CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Concrete at its fresh state allows for the occurrence of plastic shrinkage whose principal cause is the excessive and rapid rate of evaporation and the inability or lack of bleed water to replace the evaporating water. When the rate of water loss due to evaporation exceeds the bleeding rate of water within the concrete matrix, negative capillary pressures form. This results to volumetric changes in the concrete before any significant strength is attained.

Plastic shrinkage cracks can occur in concrete slabs, pavements, and flatworks and has been known on occasion to penetrate the whole depth if not controlled. Unless these cracks are shallow and narrow, such cracks would weaken the structure and permit penetration of deleterious substances. Thus, controlling plastic shrinkage cracking would be needed in developing more durable and longer-lasting concrete structure at a minimum life-cycle cost.

Since the use of pozzolan is increasing in the concrete industry due to its ability to improve concrete properties, it would be possible that such materials could provide a means to control plastic shrinkage cracking. Pozzolan tested in this study were Mae Moh fly ash and pelletized silica fume. Fly ash contents of 0 to 50% replacement by weight of cement and silica fume contents of 0, 3, and 5% replacement by weight of cement were mixed with water/binder ratios of 0.30, 0.40, and 0.50. Specimens were tested in accordance with ASTM C 1579-06. Images of the specimens were taken and processed for crack quantification with the use of Image Analysis methods and equipments. Further analysis was done using statistical tools.

This study focused on evaluating the effects of pozzolan on the plastic shrinkage cracking of concrete. Based on the results obtained from tests, the following conclusions were made:

(a) Average crack width and maximum crack width values tend to increase as the amount of fly ash increased in concrete with water/binder ratio of 0.30 and 0.40. Such behavior was attributed to the decrease in the amount of bleed water which results in stiffer concrete pastes. This would result to higher pore pressure which affects plastic shrinkage and possibly increase crack width values.

(b) As the amount of fly ash in concrete increased, the average and maximum crack widths significantly decreased at a high water/binder ratio of 0.50. This behavior was due to high bleed rate and relatively pore sizes that led to a reduction in pore pressure in the fly ash concrete. An increase in the bleed water also causes delay on the appearance of plastic shrinkage cracks. Once all bleed water has evaporated, only then would the plastic shrinkage cracks start to form.

(c) Plastic shrinkage crack area decreased as the fly ash content used was increased as a result of particle packing effect of the fine fly ash particles. It was observed that greater crack area was present in stiffer and less workable fly ash concrete mixes. Cracks also became more discontinuous as the amount of fly ash used was increased thus resulting in a decrease in the calculated crack area. The increase in the amount of bleed water for fly ash concrete with high water/binder ratio also decreased crack area.

(d) Average crack width, maximum crack width, and crack area significantly decreased as the amount of silica fume increased. This was attributed to the micro filler effect of the silica fume particles that efficiently fills voids.

(e) The cracking reduction ratio was the measure for the effectiveness of the pozzolan in reducing plastic shrinkage cracks. Based on the analysis, fly ash replacements of 10-15 percent using water/binder ratio of 0.40 would effectively reduce plastic shrinkage cracking of concrete without compromising the compressive strength of concrete. On the other hand, the use of fly ash with water/binder ratio of 0.30 to control plastic shrinkage cracking would be ineffective.

(f) The use of silica fume effectively reduces plastic shrinkage cracking in concrete (with high water/binder ratio) as expressed by the cracking reduction ratio trend from analysis.

(g) The percent change in the reduction of crack area, maximum crack width, and average crack width for both fly ash concrete and silica fume concrete exposed to moist curing by wet burlap after 28 days were greater than the percent change of values for specimens exposed to air curing conditions. This indicated the importance of moist curing in controlling or further reducing plastic shrinkage cracks in pozzolan (fly ash or silica fume) concrete.

(h) The percent change in the reduction of average crack width, maximum crack width, and crack area after 28days of curing was greater in silica fume concrete specimens than fly ash concrete specimens. This was due the early pozzolanic reaction exhibited by silica fume which further enhanced the healing properties of silica fume concrete.

(i) From experimental observation, the use of 10-15% fly ash replacement for cement and water/binder ratio of 0.40 would reduce plastic shrinkage cracking without compromising compressive strength. For concrete mixes that require high water/binder ratios, it is recommended to use silica fume as replacement for cement in order to reduce plastic shrinkage cracking of concrete and still have high early compressive strength. Moist curing would also further reduce plastic shrinkage cracks.

(j) Image Analysis was a good means to collect and process data. It is both convenient and reliable since it took not longer than 80 seconds to process one specimen for imaging and quantification and analysis could be done later.

5.2 Recommendations

Recommendations for further studies are as follows:

(a) Testing could be done in a controlled room so as to be able to effectively control, if not keep constant, the atmospheric conditions. This study only somehow controlled the conditions inside the test chamber but since the test chamber itself is not completely sealed, then outside conditions would have had some effect in the specimens studied.

(b) Increasing the amount of test samples would further improve the trends. Due to time constraints, only 3 specimens per mix design were tested. Repeatability might improve the reliability of the results.

(c) Testing binary blends using other pozzolan such as metakaolin or glass powder might have some positive effects on plastic shrinkage cracking. Silica fume in other form, such as slurried silica fume, could also be tested for its effects on plastic shrinkage cracking.

(d) Testing ternary blends made of cement, silica fume, and fly ash could more present interesting effects on plastic shrinkage cracking than the binary blends studied in this research since ternary blends are known to offer significant advantages over binary blends and even greater enhancements over plain cement.

(e) Since plastic shrinkage cracks are known to occasionally penetrate whole depths of slabs, a means to investigate the behavior of plastic shrinkage cracks in terms of crack depth would be very useful.

(f) The ninety percentile crack widths and mean crack widths determined exceeded the tolerable crack widths per different exposure conditions suggested by ACI 224R. The values could imply the need to establish necessary precautions in using fly ash or silica fume (under similar environmental conditions and sufficient restraints) in controlling plastic shrinkage cracks without compromising the durability of the structural element (or even the whole structure itself) when exposed to different exposure conditions.