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Full Length Research Paper

Influence of mineral additive type on slump-flow and yield stress of self-consolidating mortar

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Self-consolidating concrete flow mainly depends on the properties of the Self-consolidating mortar (SCM) design. SCM properties are influenced by mineral powder content, powder (mineral additive) type, and the chemical admixture content used in the mixes. In this study, the effects of mineral additives, the water/powder ratio, and the chemical admixture content on the yield stress of SCM was investigated. Five mineral additives, including limestone powder, waste marble powder, brick powder, fly ash, and limestone powder plus fly ash, were used. The SCM mixes with different powder types were prepared by using the polycarboxylate-based chemical admixture in ratios of 1, 1.5, 2, and 2.5% by powder weight. Total powder content (cement and mineral additives) was constant. The workability of fresh SCM was defined using the mini slump cone test and mini V-funnel tests. The yield stress of SCM was determined by the asymptotic flow regime approach, which depends on slump flow value. The test results show that the powder type is as effective as the chemical admixture and water/powder ratio (w/p) on the yield stress of SCM. SCM yield stress decreased as the w/p and SP dosage increased.

Key words: Self-consolidating mortar, powder type, flow-ability, yield stress.

INTRODUCTION

The slump test has been used extensively in civil engineering to estimate the "workability" of fresh concrete for two decades. Workability is a term used to describe a combination of influences associated with varying yield stress and viscosity (Pashias et al., 1996). Yield stress is the minimum stress for irreversible deformation and flow of any material which behaves like a fluid, such as concrete or mortar. The yield stress of concrete or mortar is measured by rheometry, but it is very expensive and complex for construction site (Roussel and Coussot, 2005). Thus, many researchers have investigated the yield stress by linking the slump-cone test, which is simpler and cheaper for test for site, to the Abrams-cone or mini-cone frustum (Dzuy and Boger, 1983; Saak et al., 2004; Roussel et al., 2005). This is known as a stoppage test, and is based on the assumption that if the shear stress in the tested sample becomes smaller than the plastic yield value, then flow stops. Spread or slump height is directly related to a plastic yield value that can be calculated (Nguyen and Boger, 1992; Roussel et al., 2005). Yield stress is a very important factor for concrete, especially Self-consolidating concrete, which has high fluidity (Murata, 1984; Saak et al., 2001). The production of Self-consolidating concrete (SCC) that must have lower yield stress than normal concrete involves the appropriate selection and proportioning of the constituents to produce a concrete mainly characterized by its flow-ability, passing-ability, and segregation resistance in fresh condition (Topçu et al., 2010). SCC quality is controlled by the flow behavior of cement paste, which is related to the dispersion of cement particles (Coussot and Piau, 1995). Superplasticizers (SP) provide the possibility of better cement particle dispersion, thereby producing a paste with greater fluidity (Coussot et al., 1996; Chandra and Björnström, 2002). However, mineral additives or fillers also have as many beneficial effects as superplasticizers, such as improvement of rheological and durability properties of fresh and hardened concrete, respectively (Yazici, 2008). The use of fillers in multiphase materials, such as cement-based mortar, aims to enhance the particle distribution of the

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powder skeleton, thus reducing inter-particle frictions and ensuring better packing density in the system. This can liberate part of the mixing water that was entrapped in the system (Yahia et al. 2005). Mineral additives, such as fly ash, silica fume, limestone powder and other wastage powders, which are hazardous for environment, provide additional enhancement in workability and reduction to porosity of SCC (Hassan et al., 2000).

Some researchers have investigated the effects of mineral additives and different chemical admixtures on the rheological properties of self-consolidating mortar (SCM) or SCC. Laskar and Talukdar (2008) performed a study on the effects of mineral admixtures, including rice husk, silica fume, and fly ash, on the rheological properties of high performance concrete. They observed that yield stress decreased when the replacement ratio of rice husk and fly ash increased. Leeman and Winnefeld (2007) investigated the influence of different viscosity modifying agents (VMA), such as microsilica and nanosilica slurry, high molecular ethylenoxide derivate, natural polysaccharide, and starch derivate, on the rheological properties of SCM. Mortars were also produced with different water/binder ratios (w/b) and VMA dosages. The authors reported that the addition of VMA causes a decrease in the slump flow of mortar and an increase in the yield stress and plastic viscosity at a constant w/p ratio. Yahia et al. (2005) investigated the rheological properties of SCM containing limestone filler. The limestone filler content was replaced by cement (0 - 50% by powder volume). The mixes were designed in 0.35, 0.4, and 0.45 water/cement ratios. The admixture dosage was also varied from 0.6 - 2.2%, by cement weight. They observed that an increase in SP dosage caused an increase in the relative slump flow area and relative V-box flow-time. However, with a 0.40 w/c ratio and 1.8% SP content, the mix exhibited segregation. Mirza et al. (2002) carried out a study on the rheological and mechanical properties of grouts containing high volume FA. They investigated the effects of SP on the flow time of low-w/p grouts and the stability of high-w/p grouts. The results indicate that the addition of fly ash in cement grouts reduces the flow time and improves the stability of grouts.

Chandra and Björnström (2002) investigated the fluidity of cement paste with different SP dosages and cement types. They reported that the fluidity of a cement paste is related to the hydration of the cement, which depends on the cement composition and fineness. They have highlighted the flow of cement paste. According to the authors, the surface of interstitial phases, especially of C_3A and C_4AF, adsorbs the SP at low water/cement ratios (w/c); thus, very little SP is in the pore solution. However, with an enhancement in the w/c, more alite hydrates are produced. Consequently, the fluidity increases significantly. Şahmaran et al. (2006) used fly ash, limestone powder, brick powder, and kaolin powder as filler in the SCM. They reported that among the mineral additives considered, fly ash and limestone powder increased the workability of SCM significantly. On the other hand, the addition of brick powder reduced the workability. Schwartzentruber et al. (2006) carried out an experimental study on the rheological properties of cement paste with limestone powder, such as slumped flow, yield stress and viscosity. In the study, the effects of SP and a viscosity-enhancing admixture (VEA) were investigated. They observed that high SP dosage ensures a high fluidity. However, the VEA does not modify the rheological behavior of the cement paste significantly.

Many mineral additives are used in the production of SCC, but their effects on the yield stress of SCC have not been extensively investigated to date. Many researchers have focused on the influence of SP type and dosage or viscosity enhancing admixtures on the yield stress of cement paste or SCM. In the present study, effects of different powder types, the water-powder (w-p) ratio, and SP dosage on the yield stress are determined by linking to stoppage test.

EXPERIMENTAL PROCEDURE

Materials

The SCM mixes investigated in this study were prepared with Ordinary Portland cement (OPC) of CEM I/42.5 R, produced according to the European Standards EN 197-1, and with other powders (< 125 µ), such as limestone powder (LSP), waste marble powder (WMP), brick powder (BP), fly ash (FA), and limestone powder (66.7%) plus fly ash (33.3%) (LFP). The physical and chemical properties of OPC and mineral additives are presented in Table 1. The chemical admixture was polycarboxylate-based superplasticizer (SP). Its specific gravity and solid content was 1.1 and 20%, respectively. Natural river sand was used in all mixes with a specific gravity, fineness modulus, and water absorption, by weight of 2.59, 2.07, and 3.73%, respectively.

Mix proportions and test program

The most popular mix design method used for the SCC is introduced by Professor Okamura. The method requires conducting the cement paste and mortar tests before evaluating the properties of the superplasticizer, cement, fine aggregate, and pozzolanic material to save the process from the redundancy of unnecessary testing (Hassan et al., 2000). Therefore, in the design of SCM, the w-p ratio for zero flow (β_p) was determined in the paste, with 450 kg/m^3 cement and 150 kg/m^3 mineral powder. Mini flow cone tests with water/powder ratios by volume of 1.1, 1.2, 1.3, and 1.4 were performed with the selected powder composition. The point of intersection with the y - axis is designated as the β_p value for mineral additives as filler. As a result, β_p has been obtained for every powder type (Table 2). The β_p value is the minimum water requirement to surround powder particles with water. In other words, the water or admixture added to the mix beyond the minimum water requirement would affect the slump or flow of the SCM. It will be different depending on the type, surface texture, and shape of the powder. After determination of the β_p value, the main mixes were designed.

Materials used in the study were proportioned in w/p ratios; above and below the β_p value of each type of powder. The cement and powder content are kept as 450 and 600 kg per cubic meter, respectively, in all mixes. The component content is given in Table 3. Each mix was tested with different SP content in ratios of 1.0,

Table 1. The physical and chemical properties of cement and fillers.

	OPC	LSP	FA	BP	WMP
Chemical properties					
CaO	63.56	54.97	11.34	4.65	51.8
SiO_2	19.3	0.01	51.5	63.11	4.67
Al_2O_3	5.57	0.17	23.08	15.08	-
Fe_2O_3	3.46	0.05	6.07	6.66	0.03
MgO	0.86	0.64	2.42	1.94	0.4
SO_3	2.96	-	1.32	0.36	-
K_2O	0.8	-	2.54	2.34	-
Na_2O	0.13	-	0.77	0.78	-
LOI	1.15	43.66	1.06	2.33	41.16
Physical properties					
Specific gravity	3.07	2.7	2.13	2.73	2.7
Fineness (Blaine) (cm^2/g)	3252	886	3345	3388	1094

Table 2. The minimum water requirement of powders.

Powder type	Equation	R	β_p	
			By volume	By weight
LSP	y = 0.0571x + 1.0383	0.991	1.038	0.35
FA	y = 0.136x + 1.1142	0.962	1.1142	0.403
WMP	y = 0.1021x + 1.0753	0.988	1.0753	0.36
BP	y = 0.8364x + 1.325	0.991	1.325	0.445
LFP	y = 0.061x + 1.1179	0.982	1.1179	0.40

Table 3. Mix proportion of components for per cubic meter.

Filler type	w/p	Cement ($kg.m^{-3}$)	Filler ($kg.m^{-3}$)	Water ($lt.m^{-3}$)	Aggregate ($kg.m^{-3}$)	Unit weight ($kg.m^{-3}$)
LSP	0.32	450	150	192	1518	2310
	0.36	450	150	216	1456	2272
	0.40	450	150	240	1394	2234
	0.43	450	150	258	1358	2206
FA	0.36	450	150	216	1417	2223
	0.39	450	150	234	1370	2204
	0.43	450	150	258	1308	2166
	0.47	450	150	282	1246	2128
WMP	0.35	450	150	210	1471	2281
	0.40	450	150	240	1393	2233
	0.44	450	150	264	1331	2195
	0.47	450	150	282	1284	2166
BP	0.40	450	150	240	1395	2235
	0.44	450	150	264	1332	2196
	0.47	450	150	282	1286	2168
	0.51	450	150	306	1224	2130

Table 3. Contd.

LFP	0.33	450	150	198	1489	2287
	0.36	450	150	216	1443	2259
	0.39	450	150	234	1396	2230
	0.43	450	150	258	1334	2192

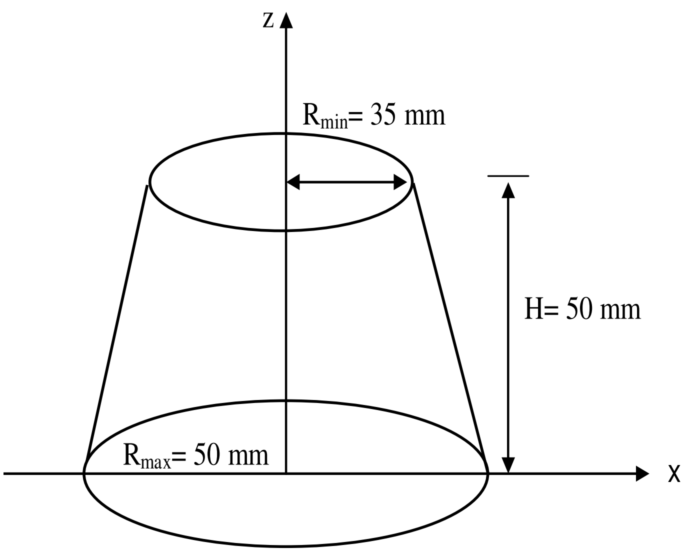

Figure 1. Schematic representation of mini frustum shape and coordinates.

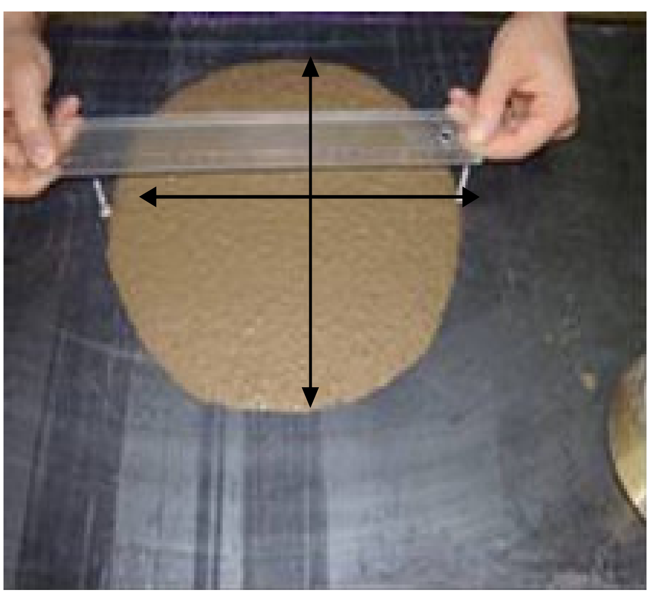

Figure 2. Measuring of diameter of slumped and flowed SCM.

1.5, 2.0, and 2.5% by powder weight. Accordingly, 80 different series were produced in the research. A 1500 ml batch was prepared for all mixtures using a mixer with a rotational velocity of 1000 rpm. The mixing sequence consisted of homogenizing the sand and powder for 1 min dry, and then the superplasticizer was diluted with the mixing water and added to the mixing container. The mortar mixture was mixed for 3 min. Following mortar mixing, the fluidity was evaluated by measuring the slump-flow and V-funnel flow time. The slump-flow was measured using a cylindrical frustum (Figure 1). The tested volume in the frustum was 0.287 L.

The slump measurement consisted of filling a cylindrical frustum with the SCM to be tested in the specified way, slowly lifting the frustum off and allowing the SCM to collapse under its weight. In order to prevent any thixotropic effect, the frustum mold was lifted immediately after having been filled with the SCM (Roussel and Coussot, 2002). The slump-flow (SF) of the final deformed, or slumped, mortar was measured on two perpendicular diameters 2 min after cone lifting (Figure 2). The relative flow area (Γ) is calculated following Equation (1):

$$\Gamma = (\frac{SF}{100})^2 - 1 \tag{1}$$

For all cone tests, in order to reduce the surface friction, the inside of the mould and the base surface were moistened at the beginning of every test, and surface effects were ignored because the same plate and frustum were used in all tests (Roussel et al., 2005). A mini V-funnel cone for mortar was used. The efflux time for the SCM to flow out was noted.

Determination of yield stress

Some models have been developed to determine how the yield stress of cement paste or mortar is related to the slump or slump-flow (Roussel et al., 2005; Roussel and Coussot, 2002; Saak et al., 2004; Pashias et al., 1996; Wallevik, 2006; Petit et al., 2007). Roussel et al. (2005) presented a suitable model for cement paste and grout yield stress measurements. The yield stress of each series was defined by the use of an asymptotic flow regime formula, which related the slump flow (SF) value given in Equation (2) as follow:

$$\tau_0 = \frac{225\rho g V^2}{128\pi^2 R^5} \tag{2}$$

where τ_0 is the yield stress of SCM; ρ is the density of mortar used; g is the acceleration due to gravity; R is the slump-flow radius; and, V is the material volume used in the frustum, Then Equation (3) can be derived as follow:

$$V = \int_0^{2\pi}\int_0^{R} h(r) r\,dr\,d\theta \tag{3}$$

Table 4. The slump-flow and V-box values obtained from tests.

Filler type	w/p	SF (mm)	V-box (s)	SF (mm)	V-box (s)	SF (mm)	V-box (s)	SF (mm)	V-box (s)
		1%		1.5%		2%		2.5%	
LSP	0.32	105	NF	110	NF	129	58.0	145	53.0
	0.36	160	5.9	220	5.7	248	5.6	275	5.4
	0.40	200	2.6	290	2.5	327	2.4	360	2.4
	0.43	228	2.2	295	1.6	400	1.5	400	1.4
FA	0.36	103	NF	108	NF	112	NF	140	NF
	0.39	115	NF	178	14.3	245	10.4	274	9.8
	0.43	135	7.0	244	5.1	294	4.7	322	4.4
	0.47	220	2.0	328	1.6	411	1.5	413	1.4
WMP	0.35	110	NF	116	NF	129	36.8	156	32.2
	0.40	123	12.1	217	8.1	266	7.3	268	7.1
	0.44	241	2.2	312	2.1	336	2.1	372	2.5
	0.47	285	1.2	420	1.3	422	1.4	439	1.5
BP	0.40	110	NF	113	NF	141	13.2	183	9.6
	0.44	114	NF	152	5.5	217	4.0	258	3.6
	0.47	128	9.1	187	3.4	249	2.9	273	2.7
	0.51	190	1.6	242	1.3	301	1.3	338	1.2
LFP	0.33	112	NF	115	NF	116	NF	134	NF
	0.36	115	NF	134	18.4	175	12.3	244	10.7
	0.39	127	11.7	196	7.7	222	6.1	277	6.0
	0.43	230	2.3	321	2.2	361	2.1	360	1.9

NF: No flow.

RESULTS AND DISCUSSION

Effect of mineral additive type on slump-flow and V-box time

The flow properties of SCMs incorporating chemical admixtures and mineral additives are defined by slump-flow (SF) and V-box flow time. The SF and V-box test results are presented in Table 4 relating to w/p, SP content and filler type. It is clearly seen that the slump flow diameter increases and the V-box flowing time decreases as the superplasticizer (SP) content for each series is increased, regardless of w/p. V-box flowing time could not be measured in some SCMs, especially in mixes with low w/p ratios and SP contents. Other times, it was measured over a very long time period. Also, V-box flow time could not be measured in SCMs with low SF. This was due to the high viscosity of SCMs because of lack of lubrication between the particles. Although SP was increased from 1 - 2.5%, the V-box flow time could not be measured in SCMs that contain the FA in the lowest w/p ratio. A partial replacement of cement by FA results in higher volume of paste due to its lower density (Şahmaran et al., 2006). Thus, the water requirement of paste increased when compared to other filler types. A mortar mixture with V-box flowing time ranging between 7 and 11 s can be desirable in a SCC mixture (EFNARC Committee, 2002).

LSP is filler that is used extensively in the production of SCC (Domone, 2006). In Figure 3, the relationship between relative slump-flow area and SP depending on w/p is presented for SCM with LSP. For 0.32 w/p mixtures, the increase of SP dosage from 1 - 2.5% resulted in increased relative slump-flow. However, this enhancement was restricted. When the w/p ratio was increased to 0.36 and 0.40, the slump-flow area reached about 4 and 7, respectively, with 1.5% SP content. By increasing the SP to 2.5%, the slump-flow area of SCM was 7 and 13, respectively, for the same w/p ratios. For 0.43 w/p mixtures, the increase in SP content from 1 - 2.5% resulted in an enhancement in the relative slump flow from 4 - 15. However, with SP content of 2.5%, the mixture segregated due to excessively low viscosity and sedimentation. Another mineral additive used in the mixes was fly ash (FA). FA has high paste volume due to its lower density. Enhancement of the paste volume with

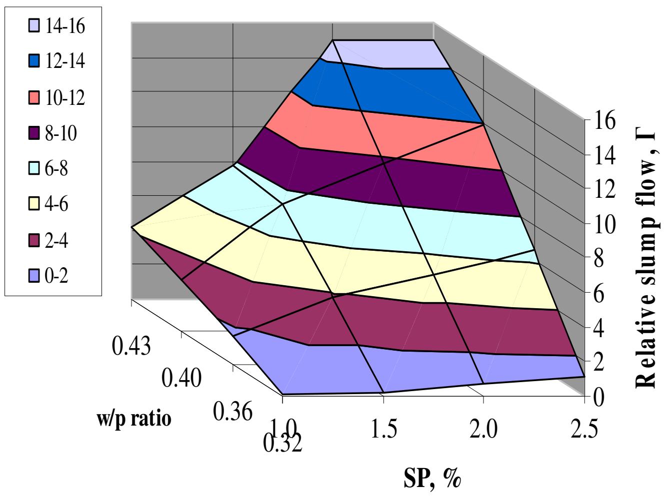

Figure 3. Relative slump-flow of SCM with LSP versus admixture.

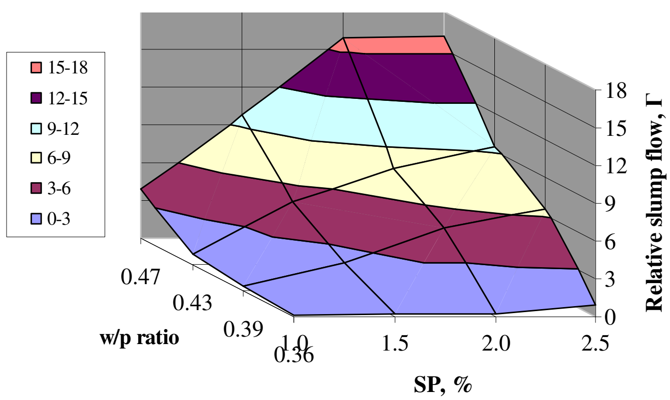

Figure 4. Relative slump-flow of SCM with FA versus admixture.

FA resulted in friction reduction at the fine aggregate-paste interface, and improving the plasticity and cohesiveness. Moreover, FA has a spherical shape. Thus, it leads to an increase of workability. Due to the low density of FA, the minimum water requirement (β_p) to surround the FA particles is 0.40, by weight. When the relative slump-flow area of SCM with FA was examined (Figure 4), the FA particles were not surrounded by liquid that incorporates the water and SP for a w/p ratio of 0.36. Thus, relative slump flow was slightly enhanced by increasing the SP dosage. However, with w/p ratios of 0.39 and greater, the increase of SP dosage resulted in a rise in the relative slump-flow. A good relationship between slump-flow and SP was obtained regardless of the w/p ratio.

On the other hand, it was observed that even though FA increases the workability of SCM; it increased the viscosity because it has greater fineness than LSP. However, the LSP reduced the viscosity of mortar. To prevent too high and too low viscosities of SCM, a new mineral additive type (LFP) was developed by combining the 66.7% of LSP and 33.4% of FA. The water demand of LFP is higher than that of LSP and, is lower than that of FA (Table 2). The effect of SP content on relative slump flow of SCM with LFP is shown in Figure 5. The relative slump-flow of SCM was decreased by using LFA mineral additive compared to SCMs that were produced with LSP. However, the slump flow area increased when it was compared with the slump flow area of SCM with FA. For a 0.33 w/p ratio, relative slump flow slightly increased with increasing SP content. SF area increased from 0.5 - 7 by increasing SP dosage from 1 - 2.5%. However, it reached values 5 - 16 by increasing the SP content from 1 - 2.5% with a w/p ratio of 0.43. WMP is similar to LSP in terms of surface structure and fineness. Thus, low viscosity is obtained with a high w/p ratio and SP dosage in SCM with WMP (Figure 6). Also, the highest SF area was obtained as 20 with SP content and a w/p ratio of 2.5% and 0.47, respectively. For a 0.44 w/p ratio, SF area increased from 5 - 13 when the SP content was increased from 1 - 2.5%. With the same SP content, the relative SF reached from 1 - 9. Like other mineral additives, the relative SF of SCM mixes with WSP in 0.35 w/p ratio changed slightly with an increase in the SP dosage. Among the mineral additives used in this study, BP has the highest effect on the viscosity of SCM because of its rough surface texture and high β_p value. Hence, the initial w/p ratio of SCM with BP was 0.4. From Figure 7, it can be seen that relative SF values for SCM with BP were obtained in higher w/p ratios than other fillers. This is probably because the brick powder (BP) is clay based. The clay-based BP mineral additive affected the viscosity by entrapping mix water and it requires more water than LSP, FA and WMP. Moreover, SP should be absorbed by BP in the lowest w/p ratio because of the high water demand. Thus, the friction between the aggregate and the cement paste surface should be increased.

There was a good relationship between relative SF and SP dosage for all w/p ratios. When the SP content increased, relative SF values also increased, similar to other fillers. Generally, it can be seen that mixtures containing FA and LSP showed better flow capability and deformability than BP. On the other hand, incorporating LSP and FA as fillers balanced the flow of SCM compared to the use of LSP or FA in the SCM mixtures. Moreover, increasing the amount of SP improved the slump flow or workability of the mortar mixtures. One of the important findings of this study is that it is possible to produce SCC with standard quality. However, any characteristic properties of materials such as humidity, water content, mineral additive type and water requirement can affect the properties of SCC. In order to achieve successful mix design of SCC, the powder type and w/p ratio, mentioned and explained above, may be

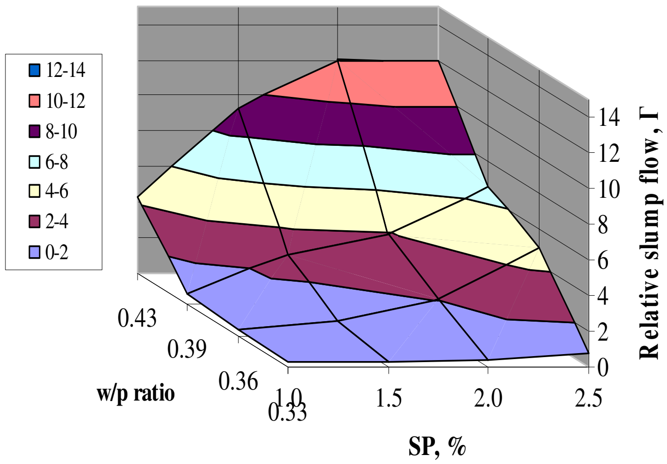

Figure 5. Relative slump-flow of SCM with LFP versus admixture.

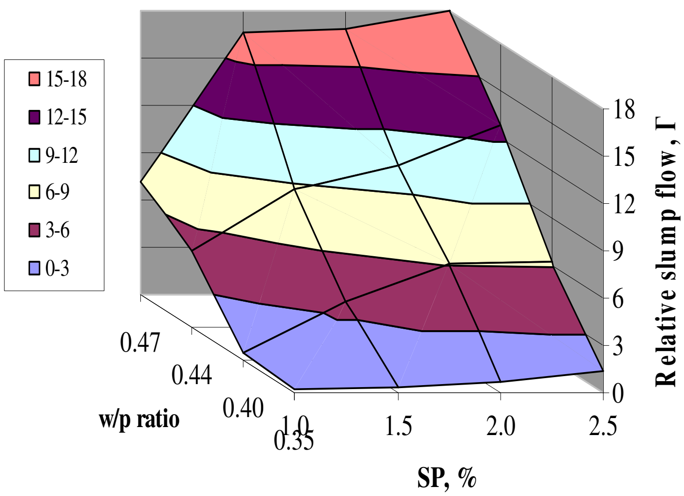

Figure 6. Relative slump-flow of SCM with WMP versus admixture.

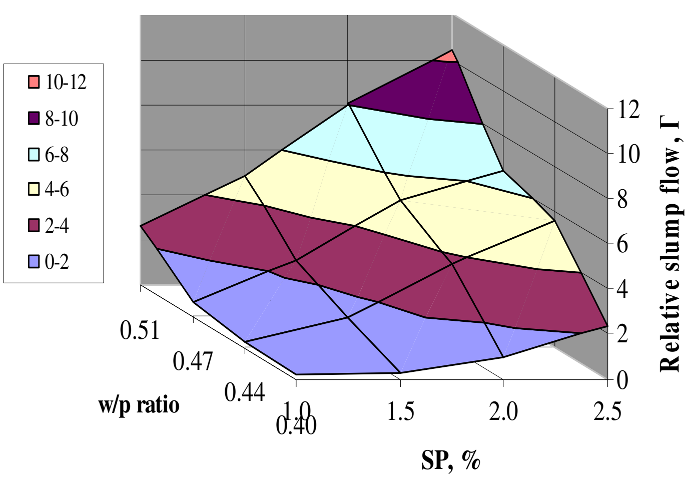

Figure 7. Relative slump-flow of SCM with BP versus admixture.

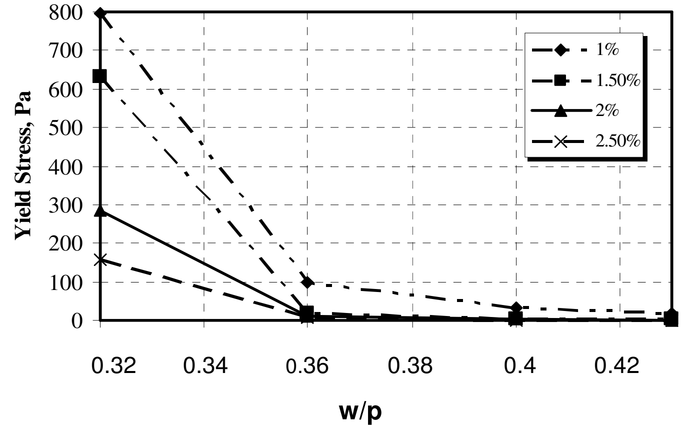

Figure 8. Yield stress of SCM with LSP relating with w/p.

used for selecting SP dosage.

Effect of mineral additive type on yield stress

The yield stress of SCM containing different powder types was determined using the asymptotic flow regime approach which depends on slump-flow value. Results showed that the yield stress effectively depends on material properties e.g. powder type, w/p ratio and SP dosage in the mixes. The yield stress of SCM with LSP is given in Figure 8 in relation to the w/p ratio. Increasing the w/p ratio resulted in lower yield stress, regardless of SP content. When SP dosage was considered, the yield stress of SCM decreased with an increase in SP. However, the influence of SP on the yield stresses of SCM was reduced with high w/p ratios. This may be explained by the loss of the flow-effect of SP in high w/p ratios. The highest yield stress was observed at the lowest SP content and the lowest w/p ratios.

On the other hand, the yield stress significantly decreased to “0” with an increase of the w/p ratio from 0.32 - 0.43 for all SP dosages, except for 1%. In the case of 1% SP content, the yield stress value decreased from 600 - 25 Pa with an increase of w/p ratio from 0.32 - 0.43. However, the yield stress of SCM with LSP ranged from 100 - 0 Pa with the same w/p ratios. As seen in Figure 9, when FA has been used as filler in the SCM, the yield stress was increased from 25 - 900 Pa with a decrease in the w/p ratio from 0.47 - 0.36 with an SP content of 1%. In the case of 1.5% SP content, the yield stress of SCM decreased to 450 Pa with the lowest w/p ratio. However, the increment of w/p ratio had a greater effect than SP dosage to reduce of yield stress. SP content of 1% was not adequate for flow to mortar. On the other hand, except for 1% SP content, the SP lost its effect on the mortar for flow with w/p ratios greater than 0.43. When the yield stress approaches "0", mortar segregates due to very low viscosity. Hence, a w/p ratio over 0.43 is not

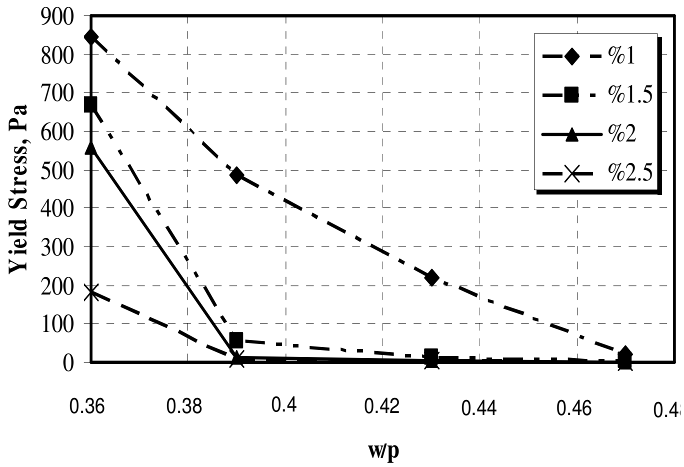

Figure 9. Yield stress of SCM with FA relating with w/p.

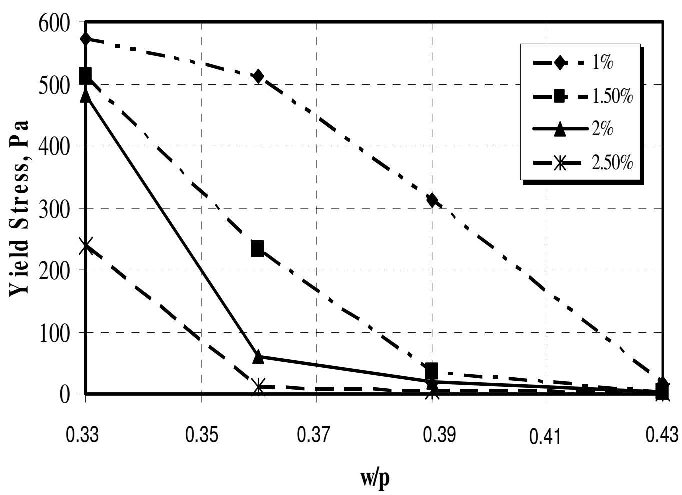

Figure 10. Yield stress of SCM with LFP relating with w/p.

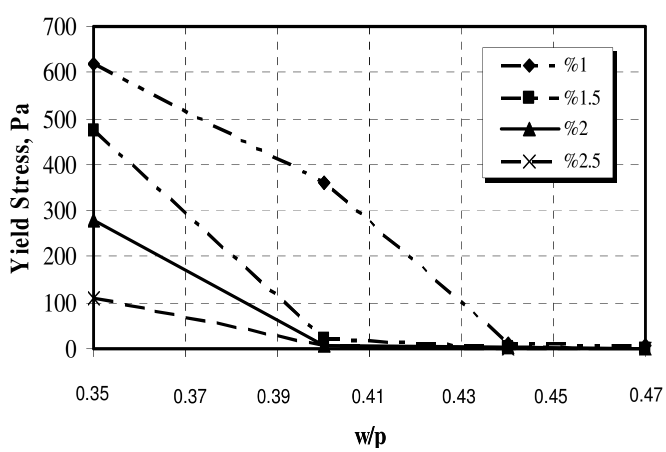

Figure 11. Yield stress of SCM with WMP relating with w/p.

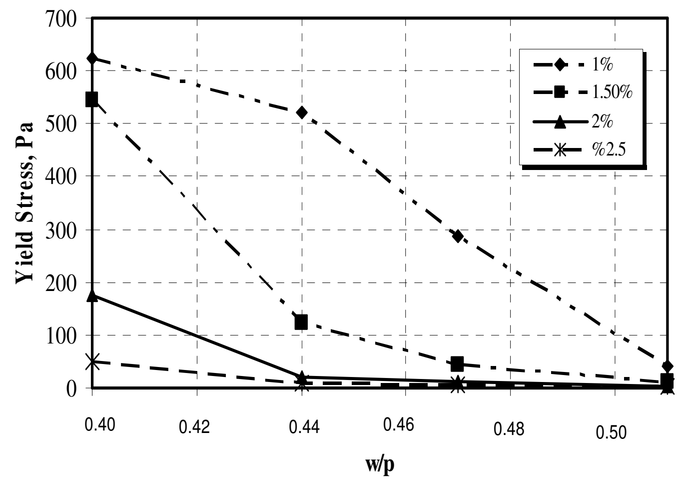

Figure 12. Yield stress of SCM with BP relating with w/p.

useful for successfully designing SCM with FA.

When the yield stress of SCM with LFP is considered (Figure 10), the highest yield stress was obtained with a w/p ratio of 0.33 and 1% SP content. The highest yield stress was observed with a w/p ratio of 0.32 and 0.36 for LSP and FA, respectively. For a 0.36 w/p ratio, the yield stress of SCM produced with LFP decreased to 350 Pa in 1% SP content. With the lowest w/p ratio, the yield stress obtained is 100 Pa with 2.5% SP. As mentioned before, the yield stress of SCM is significantly reduced with an increasing w/p ratio. Finally, the yield stress of SCM with WMP and BP are presented in Figure 11 and 12, respectively. The SCM with WMP has similar yield stress values when compared to LFP. However, the LFP has lower w/p for the same yield stress value of SCM with WMP. On the other hand, an increase in the w/p ratio from 0.43 - 0.47 with 2 and 2.5% SP content resulted in excessive bleeding and segregation of mortar. It was mentioned above that the SCM with BP has much lower slumped flow with a higher w/p ratio than SCMs produced with other powder types in same SP content. However, the yield stress of SCM with BP is close to or lowers than that of other powders. This occurs because SCM produced with BP has lower unit weight, and also has higher w/p ratios than other SCM's, which is primarily due to the high water demand of BP (Topçu et al., 2007). Including relative slump-flow, these figures can be used for defining the yield stress of SCM designed with different powder types, SP contents, and also w/p ratios in construction site.

Conclusions

In the present study, the effects of mineral additive type on the relative slump-flow and yield stress were studied to improve successful SCM design, especially on construction site. Several conclusions can be drawn from this study.

The minimum water requirement (β_p) to surround powder particles with water is affected by shape, surface texture and structure of powder. Furthermore, the physical influence of mineral additives depends on mixture parameters, such as super-plasticizer dosage and w/p ratio. Brick powder reduces the relative slump-flow. When all the figures for yield stress are considered, it can be seen that a strong relationship is observed between yield stress and w/p ratio for all amounts of SP content. Moreover, the w/p ratio is enhanced for similar yield stress, compared to that obtained with other powders. The yield stress is reduced and flow-ability is increased significantly in all SCM that contain different mineral additives by increasing the w/p ratio and SP content. There was a strong relationship between relative slump flow and SP content, and between yield stress and w/p ratio. The figures given in the present study may be used to design the desired SCM.

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