EXPERIMENTAL INVESTIGATION OF FRETTING BEHAVIOR OF TiAlN COATED NUCLEAR FUEL ROD CLADDING MATERIALS

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Fretting of fuel rod cladding material, Zircaloy-4 tube, in PWR nuclear power plants must be reduced and avoided. Nowadays the introduction of surface treatments or coatings is expected to be an ideal solution to fretting damage since fretting is closely related to wear, corrosion and fatigue. Therefore, in this study the fretting wear experiment was performed using TiAlN coated Zircaloy-4 tube as the fuel rod cladding and uncoated Zircaloy-4 as on of grids, especially concentrating on the sliding component. Fretting wear resistance of TiAlN coated Zircaloy-4 tubes was improved compared with that of TiN coated tubes and uncoated tubes and fretting wear mechanisms were brittle fracture and plastic flow at lower slip amplitude but severe oxidation and spallation of oxidative layer at higher slip amplitude.

Keywords : Fretting, TiAlN coating, Wear volume, MOC(Mutual Overlap Coefficient)

1. INTRODUCTION

Fretting means the wear phenomena occurring between two surfaces having oscillatory relative motion of small amplitude within a few hundred micro-meters[1]. Fretting has been reported and investigated for over 50 years. However, it is still one of the modern plagues for industrial machinery and the general solution for fretting has never been introduced. The analysis of fretting is very difficult because it has a lot of factors and it is influenced by many wear mechanisms simultaneously in a small contact area[2].Thus, fretting was usually studied by selecting the most influencing factors such as slip amplitude, normal load, frequency, environmental conditions and so on.

Especially, fretting of fuel rod cladding material, Zircaloy-4 tube, in PWR nuclear power plants must be reduced and avoided since the safety that prevents the unexpected accidents and minimizes radioactivity outflow should be ensured when a nuclear power plant is constructed and driven.

Nowadays the introduction of surface treatments or coatings is expected to be an ideal solution to fretting damage since fretting is closely related to wear, corrosion and fatigue[3]. Among these treatments, thin hard coatings are usually employed to improve the tribological properties such as friction and wear of conventional engineering materials. Of these coatings, TiN coating[4] is probably used frequently in PVD coatings for the mitigation of fretting wear. But few researches related to TiAlN coatings for improving fretting damage are in progress. It is known that TiAlN coating is much harder than TiN coating and high-temperature performance of TiAlN coating is also superior to that of TiN coating.

Therefore, in this study the fretting wear experiment was performed using TiAlN coated Zircaloy-4 tube as the fuel rod cladding and uncoated Zircaloy-4 tube as one of grids, especially concentrating on the sliding component. To evaluate the superiority of TiAlN coating, the fretting wear experiments of uncoated Zircaloy-4 tube were also performed.

2. EXPERIMENTAL PROCEDURES

The fretting wear tester was designed and manufactured for this experiment and TiAlN coated Zircaloy-4 tubes were used as the moving specimens, uncoated Zircaloy-4 tubes as stationary ones. The number of cycles (1×10^5, 3×10^5, 5×10^5 cycles), slip amplitude(40, 70, 100, 150, 200, 300 μm) and normal load (20, 40, 60, 80, 100 N) were selected as main factors of fretting wear and frequency was fixed at 10 Hz during all experiments. The contact configuration is cylinder-to-cylinder contact at a right angle.

3. RESULTS AND DISCUSSION

3-1 Variation of wear volume with increase of normal load

Wear volume decreased over a specific normal load with increase of normal load. In the test of TiAlN coated tube-uncoated tube contact the maximum wear volume at 40 μm was could be observed on 20 N but the maximum value at 70 μm was on 40 N and that at 100 μm was on 60 N. And at higher slip amplitudes wear volume was increased with increase of normal load.

3-2 Variation of wear volume with increase of slip amplitude

In the test of TiAlN coated tube against uncoated tube the evident critical slip amplitude could not be found but up to 70 μm remarkable differences of wear volume was not shown in all the normal loads, and above 100 μm wear volume increased as the normal load increased.

3-3 Investigation of fretting wear mechanisms

In the test of TiAlN coated tube against uncoated tube, the main wear mechanisms were partial slip → brittle fracture of

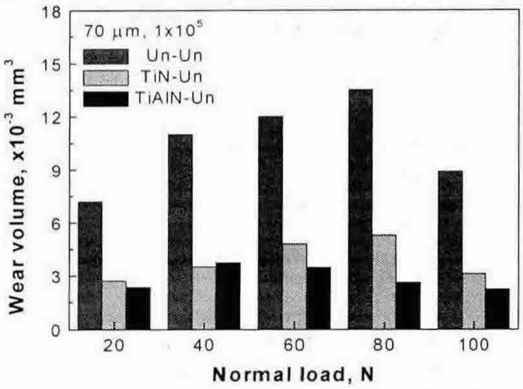

Fig. 1 Comparison of TiAlN coated tube with TiN coated and uncoated tubes
(70 μm, 1×10^5 cycles)

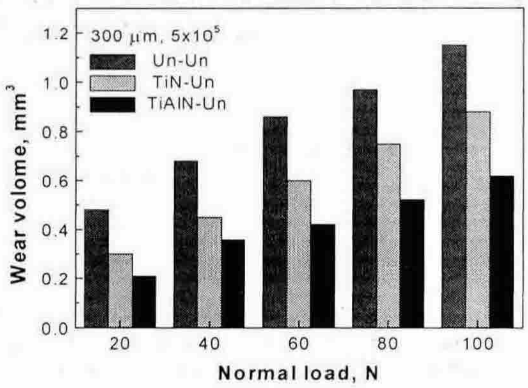

Fig. 2 Comparison of TiAlN coated tube with TiN coated and uncoated tubes
(300 μm, 5×10^5 cycles)

coating → accumulation of plastic flow → oxidation → spalling → spalling of oxidative layers as slip amplitude increased.

3-4 Fretting resistance improvement using TiAlN coating

Compared with TiAlN coated Zircaloy-4 tubes, wear volumes of uncoated Zircaloy-4 tubes were 2.95~5.0 times and those of TiN coated tubes were 1.0~2.03 times at 70 μm, 1×10^5 cycles as shown Figure 1. Even at higher slip amplitudes superiority of TiAlN coating was remained. According to Figure 2, wear volumes of uncoated Zircaloy-4 tubes were 1.85~2.31 times and those of TiN coated tubes were 1.26~1.44 times at 300 μm, 5×10^5 cycles compared with TiAlN coated Zircaloy-4 tubes.

3-5 Introduction of MOC

MOC(Mutual Overlap Coefficient) was introduced to consider effects of slip amplitude and normal load in fretting regime simultaneously.

Stick regime was shown when MOC value was in the range from 0.95 to 0.9, partial slip regime was in the range from 0.9 to 0.65 or 0.75 and gross slip regime was in the range of 0.5.

4. CONCLUSIONS

Application of TiAlN coating for fretting resistance improvement of Zircaloy-4 tubes as nuclear fuel rod cladding materials was successful and the main wear mechanisms were partial slip → brittle fracture of coating → accumulation of plastic flow → oxidation → spalling → spalling of oxidative layers as slip amplitude increased.

MOC(Mutual Overlap Coefficient) was introduced to consider effects of slip amplitude and normal load in fretting regime simultaneously.

5. REFERENCES

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