Study on localized corrosion of copper alloys in flowing seawater

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Summary

Seawater is often used as a coolant for steam condensers in thermal or atomic power plants in Japan. Typically, the heat exchanger tubes of the condensers are composed of copper alloys and, as a result, a relatively thick film of corrosion products is formed on the surface of the metal which serves as a protectant against corrosion. However, localized corrosion may occur near the tube inlet as the result of fluid flow effects. This is due to the shear stress and/or turbulent forces which mechanically erode the corrosion products on the metal surface, thus exposing the base metal to the corrosive seawater environment (flow induced localized corrosion). In a certain circumstance, the differential aeration cell may be built to cause corrosion damage at place where the flow velocity is low. In this study, corrosion tests under different fluid flow conditions were conducted for copper, and the effect of flow velocity on the rate of corrosion was investigated. The mechanism of corrosion is discussed as well.

A jet-in-slit testing apparatus which was developed by M. Matsumura et al. was used for the test. As the test liquid was injected from the nozzle into the slit (ordinary flow), turbulence and shear stress occurred in the fluid flow near the specimen surface, and, as a result, the corrosion product film formed on the metal surface was removed, thus permitting a localized corrosion. When the test liquid was allowed to flow in the reverse direction (reverse flow), shear stress was observed on the specimen surface but no turbulence was detectable. Corrosion tests for copper were conducted in a 3 % NaCl solution and a 1 wt% $CuCl_2$ solution the temperature of which was maintained at 40 °C. As an index of corrosion damage, the mass loss by the specimen after the test and the damage depth distribution, as measured through a surface roughness meter were adopted. In addition, corrosion products, which formed on the metal surface were observed and electrochemical measurements were conducted for analyzing the mechanism of corrosion of copper under conditions of fluid flow.

The following results were obtained. Under ordinary flow conditions, the central part of the specimen, where the flow velocity was high, was damaged. On the contrary, the surrounding part of specimen where the flow velocity was low was damaged by the reverse flow. The rate of corrosion of the specimen increased in a linear manner with the flow velocity up to 1 m/s for the ordinary as well as the reverse flow, and it reached a nearly constant value for velocities higher than 1 m/s. The corrosion rate increased, however, discontinuously in the case of a flow velocity of nearly 2 m/s under conditions of ordinary flow. In order to investigate the corrosion mechanism in the both flow conditions, polarization curves at a central and a surrounding point on the specimen were measured to confirm that the flow induced localized corrosion occurred under conditions of ordinary flow, and that the differential aeration cell corrosion occurred under conditions of reverse flow. The reason for why the corrosion rate increased discontinuously at a certain velocity in the ordinary flow, was the removal of corrosion product layer which had been formed on the specimen surface. The corrosion behavior of copper in a 3 % NaCl solution was similar to that in a 1 wt % $CuCl_2$ solution for all flow condition with the exception of ordinary flow at a high velocity. This is related to the difference in the types of corrosion products which were formed in each of the solutions.