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論 文 要 旨

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論文題目	Improvement of Cracking and Chloride Penetration Resistance of Slag Concrete By Utilizing High Alite Cement (高エーライトセメントの活用によるスラグコンクリートのひび割れ抵抗性と塩分浸透抵抗性の改善)		
和訳または英訳			

The durability of concrete is one of the most concerns of researchers and engineers. With high durability concrete, the cost of maintaining is remarkably reduced. In massive concrete, microcracking, which derived from the incompatibility deformation between aggregate and cement paste under elevated temperature, is the serious matter. Microcracking adversely affects mechanical properties and durability of concrete structures. Especially with the addition of mineral additives such as ground granulated blast furnace slag, concrete is susceptible to microcracking due to its large shrinkage, particularly under temperature variation. Not only microcracking, chloride penetration is one of the main factors influencing durability of concrete, particularly for structures in very cold area, where deicing agent is daily used in the winter.

This study deals with improvement of cracking and chloride penetration resistance of slag and fly ash concrete by using a new type of cement named high alite cement (HAC). HAC is a newly developed special cement with very high alite ($3CaO.SiO_2$) and almost no belite ($2CaO.SiO_2$).

Due to its sensitivity and the rich information it yields from collected parameters, the acoustic emission (AE) technique has been widely used to detect cracking in hardened concrete. Nevertheless, AE measurement at a very early age is difficult because AE sensors cannot be directly attached on the surface of unhardened concrete. Therefore, a waveguide embedded inside concrete has been employed. Unfortunately, attenuation of acoustic waves in a high moisture content ambient led to the diminished effectiveness of the waveguide in detecting AE signals in concrete with high water to binder ratio (W/B).

One part of the research is to solve the problem of attenuation. An addition of two perpendicular bars on main rod of the waveguide was proposed. Due to these wings, the distance from cracking points in concrete to waveguide was significantly reduced. It was proved that the redesigned waveguide worked more effectively than the previous one, especially in concrete with high W/B.

By using this redesigned waveguide, microcracking was intensively investigated in slag concrete with W/B of 0.3 and 0.5 subjected to temperature history simulated steam curing. In all types of concrete, the replacement ratio of slag for cement was 50%. Because the coefficient of thermal expansion (CTE) of materials is one of the important parameters affecting microcracking in concrete, two types of coarse aggregate with the same maximum particle size of 19 mm but remarkably different CTEs, namely limestone and andesite were used in the study.

The test results showed that net shrinkage of HAC mortar with W/B of 0.3 was much larger than that of OPC mortar because of its larger autogenous shrinkage. Normally, larger shrinkage of mortar results in more extensive cracking in concrete. However, the number and the degree of microcracks in HAC slag concrete with W/B of 0.3 were smaller than those in OPC slag concrete. This means that HAC slag concrete with W/B of 0.3 obviously achieved larger resistance against microcrack than OPC slag concrete. On the other hand, net shrinkage of HAC mortar with W/B of 0.5 was a bit smaller than that of OPC mortar due to its smaller thermal contraction. Therefore, microcracking in HAC slag concrete with W/B of 0.5 was also smaller than that in OPC slag concrete.

The interesting characteristic of HAC was explored in the research is that it could improve resistance against microcracking in slag concrete. AE data revealed HAC concretes could disperse tensile stress, leading to the formation of many small cracks rather than concentrating tensile stress to create a severe crack. Evenly distributed calcium hydroxide (CH) crystals acting as a kind of buffer that prevents the propagation of microcracks in HAC slag concrete might be one of the reasons. Another reason for the high cracking resistance of HAC slag concrete was the strong bond between mortar and coarse aggregate. This high bond strength was more clearly observed in concrete with low W/B than in concrete with high W/B. The high bond strength of HAC slag concrete was verified through tensile strength test, AE test, visual observation, and scanning electron microscope images. The strong bond in HAC slag concretes might be due to the formation of secondary CSH gel from the reaction of CH and active SiO_2 in slag at pores near the interface transition zone.

The effects of class F fly ash in concrete subjected to temperature variation at very young ages in term of microcracking resistance was also investigated by AE, physical and mechanical tests. Fly ash was used as a cementitious material as well as fine aggregate. In addition, a combination of fly ash and HAC, which was effective in improving resistance against microcracking in slag concrete, was studied.

Similarly to slag concrete, concrete containing fly ash is also easily subjected to microcracking under temperature variation. The level of cracking is proportional to fly ash replacement ratio. The reason is that fly ash is not so active in early ages leading to the small tensile strength of mortar. However, slag is more active than fly ash leading to the higher tensile strength of OPC slag concrete compared with OPC fly ash concrete.

It is found that HAC can improve tensile strength of concrete containing fly ash due to high hydration rate of HAC. However, high bond strength in HAC fly ash concrete was not observed from the direct tensile test result. When fly ash was used as a part of fine aggregate, it could improve tensile strength of concrete remarkably.

Another important part of the research is to improve the capacity of concrete to resist chloride ingress. Surface Water Absorption Test (SWAT) and ultimate penetration depth test were employed to evaluate the water and chloride absorption of concrete. Two kinds of cement were OPC and HAC. Slag and fly ash were replaced for cement with replacement ratio of 40% and 15% by mass, respectively. In the case of concrete with W/B of 0.4, three-binder concretes were made with slag and fly ash replacement ratio of 40% and 15% by mass, respectively. In order to obtain a wide range of concrete quality, three W/B of 0.4, 0.5, and 0.6 and five curing conditions covering from very good to very poor condition were applied. To investigate the effect of bond on mass transfer in concrete, some concretes made with limestone were added in the cases of concrete with W/B of 0.4 and 0.5.

Experimental results presented that water absorption factor (WAF) distributed in a wide range, e.g. SWAT can be utilized to evaluate quality of covercrete. There was also a good correlation between WAF and ultimate penetration depth. Prediction of penetration depth of chloride ion can be obtained from this correlation.

In OPC concrete without additive, chloride ions penetrated deeper than water. This is due to the different mechanism of penetration of chloride ions and water. In good concrete, suction is the main mechanism of chloride ingress, e.g. chloride penetration stop with the stop of water front. On the other hand, in poor concrete diffusion is the main mechanism of chloride penetration. As a result, even when water stops penetrating into concrete, chloride ions can continue diffusing into concrete. It can be inferred that OPC concrete has a low resistance against chloride ingress.

However, the trend was converse in OPC concrete with slag and fly ash. In poor concrete, although water transferred deeply into the specimens, the depth of chloride penetration was much shallower because of the capacity of slag and fly ash in binding chloride ion. The resistance against mass transportation of HAC concrete with additives was better than that of OPC concrete with admixtures. Strong bond between HAC mortar and aggregate is attributed for this characteristic.

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