Effects of Sand/Binder Ratios on the Mechanical Properties of Mortars Containing Fly ash and Silica fume

Park, Ki Bong* Lee, Han Seung**

ABSTRACT

The paper presents details of an investigation into the effect of sand content upon the strength and shrinkage of mortar. This strategy was to produces more durable strength mortar with less cement. Cement mortars containing 20 wt. % Class F fly ash, and/or 6 wt. % silica fume were prepared at a water/binder ratio of 0.45 and sand/binder ratios of 2.0, 2.5, 2.7, and 3.0. The increase in sand/binder ratio caused a decrease in the mortar flow. However, the sand/binder ratio did not affect the strength development. Drying shrinkage decreased with increasing the sand contents.

1. Introduction

The need to use less energy in the overall construction process and to produce less greenhouse gases is imperative. Cement production is one of the world's most energy intensive industries. Global carbon dioxide (CO_2) emissions from cement production were approximately 829 million metric tons of CO_2 in 2000[1], about 3.4 % of global CO_2 emissions from fossil fuel combustion and cement production. To use less cement, there are several choice in the concrete technology. One of the most popular choice is to use the mineral admixture as a cement replacement. Another one is to use less cement in concrete. This study presents details of an investigation into the effect of sand content upon the strength and shrinkage of mortar.

2. Experimental procedure

The materials used in this study were prepared using Type I Portland cement, Class F fly ash, and silica fume. The chemical compositions of cementitious materials used are given in Table 1. The sand was perfectly dried in chamber prior to use. The mortar specimens were prepared with a constant water to binder ratio of 0.45 and sand to binder ratio of the mortars was varied in the range from 2.0 to 3.0. The binary and ternary blends mortars were prepared with 20 wt. %, Class F fly ash, and/or 6 wt. % silica fume. All the mortar mixtures were mixed with following the ASTM C 192 procedure. The mixed mortars were tested for measured using a flow table in accordance with flow (ASTM C 1437), compressive strength (ASTM C 109), flexural strength (ASTM C 348), and drying shrinkage (ASTM C 490).

*Member, Rensselaer Polytechnic Institute Post-Doctoral Researcher
**Member, Hanyang University Assistant Professor

Table 1 Chemical composition of cementitious materials

	Cement	Fly ash	Silica fume
Density, g/cm3	3.16	2.27	2.2
Blaine fineness, cm2/g	3670	3890	-
Loss of ignition, %	1.3	3.95	-
SiO2, wt.%	20.5	47.89	92~98
Al2O3, wt.%	4.9	23.34	0.5
CaO, wt.%	63.0	3.41	0.8
MgO, wt.%	3.5	-	0.3
SO3, wt.%	2.9	0.58	0.2
Na2O equiv, wt.%	0.57	-	0.1
Fe2O3, wt.%	-	18.51	2.1

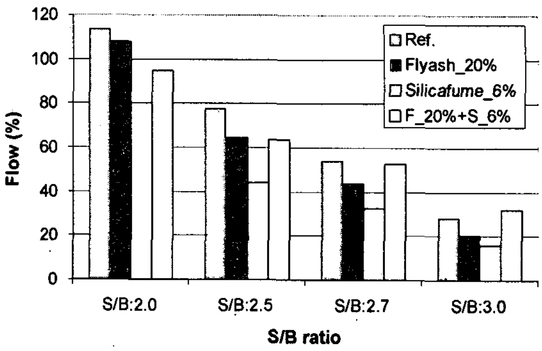

Fig. 1 Flow of mortar

3. Result and Discussion

Fig. 1 shows flow plotted against sand content in mortar with mineral admixtures. The increase of sand/binder ratio caused a decrease in the mortar flow. This results because an increase of the sand content translates into a decrease in overall water to solid ratio leading to a reduction in flow. Krell[2] reported that the flow spread was larger for increasing paste layer thicknesses as the paste acts as a lubricant for the aggregate particles. The paste layer thickness decreases with and increase in the number density, surface area, and diameter of the aggregate. Higher sand contents in the mixture increase the bulk density of the aggregate and this results in a decrease in the packing density. The decrease in packing density translates into an increase in the voids ratio, that is, the ratio of the volume of voids between the aggregate particles to the bulk volume occupied by the aggregate[3]. Thus, at higher sand contents, the voids ratio will be increased and the cement paste may not sufficiently fill the voids between the aggregate particles. Kaplan[4] reported that for a given mix proportion, the workability of the concrete decreases with an increase in the voids ratio. Similar results are shown for the flow with binary and ternary blended cement mortars. The flow testing results also show the effect of mineral admixtures containing fly ash and/or silica fume. The flow of mortar with fine mineral admixtures was lower than that of plain portland cement mortar though the water/binder ratio was held constant for all mixtures. It is well known that, if the volume concentration of solids is held constant, the addition of mineral admixtures improves mortar performance but reduces workability. This results because the addition of mineral admixtures increases the number of fine particles in the mix. The presence of these fine particles increases the density of the matrix and the surface area of the mixture. Both will affect the water distribution in the matrix and hence the flow. The increase in surface area results in an increase in water demand since more water is required to saturate the surface of the particles. The amount of adsorbed water in surface layer is proportional to the surface area of system. The addition of fine mineral admixtures increases water demand due to an increase in the surface area and so the addition of fly ash or silica fume particles should decreases the flow. However, the flow of our mortars made with ternary blend cements was higher than that of binary blends cement. This might be related to the packing density and shape of the fine particles.

Table 2 shows the effect of sand content on the strength development. We usually expect that a high sand/cement ratio leads to a reduction in the strength development comes from the hydration of cement. Another concern, if increasing volumes of a sand in a dry state are added to a cement paste, the absorption of water will reduce the free water/cement ratio and the consequent decrease in strength. However, in this experiment with a water to cement ratio of 0.45, the amount of sand does not significantly affect the strength development. We attribute this to more effective mixing of the water and a solid material so that the final mortar and cement hydration is more uniform. Table 2 also shows the strength development of mortar mixes using various combinations of portland cement, Class F fly ash, and silica fume. Adding fly ash decrease the strength of mortar at all ages tested so far, but should contribute to an enhancement of long-term strength. The addition of silica fume did not affect the strength development but mortar containing silica fume appeared to increase in strength with sand to binder ratio. When the ternary blend cements were used as a cement replacement, 20 wt.% of fly ash and 6 wt.% of silica fume, the rate of strength development at early ages was similar to fly ash addition alone, but after 7 days the strength had significantly increased and was comparable to cement alone blends. The combination of fly ash and silica fume in a ternary cement system should result in a number of synergistic effects contributing to strength development. We generally understand that incorporating fly ash leads to a delay in strength development and that silica fume compensates for the low, early strength of mortar incorporating fly ash. Thomas et al.[5] reported that the combination of silica fume and low CaO fly ash, at water-to-cementitious material ratios ranging from 0.26 to 0.35:1, results in concrete with improved early age and long-term strength. However, Khan et al.[6] pointed out that the strength development will change with each different combination of cement replacements and that the strength was reduced in ternary blended system. In Table 2, for ternary blended mortar with fly ash and silica fume, the compressive strength is significantly lower than the control mortar prior to 28 days and then the strength of the ternary

Table 2 Compressive strength, Flexural strength, and Drying shrinkage data

Series	S/B	Compressive / Flexural strength (MPa) / Drying shrinkage (10-6)		
		3 days	7 days	28 days
Ref.	2.0	49.6 / 11.2 / 197.3 (1days)	60.3 / 12.8 / 866.7	73.5 / 13.7 / 1053.3
	2.5	51.3 / 11.5 / 197.3 (1days)	62.6 / 13.1 / 797.3	74.1 / 14.0 / 949.3
	2.7	52.8 / 11.2 / 200.0 (1days)	60.3 / 11.5 / 736.0	74.1 / 13.4 / 930.7
	3.0	49.8 / 11.5 / 226.0 (1days)	58.6 / 12.2 / 720.0	75.1 / 13.4 / 896.0
FA-20%	2.0	36.5 / 11.5 / 216.0 (1days)	45.9 / 13.7 / 792.0	63.5 / 13.7 / 1037.3
	2.5	37.1 / 11.2 / 221.3 (1days)	49.5 / 13.4 / 736.0	66.1 / 13.7 / 970.7
	2.7	37.1 / 9.7 / 237.2 (1days)	49.4 / 12.2 / 712.0	62.6 / 13.1 / 898.7
	3.0	38.0 / 9.7 / 232.0 (1days)	49.2 / 12.2 / 669.3	63.5 / 13.1 / 832.0
SF-6%	2.0	45.2 / 10.9 / 194.7 (1days)	52.9 / 13.7 / 810.7	75.0 / 15.6 / 1221.3
	2.5	47.4 / 11.8 / 229.3 (1days)	57.9 / 14.6 / 741.3	76.7 / 15.9 / 1053.3
	2.7	47.3 / 11.8 / 213.3 (1days)	61.2 / 14.6 / 744.0	78.7 / 16.5 / 1034.7
	3.0	49.0 / 11.8 / 218.7 (1days)	62.3 / 14.0 / 680.0	80.7 / 17.1 / 954.7
Ternary	2.0	34.0 / 9.4 / 200.0 (1days)	45.7 / 11.2 / 914.7	68.1 / 13.4 / 1200.0
	2.5	36.0 / 9.7 / 197.3 (1days)	46.9 / 11.8 / 840.0	73.0 / 15.9 / 1072.0
	2.7	36.5 / 10.0 / 213.3 (1days)	48.8 / 11.5 / 802.7	72.4 / 15.3 / 1018.7
	3.0	37.0 / 10.0 / 226.7 (1days)	49.2 / 11.2 / 749.3	71.8 / 14.6 / 944.0

mixture is almost same as the strength of the control mortar at 91 days. Table 2 also shows the result of the flexural strength testing. The results show that for the mortar mixtures made with silica fume and for ternary blend cements, a significant increase in flexural strength at 28 days occurred, whereas the use of 20 % fly ash alone did not affect the flexural strength significantly. Flexural strength is related to an increase in surface energy and interparticle bonding upon drying[7]. The flexural strength increased as the moisture content decreased. Based on this hypothesis, the flexural strength of mortar made with high sand to binder ratio should decrease due to the poor interparticle bonding. However, the addition of silica fume improved the flexural strength development with an increase of surface energy and interparticle bonding force.

Table 2 shows the drying shrinkage results of mortar. As expected, the drying shrinkage of mortar with high sand/binder ratio decreased. The role of sand in mortar tends to restrain the shrinkage of cement paste. Consequently, the drying shrinkage of mortar is about 1/4 of that of cement paste. The relationship between the aggregate contents and the drying shrinkage is described by Pickett's equation[8], $\epsilon = \epsilon_p(1 - V_s)^{\alpha}$; ϵ= the shrinkage of mortar, ϵ_p= the shrinkage of paste, V_s= the volume ratio of sand and α is an exponent specific for each mortar blend. The equation shows that the shrinkage of mortar decreases with an increase in the sand content. The binary mixtures exhibit higher shrinkage and the ternary blend cement mortar reduced the shrinkage.

4. Conclusion

The increase in sand/binder ratio caused a decrease in the mortar flow. However, the sand/binder ratio did not affect the strength development. Drying shrinkage decreased with increasing the sand contents. The flow of mortar with fine mineral admixtures was lower than that of plain portland cement mortar. The binary mixtures exhibit higher shrinkage and the ternary blend cement mortar reduced the shrinkage.

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