INFLUENCE OF SILICA COLLOID ON RHEOLOGY OF CEMENT PASTE WITH SUPERPLASTICIZER

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ABSTRACT

Information of rheological behavior of binder paste is important for proportioning high slump concrete mixture at low water to cement ratios. This paper presents experimental data on the rheological property of silica colloid incorporated binder paste using naphthalene based and polycarboxylate based superplasticizer, compared to that of silica fume incorporated binder paste.

Experimental data showed that silica colloid incorporated binder is compatible to tested superplasticizers in the all investigated range of silica colloid content, whereas the pastes incorporated with high silica fume content (over 10%) indicated incompatibility, especially to naphthalene based superplasticizer.

There was also found out saturated content of superplasticizer corresponding to every kind of binder and water-binder ratio, with and without set retarding admixture.

Keywords: Silica colloid, superplasticizer, cement paste, compatibility, flow time, saturation content.

1. INTRODUCTION

Silica colloid is a new pozzolanic material which has been developed and investigated in making high performance mortar and concrete in recent years. Synthesized chemically, silica colloid is of high purity and its amorphous SiO_2 is of particle size much smaller than silica fume. Therefore, activity of silica colloid is very high [1, 4]. Several papers on the use of silica colloid as a highly active ultrafine additive in making high strength high performance mortar and concrete were published [2 - 4]. The reported data proved that even used at a low dosage, silica colloid remarkably improves mechanical properties of concrete. Its very high pozzolanic activity is shown by the increase of concrete strength in early stages. Silica colloid is also a respective additive in enhancing durability of mortar, concrete and reinforcement in aggressive environments such as chloride and acid media, ice-thaw cycles, carbonation *etc.* [1, 2].

For proportion design of high strength concrete with low water to binder ratio, rheology of binder paste with superplasticizer is an important criterion. Through this property there can be accessed the compatibility between superplasticizer and binder and determined the saturation content of superplasticizer (the highest content can be effectively used) for designing concrete mixture with the lowest binder content.

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This research work introduces experimental results on influence of silica colloid additive on rheology of Portland cement based binder paste with and without set retarding admixture when naphthalene and polycarboxylate based superplasticizer were used. From flow time-superplasticizer content relationship, saturation content of superplasticizer were determined. Experimental data of silica fume incorporated binder paste were set forth for comparison.

2. EXPERIMENTAL METHODS

2.1 Materials

Portland cement PC40 of Chinphong company, Blaine fineness of 3.380 m²/kg. Its chemical and mineralogical composition are given in table 1.

Table 1: Chemical and mineralogical composition of PC40 Chinphong.

Chemical composition (%)		Mineralogical composition by Bogue (%)	
CaO	64.12	C ₃ S	58.45
SiO ₂	21.13		
Al ₂ O ₃	5.52		
Fe ₂ O ₃	3.40		
Na ₂ O	0.15		
K ₂ O	0.72	C ₂ S	16.50
MgO	0.80	C ₃ A	8.87
TiO ₂	0.15	C ₄ AF	13.35
SO ₃	2.19		
MKN	1.20		

Naphthalene formaldehyde sulphonate superplasticizer Mighty 150 supplied by KAO company. Its solid content is 42.1%.

Polycarboxylate superplasticizer SELFILL-2060RS supplied by IMAG company. Its solid content is 23.4%.

Lignin based set retarding admixture KANA developed by Institute for Building Materials. Its solid content is 37.8%.

Silica colloid Cembinder 508 supplied by EKA Chemicals AB. Its characteristics are as follows:

- Solid content:	33.8%	- Specific surface area:	80.000 m ² /kg
- Density:	1.21	- SiO ₂ :	33.1%
- pH:	10 - 11	- Na ₂ O:	0.56%

Silica fume MB-SF supplied by MBT company. Its characteristics are as follows:

- SiO ₂ :	90.1%	- MgO:	1.2%
- CaO:	1.6%	- C:	4.8%
- Fe ₂ O ₃ :	1.2%	- Specific surface area:	17.300 m ² /kg

2.2 Experimental procedure

Rheology of superplasticized binder paste is investigated using the method described in detail by Larrard [7]. Binder paste with an amount of superplasticizer and set retarding admixture at a certain cement-water ratio is stirred by a high speed mixer of 2.800 rpm for 3 minutes and then fully filled a funnel as shown in Fig. 1. The duration when exactly 200 ml of paste flows down is determined.

For every cement-water ratio, flow time and superplasticizer content relationship is demonstrated on graph in order to access the compatibility between superplasticizer and binder.

In the case of good compatibility, saturation content of superplasticizer what is the lowest superplasticizer amount for gaining the shortest flow time of the paste is then determined on the graph [5, 7].

3. RESULTS AND DISCUSSION

It is known that not every superplasticizer is compatible to a kind of Portland cement or binder consisting of cement and mineral additives. For concrete mixture of low water-cement ratio, investigation for selection of compatible couple binder-superplasticizer is necessary. If they are not compatible, the amount of superplasticizer needed for gaining high slump concrete mixture will be great and workability of concrete mixture will be hardly maintained.

Fig. 1: Tool for determination of flow time of binder paste.

The compatibility between superplasticizer and binder depends on various factors such chemical structure of admixture, chemical and mineralogical composition of binder, morphology of cement minerals... There have not been practical criteria of mechanism of compatibility between superplasticizer and binder. However, many researchers agree that compatibility can be accessed through a rheological property of binder paste with admixture, specifically its flow time [5, 7, 11].

The flow time of paste of binder containing Portland cement (PC) and silica colloid (SC) or Portland cement and silica fume (SF) at cement to water ratio of 0.275 in relation to naphthalene formaldehyde sulphonate superplasticizer (NFS) content are given in Figs. 2 and 3, respectively.

Fig. 2: Relationship between NFS content and flow time of paste with different silica colloid content ($W/C = 0.275$).

Figure 2 indicates that there is a good compatibility between admixture Mighty 150 and the used Portland cement. When silica colloid is added, the NFS amount needed for keeping a certain flowability (flow time) increases with increasing amount of silica colloid. Furthermore, increasing addition of silica colloid leads to lifting up the value of the lowest viscosity of binder paste.

Fig. 3: Relationship between NFS content and flow time of paste with different silica fume content ($W/C = 0.275$).

A similar regulation can be also seen in the case of silica fume addition in Fig. 3 with one exemption when content of silica fume is 15% of the cement. This phenomenon should be further investigated. It could be caused by too high viscosity of the paste, the unburnt carbon content in silica fume or a high surface affinity of silica fume.

Fig. 4: Relationship between PCA content and flow time of paste with different silica colloid content ($W/C = 0.275$).

Fig. 5: Relationship between PCA content and flow time of paste with different silica fume content ($W/C = 0.275$).

When the lowest viscosity of binder paste reaches a certain high value, high strength concrete mixture should be hardly made since it is then too cohesive, its flowability is bad, air hardly escapes from concrete mixture during compaction *etc.* Therefore, at the water to cement ratio of 0.275, content of silica colloid of 6% and silica fume of 15% should be too high.

Fig. 6: Flow time of binder pastes with 1.5% KANA and various amounts of PCA ($W/C = 0.275$).

The results of flow time of binder pastes using polycarboxylate admixture (PCA) shown in Fig. 4 and 5 also give a similar tendency as those with NFS superplasticizer. PCA is well compatible to the investigated binder. The lowest viscosity of binder pastes with PCA is not remarkably different from that with NFS. However, the PCA amount needed for reaching a certain viscosity of the paste is lower than the NFS amount. It confirms the higher liquidifying effect of PCA than that of NFS as several published reports [8, 9].

Fig. 7: Flow time of binder pastes with 1.5% KANA and various amounts of PCA ($W/C = 0.275$).

High strength concrete is of a low water to cement ratio and a high binder content. For this type of concrete, the hydration rate is higher and slump loss is greater than normal strength concrete of higher water to cement ratio. In that case, the use of set retarding admixture should be effective in controlling slump loss and prolonging workable duration of concrete mixture.

Set retarding admixture KANA is used in the investigation. The experimental results on flow time of binder pastes with 1.5% KANA and different amounts of NFS or PCA superplasticizer are demonstrated in Figs. 6 and 7.

Figure 6 shows that with incorporation of 1.5% admixture KANA, the use of NFS does not change the lowest viscosity of binder pastes when compared to KANA-free ones (Figs. 2 and 3). However, the amount of NFS needed for achieving the lowest viscosity of the paste is reduced when KANA is present. The rule of reduction of PCA superplasticizer amount in binder pastes without affecting their lowest viscosity is also seen in Fig. 7 (when compared to data in Figs. 4 and 5).

The effect of admixture KANA to reduction in superplasticizer amount could be explained by the spontaneous adsorption of KANA and superplasticizer molecules on cement particles. Interaction of surface active agents and cement-water system is adsorption of admixture molecules on surface of cement. The adsorption mechanism depends on many factors, so the adsorbed amount of admixture also depends on practical conditions. When in the cement-water system there is superplasticizer only, the admixture molecules can perform a multilayer adsorption on cement particles, resulting in a high needed amount of superplasticizer for gaining a certain liquidifying effect [6]. When KANA admixture is present in the system, spontaneous adsorption, selected adsorption and shielding effect could be in action and that leads to reduction of superplasticizer amount adsorbed on cement particles. Further research work should be carried out to prove this hypothesis.

The saturation amount of superplasticizer also depends on water to cement ratio: the higher the ratio, the lower the saturation amount. Based on the experimental results of flow time of binder pastes at different water to cement ratios (0.275, 0.30, 0.325 and 0.35) in relation to superplasticizer amount, saturation superplasticizer amounts are determined and illustrated in table 2.

Table 2: Saturation amount of superplasticizer in binder pastes.

Type of binder	Admixture KANA (% cement)	Saturation amount of superplasticier (% cement)							
		N/XM = 0.350		N/XM = 0.325		N/XM = 0.30		N/XM = 0.275	
		NFS	PCA	NFS	PCA	NFS	PCA	NFS	PCA
PC	0	0.75	0.50	1.25	0.75	1.75	1.25	2.00	1.75
	1.5	0.50	0.50	1.00	0.50	1.25	0.75	1.50	1.00
PC + 2%SC	0	1.00	0.75	1.50	1.00	2.25	1.50	3.00	2.25
	1.5	0.75	0.50	1.50	0.75	1.75	1.00	2.25	1.50
PC + 4%SC	0	1.25	1.00	1.75	1.25	2.25	1.75	3.50	2.75
	1.5	1.00	0.75	1.50	1.00	1.75	1.25	2.50	2.00
PC + 5%SF	0	1.25	1.00	2.00	1.25	2.50	1.50	3.00	2.25
	1.5	1.00	0.75	1.50	1.00	1.75	1.25	2.25	1.50
PC + 10%SF	0	1.50	1.25	2.00	1.75	2.75	2.25	4.25	3.25
	1.5	1.25	1.00	1.75	1.25	2.25	1.50	2.75	2.25

From the table there is seen that saturation content of PCA is lower than NFS in all cases at different water to cement ratios. With the presence of 1.5% set retarding admixture KANA, the saturation content of PCA and NFS superplasticizer is reduced with all binder compositions at all investigated water to cement ratios.

The results is necessary for the concrete proportioning work when the lowest binder content and high slump are required.

4. CONCLUSION

Similarly to silica fume, the presence of silica colloid in binder paste increases its viscosity and so remarkably increases the amount of superplasticizer needed to maintain a certain paste flowability when compared to the plain cement paste. With addition of set retarding admixture KANA, the amount of superplasticizer is reduced. This phenomenon needs further research.

The data of saturation amount of superplasticizer in binder pastes of different silica colloid and silica fume content with or without admixture KANA at various water to cement ratios gathered from experiments are useful in designing proportion of high strength concrete using the above-mentioned highly active ultrafine additions and materials brought in the research.

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