Effect of SO_3 Content in Blast Furnace Slag Fine Powder on Heat Generation Characteristics and Durability of Hardened Mortar

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ABSTRACT

In a large-scale structure, the temperature is different between the inside and surface of concrete structures. It is generally known that the hydration of blast furnace slag cement has strongly temperature dependency. It is considered that the physical properties changed by the temperature difference between the inside and surface of concrete structures. And it is considered that the temperature difference between the inside and surface appears remarkably when blast furnace slag fine powder is used. The purpose of this study is to reduce the effect of the temperature difference between the inside and surface of concrete structures on the physical properties. And we focused on the amount of SO_3 in the blast furnace slag fine powder, the air permeability on the temperature history was examined. In this study, the test was conducted using mortar. As a result, the difference in the air permeability coefficient between the sealed curing samples and the adiabatic curing samples decreased as the amount of SO_3 increased. And it is considered that the effect of temperature change on the hardened mortar can be suppressed by increasing the amount of SO_3 in the blast furnace slag fine powder. In the future, it is necessary to study the effect of the temperature history on the air permeability coefficient in long-term.

KEYWORDS: *Ground granulated blast furnace slag, SO_3, Heat generation characteristics, Temperature history, Air permeability coefficient*

1. Introduction

In large concrete structures, temperature differences occur between the inside and the surface of concrete. This is because the inside is greatly affected by the increase in heat of hydration and the surface is affected by the outside temperature. This temperature difference is expected to have a significant effect on the properties of the hardened cement. And in recent years, many studies have been conducted to increase the addition rate of ground granulated blast furnace slag fine powder (GGBFS) to ordinary portland cement (OPC) in order to reduce the environmental impact, and it is generally known that blast furnace cement has a strong temperature dependency. And, when GGBFS is used, the amount of OPC used is reduced, and thus the heat generation can be suppressed. It has also been shown in previous studies that the addition of anhydrite and an increase in the amount of Sulfur trioxide (SO_3) contained in the GGBFS affects the amount of temperature increase.

In this study, the effect of the temperature difference between the inside and the surface of the concrete structure on the physical properties was examined. And the purpose of this study is to suppress this effect by the addition of anhydrite. The temperature difference between the inside and the surface of the concrete structure was reproduced by comparing high temperature history and sealed curing at 20℃. In order to investigate the phenomena in concrete structures, tests should be conducted on concrete. However, it was necessary to exclude coarse aggregate in order to evaluate porosity and mass transfer resistance, so this study was conducted in mortar.

2. Outline of Experiments

2.1 Materials and mix proportions

Table 1 shows the details of the materials used in this research. In order to adjust the amount of anhydrite contained in the GGBFS, GGBFS without anhydrite was used in this study. And Table 2 shows the mix proportion of mortar. The water binder ratio was 50% and the mass ratio of binder to sand was 1:3. Mortar was prepared by replacing GGBFS with 0, 20, 50, 70, and 85% of OPC. Anhydrite was added at 2, 5, and 8% of SO_3 equivalent to GGBFS.

2.2 Adiabatic temperature rise test

In order to reproduce the inside of a concrete structure, the test apparatus was made of insulating material to prevent the heat of the specimen placed inside from getting out. Figure 1 shows the simple adiabatic temperature rise test apparatus used in this study. The size of the specimen was φ100 × 200 mm. Mortar was poured and a thermocouple was embedded in the center of the specimen. The formwork was then placed in the center of the simple adiabatic temperature rise test apparatus. The heating value of the mortar was measured for 7 days using a data logger.

Table 1. Details of the materials used

Materials	Symbol	Types	Density (g/cm^3)	Fineness (cm^2/g)	SO_3 (%)
Water	W	Tap Water	-	-	-
Binder	OPC	Ordinary Portland Cement	3.16	3080	2.07
	GGBFS	Ground Granulated Blast Fine Slag Powder	2.91	3940	0
	$CaSO_4$	Anhydrite	2.93	3680	55.4
Materials	Symbol	Types	Density (g/cm^3)	Absorption (%)	Fineness modulus
Fine Aggregate	S	Crushed Sand	2.62	1.31	3.76

Table 2. Mix proportion of mortar

Symbol	SO_3 (%)	Replacement of GGBFS (%)	W/B (%)	Unit Weight (kg/m^3)				
				W	Binder			S
					OPC	BFS	$CaSO_4$	
N	-	0	50	225	450	-	-	1350
B20	2	20			360	87	3	
	5					82	8	
	8					78	12	
B50	2	50			225	217	8	
	5					206	19	
	8					194	31	
B70	2	70			135	304	11	
	5					288	27	
	8					272	43	
B85	2	85			68	369	13	
	5					350	33	
	8					330	52	

2.3 Air permeability test

In order to investigate the mass transfer resistance of cured concrete subjected to high temperature history, air permeability tests were conducted. And as shown in Figure 2, in order to compare the inside and surface of concrete structures, the air permeability coefficients were compared between the specimens used in the adiabatic temperature rise test and the specimens that were sealed curing in a constant temperature and humidity chamber (temperature 20°C, humidity 60%). The test specimens were taken φ100×25mm from φ100×200mm cylindrical specimen and cured for 7 days before conducting the test. The specimens were dried at 40°C until the mass became constant, and then air was allowed to permeate through the specimens at a pressure of 0.1MPa to measure the air permeability.

2.4 Porosity test

A specimen of about 40×40×20mm was taken from the specimen after compressive strength test, and the porosity test was conducted. The curing period was 7 days of sealing and curing in a constant temperature and humidity chamber. In order to calculate the porosity, vacuum saturation was performed and the water saturated mass W1 and the mass in water W2 were measured. Next, it was dried in a chamber at 40°C, and the absolute dry mass W3 was measured. These values were used to calculate the porosity by Archimedes method. The equation for calculating porosity is represented as (1).

$$\text{Porosity}(\%)=\frac{W1\text{-}W3}{W1\text{-}W2}\times 100 \tag{1}$$

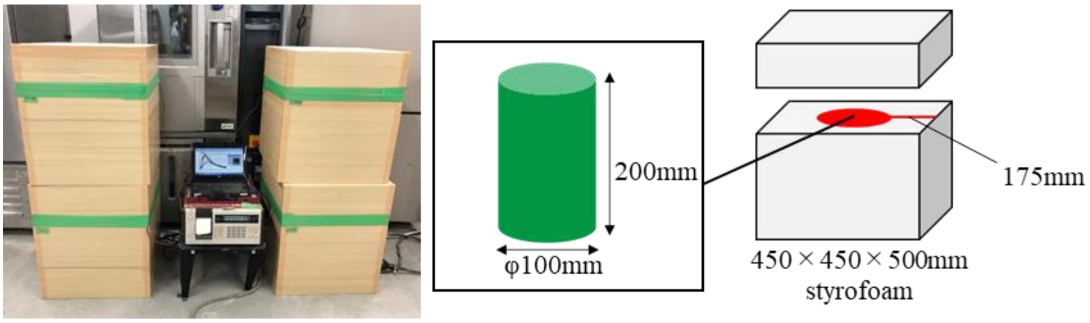

Figure 1. Simple adiabatic temperature rise test apparatus

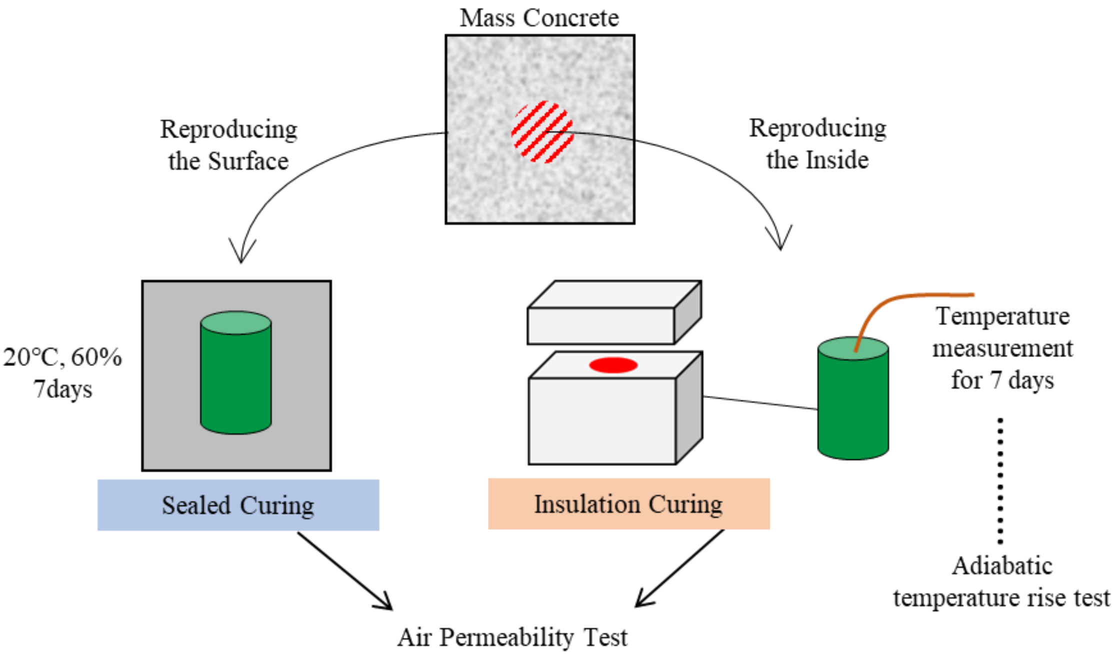

Figure 2. Outline of experiment

3. Results and Discussions

3.1 Effect of change in SO_3 content on temperature increase characteristics

Figure 3 shows the relationship between the amount of SO_3 contained in the binder and the maximum temperature rise. The maximum temperature rise is the difference between the temperature at the time of placing mortar and the maximum temperature. The higher replacement ratio of GGBFS, the smaller the maximum temperature increased. This is probably because the amount of OPC used has been reduced. And the higher the amount of SO_3 in the binder, the more blends resulted in a larger maximum temperature rise.

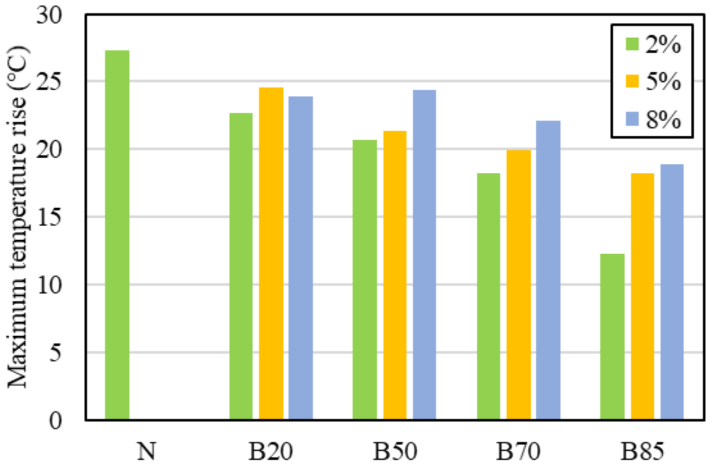

Figure 3. Maximum temperature rise

3.2 Effect of temperature change on physical properties of hardened cement

Figure 4 shows the relationship between the maximum temperature rise and the air permeability. It was confirmed that the larger the maximum temperature rise, the smaller the air permeability became. And Figure 5 shows the relationship between the maximum temperature rise and porosity. It was confirmed that the porosity tended to decrease as the maximum temperature rise increased. These indicate that the larger the maximum temperature rise, the more dense hardened cement becomes. This is thought to be due to the fact that the hydration reaction is accelerated by the increase in temperature within the hardened cement. And in the case of large scale concrete structures, the large temperature difference between the inside and surface is expected to cause a large difference in mass transfer resistance and hardened cement densification.

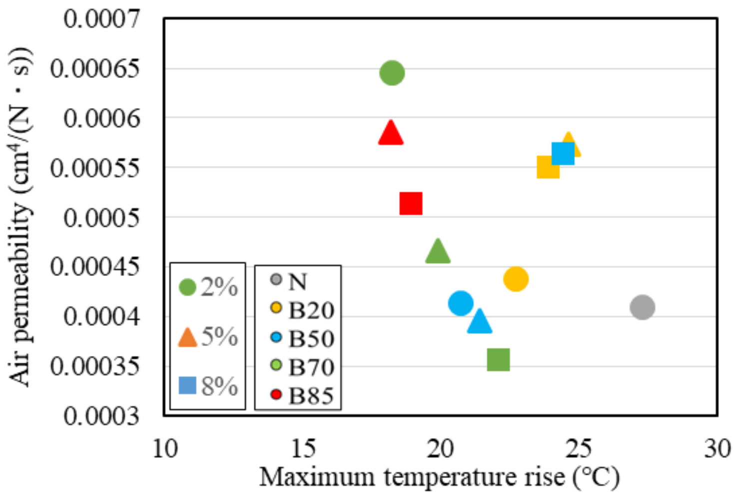

Figure 4. Temperature and air permeability

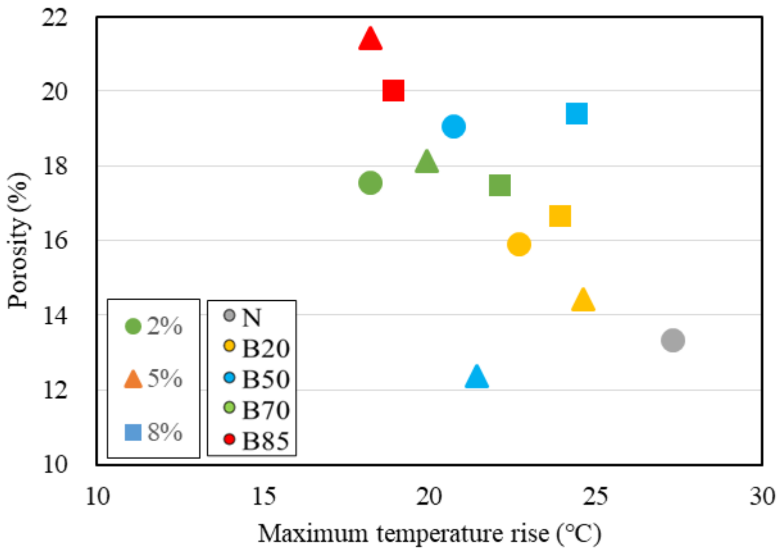

Figure 5. Temperature and porosity

3.3 Relationship between physical properties of hardened cement and SO_3 content

The inside and surface of the concrete structure were reproduced by using two curing methods: insulated curing and sealed curing. The relationship between the results of comparing air permeability coefficient with the curing method and the amount of SO_3 is shown in Figure 6. In the case of sealed curing, the permeability decreased as the amount of SO_3 in the binder increased, while in the case of insulated curing, there was no significant difference in the air permeability when the amount of SO_3 changed. It was also confirmed that the difference in air permeability between the insulated and sealed curing tended to become smaller as the amount of SO_3 increased. This suggests that the difference in mass transfer resistance between the inside and the surface of the concrete structure becomes smaller with increasing the amount of SO_3. However, if the amount of SO_3 is increased further, the value after insulated curing may exceed the value after sealed curing, so it is considered necessary to investigate further increasing the addition rate of SO_3 in the future.

The relationship between the amount of SO_3 and porosity on different curing is shown in Figure 7. The difference in porosity between insulated and sealed curing was not significant and was almost the same. This relationship was also observed when the amount of SO_3 was increased, and the difference in porosity didn't become larger. Therefore, increasing the amount of SO_3 did not have any significant effect on the porosity.

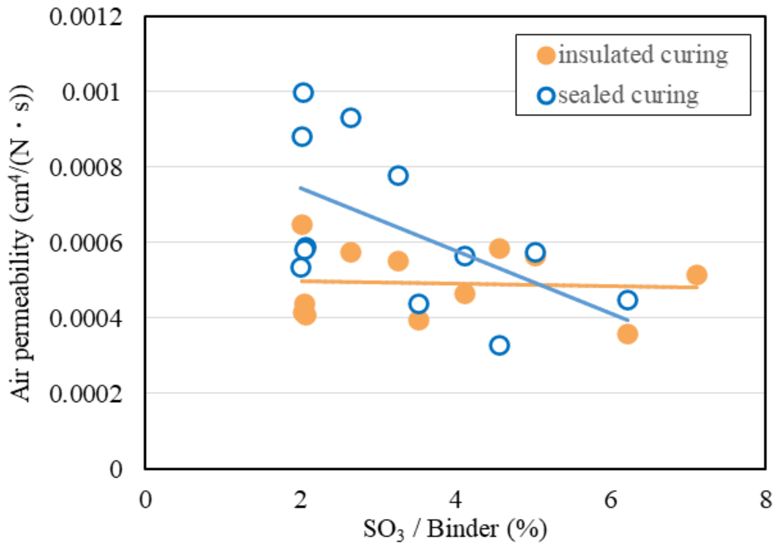

Figure 6. Comparison of air permeability

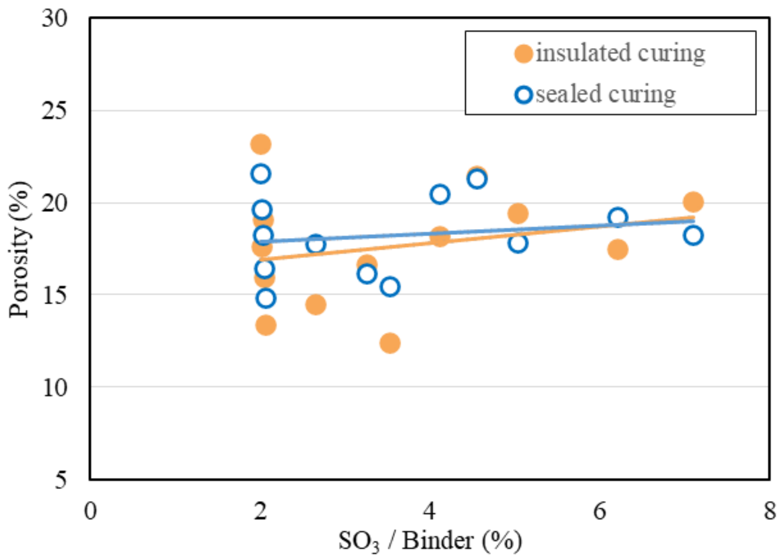

Figure 7. Comparison of porosity

4. Conclusions

In this study, the effect of temperature difference between the inside and the surface of concrete structure on the hardened cement properties was investigated by focusing on the amount of SO_3. The results obtained are shown below.

1) The greater the temperature difference between the inside and surface of the hardened cement, the greater the difference in mass transfer resistance and densification of the hardened cement.
2) When the amount of SO_3 in the binder was increased, the mass transfer resistance decreased significantly during sealed curing, but no significant change was observed when temperature history was given.
3) The difference in mass transfer resistance between the inside and the surface of the concrete structure is expected to decrease with increasing the amount of SO_3, but further investigation with increasing the amount of SO_3 is considered necessary in the future. Also, chemical studies such as the difference in hydration products with increasing SO_3 content would be necessary.

4) In the future, the effect of temperature history on air permeability needs to be investigated on a long-term.
5) In order to investigate the phenomenon in concrete structures, a similar study should be conducted with concrete in the future.

References

Iyoda, T., Kaneyasu, S. and Dan, Y. (2006) "Understanding of Various Factors Affecting Heat Generation Properties of Blast Furnace Slag Fine Powdered Cement", *Proceedings of the japan concrete institute*, Vol. 28, No. 1: 23-28