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FATIGUE DAMAGE DEVELOPMENT IN NICKEL-BASED SUPERALLOY WITH THE ALUMINA LAYER

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1. Introduction

The operating conditions of the aircraft engine turbines, made from e.g. nickel-based super alloys, require high mechanical load resistance in high temperature. To improve the parameter, protective layers are applied. They increase the heat resistance of alloys but are likely to reduce the fatigue strength. In this work the impact of the aluminide layer, deposited on the samples made from Inconel 740 alloy in a chemical vapor deposition process (CVD), on the fatigue parameters is assessed. A comparative analysis was carried out for the damage development mechanisms in both sample types. The damage parameter was defined as the sum of the strains and its plot in the function of the number of cycles. The results obtained were correlated to the factual studies of fractures.

2. Research methodology

The studies carried out were of the high-cycle test nature. Basing on the results obtained in a static tension test, the range of values for the load amplitude was defined, being 350 - 500 MPa for In740 samples and 500 - 650 MPa for In 740_Al samples. The studies were carried out for two batches of samples (4 with the layer and 4 without it) displaying axial symmetry with a narrowing in the measured section. The strain was measured by transverse extensometer, checking the narrowing values in (fig. 1)

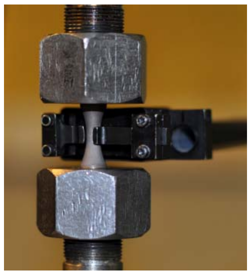


Fig. 1. A fixed sample with the extensometer.

The results obtained were used for developing the relationship between the damage parameter defined as the sum of average strain and the strain amplitude to the number of cycles, in accordance with the following formula:

$$\phi = \varepsilon_a + \varepsilon_m$$

where:

ε_w - width amplitude of the cycle hysteresis loop:

$$\varepsilon_w = \frac{\varepsilon_{min}^{F=0} - \varepsilon_{max}^{F=0}}{2}$$

ε_m - average strain in the cycle, defining the location of the hysteresis loop for a given cycle in the strain axis, expressed by:

$$\varepsilon_m = \frac{\varepsilon_{min}^{F=0} + \varepsilon_{max}^{F=0}}{2}$$

The principle of determining the damage parameter φ is presented also in the diagram in Fig.3.

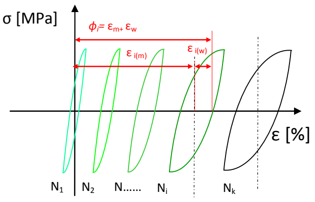


Fig. 2. Diagram showing the strain development in consecutive fatigue cycles

Thanks to describing the strain development in this way, it was possible to assess the changes in the fatigue damage dynamics in the samples with the layer and without it in the extensive amplitude range.

3. Results

Presenting the results in the form of Wohler curve (Fig. 2) enables to detect a clear increase (by about 100 MPa) in the fatigue strength of Inconel alloy with Al layer in a wide range of stress values.

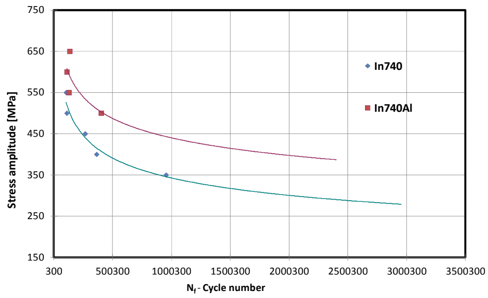


Fig. 3. Wohler diagram depicting the influence of Al. layer on the fatigue strength of In 740 alloy.

Basing on the determined fatigue damage parameters, the strain development in consecutive cycles was analyzed. Figure 4 presents the matching of these data for both sample types subject to the load with the amplitude of 500 MPa. With a significantly higher resistance (the number of cycles before breaking was 4 times greater) for the sample with the layer, a similar plot of the damage development can be observed for both samples, characterized with three stages.

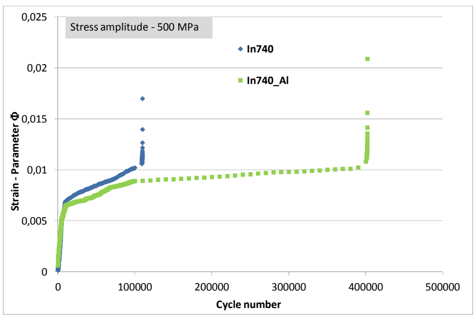
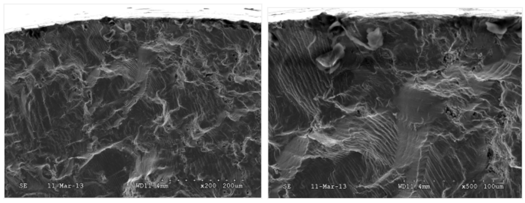


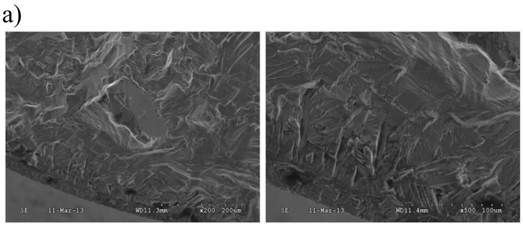
Fig. 4. Changes in φ parameter in consecutive cycles.

The first stage was a dynamic increase in the damage in over ten cycles. The second stage was a stable increase which ends earlier for the sample without the layer, leading to the third stage, connected with the crack initiation and development. The final strain level measured for both samples is similar.

The reasons for the increased fatigue strength of the samples given the surface treatment were sought in factual studies. Figure 5 presents selected fracture images. Besides various traces of cyclic load in the form of ribs, it is possible to assess the layer thickness (about 30 μm) and its diffusive nature, as well as strong integration with the substrate. However, this can hardly be used for explaining such a clear improvement of fatigue properties. Due to the function of aluminum layers which in principle can create heat barriers for nickel alloys, the results obtained should be explained rather in the context of heat-activated processes, accompanying the layers' deposition and not their presence as such.



a)



b)

Fig. 5. Fatigue fractures for In740 samples without the layer (a) and with the Al layer (b)

Acknowledgements

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[1] R. Sitek, D. Kukla, K.J. Kurzydłowski; Structure and Properties of the CrN+QlrNi3 Layer Produced on Inconel 740 by Pulse Plasma Ion Nitriding at a Frequency of 10kHz, Plasma Application and Hybrid Functionally Materials vol. 22 March 2013