Effect of setting accelerator to the initial strength of mortar with blast furnace slag cement

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Abstract. Effect of three types of setting accelerators such as calcium nitrous, calcium nitrate and C-S-H micro crystal dispersion on early strength enhancement of mortar with blast furnace slag cement were investigated. As a result, it was confirmed that compressive strength of mortar at early age had been enhanced by each accelerator, among them, the accelerator of C-S-H type showed the highest promoting effect. Furthermore, it was found that when the dosage is 4% or more, the initial strength designated by construction procedure can be secured and the productivity of construction work can also be improved.

1. Introduction
There are many mountain ranges and about 9000 tunnels in Japan. Various method for tunneling work had been developed so far. Among them, New Austrian Tunneling Method (NATM) and shield method are being used mainly. In tunnel construction site in Japan, the NATM is also being adopted for tunnel construction not only in mountains but also in urban areas [1]-[2]. In the construction process of the NATM, after excavating natural ground through after undergoing geological investigation such as boring, then shotcrete, a primary lining to fix the natural ground, is applied immediately. Afterwards, drill a hole with a punching machine, lock bolt, waterproof processing is carried out, and the secondary lining concrete is cast by using Centre for finishing. Center stands for the formwork of the arch part when placing the lining concrete, and it has an assembled and a movable mold frame. Besides, as an advantage of performing secondary lining, increasing the safety factor as a structure in consideration of uncertain factors such as geological inhomogeneities, quality of support workers, corrosion of lock bolts, etc. Moreover, the durability of structure can be improved against changes in external force after service start and deterioration of the ground and timbering members. Recently, utilization of blast furnace slag cement of which is excellent in long-term strength development, measures to reduce environmental burden and effective for suppressing alkali aggregate reaction, for the secondary lining concrete has attracted attention [3]-[7]. Blast furnace slag cement is one in which 30% to 70% of ordinary Portland cement is replaced with slag fine powder [8]. Blast furnace slag fine powder is quenched and finely pulverized molten blast furnace slag produced as a by-product in the production of pig iron and is an supplemental cementitious material having the property of being hydrated and hardened by alkali stimulation brought by calcium hydroxide which is provided through hydration of the cement, gypsum, etc. [9]-[11]. Concrete using blast furnace slag cement is slower in early strength development than ordinary cement-based concrete, and in order to exert performance such as designated strength, durability, crack resistance, etc., it is necessary to
conduct appropriately curing. It is generally known that when the initial wet curing is insufficient, it hinders the strength development [9]-[19]. Therefore, when blast furnace slag cement is used, there is a disadvantage that the construction term is likely to be extended. Among such conditions, the reason why blast furnace slag cement is being desired for the construction materials is that material cost is lower than ordinary cement and high durability is mentioned, and in order to prevent delays in the construction period when blast furnace slag cement is used in these construction work, an initial strength enhancement must be the key technology [20]-[24]. On the other hands, various concrete admixtures are currently on the market, but the current situation is that there is no achievement of use of these products in tunnel secondary lining.

In this study, an effect of three types of setting accelerators on the initial strength of the mortar with blast furnace slag cement under various curing temperature was evaluated and possibility of improvement of the productivity of construction work using blast furnace slag cement mixed concrete was also investigated.

2. Experiment summary

2.1. Materials used

The materials used are shown in TABLE Ⅰ. A polycarboxylic acid type high performance AE water reducing agent was used as a superplasticizer, and three types of setting accelerators, C-S-H micro crystal dispersion type and nitrous type A and B were used respectively. As the main component of the setting accelerators, the C-S-H type is a calcium silicate hydrate nanoparticle, the nitrous type A is an inorganic nitrogen compound, and the nitrous type B is a setting accelerators comprising both calcium nitrous and calcium nitrate.

| Material                  | Properties                              | Density (g/cm³) |
|---------------------------|-----------------------------------------|-----------------|
| Cement BB                 | Blast furnace slag cement Type B        | 3.04            |
| Fine aggregate S          | River sand from Yamakita Kanagawa       | 2.69            |
| Chemical admixture Ad     | High-performance AE reducing agent      | 1.01~1.13       |
|                           | (Polycarboxylic acid base)              |                 |
| Setting accelerators Ac   | C-S-H micro crystal dispersion type      | 1.03~1.11       |
|                           | Nitrous type A                          | 1.41~1.45       |
|                           | Nitrous type B                          | 1.49            |

2.2. Experimental condition

Experimental parameter and curing conditions of the mortar are shown in TABLE Ⅱ. Materials used were kept at a prescribed temperature beforehand so that the mixing temperature was the same as the curing temperature, and the curing temperature was set to 10, 15 and 20 °C respectively. Incidentally, the curing temperature was kept constant, and no rising and falling gradients were provided in curing pattern. In addition, water cement ratio of the mortar was set to 42 %, which was optimal for material separation resistance and fluidity. In addition, the sand cement ratio was set to 3.0. Experimental conditions are shown in TABLE Ⅲ. Total of 11 mix proportions were evaluated.
2.3. Mortar mixing method

![Figure 1. Hobart type mixer](image1)

![Figure 2. Compressive strength machine](image2)

A mixer used in this study, Hobart type mixer with a maximum capacity of 20 liters, is shown in the Figure 1. After adding cement and fine aggregate, mixing was carried out at low speed (110 r/min) for 30 seconds, immediately thereafter, admixture and water were added and mixed at low speed (110 r/min) for 60 seconds. Finally, mortar was mixed at high speed (230 r/min) for 30 seconds and was discharged.

2.4. Test items

The compressive strength test was conducted with the apparatus shown in the Figure 2. Material age is shown in TABLE III. Cylindrical specimens with φ50 × 100 mm were used for the test.

3. Results and discussion

The effect of the setting accelerators on the initial strength are shown in Figure 3 and Figure 4 for curing temperature at 10 °C and the results at 15 °C are shown in Figure 5 and Figure 6, and the...
results at 20 °C are shown in Figure 7 and Figure 8. From Figure 3 and Figure 4, it was confirmed that specimen without accelerator, as a control, can’t be demolded by 14 hours, whereas in the case of dosing a setting accelerator, it was figured out that addition of the accelerator makes demolding of mortar possible in 8 hours. In addition, when 4% of setting accelerator was added regardless of type, the strength development of about 1 N/mm² was confirmed in 14 hours. When the addition rate was increased from 4 to 6%, the strength development of much more than 1 N/mm² was confirmed as well.

From Figure 5 and Figure 6, in the case of control, when the curing temperature was 10 °C, specified demolding strength was obtained with age of 14 hours. On the other hand, in case of curing temperature of 15 °C, specified demolding strength was obtained at 8 hours. When various 4% of setting accelerator was added, strength development of about 2 N/mm² was confirmed at 14 hours. From Figure 7 and Figure 8, when 2% of nitrous type A was added, the compressive strength at 14 hours was 3.03 N/mm². Furthermore, when 4% of setting accelerators were added, a result of 4.0 N/mm² or more was confirmed in 14 hours. As the results, it was confirmed that performance of strength enhancement by C-S-H type exceeded to the other accelerators at the same dosage. There was no difference in the influence on promotion of the initial strength of the two kinds of nitrous type.

Figure 9 shows the C-S-H type 4% addition rate. After curing at 10 °C, the compressive strength at 12 hours showed 0.69 N/mm². After curing at 15 °C, the compressive strength at 12 hours was 1.31 N/mm². After curing at 20 °C. The compressive strength at 12 hours was 3.78 N/mm². This indicates that the curing temperatures of 15 °C and 20 °C were markedly higher than the curing temperatures of 10 °C and 15 °C. Therefore, according to previous research, it can be considered that the initial strength easily increases as the curing temperature becomes higher [25]-[26].
It is generally known that the temperature inside the tunnel is around 20 °C [27]. In this study, when the curing temperature is at 20 °C, promotion of strength could be confirmed by adding a setting accelerators in compared to the plain sample. In addition, as a condition required at the work site to shorten the construction period, which is the improvement of productivity of blast furnace slag cement mixed concrete for tunnel lining, which is also the object of this research, the initial strength of 3 N/mm² or more within the age of 12 hours is necessary. With no addition, only the initial strength of 1.09 N/mm² had been confirmed in 12 hours of material age at 20 °C curing. When the addition rate of...
the setting accelerators was 4%, it was confirmed that the specified initial strength of 3 N/mm² or more was satisfied in 12 hours of the material age.

4. Conclusion
In this study, an effect of three types of setting accelerators on the initial strength of the mortar with blast furnace slag cement under various curing temperature was evaluated and possibility of improvement of the productivity of construction work using blast furnace slag cement mixed concrete was also investigated. As a result, the following was found.

1) When the curing temperature was 10 °C, the mold release strength was obtained in 14 hours.
2) When the curing temperature was 15 °C, specified demolding strength was obtained in 8 hours.
3) Comparing the three kinds of setting accelerator, it was confirmed that the earliest intensity promotion was observed in the C-S-H type, and in the two types of nitrous type there was no difference in the influence on the promotion of the initial strength.
4) Materials used in the field require an initial strength of 3 N/mm² or more within 12 hours. Therefore, if the addition rate of the setting accelerator is 4% or more, the initial strength desired is satisfied.
5) When total addition rates are 4% or more regardless the type of accelerator, specified initial strength can be secured. Therefore, it leads to improvement of productivity and leads to shortening of construction period.

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