Key Technical Issues in Process and Intermediate Heat Exchangers for Nuclear Hydrogen Production System

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1. Introduction

Both Process Heat Exchanger (PHE) and Intermediate Heat Exchanger (IHE) requires a formation of He flow channels and a diffusion bonding to assemble parts into a integrated system. In the He channels a mechanical machining method can be applied, however, this method not only costs a fortune but also is not suited for a mass production and thus a chemical etching method needs to be explored. A relatively simple etching method has been devised in this work. The PHE is subjected to a high temperature extremely corrosive environment (above 900℃ in decomposed sulfuric acid environemnt), for this reason a surface modification of metallic materials for corrosion protection has been developed, in which SiC-coating on metallic substrate with an aid of ion beam mixing (IBM) has been multiply conducted. The multiply conducted coating with IBM exhibited almost no corrosion in 80% sulfuric acid at 250℃ for up to 100hrs, which suggests feasibility in a real service performance

2. Experiments and Results

2.1 Experiments

<u>He channel chemical etching</u>

Samples of Hastelloy X and Alloy 617 were used for the etching experiment. Aqua regia (HNO_3:HCl=1:3) etchant is used as an example and the etchant is heated up to 100℃ for the etching. Prior to conducting this chemical etching, the surface was spray-coated with Teflon polymeric material except for the He flow channels. An additional Teflon jig was used to prevent the polymer film delamination due to the difference in the thermal expansion coefficients between the metal and polymer.

<u>Multiple Coating with IBM</u>

SiC films were deposited with an electron beam evaporative method on metallic substrate (Hastelloy X sheet: ~ 15x15x0.5mm) surface-polished by a diamond paste up to 0.5 μm. Prior to a SiC deposition, a sputter cleaning of the sample was carried out for 10 minutes with an N ion energy of ~10 keV and a current of 0.5 Ampere. Then, the electron beam evaporative deposition of the SiC was performed to 50 nm thickness, followed by a nitrogen ion beam mixing at 70keV with a dose of ~ $5x10^{16}$ ions/cm^2. A further SiC evaporative deposition up to a total of ~ 1 μm was then conducted with a deposition rate of ~3 Å/s produced by an electron beam current of ~0.15 A. The substrate temperature during the e-beam evaporative deposition was ~150 °C. This coating-annealing process was multiply conducted to cover the cracks on the annealed SiC coated layers.

2.2 Results and Discussion

As shown in Fig.1, the etching depth of Hastelloy X sample increases with an increased immersion period in the aqua regia solution. 5 min immersion of the Hastelloy X sample in the solution etches the sample to the depth of 0.5mm, 10 min to the depth of 1mm, and 15 min to the depth of 1.1mm. Therefore, in the case of Hastelloy X an immersion in the aqua regia for more or less than 10 min should be appropriate for the etching. The reason why the etching depth is not proportional to the immersion period seems to be due to a passive layer formation on the surface of the sample.

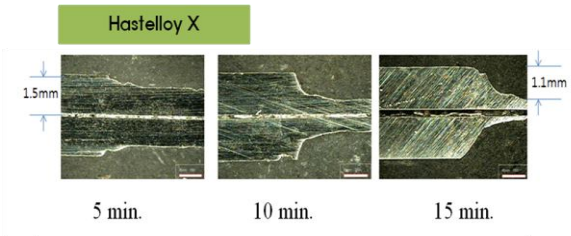

Fig.1. Etching results of Hastelloy X

Fig. 2 shows an etching experimental result of the Alloy 617. A depth of 0.7 mm was etched after 2 hrs immersion in aqua regia solution. In comparison with Hastelloy X, Alloy 617 is harder to etch, implying that Alloy 617 is more resistant to corrosion than Hastelloy X. However, an increase in the temperature along with an agitation of the solution during immersion is required to reduce the etching time.

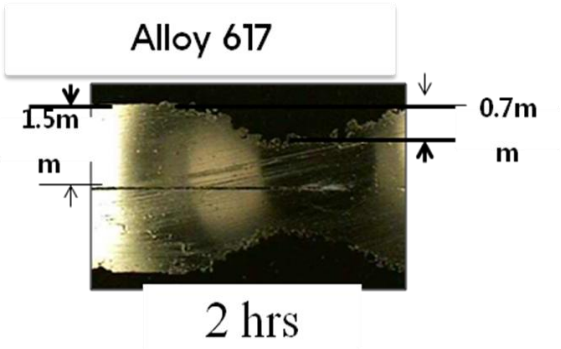

Fig. 2. Etching results of Alloy 167.

After heating at 700℃ in vacuum, SiC film was maintained as-coated on the Hastalloy-X surface, but cracked along the grain boundary of Hastelloy X substrate attributed to the thermal etching (Fig.3). After annealing at 900℃, the coated layer was all crystallized exposing the coated surface as a result of the film island formation (Fig 3). In spite of a high difference in their CTEs, no film delamination occurred. This is attributed to IBM to produce a highly adherent coated layer and an interfacial reaction during annealing [1].

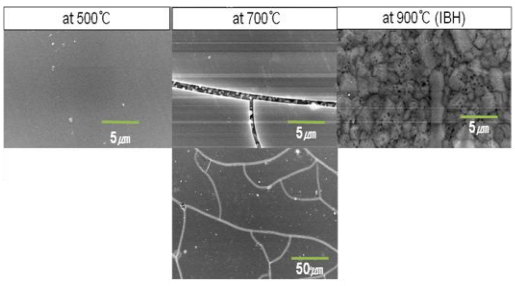

Fig. 3. The IBM coated SiC on Hastelloy X is cracked along the grain boundary of Hastelloy X substrate at ~700℃ along the grainboundary of the Hastelloy X substrate, while the coated layer is crystallized at 900℃.

As shown in Fig. 4, as-received sample was corroded out completely after ~70 hours, however the IBM SiC coated samples were sustained for much longer duration. Finally almost no corrosion occured after 4 times processing.

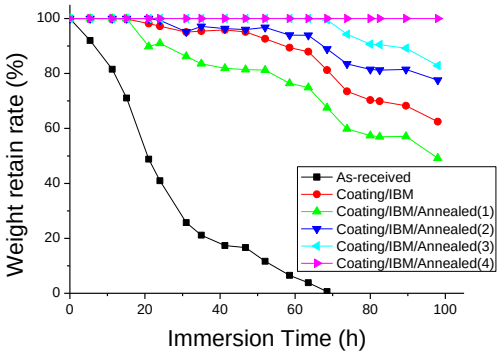

Fig. 4. 80% sulfuric acid corrosion test results of the multiple coating /IBM samples

3. Conclusions

Multiply processed IBM coated SiC on Hastelloy X showed almost no corrosion in 80%sulfuric acid up to 100 hrs, whereas the as-received is completed corroded out after 70 hours. Aqua regia is suitable to the etching of He flow channels made of Hastelloy X and Alloy 617 which are candidate materials for PHE and IHE

Acknowledgement

This study was supported by Nuclear Hydrogen Development Project sponsored by Ministry of Education, Science and Technology, Republic of Korea

REFERENCES

[1] J. Park, Z. S. Khan, H. Kim, Y. Kim, Mater. Res. Symp. Proc., Vol. 1125, p65, 2009