Life-Cycle Analysis and Assessment in Civil Engineering: Towards an Integrated Vision – Caspeele, Taerwe & Frangopol (Eds)

Shrinkage characteristics of ground granulated blast furnace slag high content cement

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ABSTRACT In recent years, global warming has become a world problem. So reduction of carbon dioxide is required in all industries against global warming. Focusing on the construction, Portland cement which is the most widely used construction material discharges large amounts of carbon dioxide during the manufacturing process. Therefore, the use of mixed cement replacing admixture materials such as ground granulated blast furnace slag and fly ash with Portland cement is receiving a lot of attention. Mixed cement has advantages such as effect of protected penetrated chloride ion, prevent of ASR, enhancement of long-term strength, etc. However, it has been reported that drying shrinkage of cement with high content of ground granulated blast furnace slag becomes large. Cracks of drying shrinkage cause decreasing resistance of the durability on concrete structures. Therefore, countermeasures to reduce drying shrinkage are essential. So we focused on fly ash in this research. In the past researches, it has been reported to reduce drying shrinkage using fly ash. So it is expected that reduction of drying shrinkage can be expected, even in cement with high replacement ground granulated blast furnace slag. Therefore, in this study, mortar with fly ash added to blast furnace slag cement was made for the purpose of reducing drying shrinkage in blast furnace slag cement, and drying shrinkage were measured. In addition, since the drying shrinkage is closely related to the pore diameter and the pore volume of the mortar, the measurement of the pores was carried out from a mercury intrusion porosimetry. And the drying shrinkage is reduced in the mortar having the high replacement rate of the ground granulated blast furnace slag. We also confirmed the effect of reducing the drying shrinkage of FA.

1 INTRODUCTION

In recent years, global warming has become a world problem. In particular, the Japanese cement industry is emitting 4% of the total greenhouse gas emissions in Japan. Therefore, reduction of carbon dioxide emissions is an important. Therefore, granulated blast furnace slag and fly ash have been drawing attention as a substitution material to Portland cement. Mixed cement can reduce clinker production and reduction of carbon dioxide. Blast furnace cement is one of the mixed cement most widely used in Japan. Blast furnace cement has advantages such as effect suppression of chloride ion, prevent of ASR, enhancement of long-term strength, etc. In addition, ground granulated blast furnace slag can have a higher replacement rate than other admixtures (Table 1). Therefore, the amount of Portland cement can be reduced (Figure 1). However, it has been reported that drying shrinkage of cement with high content of ground granulated blast furnace slag becomes large. It has been reported in past studies that drying shrinkage increases especially as the replacement rate of blast furnace slag fine powder increases. Cracks of drying shrinkage cause decreasing resistance of the durability on concrete structures. In the future, it is necessary to highly replace granulated blast furnace slag for reduction of carbon dioxide emissions. So we focused on fly ash in this research. In the past researches[1)], fly ash has been reported to reduce drying shrinkage. Also, fly ash is an industrial by-product of electrical power plants. Therefore, by using fly ash, environmental impact can be reduced. So in this study, mortar with fly ash added to blast furnace slag cement was made for the purpose of reducing drying shrinkage

Table 1. Blended cement.

Name	Type	Replacement rate
Blast furnace cement	A	5 ~ 30%
	B	30~60%
	C	60~70%
Fly ash cement	A	5~10%
	B	10%~20%
	C	20%~30%
Silica cement	A	5~10%
	B	10%~20%
	C	20%~30%

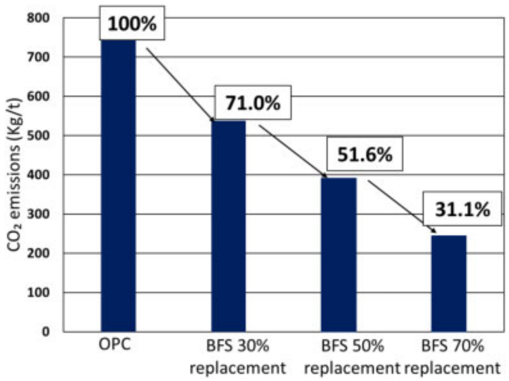

Figure 1. Effect of carbon dioxide reduction by using BFS.

Table 2. Mix proportion.

		Binder ratio		
Symbol	W/B	OPC (%)	BFS (%)	FA (%)
N100	50%	100	0	0
N50B50		50	50	0
N40B60		40	60	0
N30B70		30	70	0
N15B85		15	85	0
N15B70F15		15	70	15
N15B60F25		15	60	25
N5B70F25		5	70	25
N25B50F25		25	50	25

in blast furnace slag cement, and drying shrinkage were measured. In addition, since the drying shrinkage is closely related to the pore diameter and the pore volume of the mortar, the measurement of the pores was carried out from a mercury intrusion porosimetry. And the drying shrinkage is reduced in the mortar having the high replacement rate of the ground granulated blast furnace slag. We also confirmed which influences drying shrinkage in three component mortar.

2 EXPERIMENTAL OUTLINE

2.1 *Using material and specimen specifications*

The mix proportion is shown in Table 2. The water binder ratio (W/B = 50%), the unit water amount and the amount of fine aggregate are constant. Cement used ordinary Portland cement (N) BFS was replaced by 50%, 60% and 70% in order to measure the drying shrinkage of the mortar highly replaced BFS. Also, in order to confirm the effect of reducing FA shrinkage reduction, FA were replaced with 15% and 25% FA.

2.2 *Compressive strength test*

A compressive strength test was conducted to confirm the decrease in strength due to replacement of admixture. Sealing curing was carried out on 7 and 28 days.

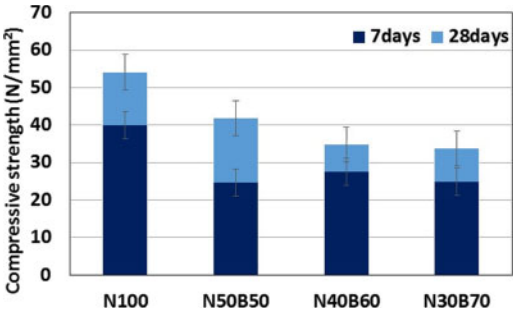

Figure 2. Compressive strength of the BFS series.

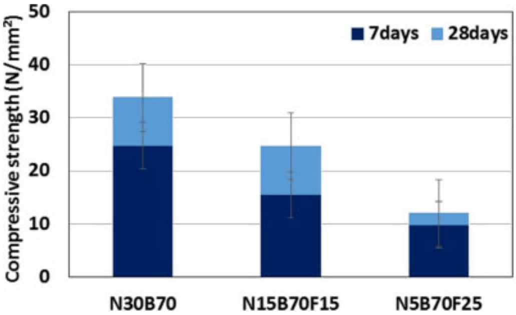

Figure 3. Compressive strength of the BFS constant series.

And the compressive strength test was carried out after curing.

2.3 *Dry shrinkage test—weight measurement*

Seal curing was carried out at a temperature of 20°C for 7 days. Experiments were conducted according to JIS A 1129-3. Also, drying shrinkage is caused by evaporation of water. So weight change measurement was carried out.

2.4 *Mercury intrusion porosimeter*

Dry shrinkage is closely related to the pore structure, so pore measurement was carried out with a mercury intrusion porosimeter.

3 TEST RESULTS

3.1 *Compressive strength*

The results of compressive strength of the BFS series are shown in the Figure 2. The compressive strength was decreased by replacement of BFS. N50B50 increased compressive strength from 7 to 28days The strength enhancement of N40B60 and N30B70 was small. The results of compressive strength of the BFS constant series are shown in the Figure 3. As a result of replacement of FA, compressive strength decreased.

N5B70F25 did not improve compressive strength. It is thought that OPC was small and hydration reaction

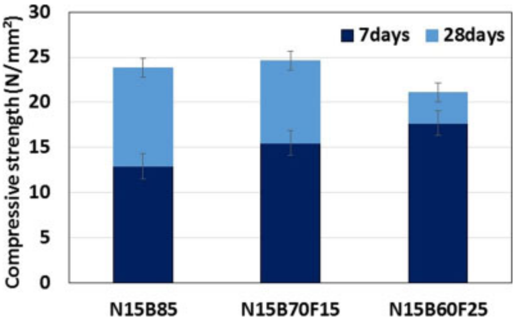

Figure 4. Compressive strength of the OPC constant series.

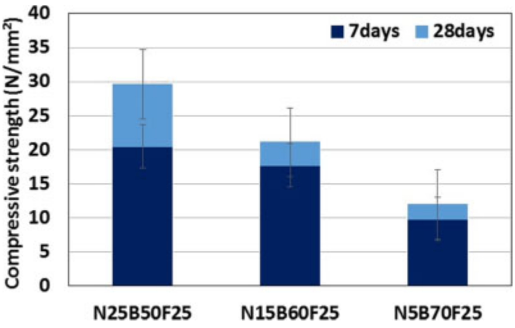

Figure 5. Compressive strength of the FA constant series.

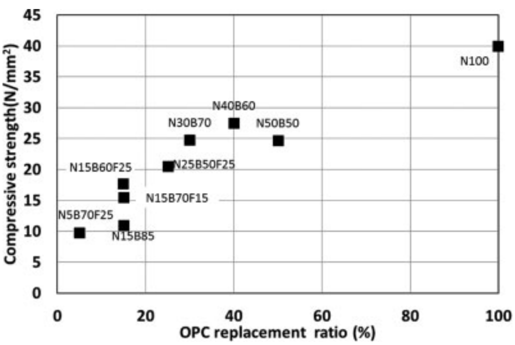

Figure 6. The relationship between the replacement ratio of OPC and compressive strength.

did not proceed. The results of compressive strength of the OPC constant series are shown in the Figure 4. Compressive strength was the same for all mix proportion. The results of compressive strength of the FA constant series are shown in the Figure 5. Compressive strength decreased as OPC decreased The relationship between the replacement ratio of OPC and compressive strength is shown Figure 6. It was found that the compressive strength increases as OPC increases. In other words, it was found that the compressive strength depended on OPC.

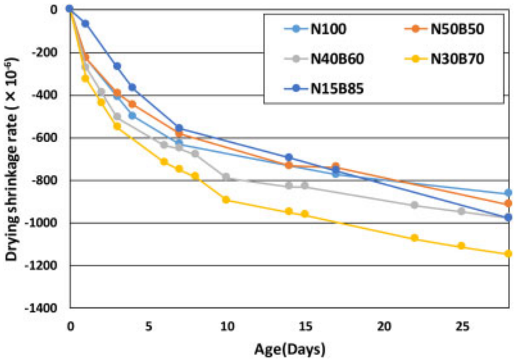

Figure 7. The results of the drying shrinkage of the BFS series.

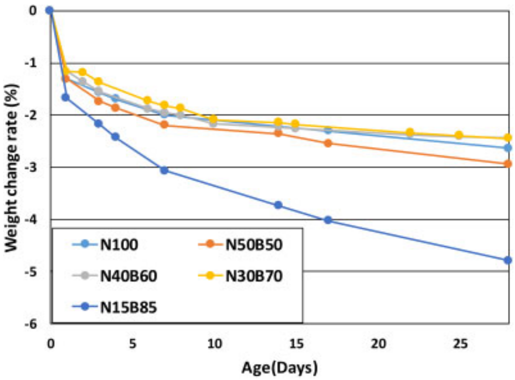

Figure 8. The results of the weight change of the BFS series.

3.2 *Dry shrinkage test—weight measurement*

The results of the drying shrinkage of the BFS series are shown in Figure 7. When replacing BFS by 50%, the amount of shrinkage became about the same as N100. Also, the shrinkage of N30B70 was the largest. The results of the mass change of the BFS series are shown in Figure 8. The weight change of N15B85 was the largest result. In addition, other mix proportion resulted in the same of mass change.

The relationship between drying shrinkage and weight change is shown in Figure 9. Dry shrinkage is caused by evaporation of water. However, in the mass change of N15B85 is large but the shrinkage is small. The weight change rate is similar to BFS replacement ratio up to 70%. However, the shrinkage increased as the replacement rate of BFS increased. In other words, replacement of BFS is thought to increase not only dry shrinkage but also autogenous shrinkage. The results of the drying shrinkage of the BFS constant series are shown in Figure 10. The shrinkage decreased as the replacement rate of FA increased. The results of mass change are shown in the Figure 11. The weight change of N30B70 is the smallest. Also, weight change increased with replacement of FA. The relationship between drying shrinkage and weight change is shown in the Figure 12. In the same weight change N30B70

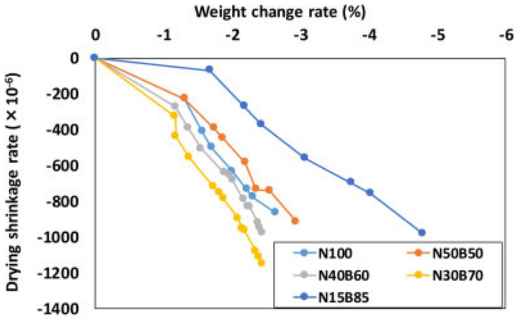

Figure 9. The relationship between drying shrinkage and weight change (BFS series).

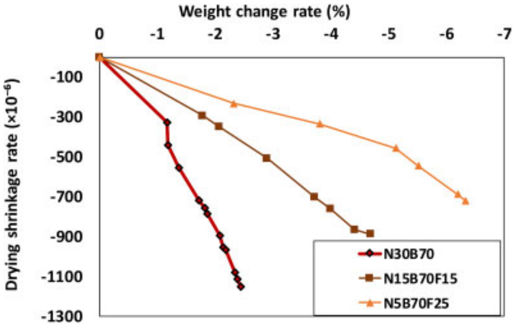

Figure 12. The relationship between drying shrinkage and weight change (BFS constant series).

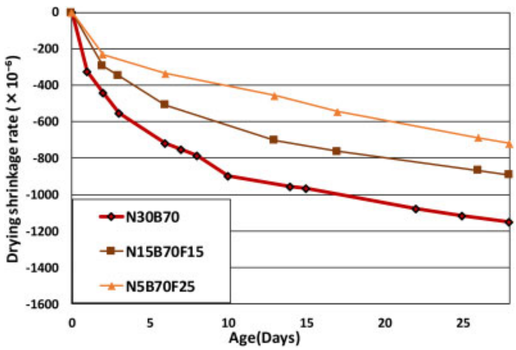

Figure 10. The results of the drying shrinkage of the BFS constant series.

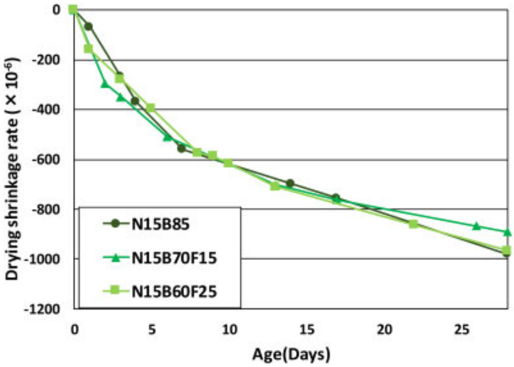

Figure 13. The results of the drying shrinkage of the OPC constant series.

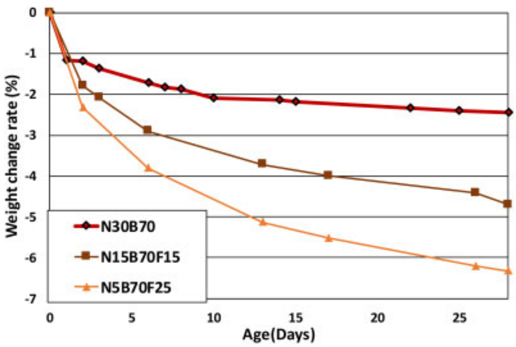

Figure 11. The results of the mass weight of the BFS constant series.

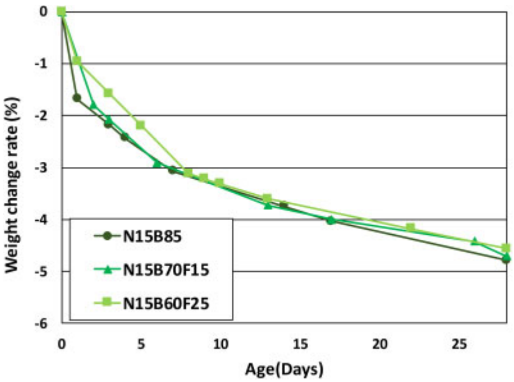

Figure 14. The results of the weight change of the BFS series.

has the largest shrinkage. Also, replacement of FA increased weight change increased. However, shrinkage was reduced. This is the same result as N15B85. The results of the drying shrinkage of the OPC constant series are shown in Figure 13. The amount of shrinkage was same. The results of weight change of the OPC constant series are shown in Figure 14. The amount of weight change was same. The relationship between drying shrinkage and weight change is shown in the Figure 15. Weight change and shrinkage amount were the same. The results of the drying shrinkage of the FA constant series are shown in Figure 16. As the amount of OPC in mortar decreased, drying shrinkage also decreased. The results of the mass change of the FA constant series are shown in the Figure 17. The weight change rate increased as N decreased. The results of drying shrinkage and weight change are shown in the Figure 18. N25B50F25 had the smallest shrinkage at the same weight change. The relationship between the replacement rate of FA and the mass change is shown in Figure 19. The weight change increased by replacing

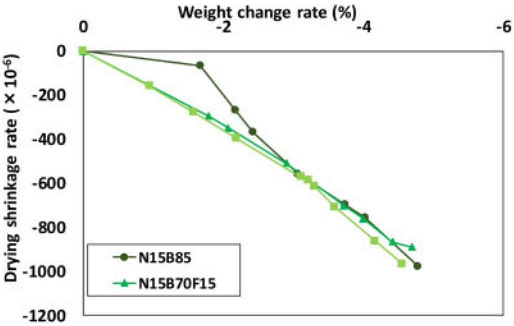

Figure 15. The relationship between drying shrinkage and weight change (OPC constant series).

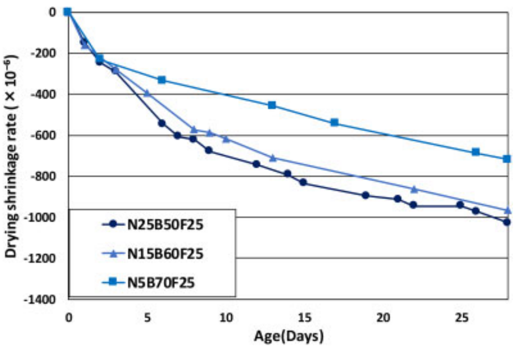

Figure 16. The results of the drying shrinkage of the FA constant series.

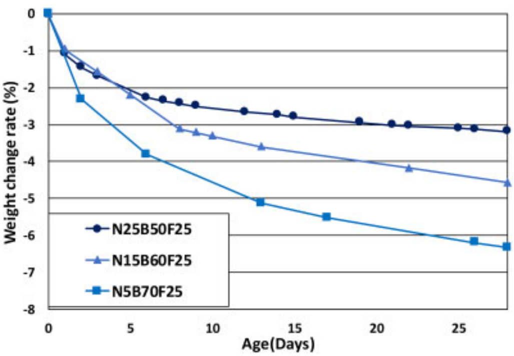

Figure 17. The results of the weight change of the FA series.

FA with N. Also, when FA is replaced by BFS, weight change is small. The relationship between the replacement rate of FA and the drying shrinkage is shown in Figure 20. By replacing FA with N, the amount of shrinkage is small. In addition, even when BFS was substituted, the change was small It was found that FA had no effect of reducing drying shrinkage. In addition, although the mass change was large. Also, when the mass change was large, the drying shrinkage was reduced. Especially, it was confirmed in mix proportion with less OPC. When the OPC is small, hydration reaction does not proceed and large pores are formed.

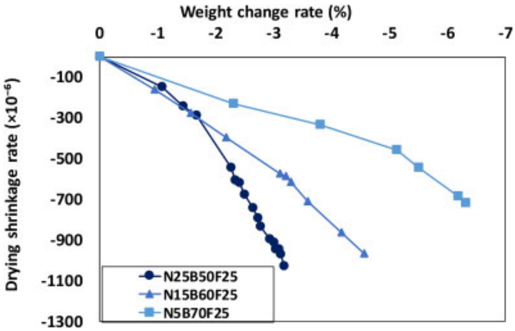

Figure 18. The relationship between drying shrinkage and weight change (FA constant series).

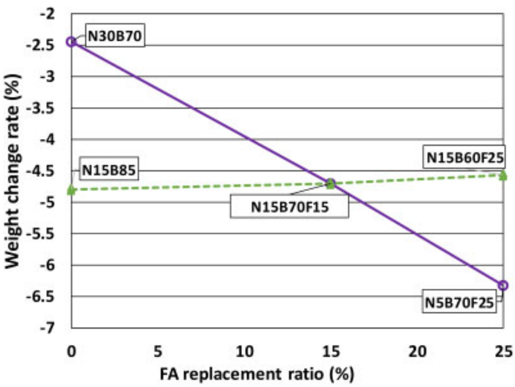

Figure 19. The relationship between the replacement ratio of FA and mass change.

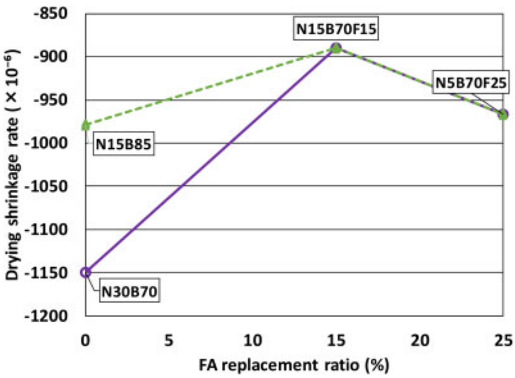

Figure 20. The relationship between the replacement ratio of FA and drying shrinkage.

It is considered that evaporation of water from large pores does not affect drying shrinkage.

3.3 *Mercury intrusion porosimeter*

The results of the pore structure of N100, N50B50 and N30B70 are shown in Figure 21. It was found that N30B70 with the largest shrinkage has small pore diameters. The results of N30B70, N15B70F15 and

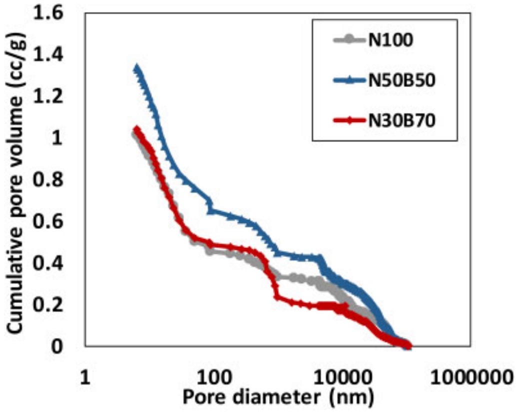

Figure 21. Pore structure (N100 N50B50 N30B70).

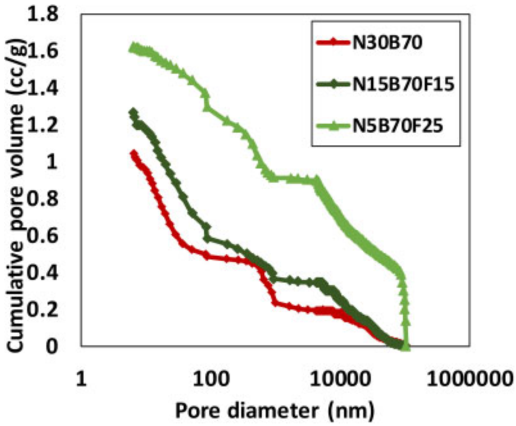

Figure 22. Pore structure (N30B70 N15B70F15 N5B70F25).

N5B70F25 are shown in the Figure 22. Pores became large due to replacement of FA. In addition, it was found that the pore diameter became large in the mortar with large mass change and small drying shrinkage. The results of N15B85, N15B70F15 and N15B60F25 are shown in the Figure 24. There was no change in pore structure when OPC was constant. The results of N25B50F25, N15B60F25 and N5B70F25 are shown in the Figure 24. It was found that the pores were large in the mix proportion with less OPC.

3.4 *Cracks*

Cracks were confirmed at demolding in N5B70F 25 and N10B85F5. These mortars have a small amount of shrinkage. Also the compressive strength is extremely small. Therefore, the tensile force is expected to be small. Therefore, in consideration of material design, compounding with small drying shrinkage is not optimal. It contains OPC and there is a need to secure strength.

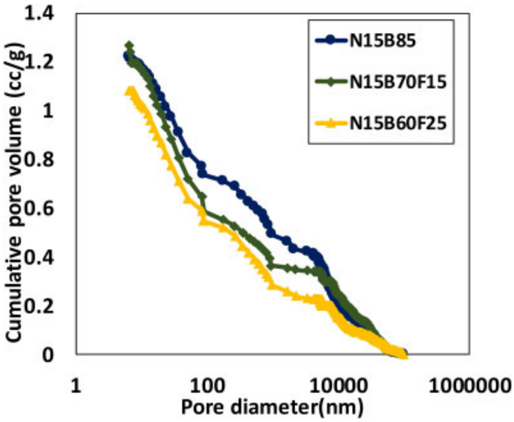

Figure 23. Pore structure (N15B85 N15B70F15 N15B60F25).

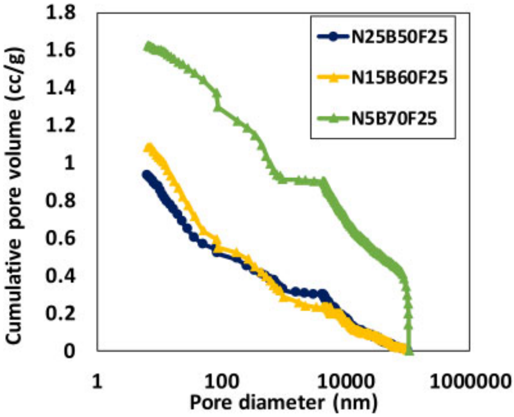

Figure 24. Pore structure (N25B50F25 N15B60F25 N5B70F25).

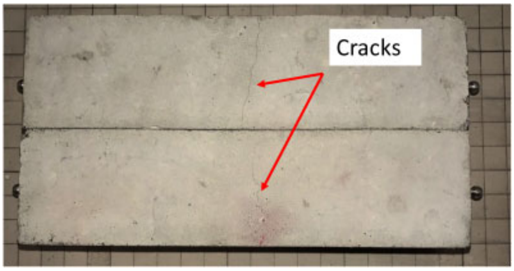

Figure 25. Cracks of mortar.

4 CONCLUSION

The results obtained in this research are summarized as follows:

1) When a large amount of admixture material is replaced, compressive strength is small and long-term strength is not improved. It was also

found that the compressive strength depends on the amount of OPC.

2) Mortar with reduced drying shrinkage has large mass change. This is because the hydration reaction did not proceed and coarse pores were formed.
3) The mortar which confirmed the crack had a small dry shrinkage.

In this research we conducted experiments with mortar. However, it is unknown that the result of mortar is the same as concrete. In the future we will continue testing with concrete.

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