学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Characterization of Ni-Based Coated Layer on Carbon Steel by Electron Microscopy and Neutron Radiography

(電子顕微鏡法と中性子透過法による炭素鋼上の Ni 基コーティング層の評価)

The geothermal energy is one of the clean and renewable energies because of almost no carbon dioxide emission. The geothermal fluid, water and steam, and their mixtures contain many kinds of the corrosive chemicals such as chlorides, sulfates, hydrogen sulfide etc, which can cause scaling and corrosion in wells and surface installations which the geothermal fluids flow through. The corrosion of components of the geothermal plants is one of the most important subjects to be evaluated.

Carbon steel is now the most widely used material for geothermal power plant industries. The use of carbon steels represents a choice based on economics and temperature operation limit, a key issue in the effective use is the poor general corrosion and oxidation performance. To improve the surface properties, a number of surface modifications are performed with different techniques where coatings are deposited on the carbon steel surface. Recently, Ni-based coatings have come into wide used because of their good wear resistance and durability at high temperatures. Additions of the cobalt, chromium, and aluminum to the coating material promote the hardness, formation of intermetallic phases, and increase the oxidation/corrosion properties.

Details of experimental methods have been showed in chapter 3. In the present study, NiCoCrAl is diffusion-coated onto low carbon steel by electrodeposition to create a NiCo coat followed by pack cementation with Cr and Al. As-coated and treated samples have been investigated by using HVEM, TEM, XRD, SEM, EPMA, and EDS. The cross sectional TEM specimens have been prepared by the combination of ion slicer (IS) and focussed ion beam (FIB). Nano to macro scale characterization presented in this study is a powerful technique to understand the material properties related to the structure of crystallized material.

In chapter 4, the effect of the Co concentration and temperature on the hardness and oxidation properties as well as phase constituent in the coated layer was investigated. An analysis of the correlations between the structure, hardness properties, oxidation behaviors, and phase formation was also discussed. The results showed that 5 % Co coated sample has good hardness properties, oxidation resistance and forms a series of high melting phases such as γ-(Ni, Fe), Al3Ni, ζ-(Al,Cr)Ni and oxidation resistant of β-(Ni,Al).

In chapter 5, the oxidation behavior of the coated samples developed by different temperature of pack cementation in isothermal oxidation at 800 C for 100 hours was studied. The sample developed at 800 C showed better oxidation resistance than that at 900 and 1000, because the oxide is mainly consist of α-Al2O3 with continuous, thin and less porous structure. Thus, it possesses the capability as a diffusion barrier for oxygen to protect the carbon steel substrate when subject to severe oxidation.

In chapter 6, the formation of meta-stable Al2O3 on NiCoCrAl coated layers during initial stage for up to 100 h exposure time under isothermal oxidation at 800 C in air was comprehensively presented. The oxide scale formed on the initial stage of 1 h and 15 h of exposure consists of several polymorphs crystalline of alumina structure such as meta-stable and stable α-Al2O3 phases. However, the oxide scale of 100 h sample was identified to be mostly composed of α-Al2O3 and a small amount of δ-Al2O3. The results were plotted on the isothermal oxidation map at lower temperature of 800 C. It is worth noted that the result in present study is the first result which will be contributed to the oxide ternary map of Ni–Cr–Al at 800 C.

In chapter 7, the implementation of the coating process on pipeline system and an experimantal simulation was carried out by developing closed loop piping system constructed by low carbon steel, ST37, and 304 SS materials. Three shapes of pipes were selected, i.e, straight, elbow and tee. The performance of uncoated and coated carbon steel ST37 was compared with 304 SS pipes after acid vapor corrosion test using 37 % HCl for 48 hours. Neutron radiography and tomography (NRT) as a new method for non-destructive testing in this field has been adopted for pipe inspection and corrosion monitoring. 2D neutron radiography (NR) and 3D neutron tomography (NT) showed the existence of corrosion product in the form of rust and blister inside the pipe wall.

Finally the general conclusion has been discussed in chapter 8. The conclusions on the performance of Ni-based coated carbon steel after oxidation and corrosion are used to make some recommendation for future research and development in geothermal power plant industries.