Study on Improvement of Early Strength of Highly Durable Concrete by Combined Use of Chemical Admixtures

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***Abstract*—At present, in Japan, the deterioration of social capital has become a serious problem, and from now on, together with the decline of the population that supports it, there is a concern about the maintenance of social capital. Japan's social capital stock was concentrated in the period of high economic growth. They are required to be maintained and managed strategically in the future. On the other hand, it is important for new products to have long-term durability. Concrete that combines low heat Portland cement and fly ash (LPC-FA concrete) is considered to be one of the materials with excellent durability based on previous research. However, when generally used, there is a problem that the early strength is low. Therefore, in this study, basic research was conducted with the aim of improving the early strength by using a combination of chemical admixtures. The chemical admixtures used in this study are Master Ease (hereinafter ME) as an air entraining and high-range water reducing admixture and Master X Seed (hereinafter MXS) as an accelerating admixture. The 3 days strength of LPC-ME-MXS concrete was as strong as OPC-ME. And, it was confirmed that LPC-ME-MXS expresses the same strength as OPC-ME-MXS at the 28 days strength. From these results, it has become clear that the combination of ME and MXS can improve the early strength. In the future, we will continue to conduct tests until long-term material age, compare data, and examine the chemical basis for the cause of strength development improvement.**

***Index Terms*—high durability concrete, LPC-FA, Air entraining and high-range water reducing admixture, accelerating admixture**

I. INTRODUCTION

In Japan, the deterioration of social infrastructure has become a serious problem, and there are concerns about the maintenance of social infrastructure as well as the decline in the population that supports it. Japan's social infrastructure stock was concentrated in the period of high economic growth. In the next 20 years, more than 50 years after construction is expected to increase further.

They are required to be maintained and managed strategically. On the other hand, it is important for new products to have long-term durability. Concrete using low heat portland cement and fly ash in combination (LPC-FA concrete) is considered to be one of the materials with excellent durability compared to previous studies [1] [2] [3]. However, when generally used, there is a problem that the early strength is low.

Therefore, in this research, basic research was conducted for the purpose of improving the early strength by using a combination of an air entraining and high-range water reducing admixture and an accelerating admixture. In particular, the combination of Master Ease (Made by BASF Japan Ltd., hereinafter ME) and Master X Seed (Made by BASF Japan Ltd., hereinafter MXS) showed a remarkable tendency to improve the early strength.

II. EXAMINATION SUMMARY

In this study, in order to confirm the improvement of early strength of LPC-FA concrete, at first, preliminary experiment was conducted with mortar. And based on the test result by mortar, after confirming the fresh property by combined use of a limestone fine powder and two types of chemical admixtures with concrete, the combination was determined and each test were conducted. Chemical admixtures used ME as an air entraining and high-range water reducing admixture and used MXS as an accelerating admixture. The mortar was subjected to V funnel test (JSCE F 512) and compressive strength test (JIS A 1108). The concrete was subjected to slump flow test (JIS A 1150) and compressive strength test (JIS A 1108). For mixing, a biaxial forced concrete mixer was used.

III. MIX PROPORTIONS DESIGN

A. Mortar

Fig. 1 shows the materials used, and Fig. 2 shows the mix proportions according to mixing ratio of fine aggregate. S200 of Fig. 2 indicates that the ratio of fine aggregate to cement paste is 200vol%. The proportions were 200vol%, 150vol% and 133vol%. In 133vol%, the weight ratio of water, cement and fine aggregate was 1: 2: 6. In the mortar flow test, material separation was observed in all cases, but since separation of S133 was the smallest, it was decided to add limestone fine powder based on the composition of S133 to prepare.

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Mix proportions by addition rate are shown in Fig. 3. LS10 indicates that the ratio of limestone fine powder to fine aggregate is 10%. The proportions were 10%, 20% and 30%. The mortar flow test was conducted, and the result is as shown in Fig. 4. Slight separation was observed at 10%. It did not separate at 20% and became high flow. At 30%, the fluidity decreased and did not flow uniformly on the flow table. From this result, the substitution rate was determined to be 20%.

Mix proportions of mortar were determined in Fig. 5. Compounding is OPC-ME which added only air entraining and high-range water reducing admixture to OPC and OPC-ME-MXS which added air entraining and high-range water reducing admixture and accelerating admixture to OPC, LPC-ME-MXS which added air entraining and high-range water reducing admixture and accelerating admixture to LPC, In three types. The FA addition rate is 30%, and the addition amounts of ME and MXS are both C ×3%.

Material	Abbreviation	Overview
Cement	OPC	Ordinary Portland Cement Density=3.160g/cm^3 Specific surface area=3340cm^2/g
	LPC	Low Heat Portland Cement Density=3.220g/cm^3 Specific surface area=3530cm^2/g
Fly ash	FA	JIS type II Density=2.190g/cm^3 Specific surface area=3610cm2/g
Limestone fine powder	LS	Density=2.700g/cm3
Air entraining and high-range water reducing	ME	Master Ease 3030 PAE、Amount to use=C×0.5~3.0%
Accelerating admixture	MXS	Master X Seed 120JP Amount to use = C×0.5~6.0%

Figure 1. Materials

Type	Unit volume weight (kg/m^3)						
	W/B(%)	W	C	F	S	ME	MXS
S 200	50	176	269	115	1776	8.1	8.1
S 150	50	213	326	140	1590	9.8	9.8
S 133	50	230	352	151	1507	10.5	10.5

Figure 2. Mix proportions (Fine aggregate mixing ratio)

B. Concrete

Fig. 6 shows the mix proportions of concrete. The mix proportions are 3 types of OPC-ME, OPC-ME-MXS and LPC-ME-MXS as well as the mix proportions of mortar.

The mix proportions of concrete are 30% of FA addition rate like mortar. The addition amounts of the air entraining and high-range water reducing admixture and the accelerating admixture differ depending on each mix proportions. The additive amount of ME was P × 1.5% with OPC-ME-MXS, B × 3% with OPC-ME, and P × 1.25% with LPC-ME-MXS, and all MXS were C × 3%. It was decided that LS/B = 40% and s/a = 55%.

IV. Fluidity and Strength Evaluation

A. Mortar

Fig. 7 shows the results of the V funnel test. From the results, it was confirmed that high fluidity was maintained for 2 hours. In particular, the mix proportions to which

Type	Unit volume weight(kg/m^3)							
	W/B(%)	W	C	FA	LS	S	ME	MXS
LS10	50	210	322	138	161	1447	9.6	9.6
LS20	50	211	322	138	322	1288	9.7	9.7
LS30	50	211	322	138	483	1128	9.7	9.7

Figure 3. Mix proportions (LS addition ratio)

LS 10 LS 20 LS 30

Figure 4. Mortar flow

Type	Unit volume weight(kg/m^3)						
	W	C	FA	LS	S	ME	MXS
OPC-ME-MXS	211	322	138	322	1288	9.7	9.7
OPC-ME	220	322	138	322	1288	9.7	-
LPC-ME-MXS	211	323	138	323	1290	9.7	9.7

Figure 5. Mix proportions (Mortar)

Type	Unit volume weight(kg/m^3)							
	W	C	FA	LS	S	G	ME	MXS
OPC-ME-MXS	154	215	92	123	1014	829	6.5	6.5
OPC-ME	154	215	92	123	1014	829	9.2	-
LPC-ME-MXS	154	215	92	123	1015	830	5.4	6.5

Figure 6. Mix proportions (Concrete)

MXS were added tended to be slightly less fluid than the mix proportion to which it was not added.

The compression strength test results are shown in Fig. 8 by curing period. Comparing the 3 days and 7 days strength results with the 28 days strength results, it can be seen that the trend of LPC-ME-MXS is changing. It can be confirmed that the LPC after change has a strength close to that of OPC-ME-MXS.

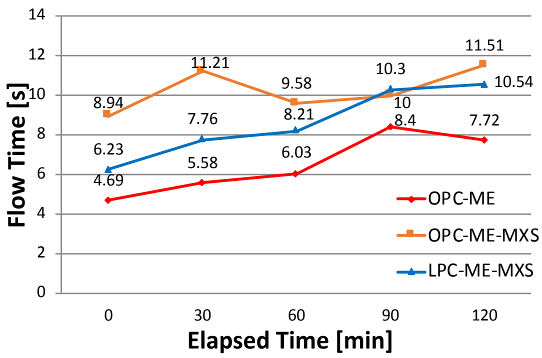

Figure 7. V funnel test results

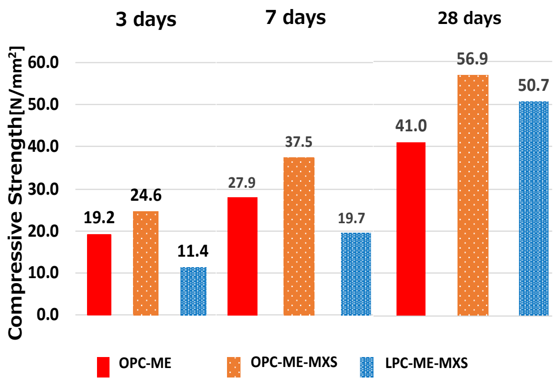

Figure 8. Compressive strength test results

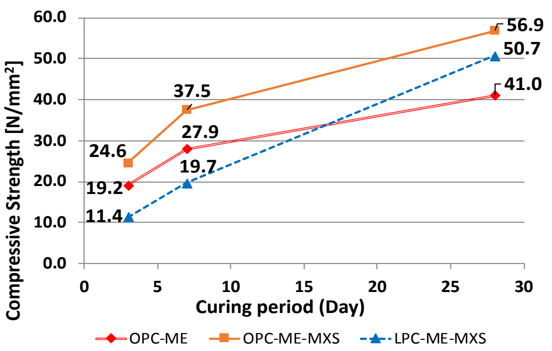

Figure 9. Compressive strength test results

The compression strength test results are shown in a line graph in Fig. 9. At the 3 days strength, the strength of OPC-ME-MXS was the highest, and that of LPC-ME-MXS was about half that strength. The strength increased at the same rate until the 7 days strength. In the 28 days strength, OPC-ME-MXS is the highest strength, LPC-ME-MXS is 50.7 N/mm^2, and strength improvement can be confirmed until the difference is about 6 N/mm^2.

B. Concrete

Fig. 10 shows the result of Fig. 7 and the result of slump flow in an overlapping manner. From the results of OPC-ME-MXS and LPC-ME-MXS, it was found that the fluidity tended to increase with the passage of time.

Fig. 11, 12 and 13 show the slump flow of the three mix proportions immediately after mixing. No separation of water was observed, and it was confirmed that all mix proportions had high fluidity.

The compressive strength test result is shown in Fig. 14 according to the curing period. Similar to the mortar results, OPC-ME-MXS has the highest strength. On the other hand, unlike the result of mortar, LPC-ME-MXS was able to confirm higher strength than OPC-ME at the time of 3 days strength. The difference with OPC-ME was confirmed more remarkable than mortar in all curing periods.

Fig. 15 shows the compression strength test results summarized in a line graph. OPC-ME-MXS was about twice as strong as the other mix proportions with 3 days and 7 days strength. The strength of LPC-ME-MXS at 3 days became equivalent to that of OPC-ME, and the strength at 7 days exceeded OPC-ME by approximately 5 N/mm^2. At the 28 days strength, it was confirmed that the increase in the strength of LPC-ME-MXS was remarkable, and that the strength was equivalent to that of OPC-ME-MXS. On the other hand, OPC-ME remained at the same strength as the 7 days strength of LPC-ME-MXS at the 28 days strength.

The compressive strength test will continue for three months strength and a year strength.

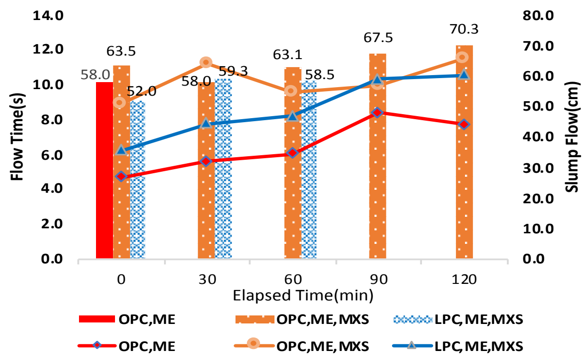

Figure 10. V funnel test results and Slump flow test results

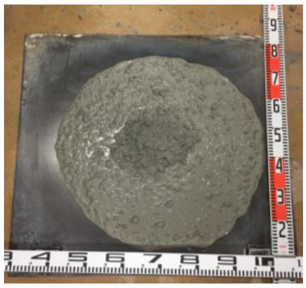

Figure 11. Slump flow (OPC-ME)

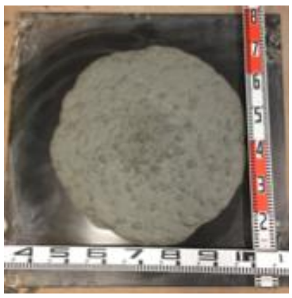

Figure 12. Slump flow (OPC-ME-MXS)

Figure 13. Slump flow (LPC-ME-MXS)

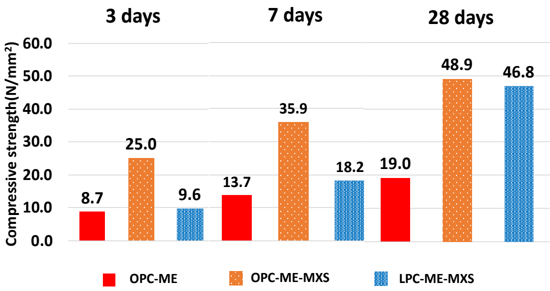

Figure 14. Compressive strength test results (Concrete)

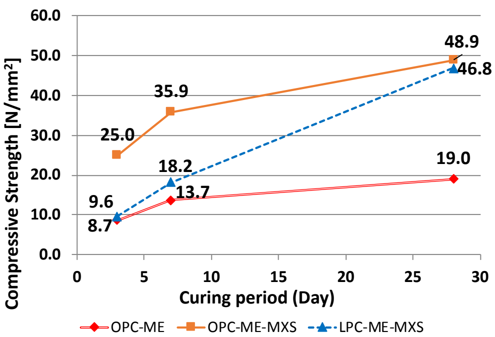

Figure 15. Compressive strength test results (Concrete)

V. Conclusions

The following findings have become clear from this study.

1) It became clear that mortar and concrete which used ME and MXS together can obtain high strength.

2) The effect of improving the early strength is considered to be very high because the concrete of LPC-ME-MXS exceeds the strength of OPC-ME at the strength of 3 days.

3) From the results of 28 days strength of mortar and concrete, LPC-ME-MXS is likely to exceed OPC-ME-MXS at 3 months strength.

4) OPC-ME-MXS of concrete was about 30 N/mm^2 higher than OPC-ME at 28 days strength. Also in mortars, the similar tendency was confirmed, and it is considered that the effect of MXS is very high.

5) Although the mix proportions to which MXS of mortar were added are inferior to OPC-ME, high fluidity was maintained for 2 hours. Even with concrete, OPC-ME-MXS maintained 2 hours of fluidity.

6) By addition the chemical admixtures, the unit water content can be greatly reduced, and the cement content can be reduced accordingly. Furthermore, it can be said that the mix proportion leads to reduction of carbon dioxide emissions including the addition of FA.

7) The combination of the concrete of this research which reduced the unit cement amount is effective in reducing the drying shrinking, and also the effective in suppressing cracking.

8) Depending on the addition amount of the chemical admixtures, the flowability and strength development were characterized by each combination, so it is important to select the addition amount and the cement type according to the purpose of construction.

VI. Future Tasks

For compressive strength, continue testing until long-term material age, compare data, and examine the chemical basis for the cause of strength development improvement. In the future, we will conduct tests on mass transfer resistance and frost damage resistance [4].

Conflict of Interest

A part of this research was conducted in response to a research grant from a research or activity related to the maintenance and maintenance of social infrastructure in fiscal 2018.

Author Contributions

Sora Suto analyzed the collected data and wrote a draft manuscript. Dr. Kazuhito Niwase built the research concept and design, critical revision of the article for important intellectual content.

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He received a paper award from the Japan Concrete Institute, which was awarded to the author for a paper recognized as having made a significant contribution to the progress of academic and technological progress in concrete.