6 which figures much larger than that of crushed stone. On the other hand the absorption of steel slag aggregate is by far a bigger value.

The reason the specific gravity of steel slag aggeregate is larger is due to the fact that a part of the iron influxes into steel slag aggregate like table 3. The reason the absorption rate is bigger despite its specific gravity being larger than that of crushed stone is because of numerous air bubbles that were formulated during the cooling process, therefore steel slag aggregate itself was formed in the state of much pore.

It is therefore thought that before the actual use of steel slag aggregate in concrete, a pre-wetting process, absorbing water within the aggregate must be preceded.

Also, as can be viewed in table 2, the abrasion of converter slag aggregate and EAF slag aggregate respectively shows approximately half and similar value of that of crushed stone, sufficiently satisfying the below-35% specified in Standard Specification for Concrete in

Korea using for concrete in slab that is highly vulnerable to abrasion.

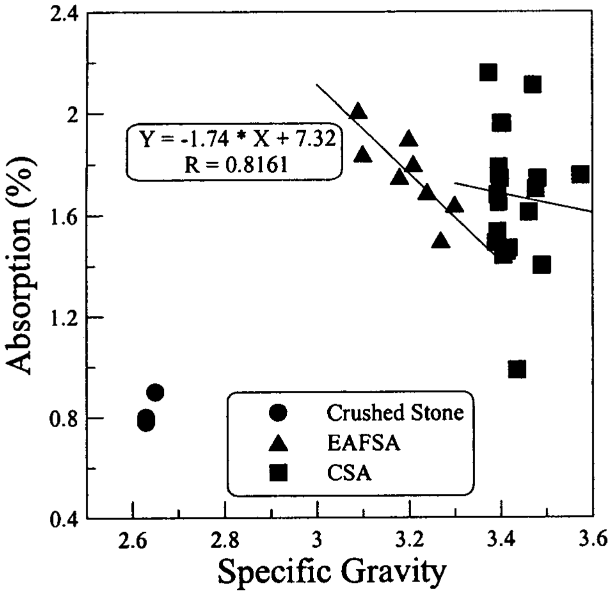


Fig. 5. Relationship between Specific Gravity and Absorption of Steel Slag Aggregate

3.3.2 Unit Weight, Percentage of Solids and Abrasion of Steel Slag Aggregate

Figure 6 shows the unit weight and the percentage of solids of the crushed stone and steel slag aggregate.

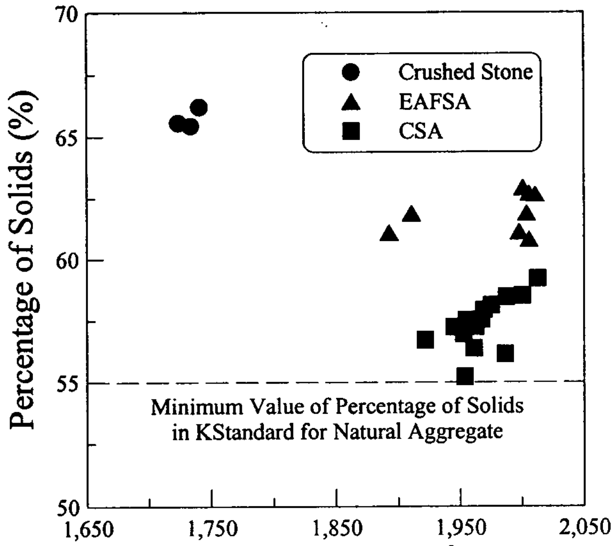


Fig. 6. Relationship between Unit Weight and Percentage of Solids of Steel Slag Aggregate

The unit weight of steel slag aggregate outclasses that of the crushed stone. It is thought that the reason unit weight of steel slag aggregate is larger than that of crushed stone owes largely to its specific gravity being larger as well.

The percentage of solids of steel slag aggregate is smaller than that of the crushed stone. The obtained percentage of solids of converter slag aggregate is about 55~59%. That of EAF slag aggregate is about 60~63%.

In converter slag, the percentage of solids is similar to the minimum of crushed stone used in normal concrete aggregate, 55% specified in KS. This presents us a little problem in particle shape, texture and etc.

3.4 Compressive Strength of Steel Slag Concrete

Figure 7 and 8 show the compressive strength of EAF slag concrete and converter slag concrete using OPC for binder at 7, 28 and 91 days respectively.

Unlike control concrete(base concrete), figure 7 and 8 show some problems that compressive strength of 1 month air aging steel slag aggregate concrete doesn't increase after 28 days distinctively. But it can be seen that compressive strength of 3 days steam aging EAF slag aggregate concrete is higher than that of control concrete at any ages.

It is thought that EAF slag and converter slag aggregate treated by air aging are not sufficiently stabilized. In this condition it has been some microcracks in steel slag aggregate. Therefore these may decrease compressive strength of concrete using steel slag aggregate.

It is thought that sufficiently stabilized steel slag aggregate by hotwater or steam aging might have potentialities in concrete aggregate in the scope of this study.

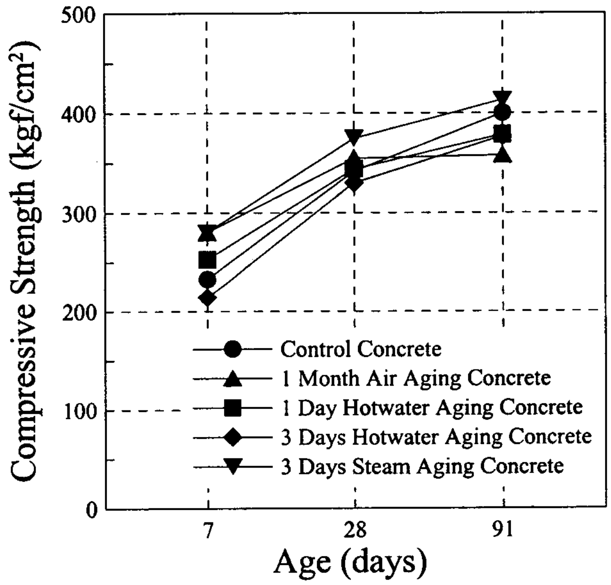


Fig. 7. Compressive Strength of EAF Slag Aggregate Concrete

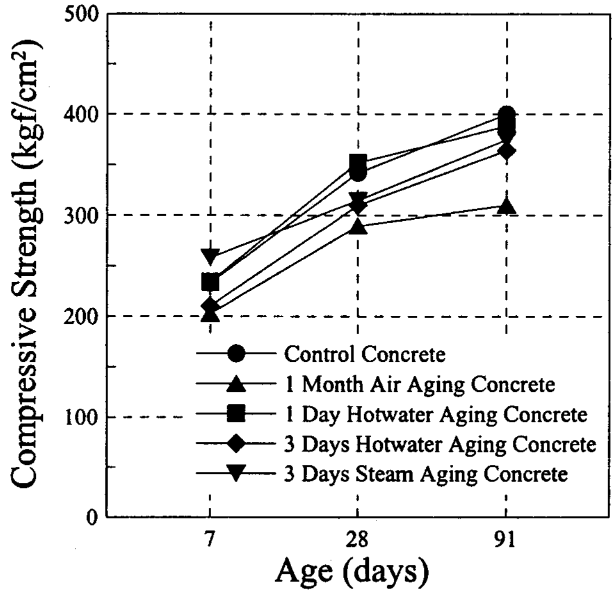


Fig. 8. Compressive Strength of Converter Slag Aggregate Concrete

This study is comparing steel slag aggregate with crushed stone for concrete aggregate. After this study, steel slag aggregate for concrete will be in progress and be advanced.

4. Conclusion

(1) The immersion expansion ratio of steel slag aggregate processed by hotwater or steam aging is much lower than that of non aging. The reason is because the unstable free CaO inside non aging steel slag aggregate reacts with water.

(2) The pH value of non aging steel slag aggregate is 1 value higher than that processed by hotwater and steam aging. The reason is that free CaO subsisted inside steel slag aggregate alters into $Ca(OH)_2$ for hydration.

(3) As steel slag aggregate is treated with aging, free CaO in it is changed to $Ca(OH)_2$ reacting with H_2O, but non aging isn't done. In the scope of this study 3 days hotwater aging of 4 aging types is good in $Ca(OH)_2$

(4) Specific gravity, absorption and unit weight of steel slag aggregate satisfy that of crushed stone in concrete. But percentage of solids of converter slag aggregate is similar to the minimum in concrete, 55% specified in KS. This presents us a little problem.

(5) Compressive strength of 3 days steam aging EAF slag aggregate concrete is higher than that of control concrete at any ages. Sufficiently stabilized steel slag aggregate by hotwater or steam aging might have potentialities in concrete aggregate in the scope of this study.

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