CHAPTER 7

CONCLUSION

7.1 Research Summary

In this study, ultra-high strength concrete with compressive strength higher than 150 MPa is produced with the conventional materials and practice in laboratory. To obtain that, several investigations of concrete components are carried out via both experiments and simulations of mathematical models. Based on the work accomplished, the following conclusion can be drawn:

1.) Microstructure of concrete materials is two-dimensional modeled by using a finite element analysis program. Up to three components, i.e., aggregate, matrix, and interfaces, can be concerned. With the hypothesis that the failure of concrete is a result of initiation, propagation, and coalition of the internal cracks, non-linear fracture mechanics is adopted to model concrete response under loading. Based on the fictitious crack assumptions, the element cracks when its tensile stress reaches tensile strength and the crack will open when the energy overcomes the cohesive pressure in the fracture process zone. Four parameters, i.e., splitting tensile strength, elastic modulus, Poisson's ratio and fracture toughness, for each component are required for simulation. The simulated stress-strain curves under compressive loading agree well with the experimental ones. The variation of input parameters shows the contribution of each concrete component to the overall behavior. The possibility of ultra-high strength concrete production by using commonly available materials is illustrated by such simulations.

2.) The microstructure of cement pastes with different water/cement ratio is examined, as well as their macro-scale mechanical properties. It is found that water/cement ratio between 0.16 and 0.18 is the optimum to attain minimum porosity and maximum strength of cement paste, providing that sufficient workability is guaranteed. This water/cement ratio is lower than the balance water content for hydration reaction because of change in nature of CSH beyond such value. The most appropriate addition of fly ash and silica fume to react with calcium hydroxide and become secondary CSH are about 20% and 10%, respectively. An increase in compressive strength of cement paste can be expressed as a function of increased CSH.

3.) The gradation and amount of fine aggregate play important roles in mortar performance. Sand conforming to the standard of ASTM C33 is advantageous to concrete flowability. Fineness modulus about 3.0 tends to supply a high packing density of fine aggregate filler. Simulation shows that mortar strength improves when a large amount of fine aggregate is consumed in the mix. However, porosity also tends to magnify with the increasing content of fine aggregate, and drops the expected mortar strength. Then, from the experiment, the sand/cement ratio is suggested to be in between 1.50 to 2.00. It is also shown that the presence of fine aggregate demands more water content to compensate water retaining.

4.) There are variations in properties of coarse aggregate with different types and sizes. Due to its high strength, basalt crushed rock is a potential to be a coarse aggregate for making ultra-high strength concrete. Nevertheless, careful consideration in its gradation has to be taken because crushing high strength rock induces imperfection of shape and packing of the particles. The SBG index is introduced as a single parameter representing both physical and mechanical properties of coarse aggregate. It is the summation of products between packing density and strength index of each size. Aggregate crushing value, aggregate impact value, Los Angeles abrasion, or point load strength index can be used to calculate strength index. Linear dependence of concrete strength on SBG index can be anticipated. In addition, for a given SBG, the ratio of binder volume to void content of dry and compacted aggregate is a linear function to ratio of concrete to mortar strength.

5.) With the above findings, the recommended mix design for ultra-high strength concrete is developed. Both physical and mechanical properties of aggregate have to be checked. The suitable sand/aggregate ratio is obtained by the concept of maximum packing density. Binder volume can be determined by using SBG index. When water/cement ratio and percent addition of pozzolanic materials are specified, the initial strength of cement paste can be estimated as well as the proportion of each material can be calculated. Afterwards, the additional water content due to the retaining of aggregate and the estimated concrete strength can be computed. The amount of superplasticizer to provide flowability is determined from trial mixes. With this mix design method, concrete with 28-day compressive strength up to 188.30 MPa can readily be produced in laboratory with conventional materials and practice.

7.2 Suggestions for Further Study

This research is a first step to systematically develop ultra-high strength concrete. Because there are several materials and many properties of each material influence determining of concrete mix design, it is very difficult to cover all aspects in a single research. There have been many subjects left for further study.

1.) The micro-mechanical model may be improved with more realistic assumptions, for example, three-dimensional analysis, arbitrary aggregate shape, non-linear stress-separation curve, as well as discrete crack modeling. The model should be improved realistically. Moreover, the model should be verified in other possible conditions.

2.) The intimately investigations concerning mechanism of cement hydration and structure of hydrated products should be done. With these, the prediction of porosity and other characteristics of cement paste may be more accurate. In addition, other types of pozzolanic materials, such as ground granular blast furnace slag, metakaolin, and rice husk ash, should be included.

3.) The packing density and its influence on mortar performance of various particle size distributions of sand should be examined. Moreover, other types of fine aggregate, i.e., quartz sand, or rock dust, should be also considered.

4.) The packing density and strength parameters of different coarse aggregates from different sources or quarries should be evaluated. The meaning of SBG may be analyzed more in mathematical manner, while the contribution of SBG on concrete properties should be re-checked.

5.) The proposed mix design of ultra-high strength concrete should be more verified. The concrete specimens should be produced both in laboratory and in construction sites.

6.) Other materials, such as fibers or polymer fillers, are possibly included.

7.) Other properties of ultra-high strength concrete, especially for durability, should be measured. The applications of ultra-high strength concrete in highlighted structures may be carried out.