APPLICATION STUDY OF VISCOSITY REDUCING TYPE SUPERPLASTICIZERS FOR LOW WATER-BINDER RATIO CONCRETE

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Abstract
In low water/binder ratio concrete such as high-strength concrete (HSC) or self compacting concrete (SCC), concrete workability, especially pumppability and finishability, decreases due to high viscosity caused by its mixture components and proportion. It is considered that reduction of concrete viscosity is significantly advantageous for placement or construction of HSC/SCC. Therefore, we try to apply viscosity reducing type superplasticizer to low water-binder ratio concrete. As the results, it is found that the newly developed superplasticizers can reduce the viscosity of cement paste in concrete, and the time to achieve 50cm slump-flow, an index of concrete workability can be reduced. Accordingly, it is confirmed that application of the viscosity reducing type superplasticizers is efficacious in workability improvement of low water/binder ratio concrete.

1. INTRODUCTION
Recently, high-strength concrete is used frequently in order to improve durability of concrete structure, expand residential space or avoid the cracking by seismic damage. In low water/binder ratio concrete such as high-strength concrete (HSC) or self compacting concrete (SCC), however in some case, pumppability or finishability of concrete are poorer than normal strength concrete due to high viscosity caused by its mixture components and proportion. Especially in HSC (60 to 100 MPa), there are some case that concrete viscosity is higher than that of ultra high strength concrete (>100MPa) since binder system of HSC is usually only portland cement without fine powder such as silica fume.

It is well known that excess reduction of concrete viscosity leads concrete sedimentation and then workability of concrete drops drastically. However, if it is possible to reduce the concrete viscosity within the range of no sedimentation, it is considered that handling of concrete at the construction job site will become more easily. For these reason, several research considering rheological behavior of HSC/SCC were carried out [1], [2], [3].

On the other hand, low-stickiness type superplasticizer is widely used in Japanese normal strength concrete field because of its good workability, pumppability and finishability [4], [5].

Based on these back ground, authors developed viscosity reducing type of superplasticizer for low water/binder ratio concrete on basis of the low stickiness type superplasticiser technology in normal strength concrete. In this paper, we described 1) viscosity reducing effect of the newly developed superplasticizer determined by mortar evaluation using
rotational viscometer, 2) applicability of developed SP to high strength concrete using focusing on slump-flow and viscosity change by passage of time, and 3) hardened properties such as strength development, freeze and thaw resistance and drying shrinkage of high strength concrete containing viscosity reducing type superplasticizer.

2. EXPERIMENT

2.1 Materials

Ordinary portland cement [hereafter OPC, Density: 3.15g/cm³], was used as cement. Land sand [from Shizuoka; Japan, Density: 2.59g/cm³ (saturated and surface-dry condition), FM: 2.66] and pit sand [from Chiba; Japan, Density: 2.66g/cm³ (saturated and surface-dry condition), FM: 2.64] were used as fine aggregate. For mortar, only land sand is used and blended sand with land sand and pit sand by weight ratio of 8 to 2 was used for concrete.

Crushed sandstone [from Tokyo; Japan, MS=20mm, Density: 2.66g/cm³ (saturated and surface-dry condition), FM: 6.67] was used as coarse aggregate.

2 type polycarboxylate based superplasticizers for high-strength concrete were used as admixture for this evaluation. Details of two superplasticizers are conventional type for high strength concrete (CSP) and newly developed viscosity reduction type (NSP). CPS is commercialized product which is well used as superplasticizer for high strength concrete at many construction projects with sufficient dispersibility and slump flow retention.

Main component of these superplasticizers are as follows:

CSP: Copolymer of methacrylic acid and polyoxyethylene methacrylate
NSP: Copolymer of acrylic acid, maleic acid and unsaturated alcohol polyoxyethylene ether

2.2 Experiment for viscosity reducing effect

Viscosity reducing effect of newly developed superplasticizer was evaluated by mortar (3 W/C conditions; 0.3, 0.35 and 0.4). Mixture proportions of mortar are shown in Table 1. Hobart N50 mortar mixer was used to mortar mixing. Dosage of superplasticizer was decided to obtain 220 +/- 10mm mortar flow. To prepare mortar sample, 180 sec. mixing after adding whole materials into mortar mixer was done. Mortar flow was measured according to JIS R 5201:1997 “Physical testing methods for cement”, without table tamping. Mortar flow cone which size is 70mm upper diameter, 100mm bottom diameter and 60mm height is used for mortar flow measurement. Viscosity of mortar was measured by rotational viscometer (RB115R by Toki Sangyo Co. Ltd.) with disc type rotor (Photo1). Torque was detected with changing rotational speed from 10rpm to 100rpm in 10rpm increments. (detected at 10 steps)

2.3 Concrete examination

Table 2 shows the mix proportions of the concretes used in this study. A double-shaft revolving paddle mixer was used to mix the concrete.
Slump and slump-flow were measured by conventional method described in JIS A 1101 and JIS A 1150, respectively. When measuring slump flow, time to achieve a 50-cm flow also measured. Time until achieving slump flow of 50cm after slump cone is pulled up is measured according to JIS 1150.

Table 1 Mixing proportion of mortar

<table>
<thead>
<tr>
<th>W/C</th>
<th>S/C</th>
<th>Admixture</th>
<th>Dosage (Cx%)*1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.30</td>
<td>1.40</td>
<td>NSP</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSP</td>
<td>0.70</td>
</tr>
<tr>
<td>0.35</td>
<td>1.80</td>
<td>NSP</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSP</td>
<td>0.80</td>
</tr>
<tr>
<td>0.40</td>
<td>2.30</td>
<td>NSP</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSP</td>
<td>0.90</td>
</tr>
</tbody>
</table>

*1: Cx% means percentage of admixture weight by cement weight

Table 2 Mixture proportion of concrete

<table>
<thead>
<tr>
<th>Cement type</th>
<th>W/C</th>
<th>Gravel*1</th>
<th>Unit weight (kg/m³)</th>
<th>Admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(m³/m³)</td>
<td>W  C    S1*2</td>
<td>S2*3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPC</td>
<td>0.27</td>
<td>0.54</td>
<td>170</td>
<td>630</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>0.55</td>
<td>170</td>
<td>567</td>
</tr>
<tr>
<td></td>
<td>0.37</td>
<td>0.56</td>
<td>170</td>
<td>459</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

*1: Bulk volume of coarse aggregate per unit volume of concrete
*2: S1 is land sand
*3: S2 is pit sand
*4: Cx% means percentage of admixture weight by cement weight

Compressive strength was measured by 100mm x 200mm cylinders according to JIS A 1132 and JIS A 1108. Freeze and thaw resistance was measured by 100mm x 100mm x 400mm specimens according to JIS A 1132 (method A). Drying shrinkage also measured by 00mm x 100mm x 400mm specimens according to JIS A 1129-3. Drying condition was according to JIS A 6204 (Temp.: 20+/-3 °C, Humidity: 60+/-5 %).
3. RESULT AND DISCUSSION

3.1 Viscosity reducing effect

Fig. 1 shows an example of the relationship between rotational speed and torque. The index of viscosity “μ” was obtained as the trend of the approximation line of this relationship, assuming a Bingham flow [6]. Fig. 2 describes the “μ” of each W/C as a mean value of three measurements. Fig. 2 clearly shows that the viscosity of mortar using NSP is lower than that of conventional mortar. Furthermore, the difference of “μ” between NSP and CSP mortars increases as W/C decreases. It is assumed that the influence of the superplasticizer on concrete viscosity is greater under lower W/C conditions. Moreover Fig. 2 shows that the “μ” of NSP at a W/C = 0.35 coincides with that of CSP mortar with a W/C = 0.375, and the “μ” of NSP in W/C = 0.30 coincides with that of CSP with a W/C = 0.34. From these results, it was clarified that NSP can reduce the concrete viscosity without increase of W/C of concrete. In other words, it is expected that NSP can produces an Fc = 80 MPa concrete with the same workability (viscosity, pumpability, etc..) as concrete containing CSP that has an Fc about 70 MPa.

Fig. 3 shows the slump-flow loss curves over time for OPC at W/C ratios of 0.37, 0.30 and 0.27. The slump-flow retention of NSP is almost the same as that of CSP.
3.2 Concrete Examination

1) Slump-flow retention.

![Fig. 3 Slump flow retention](image)

2) Time to achieve a 50-cm flow.

To evaluate concrete viscosity of low water/binder ratio concrete such as self-compacting concrete or high-strength concrete, the time taken for the concrete to achieve a flow of 50 cm (hereafter T50) is measured when slump-flow was measured. This measurement is used in RMC plants because the rate of flow of high-flowable concrete is easy to measure.

The change over time in T50 of W/C = 0.30 concrete is shown in Fig. 4. When the slump flow is almost equal, it can be assumed that the concrete with the shorter T50 is the less viscous concrete, and has better workability.

The T50 of concrete containing NSP is shorter than that of concrete containing CSP under the condition of almost equal slump flow. Fig. 4 clearly shows that the rate of increase in T50 over time in NSP concrete is less than that of CPS, even though the slump-flow retention is almost identical, as shown in Fig. 3.

As the results of these evaluations, it is considered that NSP enhances not only the viscosity reducing effect but also prevents viscosity increasing over time compared with CSP.

3) Compressive strength

Figs. 5 show strength development under each condition. In all conditions, the strength development of NSP is almost the same as that of CSP. Based on this result, it is clear that the viscosity reducing effect has no impact on strength development.
4) Freez e and thaw resistance
Fig. 6 shows the result of freeze and thaw resistance (hereafter F/T resistance) and shows Mass loss until 300 freeze/thaw cycles. Relative dynamic modulus of elasticity of concrete using NSP was kept stable during 300 cycles as the equal as CSP concrete. In high strength concrete area, since microstructure of concrete become denser by its lower water/binder ratio, it is considered that high F/T resistance can be obtained in spite of low air content as less than 3%. Furthermore, weight of the concrete specimen also stable and surface damage by scaling is hardly observed.

![Fig. 6 Result of freeze and thaw resistance (W/C=0.30)](image)

5) Drying shrinkage
Length change and weight loss by drying until 3 months is shown in Fig. 8 and 9. Drying shrinkage of concrete using NSP is almost equal as concrete containing CSP. From the result of F/T resistance and drying shrinkage, it is found that the fundamental durability of high strength concrete with NSP is secured at least the same level of CSP concrete.

![Fig. 7 The result of drying shrinkage (W/C=0.30)](image)
4. CONCLUSION

Viscosity reducing superplasticizers have been developed to maintain good workability by reducing the viscosity of concrete (a major problem of low-water/binder-ratio concrete). In this study, mortar and concrete examinations were carried out to clarify the viscosity-reducing effect and the applicability of superplasticizers to low-W/C concrete. The measurements revealed the following:

1. Viscosity reducing superplasticizers can reduce the viscosity of mortar and this effect increases as the water/binder ratio decreases.
2. It can be assumed that workability of high strength concrete with viscosity reducing type superplasticizer coincides with that of the concrete using conventional one whose Fe level is lower by around 10MPa, even though actual Fc level (W/C) is equal.
3. Even if the viscosity reducing type superplasticizer is used instead of conventional one, influence on the strength development and fundamental durability (freeze and thaw resistance, drying shrinkage) is hardly observed.

The new superplasticizer has a better viscosity reducing effect not only immediately after mixing but it also prevents viscosity increasing over time compared with the conventional superplasticizer; therefore, low-W/C concrete containing this new superplasticizer can maintain a good workability from just after mixing at an RMC plant all the way to pumping, casting and finishing at the construction site.

REFERENCES