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学 位 論 文 要 旨
Dissertations Summary

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論 文 名:
(Dissertations Title)　**Study on Corrosion of Steel in Copper Slag Concrete**

Deterioration due to chloride penetration has been regarded as the major problem among the factors leading to a decrease in durability of reinforced concrete (RC). Corrosion of steel bars in concrete propagates in the presence of water and oxygen by electro-chemical reactions. When corrosion of steel bars occurs due to chloride attack or carbonation, an anodic reaction in which iron is ionized and a cathodic reaction in which oxygen is reduced take place on the surface of steel bars. Ingress of chloride-ions destroys the passive film of the steel bars and leads to the corrosion of steel in concrete structures when the chloride ion concentration at the depth of steel bars exceeds chloride threshold, e.g., 1.2 kg/m^3. In recent years, the use of industrial by-products as construction materials has been promoted since it reduces pollutant waste and beneficial in construction works toward sustainable development. In the previous research, the use of copper slag fine aggregate (CUS) as sand substitution improves strength and durability of high strength concrete characteristics at same workability while superplasticizer is a very important ingredient in high strength concrete made with copper slag. To provide good workability and better consistency for the concrete matrix, and the substitution up to 40–50% (by weight of sand) of copper slag can be used as a replacement of fine aggregate to obtain concrete mixtures with good strength and durability.

Based on the background mentioned, the aim of this study is to investigate the effects of CUS on the ingress of corrosive substances including chloride ions and water including dissolved oxygen associated with corrosion behavior and processes of horizontal steel bars in the reinforced concrete prototype specimen. A detailed analysis was carried out on the heterogeneity in cover concrete and integrity of horizontal steel bars due to bleeding water in concrete mixtures with a partial replacement of CUS and fly ash (FA) and ordinary Portland cement (OPC) as a control specimen. In this study, it is assumed that the deterioration of concrete structures results from chloride ion penetration in the sea. Chloride-induced corrosion through the wet and dry cycles are examined with respect to chloride ion concentrations and some parameters related to electro-chemical measurements. The experiment used various percentages of replacement ratios such as 15 vol%, 30 vol%, and 45 vol% of CUS for RC prism specimens and 30 vol% for RC column specimens cast from the height of 1.5 m.

Whole series of test were performed based on specific objectives of each experiment in this study. First, investigations using reinforced concrete prism specimens were intentional to evaluate the effect of CUS on corrosion processes with less influence of bleeding which is typically observed in concrete column specimen. Subsequently, the influence of CUS on corrosion resistance of horizontal steel bars in reinforced concrete column specimen was explored due to chloride-induced corrosion through wet and dry cycles. It should be noted that segmented steel bars were embedded to analyze corrosion behavior and processes in detail in this study. Finally, the influencing factors on the corrosion including chloride ion concentration, oxygen permeability, content of cement hydration products/calcium carbonate and microstructures around the horizontal steel bars in concrete column specimens were examined.

Based on chloride migration test which was obtained from the cumulative increase of chloride ion concentration, the results indicate that concrete with longer curing period achieved lower chloride-ion concentration, thus suggesting that there is an increase in the resistance of concrete against chloride attack. The chloride penetration depth and distribution of chloride content in CUS prism specimens after exposed to wet and dry cycles for 1 year are almost similar to those of the OPC specimens. Thus, durability performance of CUS concretes with respect to the resistance against chloride ingress was comparable to that of OPC concrete. Besides that, it is generally recognized that the incorporation of fly ash in blended cement by its the pozzolanic reaction of FA improves concrete protection against chloride-induced corrosion of steel bars by reducing its diffusivity and the rate of oxygen permeability.

The probability of corrosion differs in the upper, middle, and lower locations of concrete column specimens with various material resistance affected by bleeding against the ingress of corrosive substances. The results displayed that the partial replacement of CUS in fine aggregate could lead to reduction of oxygen permeability on the cathodic reactions, thus leading to the smaller microcell corrosion current density. The potential differences developed between the upper and the lower section of steel elements in the segmented steel bar through the wet and dry cycles up to 2 years contribute to macrocell corrosion formation especially in the CUS specimens. This draws a distinction between OPC and CUS concretes in that the corrosion behavior is significantly different, which could be attributed to loss of integrity at the interface of steel bars and the surrounding concrete. This can be illustrated by the changes of rate of oxygen permeability and variations of corrosion processes observed in the segmented steel bars embedded at three locations of column specimens in the cases of OPC and CUS specimens.

Regarding the influencing factors on the corrosion processes and behavior, the content of chloride ions measured in the CUS30 specimens seemed to be lower than those of the OPC specimens. The results suggest that the addition of CUS could lead to lowered effective water-to-cement ratio in part especially in the column specimens, thus suggesting that CUS replacement affects the diffusion of chloride ions. Also, the availability of water and dissolved oxygen through the wet and dry cycle may be varied in the presence of CUS. This could be illustrated by the smaller amount of calcium carbonate precipitation at the depth of steel bar and lower rate of oxygen permeability especially for the CUS specimens with a cover depth of 30 mm. Based on the results obtained by XRD analysis, the addition of CUS in concrete mixtures as sand replacement do not register new peaks but increases in peak intensity. The result indicates that CUS replacement does not affect the composition of minerals of concrete mixtures tested and thus it is evidently compatible with OPC mixtures.