HIGH TEMPERATURE FATIGUE PROPERTIES OF MICRO SPARK COATED NI-BASE SUPERALLOY

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1. Background

There have been many kinds of requirements for surface modification of Ni-base superalloy used for advanced gas turbines. More recently, Micro Spark Coating (MSC) has been developed as a new candidate coating method for Ni-base superalloy, Ochiai et al. [1]. The attractive points in this method are its high potential capability to be applied to complex three dimensional high temperature components as well as to control the coatings microstructure. Although some of studies have been made on to optimize microstructure, hardness, and wear resistance of MSCed Ni-base superalloy, Ootera et al. [2], little is known about its microstructural stability and fatigue properties at elevated temperature. In this work, high cycle and low cycle fatigue properties of the Inconel 718 specimens to which a Co-base wear resisting alloy, Stellite 31, was coated by a selected MSC condition were studied at elevated temperatures, as well as the microstructural stability of the coatings.

2. Experiment

2.1 Specimen

A Co-base wear resisting alloy, Stellite 31 and a typical Ni-base superalloy, Inconel 718, were used for MSC material and substrate, respectively. Two types geometries of Inconel 718 substrate were prepared; one was plate shape for high temperature exposure tests and the other was solid cylindrical one for the fatigue tests. MSC layer was coated by using the MSC system based on the Electro Discharge Machining device. After the coating, the latter specimens were subjected to a heat treatment by 700 ºC x 1 hr in vacuum. The SEM micrograph after the heat treatment is shown in Fig.1. Here, MSC layer shows a porous microstructure which is composed of several micrometers pores in diameter.

2.2 High temperature exposure test

High temperature exposure tests were performed at 480 ºC and 650 ºC in the muffle furnace. Microstructural evolutions in the MSC layers were observed each after 10, 100, and 1000 hrs by using the SEM, where the specimen surface was carefully polished by the SiC emery paper (#600-#4000) and 0.3μm Al₂O₃ powder. The evolutions were characterized by area fraction of the cavity in 750 times resolution SEM image which had been binarized by original image processing program.

2.3 High temperature fatigue tests

HCF and LCF tests were carried out at 480 ºC and 650 ºC, utilizing a servo-electro hydraulic test system. The HCF test was conducted under load controlled, sinusoidal tension-compression wave form, (-1 in stress ratio, and 10 Hz in loading), while the LCF test was under a strain controlled, triangle waveform (-1 in strain ratio, and 1/3 Hz in loading), where the strain range
$(\Delta \varepsilon)$ was held constant; $\Delta \varepsilon = 0.6\%$. The specimens were heated in air by using a high frequency induction heating system, which provided a uniform temperature distribution along the specimen gauge section within 5 °C. In this study, the number of cycles to failure in the HCF tests was defined by the number at which the specimen was broken completely, whilst that in the LCF tests was determined by the number of strain cycles at which the tensile stress was reduced by 30% from the stationary value.

3. Results and Discussions

3.1 High temperature exposure test

Fig.2 shows the MSC microstructures after the thermal exposure tests for 10 and 1000 hrs at 480 °C and 650 °C. Comparing Fig.1 with Fig.2, it is found that the microstructure in the MSC layer was almost stable even after the isothermal exposure to 1000hrs at 480 °C (Fig.2 (c)), while it significantly changed at 650 °C, associated with the formation of dark gray region which generated between the original grains (Fig.2 (b), (d)). Fig.3 shows the variation of the cavity area fraction with exposure time, indicating the fraction was dramatically decreased at 650 °C. Analysis using the Energy Dispersive x-ray Spectroscopy (EDS) revealed that the dark region in Fig.2 (b) and (d) was oxidized phase of original phase in Fig.1. The Vickers hardness of before and after exposed MSC layer was measured with 4.9N load on the out-of-plane of the coating, and indicated in Fig.4. This figure shows that the Vickers hardness of the 650 °C exposed specimen was immediately increased during first 10hrs, and then slightly increased with exposure time. Such a hardness change was might be attributed to the generation of the oxidized second phase as well as the progress of sintering of MSC layer during the high temperature exposure.
3.2 High temperature fatigue tests

HCF and LCF test results are shown in Fig.5 and Fig.6, respectively. The stress value of the vertical axis in Fig.5 was calculated by the substrate cross sectional area, neglecting the coating thickness. It is found in Fig.5 that the MSCed specimens showed shorter fatigue lives than the substrate at 480 ºC, while they were almost comparable when tested at 650 ºC. However, it is worth noting that there might be strong dependence of stress amplitude and test temperature in the effect of coating on fatigue lives: i.e., at 650 ºC under the higher stress amplitude, the MSCed specimen life was shorter than the substrate life, this relative relation was reversed under lower stress amplitude. These trends were attributed to the following characteristics of the MSCed specimen: according to the SEM observation on the longitudinal cross-section of the tested specimens, the prior interface between the substrate and the MSC layer was roughed by the MSC process. Such a wavy interface might accelerate the fatigue crack initiation there (Fig.7), resulting in the shorter fatigue lives. On the other hand, MSCed specimens failed, associating with a significant increase of hardness, compared with the specimen exposed to a mere thermal exposure (Fig.4). This suggests the external load accelerated the sintering and promoted a load transfer capability of the coating. These two conflicting factors would lead to the complex fatigue properties in Figs.5 and 6.
4. Conclusions
The fatigue properties of Micro Spark Coated Inconel 718 and the microstructural stability of the coatings were investigated at elevated temperatures. It was found from a series of experiments that the MSCed Inconel 718 had fatigue properties almost comparable to the substrate at 650°C. To improve the fatigue property of the MSC in future, at least two different types of phenomena should be taken into account: One was the affected areas formed by MSC process which might influence the crack initiation life, and the other was a load transfer capability of the coated area, dependent on the test temperature and test time.

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6. References