A comparision between plastic shrinkage of concrete containing silica fume and the normal concrete

P. Ghoddousi[1], **A.M. Raiss ghasemi**[2], **T. Parhizkar**[3]
[1] Assistant Professor, Science and Technology University of Iran, Researcher in Building and Housing Research Center
[2] Researcher of concrete section, Building and Housing Research Center
[3] Assistant Professor and deputy of Building and Housing Research Center

Abstract: *Plastic shrinkage is one of the most important parameter which must be considered in hot weather concreting. If plastic shrinkage is not prevented, cracking will be significant, especialy if silica fume is used in the mix. In this paper, the effect of silica fume in bleeding and evaporation was investigated in laboratory. The results showed that in restrained shrinkage, beside relative humidity, temperature and wind velocity, sun rediation also is very important factor in evaporation rate. It is found that under solar radition condition, the evaporation was much larger than the estimated value in ACI 305 Nomogram. The rate of evaporaion under solar radiation was about two folds of evaporation rate under shade condition.*

The results showed that in terms of crack initiation time, crack width and total cracking area, concrete containing silica fume is more severe than concrete with no silica fume. Reduction of water cement ratio in concrete with silica fume makes the concrete more sensitive in cracking. The results of this project also showed that the severity of the cracking is not related only to rate of bleeding but all environmental factors including like sun radiation or shading and also mix compositions have important roles.

Keywords: *Plastic shrinkage, Cracking, Concrete containing, silica fume, Environmental conditions.*

1. Introducttion

Plastic shrinkage is the shrinkage that occurs in fresh concrete during the first few hours after it has been placed; that is, while the concrete is still plastic and before it has attained any significant strength. The principal cause of plastic shrinkage cracking, is an excessively rapid evaporation of water from the fresh concrete. Plastic shrinkage and cracking are likely to occur if the rate of evaporation exceeds the rate at which bleeding water rises to the surface [1].

Estimation of evaporation loss from fresh concrete is most commonly done by reffering to the graphical method given by ACI 305R [1]. This committee suggests that when the rate of evaporation is 1 kg/m^2/h and above that, the surface of concrete will crack. While the ACI nomogram is a useful tool for prediction for plastic shrinkage cracking of ordinary concrete, but at what evaporation rate which concrete containing pozzolans like silica fume will crack is not considered in ACI nomogram.

There are many works on plastic shrinkage of the mixes containing fibers [2,3], but limited studies were with mixes without fibers[4,5,6]. Samman et al [4] reported data on plastic shrinkage of high-strength concretes. They found that the “single value” critical evaporation rate can not be used to predict cracking of high-strength concrete. Their research showed that high-strength concrete mixes containing high proportions of cement produced concretes with low bleed rates and subsequently high susceptibility to plastic shrinkage cracking. Samman et al [4]

Table 1 Chemical analysis of Portland cement and silica fume

Chemical analysis	Portland cement %	Silica fume %
SiO_2	20.96	91.1
Al_2O_3	4.2	1.55
Fe_2O_3	4.6	2.00
CaO	61.88	2.24
MgO	3.4	0.60
NaO_2	0.5	-
K_2O	0.4	-
Ignition Loss	1.74	2.10
Free lime	0.84	-
SO_3	1.79	0.45

concluded that the prediction of plastic shrinkage cracking it is not associated with only using 1 kg/m^2/h evaporation rate. Hasanian et al [5] studied the effect of solar radiation on evaporation rate. They reported that, shading concrete from direct, intense sun can reduce evaporation by as much as 50 percent. But research by Van Disk and Boardman [6] indicated that while radition raises the temperature of the surface of the concrete and rate of evaporation, it also induces accelerated hydration of the cement and thus strengthes the concrete surface. Due to this phenomenon they indicate that slabs cast in the sun.

Restrain shrinkkage is also another factor which makes the concrete more succeptible to cracking. Restraint stresses are strongly influenced by the geometry and restraint conditions of the actual concrete placement and also by the materials and environmental variables [7].

Much research has been carried out regarding the plastic shrinkage cracking of concretes. However, only very limited work has been done to to assess plastic shrinkage of concrete containing silica fume in hot environment. This paper reports the results of a study undertaken to investigate the effects of environment condition on the restrained plastic shrinkage cracking of concretes with and without silica fume.

2. Research Significance

The restrained plastic shrinkage cracking of high strength concrete mixtures are shown to be influenced by the evaporation rate much less than known critical value of 1 kg/m^2/h. The objective of the research program was to evlauate the effects of different exposure condition on the rate of concretes made with silica fume.

3. Experimental Program

The cement was ordinary portland cement conforming to the requirements of ASTM C 150 (Table 1). The coarse aggregate was 19 mm maximum size crushed limestone. The fine aggregate was a mix of river sand and crushed type which its grading is given in Figure1.

3.1 Mix Proportions

Two series of concrete were made, the series

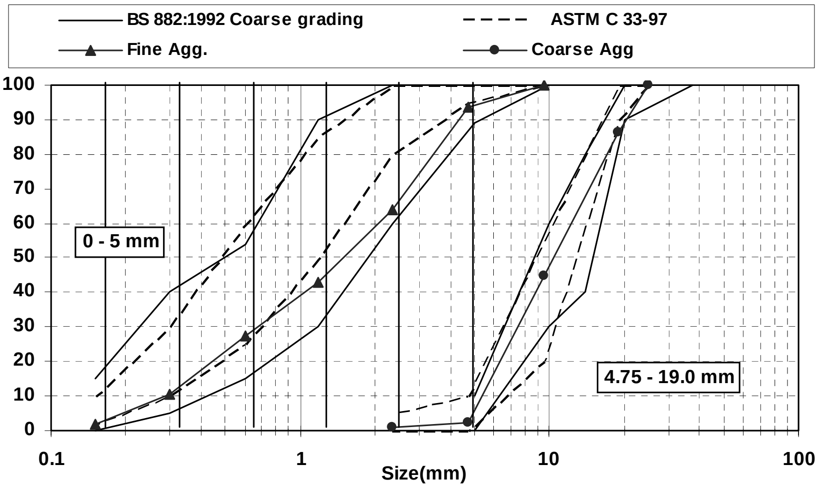


Fig.1 The grading curve of Coarse and fine aggregate

Table 2 Details of 12 mixes

Mix designation	**Cement content (kg/m^3)**	**Silica fume (kg/m^3)**	**Fine aggregate (kg/m^3)**	**Coarse aggregate (kg/m^3)**	^{W}/Cem	**Superplasticizer (% cementious)**
C42	400	0	830	927	0.42	0.20
M42	372	28	830	927	0.42	0.60
C40	400	0	827	933	0.40	0.50
M40	372	28	827	933	0.40	1.0
C55	400	0	863	797	0.55	0
M55	372	28	863	797	0.55	0
C65	400	0	885	723	0.65	0
M65	372	28	885	723	0.65	0

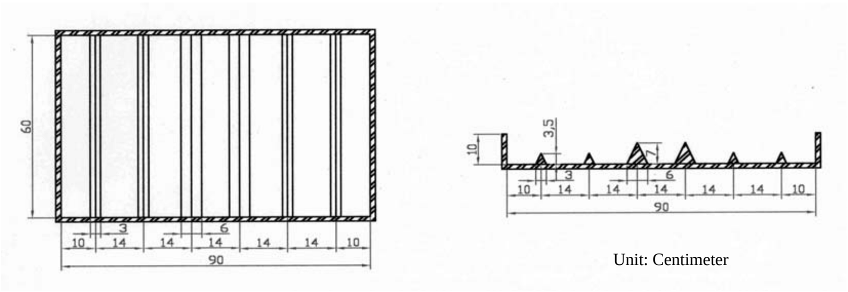
1 consisted mixes were made with portland cement and silica fume and the series 2 were made with portland cement. Details of the mixes are given in Table 2.

3.2 Restrained Plastic Shrinkage Test Technique

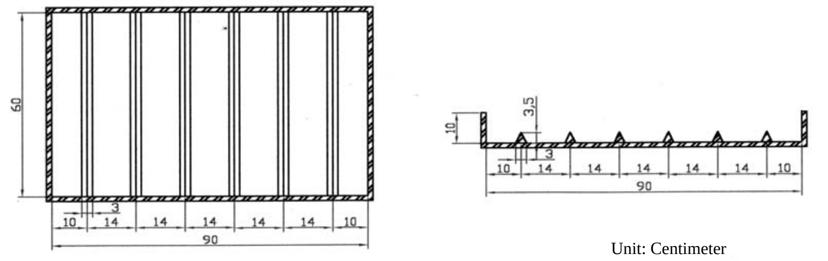
The restrained plastic shrinkage test which was adopted for this investigation uses risers to produce restraints to promote the formation of cracks. Two sets of slabs were tested. In the first set of slabs, the size of the risers were unequal, and the second set of slabs were made with equal size of risers. Figure2 shows the test specimen and restraint conditions. The molds were made from plywood with 100 mm thick and 600 by 900 mm dimensions. These slabs are similar to those used in refrences [4] and [7].

To monitor the weight of waterlost or evaporation rate from the concretes during the test, two 100′200 mm panels were placed adjacent to the slabs.

Concrete was mixed in a 250 Lit pan-type mixer for 5 minutes. Then concretes were placed to the forms and leveled with wooden straight edge. After the completion of leveling, the slabs transported and placed to



a) plan View Section



b) plan View Section

Fig.2 Restrained plastic shrinkage test specimens
a) with unequal risers, and b) with equal risers

Table 3 Exposure conditions for different panel tests

Mix designation	Exposure condition	Panel designation	Air temperature (°C)	Relative humidity (%)	Wind (Km/h)
C 42	Field - Shade	CS	38 to 40	24 to 25	0 to 3
M 42	Field -Shade	MS	38 to 42	24 to 26	0 to 3
C 42	Field-Solar radiation	CH	28 to 31	28 to 29	0 to 5
M 42	Field -Solar radiation	MH	29 to 31	27 to 29	0 to 3
C 42	Field -Laboratory	CL	25 to 27	28 to 30	0
C 40	control	C 40	40	20	12
C 40	control	C 40	40	20	12
C 55	control	C 55	40	20	12
C 55	control	C 55	40	20	12
C 65	control	C 65	40	20	12
C 65	control	C 65	40	20	12

the exposure conditions.

3.3 Exposure Conditions

In this work, two different exposure conditions were used. In field exposure, the slabs were placed in an exposure site under the natural hot-weather environment, where the temperature and relative humidity varied naturally. Therefore, the rate of evaporation were different in the mixes. Other exposure condition was in the laboratory (controlled exposure), therefore the evaporation rate was constant which was 1 kg/m^2/h.

3.4 Test Procedures

Crack width : Crack width on the surface of

Table 4 Plastic shrinkage observations from panels tests in Field Exposure

Slabs designation	Maximum rate of evaporation ($kg/m^2/h$)	Rate of evaporation according to ACI ($kg/m^2/h$)	Crack initiation time (min.)	No. of cracks	Crack width (mm)	Cracking area (mm^2)
CS	1.27	0.3	60	2	0.72	864
MS	1.40	0.4	45	2	0.43	516
CH	0.65	0.4	75	2	0.84	1008
MH	068	0.4	65	2	0.72	864
CL	0.24	0.2	205	1	0.50	300

concrete was measured by hand microscope. Cracking area : Cracking area was calculated by measured length divided by crack width. Amount of evaporation : Cumulative water loss of the panels was measured at any given time by measuring the weight of panels.

Amount of bleeding : The amount of bleeding at any given time was measured complied with ASTM : C 232 [8] by the means of pipet. The measurement was made on the panels 200´100 mm. In order to reduce the evaporation to minimume, the specimens were kept in the room with relative humidity of 100% and 20°C.

4. Test Results And Discussion

4.1 Variable Evaporation Rates (Field Exposure)

Table 4 compares rates of evaporation and crack characteristics of different mixes in Field Exposure. Values of maximum rate of evaporation are higher under solar radiation exposure. The rates of evaporation under solar radiation are almost double of the values under shade exposure. Average rate of evaporation under solar radiation was about 1.34 $kg/m^2/h$, but average rate of evaporation exhibited 0.66 $kg/m^2/h$ under shade condition this results confirm the found of Hasanain et al [5].

The crack width and cracking area of the slabs under solar radiation exposure were less comparing to the slabs at shade condition. This found is verification of the results obtained by Van Dijk and Boardman [6]. Comparing the measured rates of evaporation and the predicted values from ACI nomograph, Shows that the values of ACI nomograph are much less than measured value. The difference in values are more noticeable for panels under solar radiation condition. As an example, for panel MS, the measured value 1.40 $kg/m^2/h$, but the estimated value was 0.4 $kg/m^2/h$. Therefore, solar radiation has two opposite effects, which are increasing evaporation rate and at the same time, the tensile strength of concrete may be increased. The result of these two opposite effect, from cracking point of view, makes the solar radiation less sever than shading condition. Hence, even ACI Nomogram did not consider solar radiation effect, but using this Nomogram is safe from this respect.

But for panel exposed under laboratory condition, the both values of measured and estimated are almost equal (0.24 comparing to 0.2 $kg/m^2/h$). In other words, ACI nomograph does not include solar radiation as a variable. Therefore appreciable error in predicted evaporation rates can be introduced by using ACI nomograph. On the other hand,

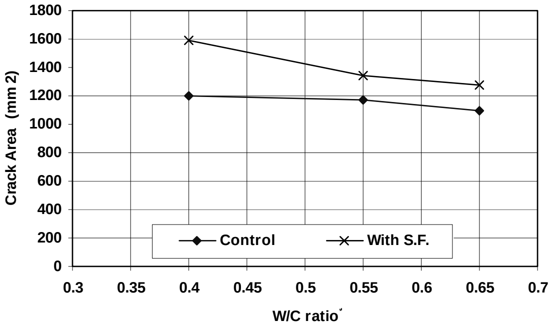


Fig.3 Relationship between w/c and cracking area for mixes made with silica fume and without silica fume

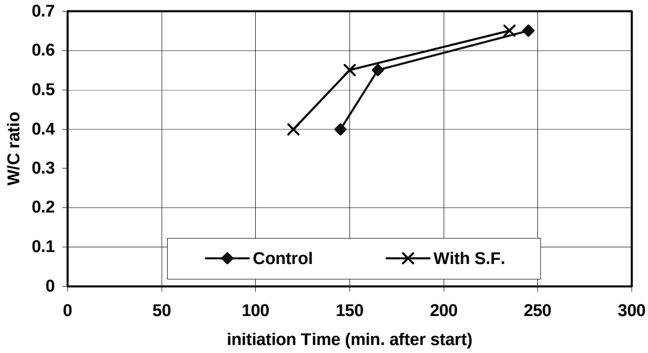


Fig.4 The effect of w/c on crack initiation time for mixes made with silica fume and without silica fume

when the panels are under restrained shrinkage, the threshold value for initiation cracking may not be1 kg/m^2/h has specified by ACI. As the results in table 3 howed that the pannels CH, MH and CL cracked in much lower rate of evaporation of 1 kg/m^2/h.

The table 3 also shows that the concretes made with silica fume (panels MH and MS) exhibited smaller cracking width and cracking area comparing to the concretes without silica fume (panels CS and CH). That may be attributed to higher tensile strength of of concretes containing silica fume. But the crack initiation time in concretes made with silica fume was shorter than concretes without silica fume.

This can be due to smaller bleeding rates of concretes made with silica fume. Therefore in panels with restraint condition, there is no prove that concretes with silica fume are more susceptible to cracking comparing to concretes with no silica fume.

4.2 Constant Evaporation Rate

In this series of tests, the rate of evaporation kept constant at 1 kg/m^2/h under control condition. Figure 3 shows the relationship between w/c and cracking area. As it can be seen, cracking area increased with decreasing w/c.

The figure 3 also shows that mixes made with silica fume are more susceptibile to cracking. Figure 4 shows the relationship between w/c and crack initiation time. As it can be seen with increasing w/c, the time of cracking is increased.

Figure 4 also shows that the initiation time of cracking for mixes with silica fume are shorter than mixes without silica fume. This found complies the results of the table 3.

But at first sight it may be seem that results of Figure 3 oppose the results of Table 3. As

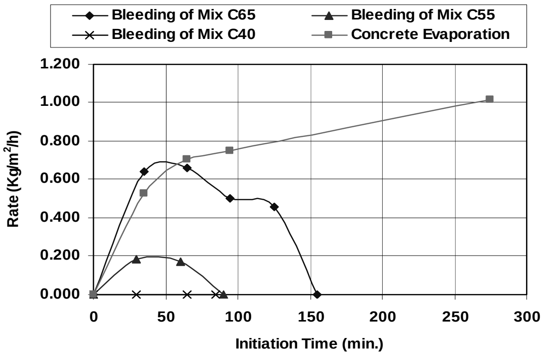


Fig.5 Relationship between rate of bleeding and rate of evaporation with time for mixes without silica fume

in Figure 3 shows, mixes with silica fume are more susceptible, which results of table 3 does not exhibit similar results.

The reasons for this phenomenon may be attributed to results in Figure 5.

Figure 5 shows the rate of bleeding and rate of evaporation with time for mixes without silica fume. For better comparison, the results of mixes with silica fume are omitted, to make the clear picture of results. However, the rate of bleeding of mixes with silica fume were 20 to 40 percent lower than corresponding mixes. The results of figure 5 indicate that bleeding time is important factor for cracking. According to the work of Cabrera et al [9], mixes exhibiting a longer bleeding time also exhibited later achievement of the initial high capillary pore pressure value. Because plastic shrinkage of concrete has been attributed to capillary stress. Therefore mixes showed longer bleeding time exhibited longer initiation time of cracking and also lower cracking area. In other words, the threshold value of 1 kg/m^2/h can not be the only criterion. Also, the statement which says that when rate of evaporation is more than rate of bleeding is not true at all situations. But, the total amount of bleeding and duration of bleeding also are influencing factors in cracking.

On the other hand, the results of series 2 panels showed that mixes with silica fume are more susceptible than mixes without silica fume. This can be attributed to higher wind velocity in this series of tests. Higher wind velocity (12 km/h) makes rate of evaporation to reach to the higher value in shorter time. Therefore, before the mixes with silica fume gains enough tensile strength, the rate of evaporation reaches to the higher value in a very short time.

Therefore to assess the susceptibility of a particular concrete placement to plastic shrinkage cracking, all the influential factors should be considered.

5. Conclusions

The conclusions which follow are drawn entirely from the experimental results obtained from this study to date:

The effect of solar radiation is not included in ACI nomograph for predicting evaporation rates. The rates of evaporation under solar radiation condition were more than double of the values under shade exposure.

When the shrinkage is restrained, the threshold value for initiation cracking is not 1 kg/m^2/h as specified by ACI . The results showed that cracking can occur in much lower rate of evaporation of 1 kg/m^2/h.

There is no prove that concretes with silica fume are more susceptible to cracking comparing to concretes. With no silica fume, when the plastic shrinkage is restrained. The concretes made with silica fume exhibited smaller cracking width and cracking area comparing to the concrete without silica fume were less than concretes without silica fume.

6. Acknowledgment

The authors gratefully acknowledge the support provided by the Building & Housing Research Center of Iran, for this research. This project was a part of National Project under name of Durability of Concrete in South of Iran.

7. References

[1] ACI 305 R-99, “Hot Weather Concreting “, Manual of concrete practice, part 2, American Concrete Institute, 1996.

[2] Christopher K. Y. Leung, M.ASCE; Augustus Y. F. Lee; and Raymond Lai, “New Testing Procedure for Shrinkage Cracking of Fiber-Reinforced Shotcrete”, Journal of Materials in Civil Engineering, Vol. 19, No. 3, March 1, 2007.

[3] Shao Y., Mirmiran A., “ Control of Plastic Shrinkage Cracking of Concrete with Carbon Fiber-Reinforced Polymer Grids”, Journal of Materials in Civil Engineering, Vol. 19, No. 5, May 1, 2007.

[4] Samman, T.A., Mirza.W.H, and Wafa, F.F., “Plastic Shrinkage Cracking of Normal and High-Strength Concrete : A Comparative Study “, ACI Materials journal, Jan-Feb, 1996, pp. 36-40.

[5] Hasanain, G.S., Khallaf, T.A., and Mahmood, K., “ Water Evaporation from Freshly placed Concrete in Hot Weather, “ Cement and Concrete Research, V.19, 1989, pp. 465-475.

[6] Van Dijk, J., and Boardman, V.R., “ Plastic Shrinkage Cracking of Concrete “, Proceedings, RILEM International Symposium on Concrete and reinforced Concrete in Hot Countries, Technion, Haifa, 1971, pp. 225-239.

[7] Soroushian, P., and Ranvanbakhsh, S., “ Control of Plastic Shrinkage Cracking with Specialty Cellulose Fibers “, ACI Materials journal, July-Aug. 1998, pp. 429-435.

[8] American Standards Tests Methods, C 232-2005, “ Standard Test Methods for bleeding of Concrete, “ ASTM, Vol 04.02, Philadelphia, 1992.

[9] Cabrera, J.G., Cusens, A.R., and Brookes-Wang, Y., “Effect of Super plasticizers on the Plastic Shrinkage of Concrete, magazine of Concrete RESEAR.