The Study of Microstructure and Fretting Wear Behavior for Nitrogen Ion Implanted Zircaloy-4

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1. Introduction

Nitrogen implantation has been known to be precise hardening process for improvement of tribological properties of various ferrous alloys and other materials. The major hardening by nitrogen implantation is contributed due to fine precipitation of nitrides, irradiation damage generation and dislocation pinning by nitrogen etc.

In this study, nitrogen implantation process has been applied to Zircaloy-4, which is being used for a fuel cladding tube in pressurized light water nuclear power reactor, for improvement of wear and fretting wear resistance. The formation behavior of ZrN as well as ZrO_2 was studied at various total ion dose and elevated temperatures. Wear and fretting wear behavior changes by nitrogen implantation were evaluated in conjunction with structural modification associated with implantation conditions.

2. Experimental procedure

Zircaloy-4 plate and tube were implanted with nitrogen ion at various total ion doses and temperatures at 120keV. In addition, a part of plate specimens were implanted with nitrogen at O_2 partial pressures of 2.1×10^{-5} torr and 4×10^{-5} torr for promoting formation of ZrO_2 layer as well as ZrN precipitates.

The composition profile and compound formation at implanted surface region were then analyzed by AES and XRD. Ball-on-disc wear test was carried out using AISI52100 and Al_2O_3 balls against plate specimen at various loads of 0.1N to 1.0N under unlubricated condition. Fretting wear test was performed using laboratory designed fretting wear tester. Two tube specimens were cross contacted and moved each other in vertical vibration of 10Hz between $\pm15\mu m$ distance and reciprocating translational movement of 1㎜ under water immersion at 20℃. Applied load range and translational cycles for fretting wear teat were 1N to 10N and 9,000 to 360,000 cycles respectively.

3. Conclusion

Wear and fretting wear behaviors with structure changes have been studied for nitrogen implanted Zircaloy-4 at various total ion doses and elevated processing temperatures. ZrN precipitates of (111) and (200) orientations were produced for nitrogen implantation above 620℃.

Nitrogen implantation at oxygen atmosphere promoted ZrO_2 layer formation to a thickness of 0.5㎛. The formation of ZrN and ZrO_2 significantly enhanced surface hardness of by a factor of 5.5 corresponding to 1780 Hk (0.1N), and thereby improving wear and fretting wear resistance. Wear resistance was enhanced as much as 4 times for nitrogen implanted Zircaloy-4 at 620℃ to a total ion of 1×10^{18}ions/㎠. Nitrogen implantation at oxygen atmosphere at elevated temperature also greatly reduced friction coefficient against Al_2O_3 ball and thereby improving wear resistance. Fretting wear resistance was also fairly improved nitrogen implantation to a total dose of 8×10^{17}ions/㎠ at 550℃.