Development of Inseparable Injection Material in Water with Conflicting Viscosity and Flowability

Y.Ohashi[1*], T.Amano[2], Y.Takabayashi[3], and T.Iyoda[4]

[1] *Shibaura Institute of Technology, Tokyo, Japan*

Email: ah17208@shibaura-it.ac.jp
[2] *Shisuikyo, Tokyo, Japan*

Email: amano@shisuikyo.or.jp
[3] *Nippon Steel Cement Co., LTD, Sapporo, Japan*

Email: Takabayashi.yoshitaka@sement.nipponsteel.com
[4] *Shibaura Institute of Technology, Tokyo, Japan*

Email: iyoda@shibaura-it.ac.jp

ABSTRACT

Underwater cracks on the sides of caissons, which are representative of port structures, cause sinking of the road surface. In order to prevent this happening, immediate repair is desirable. The important thing is to use a viscosity agent to prevent material separation in water. However, the addition of that decreases the flowability and causes filling failure. In addition, there is no injection material has been developed that combines the performance of these opposing relationships. In this study, we developed a combination of ultrafine particle slag cement and two types of special viscosity agent, liquid and powder. Slump flow tests in air and water, simulated crack injection tests, and crack injection tests in water were conducted to determine the mix for on-site construction. As a result, the powder type with 1% addition was superior as an inseparable injection material in water. On site construction, the fresh properties of the injection material vary depending on the season and the temperature of the water used for mixing. However, the values of fresh properties in air and water are close for the inseparable injector in water.

KEYWORDS: *Underwater, Viscosity agent, Liquidity, Material separation, Injection material*

1. Introduction

In the case of underwater cracks in caissons, which are representative of harbor structures, the filling sand flows out due to the penetration of deterioration factors. This phenomenon leads to deterioration of the concrete, such as sinking of the upper concrete. This is reported as a problem that damages the social infrastructure. Therefore, it is desirable to repair the cracks as soon as possible. However, the injection material used to close the cracks in the air cannot be used because it causes material separation in water. A thickening agent can be used to increase the inseparability in water. However, the addition of a thickening agent reduces the flowability and may cause filling failure. In other words, the inseparable-in-water injection material needs to have both flowability and viscosity. At present, there is no mix proportions that combines these two properties. In this study, we attempted to develop an inseparable underwater injection material with both viscosity and flowability by combining ultrafine particle slag cement and a thickener that gives surface-active action.

2 Outline of Experimental

2.1 Using Material

In this study, slag cement with a specific surface area of 8,000 brain value was used to provide flowability to fill narrow cracks, and two special thickeners were used to provide material separation resistance. The liquid type of the special thickeners is called "LV" and the powder type is called "PV". **Table 1** shows an overview of the thickeners and **Table 2** shows mix proportion. 1 to 10% of LV was added to the water content of the injection material, and 0.1 to 2% of PV was added to the cement content. Based on the results, the appropriate range of the amount of thickener to be added was selected, and the formulation of the injection material was determined based on the injection effects of simulated crack injection tests and underwater crack injection tests. The abbreviation of the injection material is, for example, PV3% when 3% PV is added.

Table 1 Outline of thicker

Symbol	**Type**	**Ration of method**	**Rate of addition**
LV	Liquid	Water*%	1-10%
PV	Powder	Cements*%	0.1-2%

Table 2 Mix proportion

LV addition rate (%)	Mix proportion (g)		
	Water	Cement	Thickeners
0	350.0	500.0	0.0
1	346.5	500.0	3.5
2	343.0	500.0	7.0
3	339.5	500.0	10.5
4	336.0	500.0	14.0
5	332.5	500.0	17.5
6	329.0	500.0	21.0
7	325.5	500.0	24.5
8	322.0	500.0	28.0
9	318.5	500.0	31.5
10	315.0	500.0	35.0

PV addition rate (%)	Mix proportion (g)		
	Water	Cement	Thickeners
0	350.0	500.0	0.0
0.1	350.0	500.0	0.5
0.2	350.0	500.0	1.0
0.3	350.0	500.0	1.5
0.4	350.0	500.0	2.0
0.5	350.0	500.0	2.5
0.6	350.0	500.0	3.0
0.7	350.0	500.0	3.5
0.8	350.0	500.0	4.0
0.9	350.0	500.0	4.5
1.0	350.0	500.0	5.0

2.2 Flowability test

In order to select the appropriate addition rate of the thickener, the flowing time was measured using a J-funnel shows Figure 1. Seal the outlet of the funnel with your finger and fill with injection material. The filling was completed, the time taken for the injection material to finish flowing out of the funnel was measured after the finger was removed. The measurement was completed when the space beyond the outlet was confirmed from the top of the funnel.

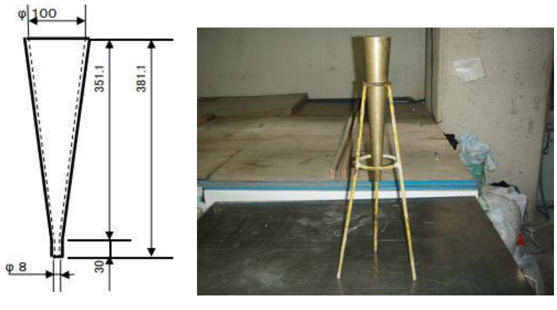

Figure 1. JA-funnel

2.3 Underwater slump flow Test

Figure 2 shows the measurement method of slump flow in water. The purpose of this study is to understand the relationship between the behavior of the injected material in water and the actual testable condition in air. A simple mold (φ50×100mm cylinder) was used to measure the slump flow in air and water. The mold was filled with injected material and the maximum diameter of the injected material and the diameter perpendicular to it were measured when the mold was pulled out vertically. The slump flow in water was measured by placing a slump cone in a water tank and filling it with the injection material. The slump flow in water was then measured by pouring water up to 100 mm, pulling out the mold, and measuring the slump flow in water. In the case of low addition rate of thickener, if the trend of the injected material could not be seen due to water pollution, the addition rate was considered inappropriate.

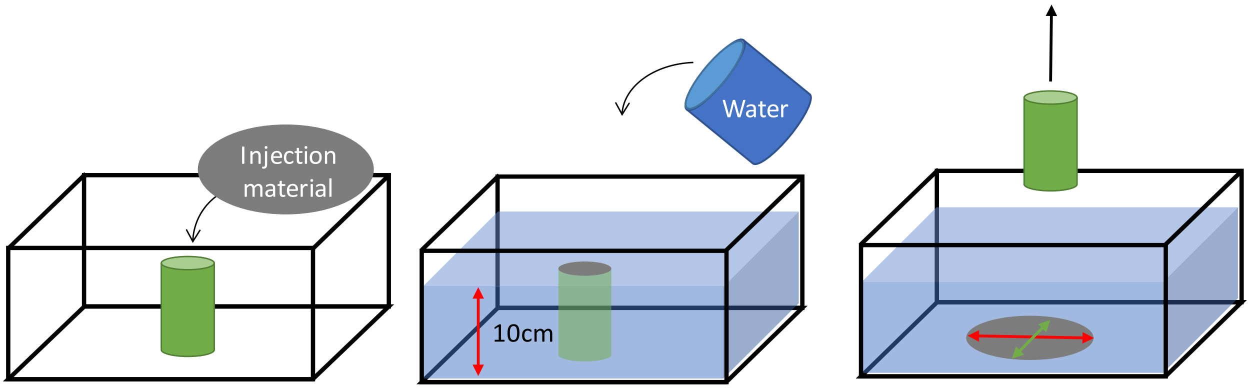

Figure 2. Water slump flow method

2.4 Simulated crack injection

Figure 3 shows an overview of the simulated crack injection test, in which two acrylic sheets were fixed vertically between Teflon sheets and injected manually from the side using a syringe. The width of the cracks was set between 1 and 3 mm. The injection effect was evaluated by focusing on the time elapsed and the injection point. If the injection point was still closed after a certain period of time, the injection material was appropriate. On the other hand, if the material flowed downward from the injection point after a certain period of time, it was considered inappropriate as an injection material. The elapsed time was 5 minutes, and the movement of the injected material was observed at 1-minute intervals from the start of injection.

The tip of the syringe has grooves carved into it to hold it in place on the cracked surface. Therefore, direct injection is difficult. Therefore, a rubber tube with the same cross-sectional area as the syringe tip was fixed to the syringe.

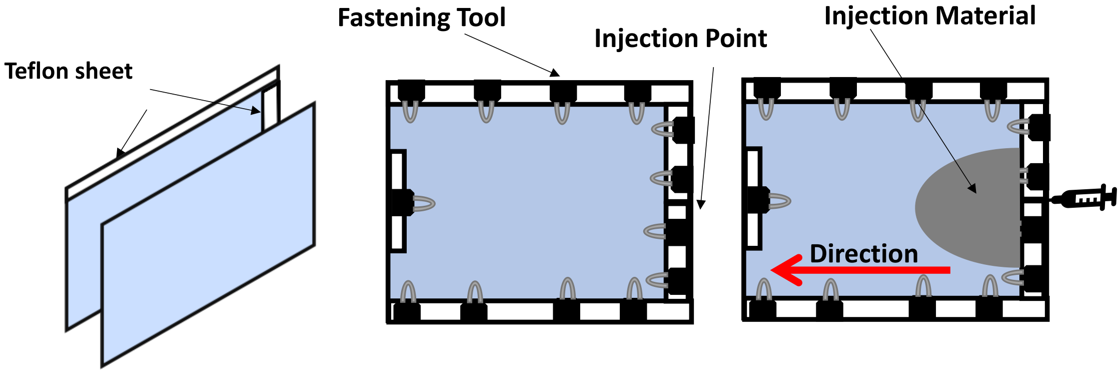

Figure 3. Simulated crack Injection method

2.5 Underwater crack injection test

Figure 4 and Figure 5 shows the outline of the underwater crack injection test. A cylindrical specimen (φ50×100mm) was cracked. A Teflon sheet was sandwiched between the cracks and fixed at a crack width of 0.5 mm. The specimen was submerged in water to fill the cracks, and rubber was injected into the cracks with a syringe from the side. The cracks were submerged in water and filled with water. The cracks were cracked and the movement of the injected material in the cross section was checked. The injection material was injected in sufficient quantity to flow out from the back of the crack.

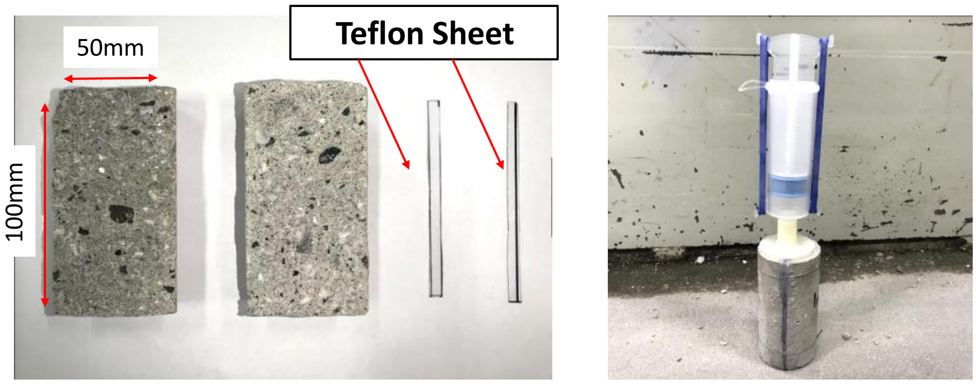

Figure 4. Underwater crack Injection outline

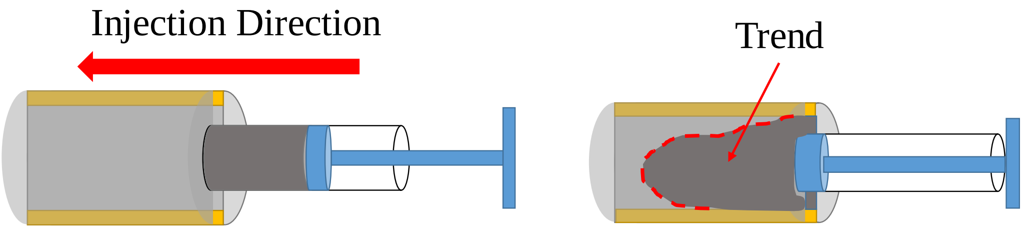

Figure 5. Underwater crack Injection method

3 Results and discussion

3.1 Liquidity test

Figure 6 shows the measurement results of the flowing time using a funnel. When the thickener LV was added, a gradual increasing trend was observed from no addition to 6% addition rate. However, at an addition rate of 6% or more, the injected material clogged the outlet of the roto and did not come out. Therefore, the appropriate addition rate of LV is 6%. On the other hand, when the thickener PV was added, a dramatic increase was observed from no addition to 1.25% addition. When PV was added at a rate of 1.25% or higher, a large amount of the injected material remained inside the rotor. Therefore, the appropriate addition rate for PV is 1.25%. For slag cements with high brain values, LV and PV showed the appropriate addition rates of 6% and 1%, respectively, and differences in the tendency to lose flowability due to the type of thickener were observed.

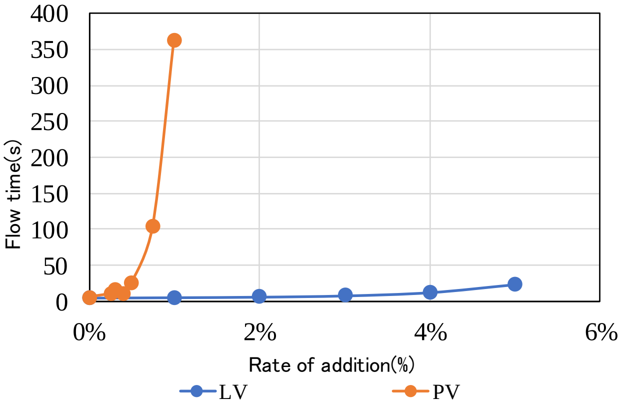

Figure 6. Flow time

3.2 Underwater slump flow

Figure 7 and Figure 8 show the slump flow of LV and PV with thickener, respectively. After 5% LV, the water pressure equilibrated with the settlement of the injected material and the injected material was not discharged. This means that the flow suppression effect is small compared to the thickening effect, and it is easy to handle as an injection material. On the other hand, PV showed relatively close values of flow in air and water at each addition rate. However, many injected materials remained in the inside the slump cone when the ratio of PV exceeded 1%. Therefore, it was considered inappropriate. Therefore, LV1 to 5% and PV0.25 to 1% were selected as the appropriate addition rates.

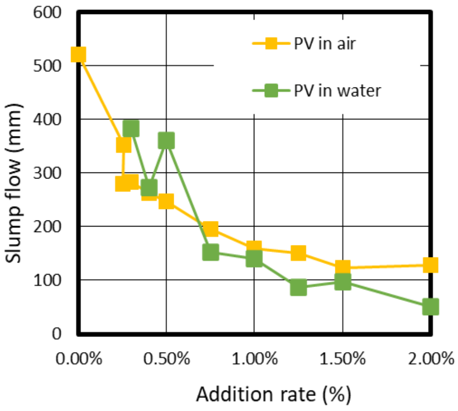

Figure 7. Slump flow by PV

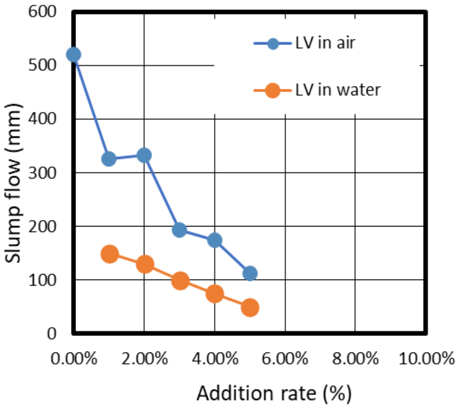

Figure 8. Slump flow by

3.3 Simulated crack injection

The results of the simulated crack injection tests are shown in Table 2. LV3% and PV1% showed the best sealing effect in all crack widths. In Table 3, "◯" indicates that the injection site was closed, and "×" indicates that the injection material flowed down to the bottom of the simulated crack without blocking the injection site.

Table 3 Result of simulated crack injection

Crack		1mm	2mm	3mm
LV	1%	×	×	×
	3%	○	○	○
	5%	×	×	×
PV	0.25%	×	×	×
	1%	○	○	○

Figure 9 shows the results of the 2 mm simulated crack injection test as an example. After injection, the LV1% and PV0.25% cracks spread in concentric circles, but with the passage of time, they flowed downward from the injection point. This indicates that the flow did not block the injection point. Figure 10 shows the injection condition with 5% LV and a crack width of 3 mm. Numerous voids were observed due to air entrainment during injection. Manual injection was not possible for cracks of 2 mm or less. This is thought to be due to the strong thickening effect and high deformation resistance of the injection material. On the other hand, LV3% and PV1% did not flow and stayed after spreading in concentric circles after injection. These results were similar for all crack widths. Based on these results, LV3% and PV1% were selected as the appropriate addition rates.

LV1% is considered to have relatively high flowability. From the freshness test, it is expected that the LV blending has the effect of closing cracks with a width narrower than 1 mm.

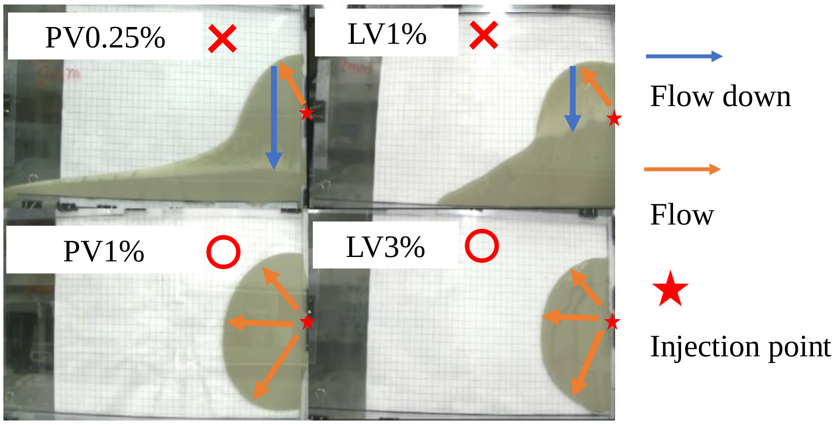

Figure 9. Injection test at crack width 3mm

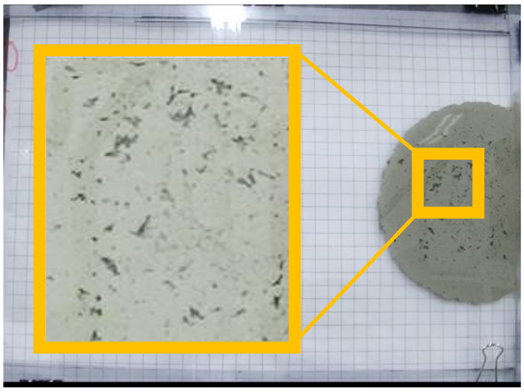

Figure 10. Injection test of LV5% at crack width 3mm

3.4 Underwater crack injection

Figure 11 shows the trend of the injection material obtained from the underwater crack injection test. It was also confirmed that PV1% had sufficient blocking effect combined with viscosity to stay in the cracks. On the other hand, in the case of LV3%, the injected material flowed down behind the crack, and the unfilled area in the shaded area was confirmed. The other side of the crack was not filled by the injected material. It is assumed that the injected material followed a flow path due to the influence of water pressure or gravity. In this study, it was suggested that PV1% thickener was superior as a non-separable injection material in water.

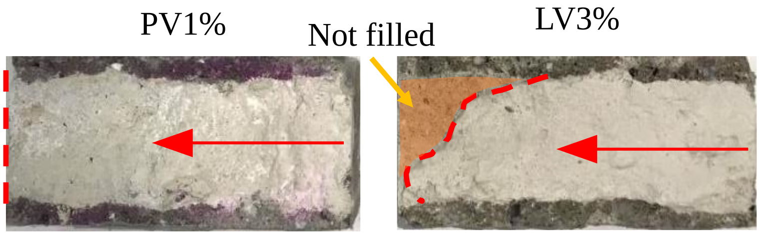

Figure 11. Water crack Injection status

4. Conclusion

In order to develop an inseparable underwater injectable material with conflicting viscosity and flowability, we used ultrafine particle slag cement and thickener, and selected the formula through freshness and physical property tests. As a result, PV1% is suitable for the inseparable underwater injection material. This injection material has enough flowability to fill in wide and narrow cracks, enough viscosity to stay in place, and inseparability in water.

5. Management of quality

On the other hand, in the field construction, the flowability and viscosity of the injection material vary depending on the temperature of the mixing water and seawater, which changes with the season. Figure 12 shows the flow values in air and water at 1% PV. In this data, the slump flow in air and water are relatively close at PV1%. This means that it is possible to confirm the performance of the injected material in water by testing its fresh properties in air.

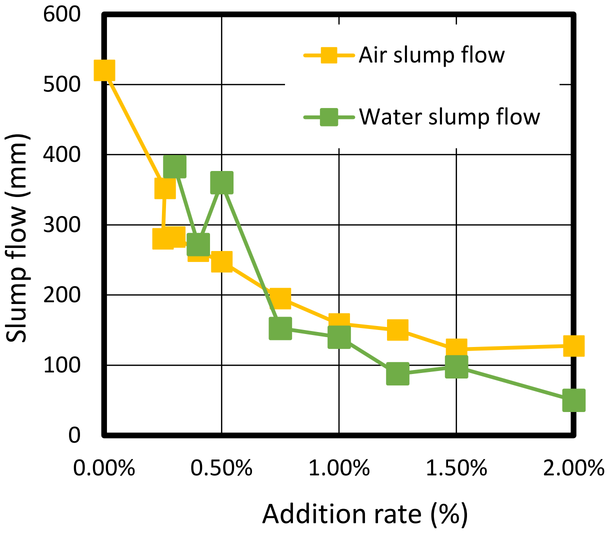

Figure 12. Water crack Injection status

6. Future work

In the case of actual construction, the temperature of seawater and the temperature of the injected material will be different depending on the construction period. Therefore, we would like to investigate the effect of the thickening agent on the freshness or physical properties of the test by changing the temperature of the mixing water. When the environmental conditions of the simulated crack injection test are changed to water, the pressure in the crack will be changed. Therefore, it is possible to select a more accurate injection material by evaluating its ability to push water out of the crack and its retention in the crack in water.

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