CHAPTER 10

CONCLUSIONS AND RECOMMENDATION

10.1 Conclusions

Considering the results obtained from this study, the following conclusions can be drawn:

1. Concrete was considered as a two-phase material comprising of paste phase and aggregate phase. However, shrinkage was regarded to occur only in the paste phase whereas the aggregate phase was considered to restrain the shrinkage by their particle interaction.

2. The phenomenon of autogenous shrinkage of paste was divided into two mechanisms, which are macroscopic volume reduction by chemical process and capillary surface tension by physical process.

3. The greater autogenous shrinkage by chemical effect was found in paste with larger cement fineness and larger contents of the most reactive phases (C_3A and C_3S) of cement. Also, it will be increased with increasing in water to binder ratio due to higher reaction.

4. The autogenous shrinkage by physical effect depends on capillary tension of capillary pores. The capillary attraction forces are mainly affected by pore size. In the model, the average pore represents pore size distribution. It was found that the average pore size decreases with time due to hydration reaction and pozzolanic reaction. Also, it will be reduced when C_3S, C_3A, and fineness of cement increase, whereas water to binder ratio.

5. The hydration products of higher temperature formed by rapid early hydration causes larger autogenous shrinkage than lower curing temperature at the initial state. At long term, the rate of hydration of high temperature is lower and pore radius gets larger than normal temperature. As a result, autogenous shrinkage from self-desiccation by physical effect of high temperature in long term will be small.

6. It was proved that high SO_3 fly ash are more effective for reducing autogenous shrinkage than low SO_3 fly ash. Increased fly ash content in the mixture results in smaller autogenous shrinkage. Chemical expansion is effective to compensate autogenous shrinkage in the mixture containing fly ash with higher SO_3.

7. Regarding the effect of aggregate phase, concrete shrinkage was found to be affected by the aggregate content, strain of the aggregate phase, and the proportion between coarse aggregate and fine aggregate.

8. The stress of particle interaction contact of single material (fine aggregate or coarse aggregate) was proposed based on the contact density concept. The stress of combined coarse aggregate and fine aggregate as binary mixture was considered to be the combined results of stresses contributed by each single material.

9. There is an effect of particle interference of fine aggregate on the contact area of coarse aggregate. The reduction of contact area of coarse aggregate in the binary mixture reduces the stress produced by coarse aggregate.

10. Increasing water content has an effect to increase the thickness of surface water around particles of aggregates. Then, the contact area among aggregates will be reduced, and the aggregates slip easily when concrete shrinks. As a result, aggregate stiffness will decrease when water to binder ratio is increased.

11. The aggregate stiffness increases with the increasing of volume concentration ratio of aggregate ($n_g/n_{g,max}$ or $n_s/n_{s,max}$). However, the stiffness of coarse aggregate is larger than the stiffness of fine aggregate at the same volume concentration ratio.

12. Initial contact of coarse aggregate will be decreased when reduce the maximum size of coarse aggregate (G_{max}). As a result, aggregate stiffness of coarse aggregate is decrease.

13. The shrinkage of concrete was found to decrease when the stiffness of aggregate increases and also the volume concentration of total aggregates (n_a) increases.

14. The aggregate stiffness model can be applied for autogenous shrinkage and drying shrinkage.

The limitations of autogenous shrinkage of concrete prediction model are as follows:

- The water to binder ratio up to 0.50
- The percent replacement of fly ash up to 60%
- Fineness of cement up to 8000 cm^2/g
- Fineness of fly ash up to 6000 cm^2/g
- The temperature up to 40°C
- No admixture
- Curing condition

10.2 Recommendations for Future Study

1. The model of autogenous shrinkage should include the effect of the size of specimen.

2. The autogenous shrinkage should be tested and verified under variable temperature conditions depending on heat produced by hydration reaction same as real concrete structure.

3. The autogenous shrinkage model should be extended to the reinforced concrete structure.