Influence of aluminum layer thickness on the fatigue properties of super-nickel alloy

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Abstract

The paper presents the results of fatigue tests performed on the super-nickel alloy after Chemical Vapor Deposition (CVD). CVD process was carried out for the periods of 4 and 12 hours, and as a consequence, a layer of the aluminum of the thickness 20 µm and 40 µm, respectively, was obtained on the surface of nickel alloy. The specimens with layers were tested on the servo-hydraulic testing machine under dynamic loading at high temperature of 900^{o}C. The profiles of micro hardness on the cross-sections of specimens enabled identification of hardness variations. The main aim of this paper was to evaluate the effect of a film thickness on the fatigue properties of the alloy. Additionally, an identification of crack propagation in the layer subjected to cyclic loading was analysed on the basis of deformation changes in the subsequent cycles.

Keywords: aluminium layer, super nickel alloy, fatigue testing, CVD technique

1. Introduction

The extreme operating conditions of modern aircraft engine turbines require an application of the heat-resistant and high-temperature materials. The gas temperature at the combustion chamber outlet reaches 1600˚C while the maximum operating temperature of contemporary nickel super alloys (with a monocrystalline structure) is 1100˚C. This fact well reflects a response into the question why it is necessary to produce protection covers on the hot parts of the aircraft engine turbines [1]. The most popular method for obtaining diffusion layers is Chemical Vapour Deposition (CVD). In this work an influence of thickness of the diffusion aluminide layers on the high-cycle fatigue strength of nickel super alloy MAR 247 [2] is studied.

2. Methodology

The films for tests were obtained basing on the nickel alloy MAR 247. The aluminizing process was carried out by the Chemical Vapour Deposition (CVD) method using $AlCl_3$ vapours in hydrogen atmosphere as the carrier gas at temperature of 1040˚C for the periods of 4 h or 12 h, and the reduced pressure of 150 hPa. Depending on the duration of this process the aluminum layers of 20 µm or 50 µm thickness were obtained on the nickel alloy surface.

The fatigue tests were carried out on the MTS 810 testing machine of the axial force capacity equal to +/- 25 kN and equipped with the FLEX digital controller. The specimen temperature of 900^{o}C during tests was obtained by means of the induction heater mounted on the testing stand as it is shown in Fig.1a. The geometry of specimens applied in the experimental programme is presented in Fig.1b.

All fatigue tests were force controlled under the assumption of the zero mean level and constant stress amplitude for a given specimen tested. The frequency during fatigue tests was equal to 20 [Hz], whereas the magnitudes of stress amplitude varied from 380 [MPa] up to 520 [MPa].

Since it was assumed that the diffusion layer is more susceptible to brittle fracture, micro hardness profiles on the cross section of specimens were prepared in order to evaluate a hardness gradient. The micro hardness was measured using the Hysytron device, under load of 0.0005 [N] starting from the edge of specimen. Observation of the fatigue damage development was conducted by means of the light and scanning microscopes in order to confirm whether the layer cracks are generating before the specimen's decohesion.

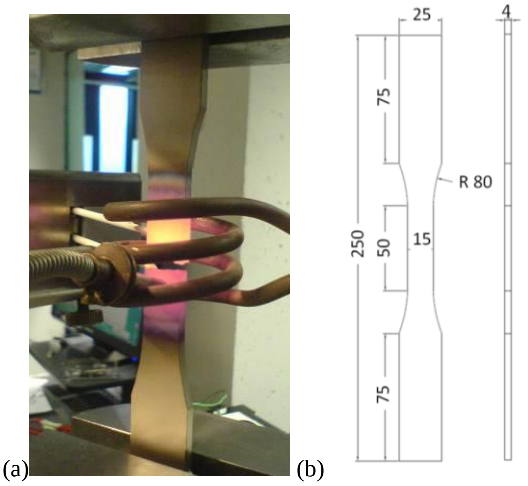

Figure 1: Specimen mounted in the griping system of the testing machine with heater (a), and engineering drawing of the specimen (b)

3. Results

Experimental programme contained 14 fatigue tests (7 tests for each layer thickness considered). Microscopic measurements were carried out directly after fatigue tests.

The results of fatigue investigations were elaborated in the form of Wöhler diagrams presented in Fig. 2. The figure shows variation of the cycles number up to failure depending on the thickness of the aluminum layer deposited on the surface of the super-nickel alloy specimen. It has to be noticed, that the fatigue results are not consistent taking into account the effect of the layer thickness. For three levels (of seven levels considered) of the stress amplitude a longer fatigue lifetimes were achieved for 20 µm layer thickness, for the remaining tests, however, longer lifetimes were obtained for thicker layer.

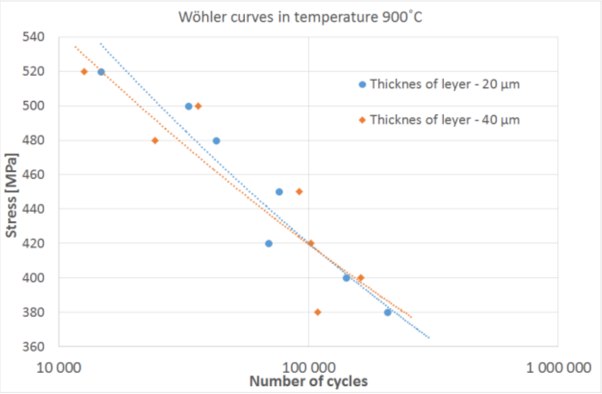

Figure 2: Wöhler characteristics for specimens with surface deposited by the aluminum layer, fatigue in temperature 900˚C

The profile of micro hardness variations is shown in Fig.3. It also contains a topography map of the surface tested where the spots of indentation are illustrated. As it is shown in this figure, the values of micro hardness of the aluminium layer are significantly higher than those for the nickel core determined.

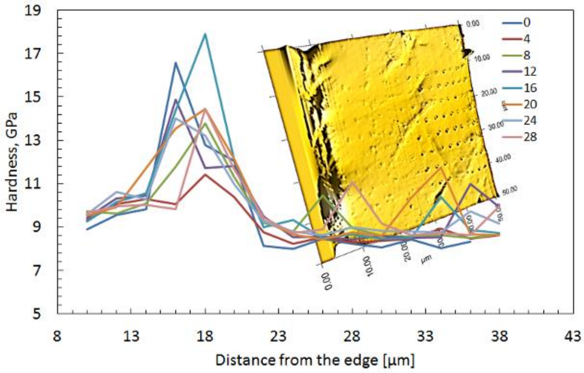

Figure 3: Micro hardness profiles and the map of indenter positions for micro hardness measurement.

Observation of the fatigue fracture using the light microscope, Fig. 4, and SEM technique, Fig. 5, enabled identification of the layer cracks generated just before the decohesion of the specimens tested.

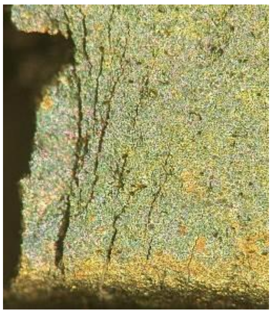

Figure 4: Illustration of cracks in the layer area close to the specimen failure - photo from light microscope.

In the microscopic damage analysis of tests carrying under fatigue conditions usually such damage sensitive strain parameters as the accumulated inelastic strain or accumulated mean strain level well describe a damage development in the subsequent loading cycles. They can be easily determined on the basis of hysteresis loops [3, 4].

In this case however, it has to be emphasized, that the effect observed during microscopic inspections could not be confirmed by the damage sensitive strain parameters mentioned above.

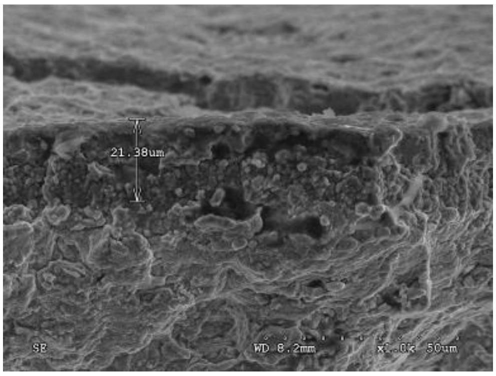

Figure 5: Illustration of cracks in the layer area close to the specimen failure - photo from SEM

A process of the layer cracking was completely not visible looking on the hysteresis loops evolution for subsequent cycles of loading.

4. Conclusions

The cracks of layer are responsible for damage initiation of the nickel based specimens after CVD process. It has to be noted that the aluminum layer does not affect the fatigue strength of the nickel alloy, also a thickness of layer is not important in this matter. The identification of the layer's cracking initiation is impossible by monitoring of the deformation, only. Therefore, in further studies an application of the non-destructive methods to capture the layers cracking start and development is necessary.

References

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