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DISSERTATION ABSTRACT

博士の専攻分野の名称 博士（工学） 氏名 Onnicha RONGVIRIYAPANICH

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Title of dissertation submitted for the degree

Mesoscale damage assessment of cementitious material exposed to high temperature

(高温を受けたセメント系材料の準微視的損傷評価)

Cementitious materials, such as cement paste, mortar or concrete, are among the most widely used typical construction material because of their own benefits in use. The performance, such as workability, strength and durability, varies with mix proportions including the cement content, type of aggregate, additives and water consistency, as well as the service conditions that the structural concrete is subjected to. The structural concrete can be deteriorated owing to various factors, such as decrease in overall performance with service time and deterioration of cementitious material. Fire exposure is one of the most serious accidents to which structural concrete can be exposed, and can introduce the severe and devastating deterioration to cementitious material. In one-directional fire problem, the multi-scale material properties, including chemical structure, physical appearance and mechanical behavior, deteriorate with the different degree of deterioration dependent upon the distance from the fire origin. The conventional methods which are able to only report an average response of typical cylindrical specimen may not adequate to investigate the characteristics of fire damaged cementitious material. Furthermore, it is obvious that much less attention has paid to numerical studies of structural response of concrete after exposure to fire in comparison to the experimentations. Therefore, the analytical methods with the viewpoint of small scale assessments that can simulate the behavior of mortar against fire exposure are strongly needed. In this research, both of experimental and analytical studies are conducted in order to develop the methodology to investigate the mechanical behavior of one-directional fire-damaged mortar.

The series of experiments have been designed in order to investigate the influence of external thermal loadings and types of raw materials made mortar specimens, how damage progresses after one-directionally expose to fire, and to develop the meso scale constitutive model. The 100 by 100 by 400 mm mortar prisms were made from carbonate and siliceous fine aggregates and two lots of ordinary Portland cement that are typical raw materials made mortar in Japan and Thailand. The mass ratio among water, cement and sand is 0.55:1.00:2.00 for all mortar series. Thermocouples were embedded at various depths from the surface during fabrication. At the age of 28-day old, all mortars were dried at 105 °C in the oven, and keep constant moisture content until fire test, to control only the fire damage induced by a deterioration of material. The uni-directional fire exposure, conforming to standard fire curves of ISO 834 and ASTM E119, was simulated by applying the thermal loading to one face of mortar (100 by 400 mm), developed temperatures were gathered during entire period of fire tests. After fully cooled-down to ambient temperature, the multi-scale experimentations begin with assess-

ments of surface damage, test of meso scale mechanical characteristics (3-point flexural test), porosity by water absorption and chemical properties (calcium hydroxide, CH, and calcium silicate hydrate, CSH), respectively. Experimental results clearly indicate that mortar was obviously deteriorated by fire exposure. The degree of deterioration increases with an increment of temperature, with high variation in post-fire strength because of the non-uniform distribution of crack induced by fire. In addition, the crack induced by fire has a strong effect to the mechanical properties of damaged mortar, i.e., reduced in strength, and failure location after bending test; therefore, it must be taken into account in order to achieve the fire-damaged material properties more precisely. As for mechanical properties, the cement hydration products were also fully decomposed after fire exposure, while the porosity does not change. However, the relationships between physico-chemical and material strength show that there are some complexities for describing the reduction of strength and stiffness of fire-damaged mortar. The temperature is the most appropriate index to describe how the damage of cementitious material in fire problem progresses and to understand the post-fire mechanical properties, and it could be involved in all aspects of damage. Also, the different in raw material used in mix proportions could introduce the different damage characteristics of material exposed to fire.

The analytical study aims at to simulate an internal temperature distribution along the cross section, a propagation of cracks of mortar under one-directional fire exposure, and to evaluate the post-fire strength in semi-macro scale. The present analytical investigation was conducted with a two dimensional coupling analysis of heat transfer using Finite Volume Method (FVM) and structural analysis using Rigid Body Spring Method (RBSM). Prediction equations with the function of temperature for meso-scale tensile strength and Young's modulus, which is developed based on the experiment, is introduced in the analysis. In RBSM, since cracks initiate and propagate along boundaries between elements, mesh arrangements affects the crack pattern. To avoid a formulation of cracks in certain direction, a Voronoi diagram was used to create a fine and random geometry. By means of heat transfer using FVM, a temperature as time dependence at any points was calculated based on the energy conservation equation. The developed temperature introduces an expansion strain which can be treated as an initial strain in the structural analysis. This method of analysis was able to simulate the temperature distribution along the cross section and the crack mapping of mortar beam subjected to fire exposure applied at one surface, while other surfaces are free of loadings. The analytical result shows that an increase in temperature depends on elapsed exposure duration and distance from fire boundary. In addition, the analytical result also illustrates a propagation of crack induced by fire exposure. Finally, the outputs of analytical study were validated with the relevant experimental results in order to verify the reliable of developed numerical code.