

The High Temperature Oxidation Behavior of Diffusion Aluminized MarM247 Superalloy

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The MarM247 based superalloy (8wt.%Cr- 9wt.%Co- 3wt.%Ta- 1.5wt.%Hf- 5.6%wt.Al- 9.5wt.%W- Bal. Ni) specimens were diffusion aluminized by for types of pack cementation methods, and their coating structure and their high temperature oxidation resistance were investigated.

The coated specimens treated at 973K in high aluminum concentration pack had a coating layer containing large hafnium rich precipitates, which were originally included in substrate alloy. After the high temperature oxidation test in air containing 30 vol.% H₂O at 1273K ~ 323K, the deep localized corrosion which reached to the substrate were observed along with these hafnium rich precipitates. On the other hand, the coated specimens treated at 1323K using low aluminum concentration pack showed the coating layer without the large hafnium rich precipitates, and after the high temperature oxidation test at 1273K for 1800 ksec, it did not show the deep localized corrosion. The nickel electroplating before the aluminizing forms thick hafnium free area, and its high temperature oxidation resistance were comparable to platinum modified aluminizing coatings at 1273K.

Keywords : high temperature oxidation, diffusion aluminizing, superalloy, coating, hafnium

1. Introduction

In recent years, because of the requirement to increase the heat efficiency of industrial gas turbines, the turbine inlet gas temperature is tend to be raised. Since the base alloy compositions of blades and vanes are designed to satisfy mechanical properties, surface coatings are applied to protect these components to overcome high temperature oxidation and corrosion. Over the past decades, considerable studies have been done on developing coating system for protection against high temperature oxidation.

Diffusion aluminizing method were widely applied on the gas turbine blade or vanes as the high temperature oxidation resistance coating, since it is relatively inexpensive and easy to apply. The coating morphology varies widely by the pack cementation conditions, however, the relations between aluminizing conditions with the high temperature oxidation resistance are still not studied systematically.^{1),2)}

In this study, a nickel based superalloy, MarM247 was diffusion aluminized by various pack cementation methods, and the high temperature oxidation resistance at 1273 to 1323K were investigated.

2. Experimental

As the substrate, a nickel based superalloy (8wt.%Cr- 9wt.%Co- 3wt.%Ta- 1.5wt.%Hf- 5.6%wt.Al- 9.5wt.%W- Bal.Ni; MarM247) were employed. The specimens were cut to 25 mm X 10 mm X 3 mm size of rectangular specimens. These specimens were embedded in a certain compositions of pack mixture and heated in hydrogen, to diffuse aluminum on the surface of the specimens. Two types of pack cementations were employed. The pack A is consisted of 10wt.% of aluminum, 5wt.% of activator and alumina as balance, and heated at 973K. The pack B is consisted of aluminum containing alloy powder, activator and alumina as balance, and 3.5 wt.% of metallic aluminum is contained in the pack mixture. In the pack B, the specimens were heated to 1323K in hydrogen atmosphere.

Some of test pieces were coated by nickel or platinum layer before the diffusion aluminizing. These layer were electroplated and the thickness of these layers were 10 X 10⁻⁶ m. The nickel plated specimens were subjected to the diffusion aluminizing by pack B method. The platinum plated specimens were subjected to heat treatment at

Fig. 1. Schematic diagrams of the test apparatus

Fig. 2. The cross section and hafnium distribution of pack A coating specimens.

1273K, and then subjected to the diffusion aluminizing by the pack B method. After the diffusion aluminizing, all specimens were heat treated at 1323K.

These specimens were subjected to high temperature oxidation test in air containing 30 vol.% H₂O at 1273K and at 1323K in electric furnace. The schematic diagrams of test apparatus were shown in Fig. 1. After the high temperature oxidation test, the cross sections of the specimens were observed and the corrosion penetration depth were measured.

Fig. 3. The cross section and hafnium distribution of pack B coating specimens.

3. Results and discussion

Fig. 2 shows the cross section and the electron microprobe analysis image of hafnium of diffusion aluminized specimens in pack A. The coating layer of the specimen aluminized in pack A showed two layers structure; the outer layer was the coating layer mainly consisted of nickel aluminide, and the inner layer was the diffusion layer which includes a lot of refractory metal rich precipitates. In the coating layer, large hafnium rich precipitates were observed. These precipitates were originally contained in MarM247 substrate alloy. Part of the precipitates located on the alloy surface. Fig. 3 shows the cross section and the electron microprobe analysis image of hafnium of diffusion aluminized specimens in pack B. The coating layer contained the hafnium rich precipitates too, however, there was a precipitate free layer of approximately 5×10^{-6} m thickness at outermost part of the coating layer. Fig. 4. shows the cross section of the nickel modified aluminized specimen. The nickel modified aluminum

Fig. 4. The cross sections of the nickel modified aluminizing specimens.

Fig. 5. The cross sections of the platinum modified aluminizing specimens.

Base alloy

Pack A specimen

Pack B specimen

Nickel modified aluminized specimen

Platinum modified aluminized specimen

Fig. 6. The cross sections of the specimens after the high temperature oxidation test at 1273K, for 1800 ksec in air-30%H₂O atmosphere.

specimens had approximately 40×10^{-6} m thickness of nickel aluminide layer and a diffusion layer. In the coating layer, no hafnium rich precipitates were observed. Fig. 5 shows the cross section of the platinum modified aluminized specimen. The platinum aluminide specimen had three layers morphology. The outermost layer was consist of the mixture of platinum rich phase (which shown as

lighter phase in the Fig. 5) and nickel aluminide phase. The middle layer was consisted of nickel aluminide layer with less platinum. The innermost layer was the diffusion layer similar to the other aluminized specimens.

Fig. 6 shows the cross sections of specimens after the high temperature oxidation test in air containing 30 vol.% H₂O at 1273K for 1800 ksec. The maximum corrosion

Fig. 7. Maximum corrosion penetration depth of the specimens after high temperature oxidation test at 1273K in air-30% H_2O .

Fig. 9. Maximum corrosion penetration depth of the specimens after high temperature oxidation test at 1323K in air-30% H_2O .

Base alloy

Pack A specimen

Pack B specimen

Nickel modified aluminized specimen

Platinum modified aluminized specimen

Fig. 8. The cross sections of the specimens after the high temperature oxidation test at 1323K, for 1800 ksec in air-30% H_2O atmosphere.

penetration depth of each specimens were shown in Fig. 7. The pack A coated specimens showed deep localized corrosion which reached to the alloy substrate. Electron probe microscope analysis shows that the localized corrosion area is corresponded to the hafnium rich precipitates existed in the coating layer. On the other hand, the pack B coated specimens did not show the deep localized corrosion. This difference could be considered to be caused by the difference of coating structures. The pack B coating had the thin outermost layer without the hafnium

rich precipitates, therefore the localized corrosion like pack A coating did not occur. Das et.al mentioned that the difference of pack aluminizing conditions will form different morphology of coating layer.²⁾ When aluminizing was conducted in high aluminum concentration (15%) pack, the growth of coating layer was caused by the inward diffusion of aluminum. On the other hand, when aluminizing was conducted in low aluminum concentration (5%) pack, the growth of coating layer was caused by the outward diffusion of nickel from substrate, and after heat

treatment, the layer without precipitates such as hafnium carbide or tungsten rich precipitates were formed at the outermost part of the coating layer. The coating morphology in this study also fit with their results. The hafnium or tungsten could reduce the oxidation resistance of the coating layer and this could be the reason of difference in the corrosion resistance between the pack A coating and the pack B coating.³⁾

The nickel modified aluminizing specimen show no localized corrosion like as the platinum modified aluminized specimen at 1273K. This results shows that the nickel modified aluminizing is effective to improve high temperature oxidation resistance at 1273K. Since the relatively good oxidation resistance of pack B coating at 1273K was come from the thin precipitates free layer, the oxidation resistance will be reduced after the long term oxidation by the outward diffusion of tungsten or hafnium or the inward diffusion of aluminum.^{3),4)} On the other hand, the nickel modified aluminized specimens have thicker precipitate free nickel aluminide coating layer, it is expected to have good oxidation resistance for longer time.

Fig. 8 shows the cross sections of specimens after the high temperature oxidation test in air containing 30 vol.% H₂O at 1323K for 1800 ksec. The maximum corrosion penetration depth of each specimens were shown in Fig. 9. The oxidation became severer than at 1273K, therefore, except the platinum aluminized coating specimen, all specimens showed severe corrosion. This results shows that the high temperature oxidation resistance of nickel aluminide will be reduced above 1323K, and in these temperature, the platinum modified aluminizing is required to apply.

4. Conclusions

By the observation of coating structure and the high temperature oxidation tests, the following conclusions could be made;

1) The coated specimens treated at low temperature (973K) in high aluminum concentration pack (pack A) had a coating layer containing large hafnium rich precipitates. After the high temperature oxidation test in air containing 30 vol.% H₂O at 1273K~1323K, the deep localized corrosion along with the hafnium rich precipitates were observed.

2) The coated specimens treated at high temperature 1323K using low aluminum concentration pack (pack B) showed thin outermost layer without the hafnium rich precipitates. After the high temperature oxidation test at 1273K for 1800 ksec, it showed the better oxidation resistance than the pack A coated specimen.

3) The nickel modified aluminized specimen formed thicker hafnium free layers and showed good oxidation resistance at 1273K, which was comparable to platinum modified aluminized specimen.

References

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