Selective Leaching of Gray Cast Iron – Electrochemical Aspects

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1. Introduction

Currently, to keep step with increases in energy consumption, much attention has been paid to the construction of new nuclear power plants (NPPs) and to the continued operation of NPPs. For continued operation, the selective leaching of materials should be evaluated by visual inspections and hardness measurements as a part of One-Time Inspection Program according to the requirements of the guidelines for continued operation of pressured water reactors (PWRs) in Korea and license renewals in the United States, entitled the 'Generic Aging Lessons Learned (GALL) report[1,2].' However, the acceptance criteria for hardness have yet to be provided.

Recently, USNRC released a new draft of the GALL report for comment and plans to publish its formal version by the end of 2010. In the new draft, the quantitative acceptance criteria for hardness are given at last: no more than a 20 percent decrease in hardness for gray cast iron and brass containing more than 15 percent zinc.

Selective leaching is the preferential removal of one of the alloying elements from a solid alloy by corrosion processes, leaving behind a weakened spongy or porous residual structure[3]. The materials susceptible to selective leaching include gray cast iron and brass, which are mainly used as pump casings and valve bodies in the fire protection systems of NPPs. Since selective leaching proceeds slowly during a long period of time and causes a decrease in strength without changing the overall dimensions of original material, it is difficult to identify.

In the present work, the selective leaching of gray cast iron is investigated in terms of its electrochemical aspects as part of an ongoing research project to study the changes in metal properties by selective leaching.

2. Methods and Results

2.1 Methods

The material used in this study was gray cast iron, KS D4301 GC250. Pure iron and graphite were also used for comparison because gray cast iron is composed of pure iron and graphite. The electrolyte used in this study was an aqueous solution containing FeS, HCl and Na_2SO_4 (900 ml of the test solution was prepared by adding 2.25g of FeS, 45 ml of HCl, and 45g of Na_2SO_4 to double distilled water).

A three-electrode electrochemical cell was employed for the potentiodynamic polarization experiment. It was performed with a scan rate of 0.5mV/s to investigate the electrochemical behavior of the materials. A platinum gauze and a saturated calomel electrode (SCE) served as the counter and reference electrodes, respectively.

To confirm whether selectively leached gray cast iron can be made chemically, the GC250 specimen was immersed in a FeS+HCl+Na_2SO_4 solution at 75°C. A cross-section of the specimen was then observed using an optical microscope.

2.2 Results

Fig. 1 depicts potentiodynamic polarization curve for gray cast iron GC250 in an aqueous FeS+HCl+Na_2SO_4 solution. In the figure, a typical active dissolution region is clearly observed in the anodic branch. Even in the presence of chloride ions that promote pitting corrosion by the breakdown of the oxide film, pitting potential is not observed. This indicates that the protectiveness of the oxide film against corrosion is relatively low and as a result, uniform corrosion occurs on GC250.

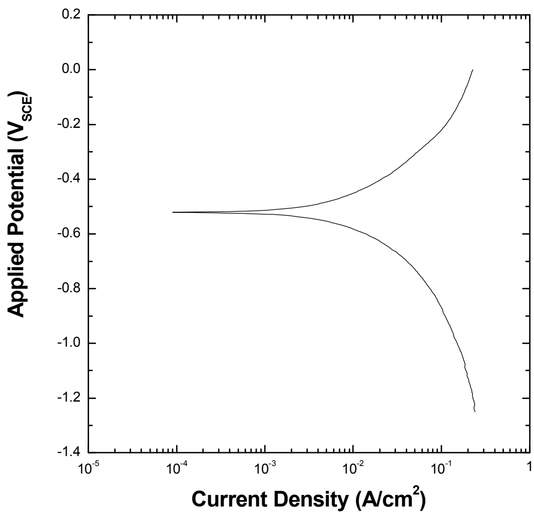

Fig. 1. Potentiodynamic polarization curve obtained for gray cast iron, GC250 in a FeS+HCl+Na_2SO_4 solution with a scan rate of 0.5mV/s.

From the Galvanic series table, it can easily be estimated that pure iron will selectively leach from gray cast iron, as graphite is electrochemically nobler than pure iron. A similar tendency can be observed in the potentiodynamic polarization curves of pure iron and graphite in an aqueous FeS+HCl+Na_2SO_4 solution as shown in Fig. 2; the open-circuit potential (corrosion potential) of graphite (+0.10V_{SCE}) is higher than that of pure iron (-0.64V_{SCE}).

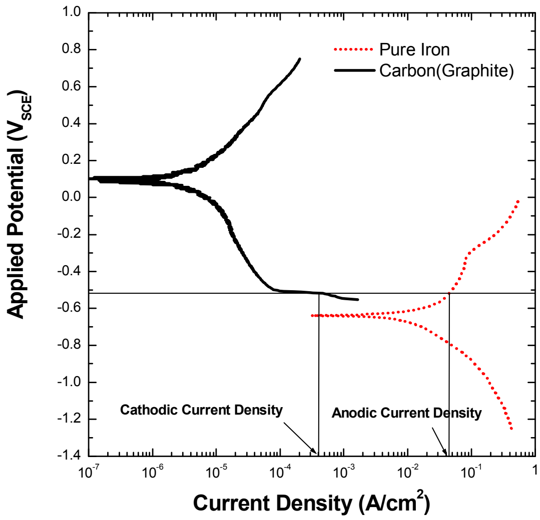

Fig. 2. Potentiodynamic polarization curves obtained for pure iron and carbon (graphite) in a FeS+HCl+Na_2SO_4 solution with a scan rate of 0.5mV/s.

Furthermore, it is worthwhile to note that the open-circuit potential of gray cast iron GC250 (-0.52V_{SCE}) is located between the open-circuit potentials of pure iron and graphite. This indicates that selective leaching of gray cast iron proceeds electrochemically according to the mixed potential theory, which states that the open-circuit potential of an alloy is determined by coupling all relevant anodic and cathodic reactions on the respective alloying elements. Thus, the total anodic current (corrosion current) is identical to the total cathodic current[4].

Since the open-circuit potential of gray cast iron GC250 is -0.52V_{SCE}, alloying elements (pure iron and graphite) in gray cast iron are also exposed to this potential. It can be found in the figure that the cathodic current density of graphite is close to one hundred times lower than that of pure iron at -0.52V_{SCE}. This addresses two points: the first is that the area ratio of pure iron to graphite, exposed to environment, will be approximately 0.01 at the steady-state condition as a result of selective leaching under the assumption of the mixed potential theory. The second point is that the selective leaching of gray cast iron can be controlled by electrochemical methods.

Fig. 3 shows a cross-sectional view of an optical micrograph of GC250, taken after it was immersed in a hot aggressive solution for 30 hours. It is found that selective leaching occurs actively on GC250 via a chemical method. It is expected that selective leaching will be more enhanced if an electrochemical method is employed. We plan to prepare selective leached gray cast iron specimens with various leached thicknesses as a next step of this work. These specimens will be useful to investigate the selective leaching process of gray cast iron in terms of its mechanical aspects, and finally to reduce conservatism in acceptance criteria of hardness measurement given in the draft of the GALL report.

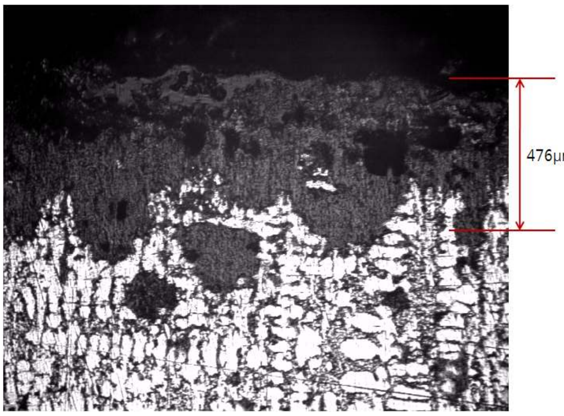

Fig. 3. Cross-sectional view of optical micrograph for gray cast iron (GC250), selectively leached for 30 hours in a FeS+HCl+Na_2SO_4 solution at 75°C.

3. Conclusions

Selective leaching of gray cast iron (GC250) was investigated in terms of its electrochemical aspects. It was found that the selective leaching process proceeds according to the mixed potential theory; the selective leaching of gray cast iron can be controlled by electrochemical methods. A next step in this project will be to prepare selectively leached gray cast iron specimens with various leached thicknesses using electrochemical methods for a mechanical evaluation. This work will be useful to reduce conservatism in acceptance criteria of hardness measurement given in the draft of the Generic Aging Lessons Learned (GALL) report.

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