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Applicability of CLSM with Incinerated Sewage Sludge Ash and Crushed-Stone Powder

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ABSTRACT

This paper discusses the applicability of new CLSM (Controlled Low Strength Materials) with using incinerated sewage sludge ash from municipal solid waste (MSW). This incinerated sewage sludge ash was used as a replacement of fly ash which is the main component of CLSM. Moreover a dust powder from crushed stone production was used as a fine aggregate. This new type of green CLSM is a promising sustainable cementitious material to reduce CO_2 emissions. Test results showed that the adequate strength development and reasonable flow-ability are achieved if the mixture proportion is carefully designed. The leachate characteristics of new CLSM are evaluated in this paper. Test results showed acceptable leachate levels. From these tests results, it was confirmed that a wide range of MSW could be applied as materials of the new green CLSM. Finally, backfill construction was conducted with this new CLSM and the excellent performance was confirmed.

INTRODUCTION

Effective recycling technology by using industrial by-products or industrial wastes is one of the major requirements in this new millennium. Most of by-products and industrial wastes can be effectively used in CLSM [Ramme and Naik, 1999]. For example, glass cullet, off-specification fly ash and low sludge aggregate have been used in CLSM and there are many reports about properties of CLSM using these by-products [Adaska, 1997], [Horiguchi et al, 2001], [Horiguchi and Saeki, 2004]. However, there is little information about CLSM with high volume incinerated sewage ash and dust powder from crushed stone production. These industrial waste and MSW are expected to be a useful material in CLSM. CLSM (Controlled Low Strength Materials) are slurry materials that are prevailing technology in North America. This material sets a limit to maximum strength in accordance with the intended use, and the ACI (American Concrete Institute) defines maximum compressive strength of 8.3 MPa or less in 28 days [ACI committee 229, 1994]. CLSM has many features such as high fluidity, self-curing and controllability of low-strength (possible to re-excavation) [Nakagawa et al, 2006]. In this study, physical properties of a new type of green CLSM were evaluated by uniaxial compressive strength test, flow test (Japan Highway

Public corporation standards, JHS A 313-1922, cylinder test), rate of volume loss (bleeding) and leaching test. Moreover, backfill construction was conducted with this new CLSM. One of the main purposes of this study is to find the optimum mix proportion which has the same level of performance as an ordinary CLSM mixture (i.e. cement + sand + fly ash) [Horiguchi et al, 2001]. Then, leaching test was performed to evaluate the leachate characteristics of this new CLSM.

EXPERIMENTAL PROCEDURES

Mix design of CLSM

Many types of mix proportions for new CLSM and an ordinary CLSM were examined (see Table 1).

Table 1. Mix Proportion of CLSM

Mix No.	Cement	Filler aggregate ratio (f/a)	Blast furnace slag powder (%)*	Unit content (kg/m^3)					
				C	W	Sr	CSP	ISA	NISA
Mix 1	OPC	20	0	100	258	1545		363	
Mix 2-1	OPC	10	0	100	330	1521		176	
Mix 2-2		20			419	1158		301	
Mix 2-3		30			502	861		384	
Mix 3-1	OPC	10	0	100	416		1351	141	
Mix 3-2		20			464		1066	258	
Mix 3-3		30			524		821	341	
Mix 4	OPC	20	0	120	446		1122	265	
Mix 5-1	OPC	20	30	100	453		1117	263	
Mix 5-2			50		457		1107	261	
Mix 6-1	OPC	20	30	120	456		1098	260	
Mix 6-2			50		481		1041	246	
Mix 7	OPC	20	0	100	467		1090		256
Mix 8	OPC	20	0	120	463		1082		254
Mix 9-1	BFSC-B	20	0	100	446		1133	267	
Mix 9-2				120	481		1045	247	
Mix 10-1	BFSC-B	20	0	100	466		1089		256
Mix 10-2				120	466		1075		253

OPC: Ordinary Portland Cement, BFSC-B: Blast Furnace Slag Cement type-B Sr: River Sand, CSP: Crushed Stone Powder, FA: Fly ash, ISA: Incinerated Sewage Ash NISA: Non-leaching (insoluble) Incinerated Sewage Ash. *: Blast furnace slag powder replaces by cement weight rate.

The new CLSM used blast furnace slag fine powder or blast furnace slag cement type-B in some of mix in order to provide resistance against leaching of Hexavalent chromium. According to some literatures, blast furnace slag has resistibility against leaching of Hexavalent chromium [Horiguchi et al, 2007]. Flow-ability, bleeding rate and compressive strength were measured and compared with an ordinary CLSM by laboratory experiment. The target flow value is 200 mm ± 10 mm and the target bleeding rate is less than 5 % (using Japan standards for liquefied soil stabilization that is to be set to prevent material segregation). The target of compressive strength is greater than 60 kN/m^2 at the age of 1 day and greater than 500 kN/m^2 at 28 days. This CLSM is a replacement of sand-filled materials. To be a competitive, CLSM was set to be the similar strength. Filler-aggregate ratio (f/a) is set to be 10, 20 and 30.

TEST RESULTS AND DISCUSSIONS

Application of incinerated sewage sludge ash and crashed stone powder

(a) Flow-ability

Target flow value of an ordinary CLSM is set to be 200 mm. When the incinerated sewage sludge ash for CLSM is used, viscosity increases and the flow-ability of the CLSM decreases. Accordingly, CLSM using incinerated ash has different characteristics compared to ordinary CLSM. However, target flow value used for new CLSM is the same value as that of ordinary CLSM because new CLSM is expected to obtain enough flow-ability in real backfill construction [Nakagawa et al, 2006].

The relationship between unit water content for the target flow value and different mixture is shown in Fig. 1 (unit cement content 100 kg/m^3, f/a 20). CLSM using fly ash was confirmed to require the least unit water content among four mixtures. This is because fly ash has 'ball bearing effect' due to a spherical shape and incinerated sewage sludge ash has indeterminate form as shown in Fig. 2.

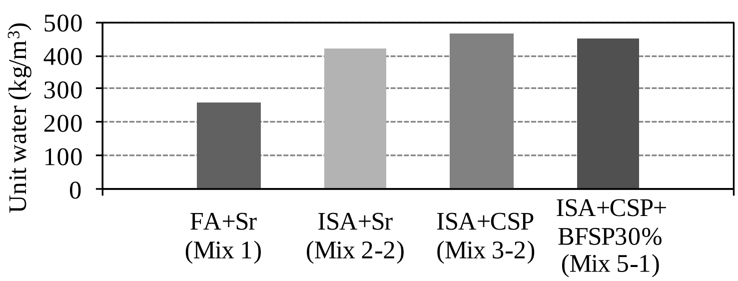
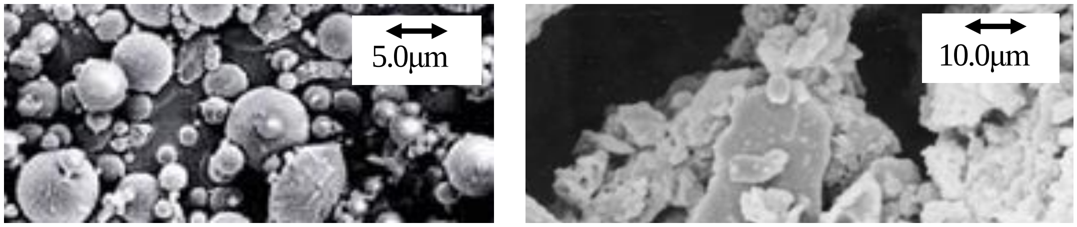


Fig. 1. Unit Water Content for the target flow (unit cement content 100 kg/m^3, f/a 20)



(a) fly ash (b) incinerated sewage sludge ash

Fig. 2. Microscopic properties of the fly ash and the incinerated sewage sludge ash

Then because the crushed stone powder has the effect of increasing viscosity, unit water content for the required flow value increases. In addition, CLSM using blast furnace slag powder was confirmed to need almost the same unit water content against a non-blast furnace slag powder type.

Fig. 3 shows relationship between unit water content for the target flow value and the filler-aggregate ratio (f/a). Unit water content has positive correlation with f/a (i.e. when f/a increases, unit water content for the target flow should be increased for maintaining the flow-ability).

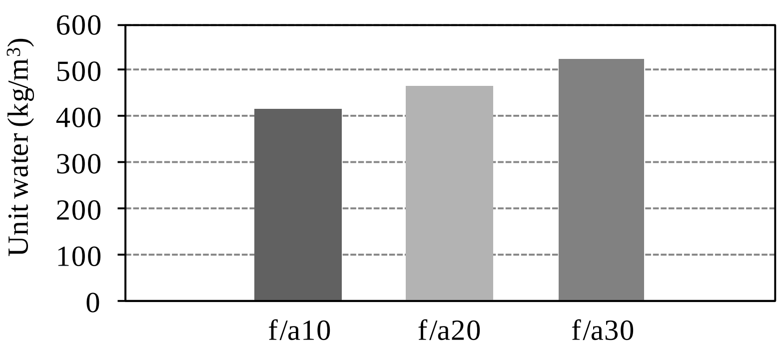


Fig. 3. Unit water content with f/a
(OPC, unit cement content=100 kg/m^3, Mix 3-1, 3-2, 3-3)

(b) Bleeding rate

Fig. 4 shows the results of bleeding test for CLSM with river sand and crushed stone powder. It is very clear that the bleeding of CLSM using crashed stone powder shows a lower value. This result indicates the effectiveness of crushed stone powder. The other result of bleeding rate for different mixture is shown in Fig. 5. This Figure shows almost same bleeding rate between using blast furnace slag powder (ISA + CSP + BFSP30%) and without using it (ISA + CSP). Then, bleeding rate obtained when using insoluble incinerated sewage sludge ash was zero. This phenomenon is not clear because insoluble incinerated sewage sludge ash may have some effect on bleeding.

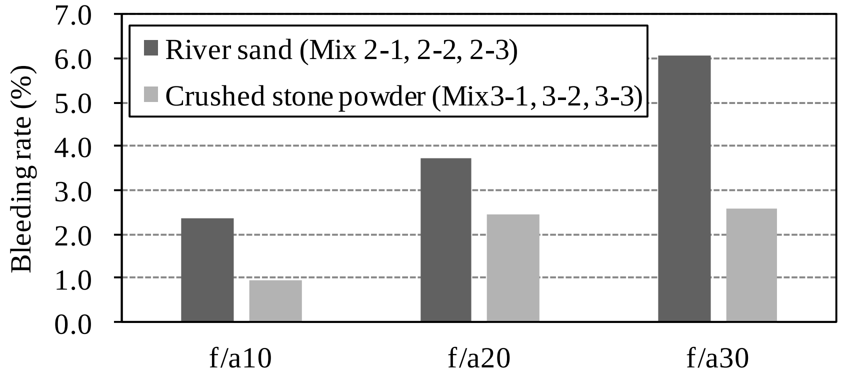


Fig. 4. Bleeding water rate for CLSM with different fine aggregate (OPC, unit cement content=100 kg/m^3)

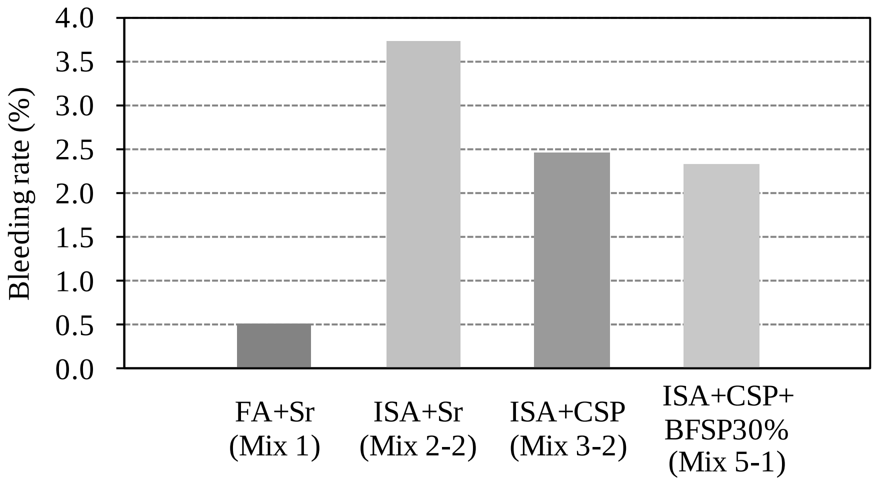


Fig. 5. Bleeding water rate for different mixture (f/a 20)

(c) Compressive strength

Compressive strength developments for each mixture are shown in Figs. 6 - 11. When incinerated sewage sludge ash was added, compressive strength decreased in comparison with an ordinary CLSM (Fig. 6). Compressive strength between new CLSM using river sand (Mix-2) and crashed stone powder (Mix-3) was obtained almost same value. Therefore, the result showed that difference of compressive strength by fine aggregate was not observed.

The relationships between compressive strength and f/a ratio are shown in Fig. 7. When f/a ratio become smaller, compressive strength tends to become higher. The changes in compressive strength with the different cementitious binder are shown in Figs. 8 and 9. Blast furnace slag cement type-B contains

40-45% of blast furnace slag powder. These figures show that when quantity of blast furnace slag powder is increased, the compressive strength decreases. Accordingly, when unit cement content without blast furnace slag powder is decreased, the compressive strength decreased. Furthermore, Figs. 8 and 9 show that compressive strength results have a high correlation with blast furnace slag powder content at 28 days. However, compressive strength at 1, 3 and 7 days did not show the same tendency like that at 28 days because the hydration reaction of CLSM after 28 days leads to a higher compared to that at 1, 3 and 7 days.

Fig. 10 and Fig. 11 showed compressive strength comparisons between CLSM using normal sewage sludge ash (ISA) and using insoluble sewage sludge ash (NISA). When insoluble sewage sludge ash was used, compressive strength became higher than when using normal sewage sludge ash. In particular, Mix-7 in Fig. 11 shows significant difference of compressive strength. However, this is not clear and further experiments are required to investigate this phenomenon.

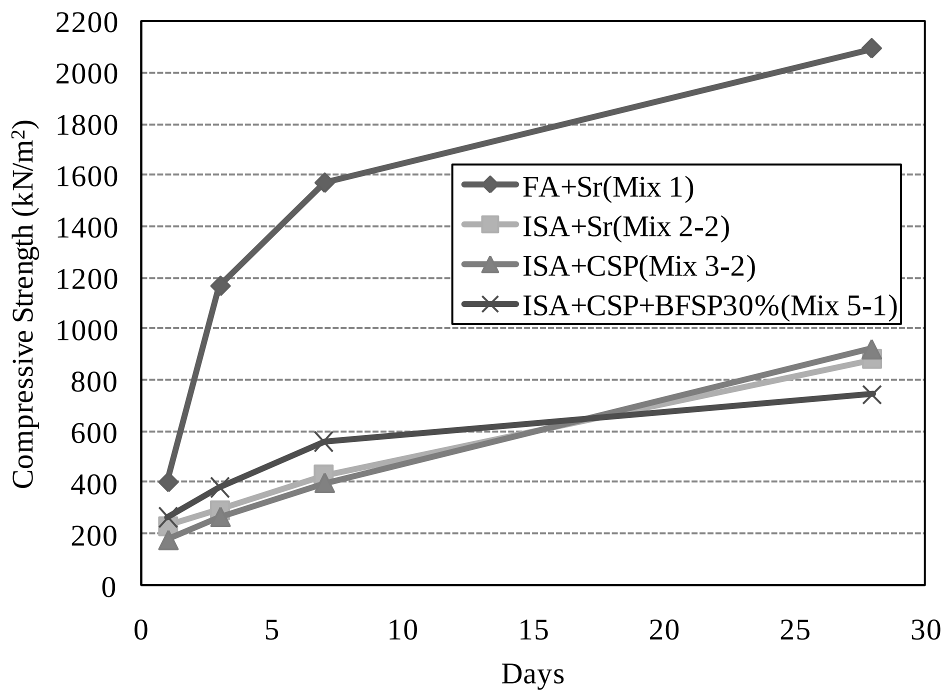


Fig. 6. Compressive strength development for different mixture (OPC, unit cement content=100 kg/m^3, f/a 20)

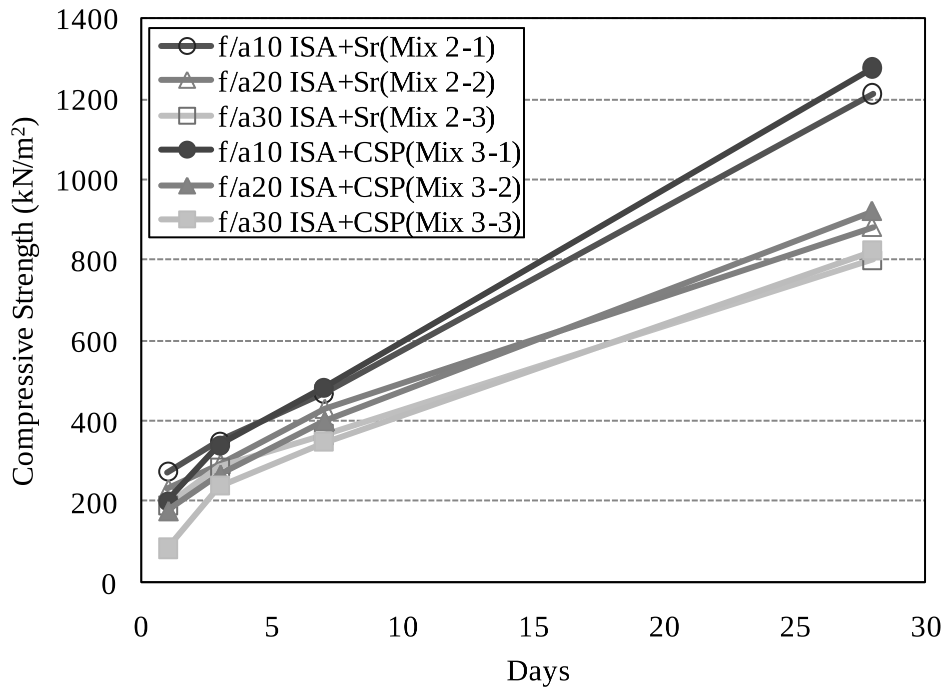


Fig. 7. Compressive strength development for different f/a ratio (OPC, unit cement content=100 kg/m^3)

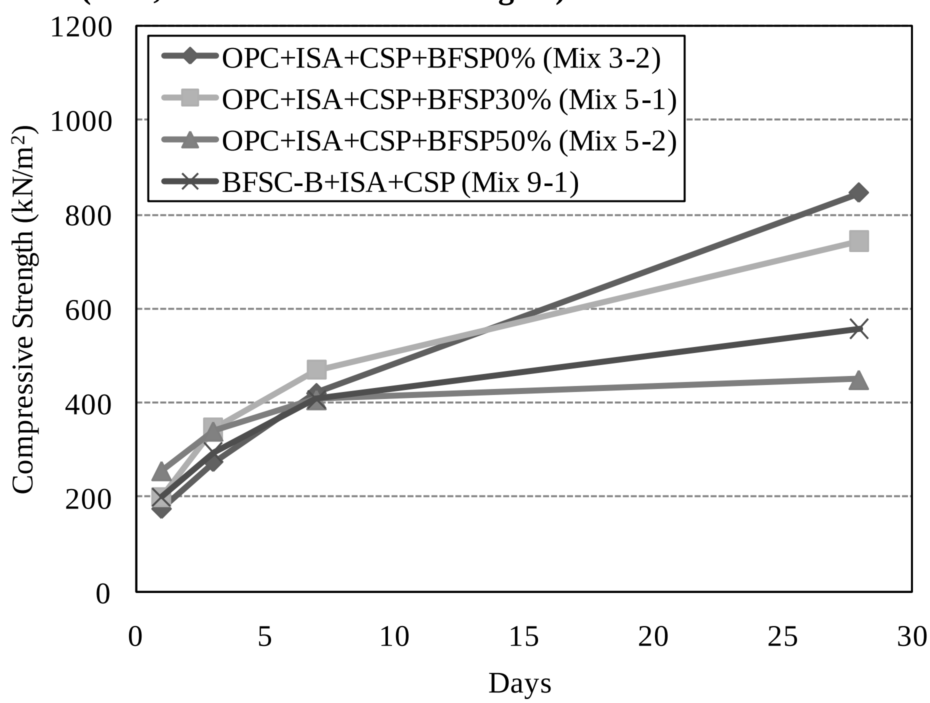


Fig. 8. Compressive strength development for different cement binder (unit cement content=100 kg/m^3, f/a20)

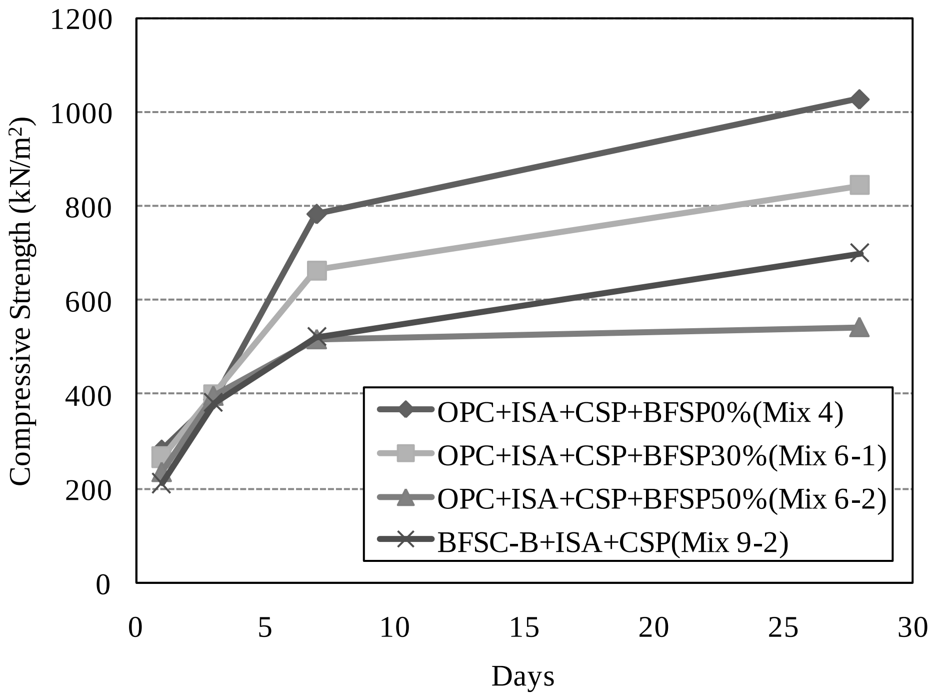


Fig. 9. Compressive strength development for different cement binder (unit cement content=120 kg/m^3, f/a20)

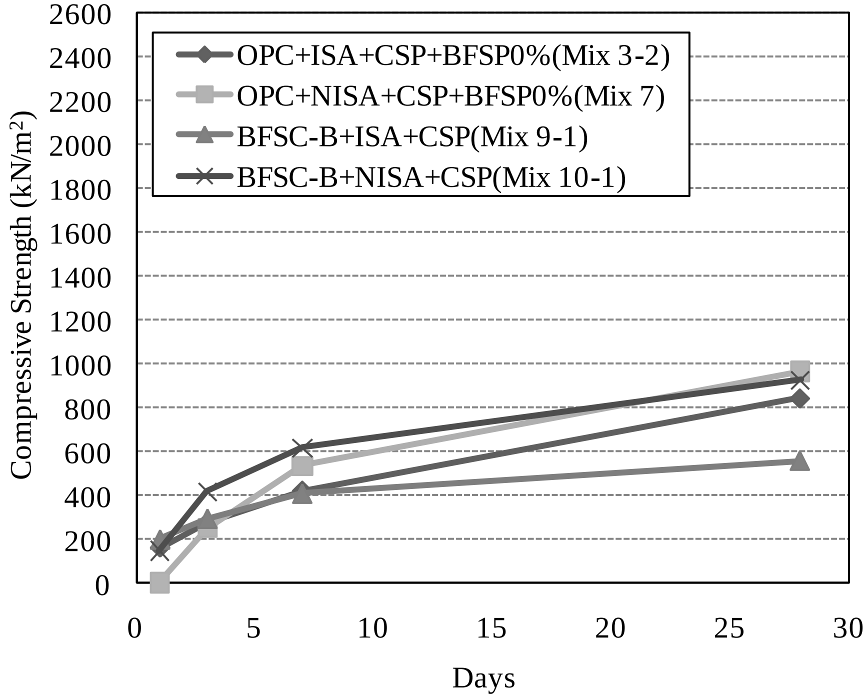


Fig. 10. Compressive strength development for different sewage sludge ash (unit cement content=100 kg/m^3, f/a20)

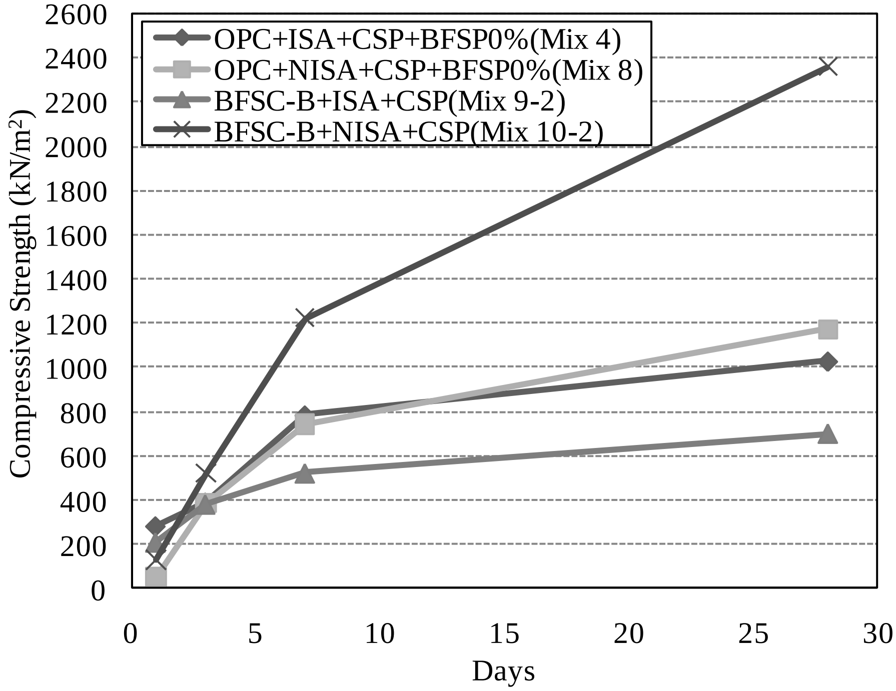


Fig. 11. Compressive strength development for different sewage sludge ash (unit cement content=120 kg/m^3, f/a20)

Backfill construction with new CLSM

(a) Selection of mix proportion

Many possibilities for the mix proportions adapted to target value and good performance could be obtained through the various experiments. However, backfill construction was conducted using Mix 10-2 (unit cement content=120 kg/m^3) due to consideration for leachate characteristics. Mix 10-2 used blast furnace slag cement type-B and insoluble incinerated sewage sludge ash that has resistibility against leaching of harmful substance. In addition, compressive strength development might be disturbed because backfill construction is performed in the cold region, and maximum compressive strength is not restricted because there is no need for re-excavation. Therefore, Mix 10-2 was selected to obtain the performance that adapted to target value.

(b) Compressive strength

The relationships of compressive strength between in-situ backfill construction and laboratory experiment are shown in Fig. 12. Compressive strength of the backfill construction shows strength reduction in comparison with laboratory experiment. Flow value and bleeding rate are obtained with in the range of the target value.

(c) Leachate characteristic

The result of leaching test is shown in Table 2 and 3. Leaching of Hexavalent chromium could be controlled to less than limit value of environmental quality standards for soil if blast furnace slag cement type-B is used. Other harmful leachates shown in Table 3 could also be controlled.

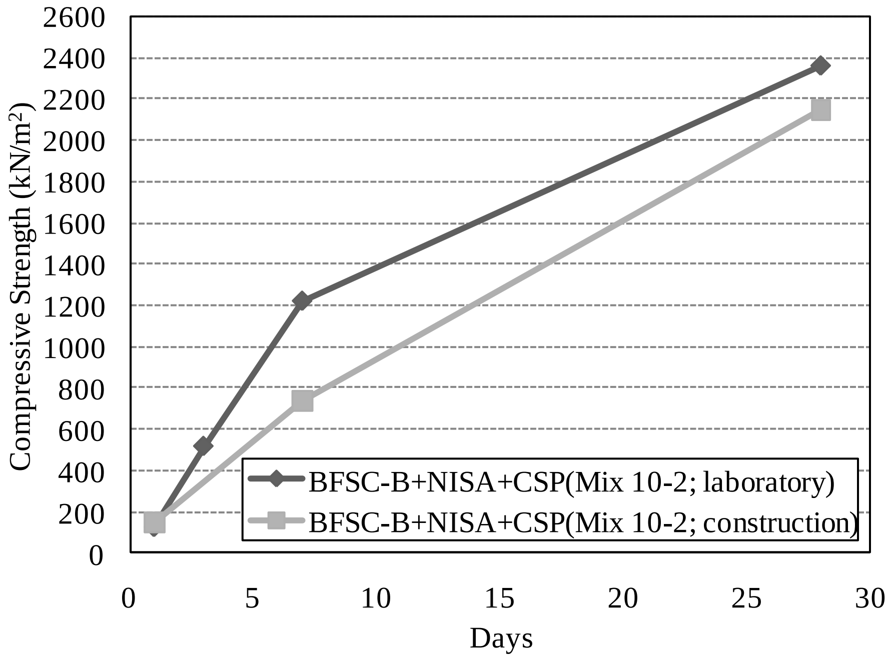


Fig. 12. Compressive strength (laboratory and backfill construction, unit cement content=120 kg/m^3, f/a20)

Table 2. Leaching test for CLSM with different cement binder (unit: mg/l)

Analysis sample	Ordinary portland cement	Using blast furnace slag powder	Environmental quality standards for soil*
Hexavalent chromium	0.13	0.02	≤ 0.05

*Japanese standards established by Ministry of environment

Table 3. Leaching test for incinerated sewage sludge ash (unit: mg/l)

Analysis sample	Incinerated sewage sludge ash		Environmental quality standards for soil*
	Original	Non-leaching	
Cadmium	< 0.001	< 0.001	≤ 0.01
Plumbum	< 0.005	< 0.005	≤ 0.01
Hexavalent chromium	< 0.005	< 0.005	≤ 0.05
Aresevic	0.332	< 0.005	≤ 0.01
Mercury	0.0007	< 0.0005	≤ 0.0005
Selenium	0.156	< 0.004	≤ 0.01
Fluorine	1.9	< 0.1	≤ 0.8
Boron	2.24	0.1	≤ 1

*Japanese standards established by Ministry of environment

(d) Evaluation of backfill construction

Schematical view of backfill construction is shown in Fig. 13. Backfill construction using the new CLSM does not require compaction compared to ordinary backfill construction which requires a lot of equipment and thus it is easier to do backfill construction using CLSM than ordinary backfill. In addition, backfill construction using CLSM has some characteristics that can reduce noise and vibration and are possible for short time working. Therefore, the excellent performance was confirmed.

Fig. 13. Schematical view of backfill construction

CONCLUSIONS

In this study, the applicability of new CLSM with incinerated sewage sludge ash from MSW and crushed stone powder is investigated and summarized as follows:

- Incinerated sewage sludge ash led to negative effects on the properties of CLSM. It decrease flow-ability and compressive strength and increase bleeding in comparison with ordinary CLSM. However, incinerated sewage sludge ash could be used successfully to adjust the mix proportion to overcome these negative effects.
- CLSM using crushed stone powder instead of fine aggregate could mitigate the bleeding in comparison with CLSM using ordinary fine aggregate, and it is possible to use it as an applicable material that maintain compressive strength.
- Using blast furnace cement type-B or blast furnace slag powder led to the reduction of compressive strength. But it is possible to apply for new CLSM from a standpoint of ecology and mitigation of leaching.
- Consideration for leaching is needed for real construction. This study has confirmed that blast furnace slag cement and insoluble incinerated sewage sludge ash are useful material for leaching problems.
- Unit water content of new CLSM should be increased with increasing the f/a ratio.
- Compressive Strength of new CLSM with high volume incineration ash shows lower value than that of ordinary CLSM with fly ash.

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