Identification of the fatigue cracking of the aluminide layers on the nickel alloy with the application of the optical method ESPI and eddy current method

Dominik KUKLA [1], Justyna SZLAGOWSKA-SPYCHALSKA [2]
[1] Polish Academy of Sciences, Adolfa Pawinskiego 5b, 02-106,Warsaw, Poland
[2] Warsaw University of Technology, Faculty of Materials Science and Engineering, Wolowska 141, 02-507,Warsaw, Poland

Contact e-mail: dkukla@ippt.pan.pl, szjustyna@inmat.pw.edu.pl

Abstract. Research on the evaluation of the fatigue life of aluminum layers on the nickel alloys are usually limited to cracks identification through carrying out observations of the microstructure of the samples after cyclic load. This methodology is subjected to the considerable errors. The dismantling of samples from the testing machine changes the load conditions, what affect the reliability of the results. That is why there are attempts to use non-destructive methods that allow the detection of cracks during the stress test (until sample rupture) without removing the sample from the machine. Those possibilities gives us eddy current method, commonly used in flaw detection and ESPI, an optical technique which enables interferometric measurements of surface displacements.

The work concerns the use of eddy current method and optical method ESPI to the identification of the cracks of the diffusion aluminide layers on the nickel alloy MAR 247. Fatigue tests were performed on the samples with thicknesses of 20 and 40 µm in the tensile load condition. Eddy current and ESPI measurements were performed after predetermined sequences of load cycles and after the load was stopped at maximum tensile stress. On this basis the fatigue life of layer and its effect on durability of the samples was determined.

Introduction

Research on the evaluation of the fatigue life of aluminum layers on the nickel alloys are usually limited to cracks identification through carrying out observations of the microstructure of the samples after cyclic load. This methodology is subjected to the considerable errors. The dismantling of samples from the testing machine changes the load conditions, what affect the reliability of the results. That is why there are attempts to use non-destructive methods that allow the detection of cracks during the stress test (until sample rupture) without removing the sample from the machine. Those possibilities gives us eddy current method, commonly used in flaw detection and ESPI, an optical technique which enables interferometric measurements of surface displacements. The illumination of a rough surface with coherent laser light and subsequent imaging using a CCD camera generates statistical interference patterns, the so-called speckles. When the object under test is loaded, e.g. by mechanical means, and the surface is deformed, the speckle interferogram also changes. Comparing an interferogram of the surface before and after loading will result in a fringe pattern, which reveals the displacement of the surface. This measurement allows the calculation of the three dimensional distribution of the displacement.

1. Methodology

The research which involved the identification and localization of fatigue cracks in the nickel alloy samples with aluminide layer were carried out with the use of servohydraulic, dynamic testing machine MTS 810, DANTEC DYNAMICS system ESPI Q-300 and defectoscope NOTREC 600 (OLYMPUS).
The nickel alloy MAR 247 samples (fig. 1) with different structures (finely and coarsely crystalline) and with the aluminide layers with thickness 40 µm were subjected to alternating, cyclic tensile load with amplitude in the range of 600 - 650 MPa. Samples used in the ESPI measurements were covered with the developer ZP-9F (commonly used in penetration method) in order to avoid reflections from the metallic surface of the sample and to obtain the optimal conditions for displacement measuring.

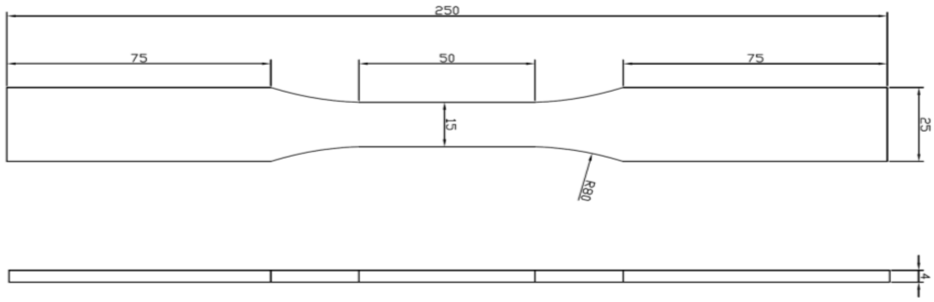


Fig. 1. The geometry of the sample used for deformation measurement

Non-destructive testing measurements were conducted after established sequence of fatigue cycles, under static conditions, starting from the first cycle. Detection of the damage were based on the identification of the concentration on the map of deformation and by scanning the surface of the sample with the eddy current probe.
The load cycles program was carried out in the sequences that allow for the maintenance of stability of the interference fringes, which enabled measurement of the displacement. Due to the high accuracy of the method, it has a very small measuring range. Too big displacement, caused by too much force, causes a loss of image of the motion of interference fringes, making it impossible to measuring. Therefore, it was necessary to perform each measurement sequence with the step of 2kN, which ensured the stability of the interference fringes. Thus, to achieve the strength of 2360N which was equivalent to the stress of 600 MPa, it was necessary to conduct measurements in the 20 sequences (19 was carried out with the step of 2kN and the last one with the step of 2360N).
Due to the noises in the image, caused by the hydraulics of the testing machine, for recording the images of the phase maps, it was necessary to use the hand pump to add load.
At the fig. 2 the methodology of the measurement was shown. That methodology was repeated at the determined sequence of the cycles until the crack of the layer, before the rupture of the sample.

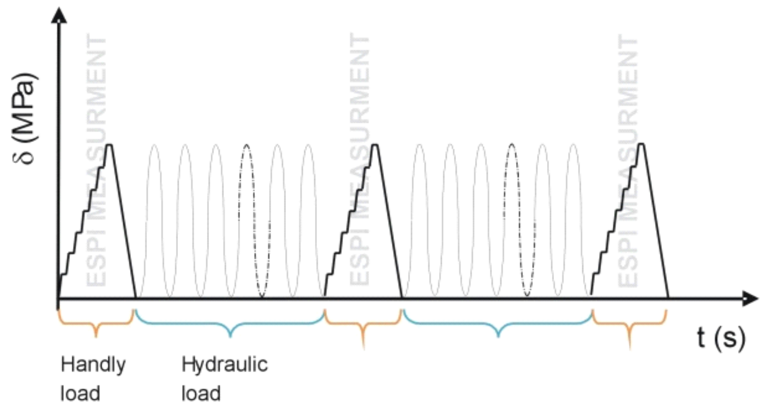


Fig. 2. Diagram of the sample loads and ESPI measurements

For each of the tested samples (with layer) from 5 to 12 displacement images were performed. That allowed us the observation of the damage development in the form of the displacement localization.

For eddy current measurements the base of reference samples with defined discontinuities (depths: 0.2, 0.5 and 1mm) were created.

Tests were carried out with the use of pencil probes under the static load with the value of the fatigue stress amplitude, which by definition should facilitate the detection of the cracks.

Quantitative assessment of the crack size was possible on the basis of a comparative analysis of the signals from the tested samples and standard samples. On the fig. 3 the changes in eddy currents signal due to: detected discontinuities in the reference samples (a), a crack in the unloaded sample (b), a crack in the loaded sample (c) were shown.

The frequency of the measurements increased with the number of cycles (with increasing probability of the appearance of cracks).

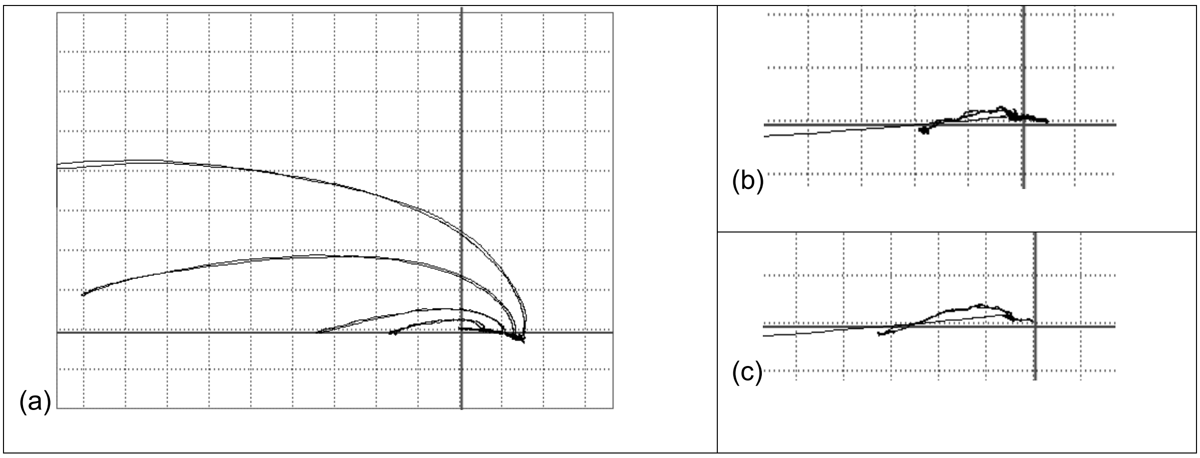


Fig. 3. Eddy current characteristics due to: discontinuities in the reference samples (a), a crack in the unloaded sample (b), a crack in the loaded sample (c)

Identification of cracks in the aluminide layer (40 µm) with the use of eddy current method is impossible due to the limitation of the method. However, we were able to confirm that in some areas of concentration of deformation, the development of crack in the layer occurred which lead to the decohesion of the sample.

2. Results

On the basis of microstructural observation of the surface of the fatigue scrap, appearing of the cracks in the aluminide layer (fig 4a), which are progressing deeper into the material, were confirmed (fig. 4b).

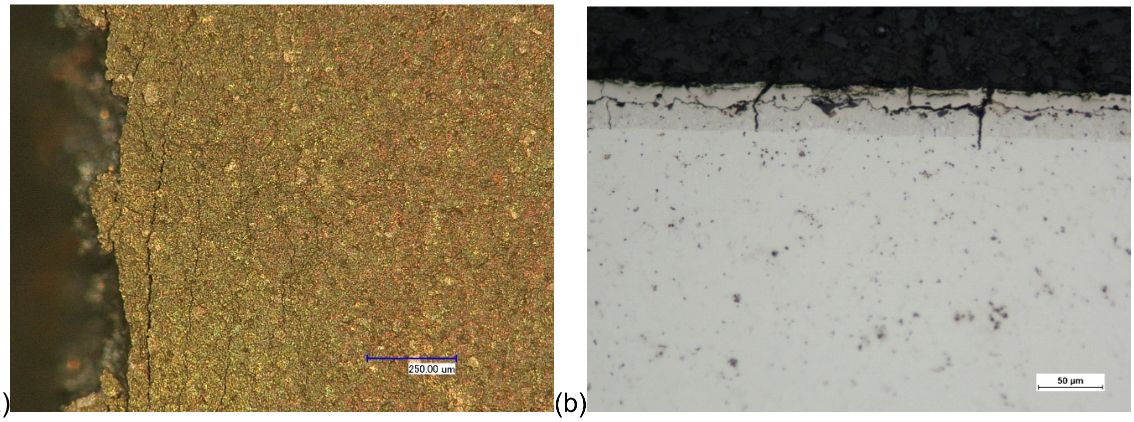
(a) (b)


Fig. 4. A macro image of the side surface of the fatigue scrap, with visible cracks (a) and longitudinal fatigue scrap with the cracks in the aluminide layer (b)

A similar effect was observed, during the fractography of the fatigue scrap with the use of scanning electron microscopy (SEM).

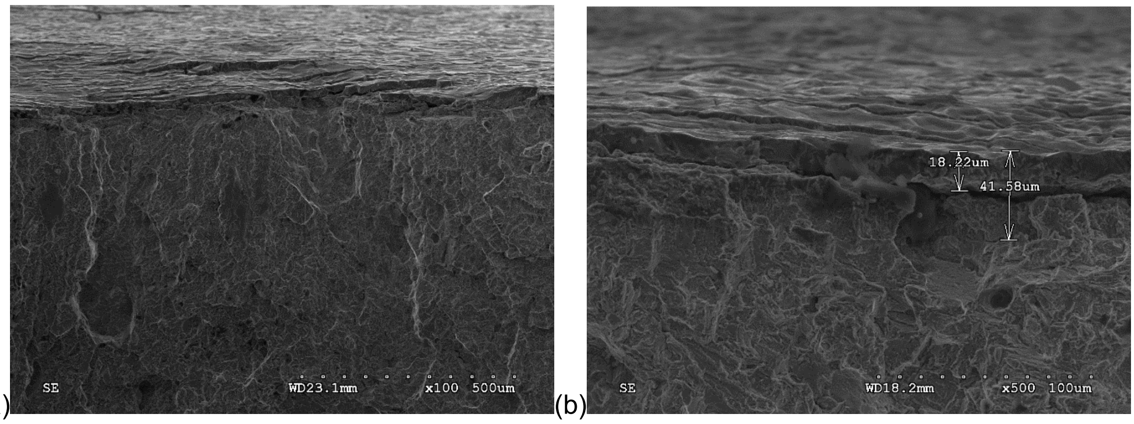
(a) (b)


Fig. 5. Image of the fatigue fracture with the visible cracks in aluminide layer, obtained with the use of SEM

The eddy current measurements, allowed identification of the cracks in the layer, before the damage of the sample, only in few cases. It was when the crack was progressing deeper into the material. It was due to the limitation of the ET method which occurred during the comparison between sample and reference sample. Because the smallest size of the depth of discontinuities in the reference sample is 0.1 mm (100 µm), then this is theoretically the limit value of the detection of discontinuities. In practice, it is possible to detect the shallower cracks, but looking at the indication of the reference discontinuity 0.1 mm (the smallest indication at the fig. 3a), it is difficult to identify the crack which have size of 40 µm (layer thickness).

At the fig. 6, the sketch of the sample, retained after 80 000 load cycles (amplitude 600 MPa) with marked cracks along with an estimation of their depth, was shown.

These estimation was possible due to comparison of the signal obtained from sample with the signal obtained from the reference sample (Fig. 3a).

Changes in the phase angle and amplitude of the signal provides information on the size and the depth of the defect.

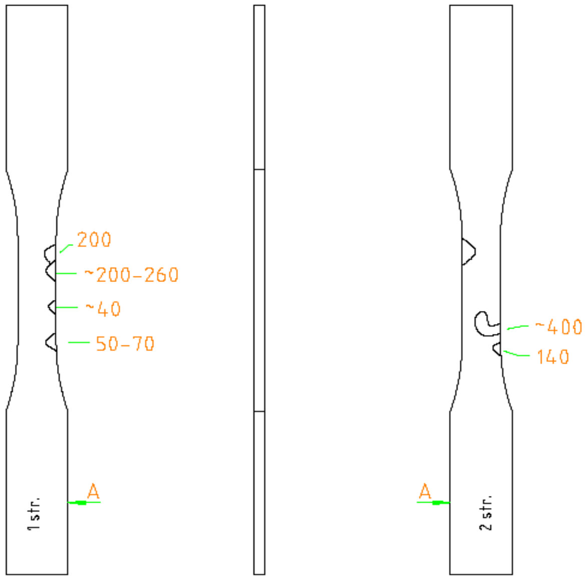


Fig. 6. Sample after 80 000 load cycles used in eddy currents measurements (draft)

For the sample, which has not been destroyed during the fatigue test (fig. 6), six cracks were identified, all of which showed a depth bigger than the thickness of the aluminide layer. This sample was cut along the side edge, and from obtained cross-sections the metallographic sections were prepared. Which showed numerous cracks on either side of the sample. Cracks size was estimated with the use of comparative analysis (standard sample).

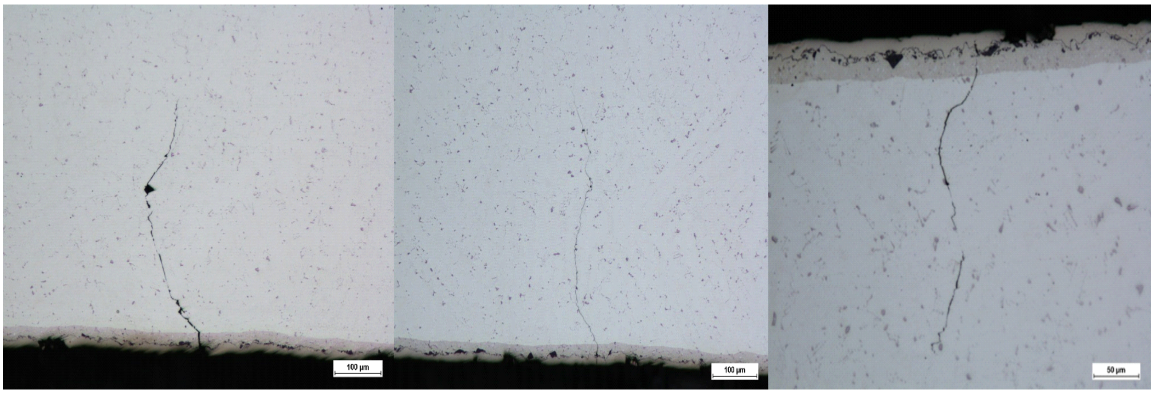


Fig. 7. Propagation of the cracks from layer to the matrix from nickel alloy

These results show the possibility of detecting fatigue cracks with the use of eddy current method. However, only after the propagation of the crack deeper into the material. In the case of testing the surface of the samples immediately after the identification of the cracks with the use of phase maps (ESPI),the indications with the use of ET defectoscope were not obtained. That means that the crack of the layer (fig. 4b) is not possible to identified with the use of eddy current method.

The results of the test by ESPI method, which were conducted parallel to the ET method were shown for two samples.

First sample, with the finely grain structure, was subjected to the loads with the amplitude 650 MPa. For this sample, five deformation maps after: 1k, 20k, 40 and 60k load cycles, were obtained. Sample ruptured after Nf=61968 cycles. Images of recorded maps were shown on the fig. 8.

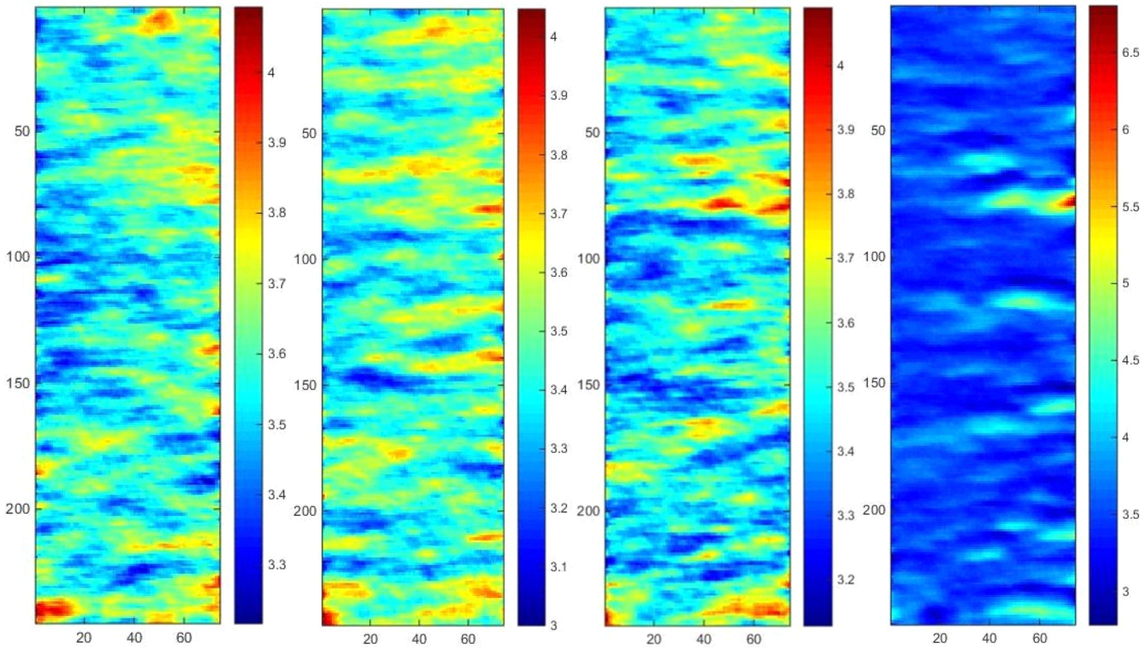


Fig. 8. Map of deformation in the selected load cycles (1k, 20k, 40k anf 60k), amplitude 650 MPa, sample with layer 40 µm

The sample with coarsely grain structure, with the layer thickness 40 µm, was subjected to the loads with the amplitude 600 MPa. The tests allowed the registration of the local damage development. The area of concentration is visible from the first cycle. For this sample, deformation maps for initial stage and after 20k, 40k and 50k load cycles were recorded. Sample ruptured after Nf=54315 cycles. Images of recorded maps were shown on the fig. 9.

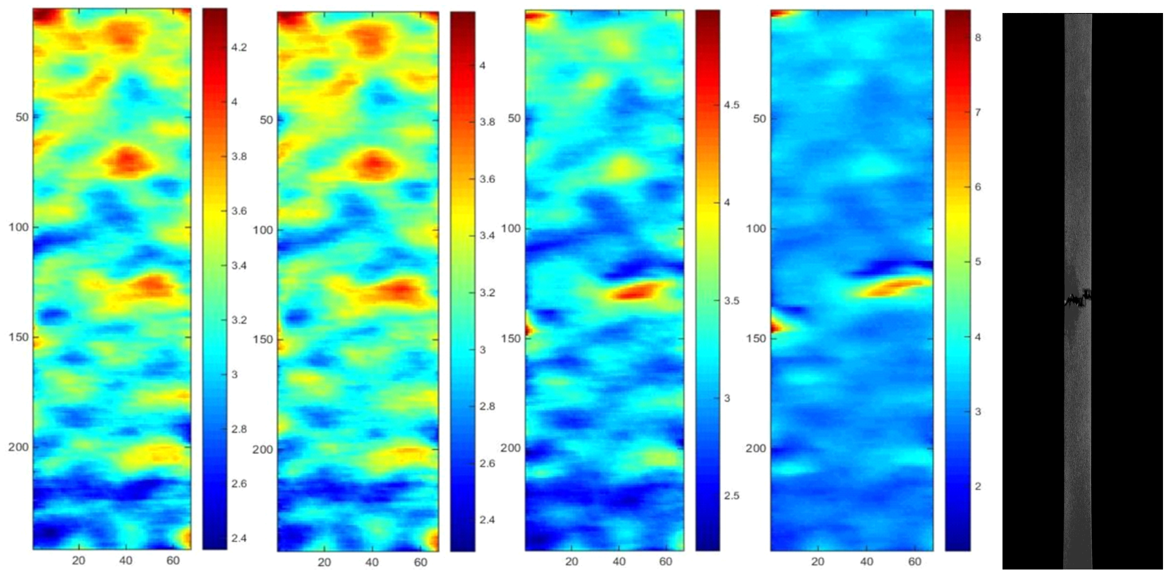


Fig. 9. Map of deformation in the selected load cycles (1k, 20k, 40k and 50k), amplitude 600 MPa, sample with layer 40 µm

At the presented maps of deformation, the areas with increased local deformation value, could have be already seen from the initial load cycles. However, the most visible concentration of the deformation, was visible only at the last registered image, prior to the rupture of the sample.

Value of the deformation could be estimate after conversion * mm/mm*10-3, based on the color scale, which is different for the subsequent maps (which results from the local concentration).
It could be assumed, that the occurrence of the local concentration of the deformation, is related to the appearance of the cracks in the layer, which eventually propagates deeper into the material.

3. Conclusions

Identification and localization of the cracks of aluminide layers on the nickel alloy with the use of optical technique ESPI is possible and allows generating the deformation maps.
Concentration of deformation formed during the load cycles could be a result of the cracks in the layer, which are progressing deeper into the material.
These kind of cracks, which appear during the final step of fatigue test, could be found with the use of eddy current method.
Thus, ESPI permits relatively early identification of cracks (with the appropriate density of measurements).
Eddy current method allows to verify the indications obtained from the optical method. However, only after the propagation of the crack to the depths, which are possible to detect by this method.

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