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SHORT RESEARCH COMMUNICATION

ASSESSMENT OF FATIGUE LIFE OF ALUMINIZED, COARSE-GRAINED MAR 247 ALLOY SUPPORTED BY FULL-FIELD ESPI MEASUREMENTS

Mateusz Kopec
Institute of Fundamental Technological Research Polish Academy of Sciences, Warsaw, Poland; and
Department of Mechanical Engineering, Imperial College London, London, UK
Corresponding author M. Kopec: e-mail: mkopec@ippt.pan.pl

Dominik Kukla, Zbigniew L. Kowalewski
Institute of Fundamental Technological Research Polish Academy of Sciences, Warsaw, Poland

In this paper, fatigue performance of an aluminide layer coated, coarse-grained MAR 247 nickel superalloy was monitored by using the full-field Electronic Speckle Pattern Interferometry (ESPI) method in the range of stress amplitude from 350 MPa to 650 MPa. It was found, that the ESPI method enables precise monitoring of the fatigue behaviour of coated MAR 247 specimens since the area of potential failure was accurately indicated within the initial stage of fatigue damage development.

Keywords: fatigue development, damage, nickel alloys, electronic speckle pattern interferometry

1. Introduction

ESPI is an optical technique which is widely used for full-field stress and strain measurements (Kopec *et al.*, 2021). Although such a technique is not as popular as Digital Image Correlation, it is still recently utilized for fatigue crack monitoring (Farahani *et al.*, 2022), fatigue life analysis of engineering constructions (Chen *et al.*, 2018) or residual stress determination (Gao *et al.*, 2021). Since ESPI is a very sensitive method, it requires precise setup and low vibrational environments, thus, it is mainly used on a laboratory scale. Such high precision enables ESPI to successfully monitor damage including strain localization and macro crack formation of structural steel (Ritter and Thiele, 2019) or to visualize the macroscopic deformation behaviour of aluminium alloys during fatigue (Sasaki *et al.*, 2018). The advantages of the ESPI system for fatigue damage monitoring were found extremely useful and, therefore, this method was used in this paper to assess the fatigue life of the aluminized, coarse-grained MAR 247 alloy.

2. Materials and methods

Specimens made of MAR 247 nickel superalloy were manufactured using a conventional vacuum casting process. The casting was followed by subsequent quenching with a furnace to achieve coarse microstructure. The chemical composition of MAR 247 nickel superalloy is presented in Table 1.

Table 1. Chemical composition of MAR 247 superalloy [wt. %]

C	Cr	Mn	Si	W	Co	Al	Ni
0.09	8.80	0.10	0.25	9.70	9.50	5.70	bal.

Aluminide coatings of 40 μm were obtained using the CVD process and Ion-Bond setup. The optimized CVD parameters were obtained for the hydrogen protective atmosphere, with a deposition time of 8 h at temperature of 1040°C. Standard fatigue tests were carried out using the MTS 810 testing machine and the conventional MTS extensometer. Uniaxial tensile tests were performed at a strain rate equal to $2 \cdot 10^{-4}\,\mathrm{s}^{-1}$ using five specimens to ensure credibility of the research. Fatigue tests at temperature of 23°C were force-controlled under the zero mean level, constant stress amplitude ranging from 350 MPa to 650 MPa and a frequency of 20 Hz. Every fatigue test was performed at least twice to guarantee reliability of the results obtained. The range of stress amplitude was fixed based on the determination of the conventional yield point $R_{0.2}$ from a uniaxial tensile test. The engineering drawing of the specimens is presented in Fig. 1a. The fatigue development was monitored using Dantec Dynamics Q100 ESPI system. The ESPI measurement started with the first cycle conducted manually. Subsequently, a block of cycles under the frequency of 20 Hz was performed by the testing machine (Fig. 1b). The cyclic loading process was interrupted several times to perform displacement measurements using an ESPI camera. The ESPI measurements were performed on the effective gauge of 15 × 50 mm. The experimental setup is presented in Fig. 1c. The microstructural observations were performed by using Nikon ECLIPSE MA-200 optical microscope.

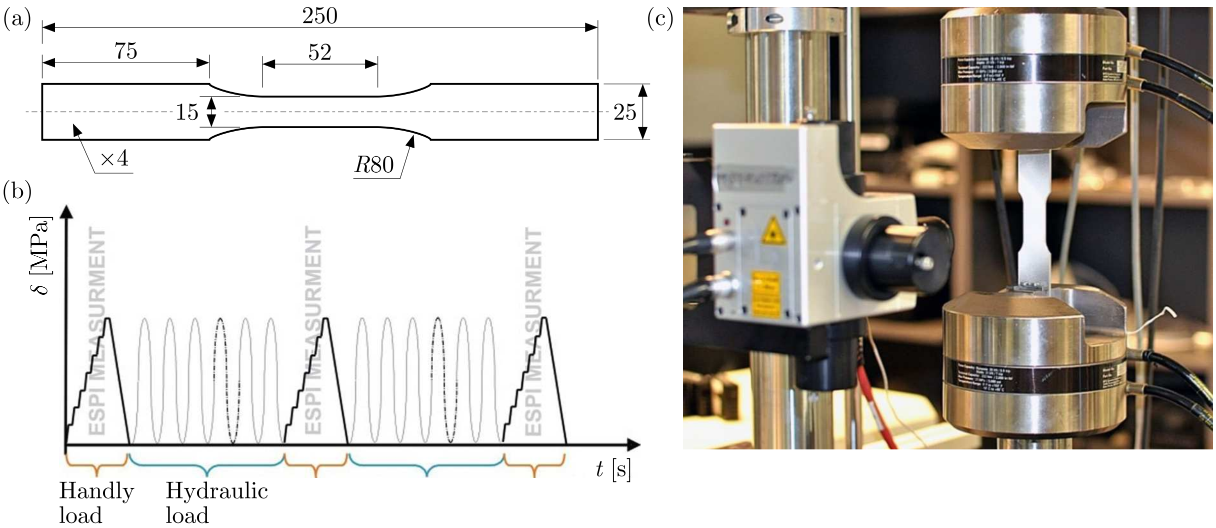

Fig. 1. (a) Geometry of the specimen, (b) loading program, (c) general view of the experimental setup with ESPI

3. Results

The uniaxial tests of coated MAR 247 nickel-based superalloy with coarse microstructure and coating thickness of 40 μm were performed at room temperature (Fig. 2a). The material was characterized by limited elongation of 3-4% and tensile strength of about 940 MPa, which is typical for nickel-based alloys with an aluminised coating (Sitek *et al.*, 2021). Based on the results obtained, standard fatigue tests with different values of stress amplitude were carried out and presented in form of a S-N curve as shown in Fig. 2b. The application of the aluminization

Table 2. Mechanical parameters of coated MAR 247

R_m [MPa]	$R_{0.2}$ [MPa]	A [%]	E [GPa]
940 (±15)	687 (±9)	3 (±1)	200 (±5)

process enables slight enhancement of the fatigue response of MAR 247 nickel-based alloy in comparison to alloys with similar chemical composition (Pereira *et al.*, 2018).

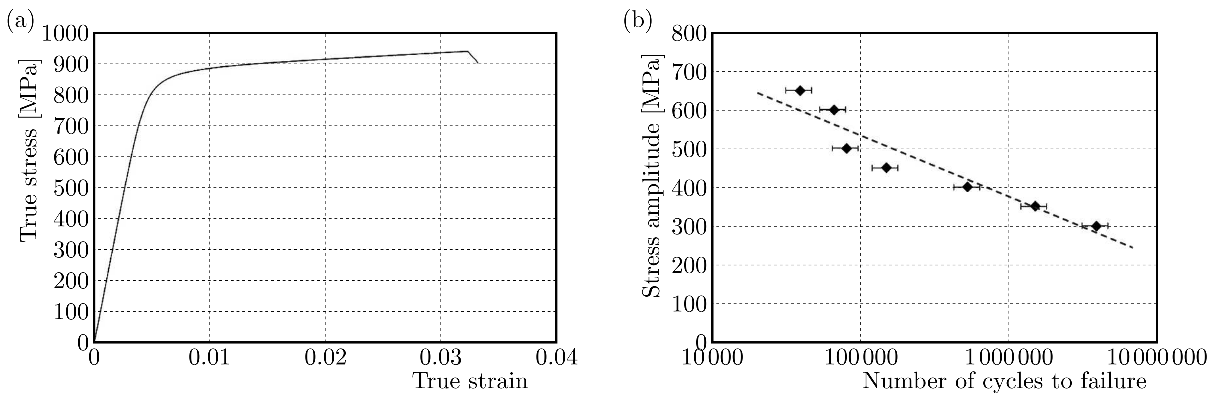

Fig. 2. Representative strain-stress characteristic (a) and S-N curve (b) for the coated MAR 247

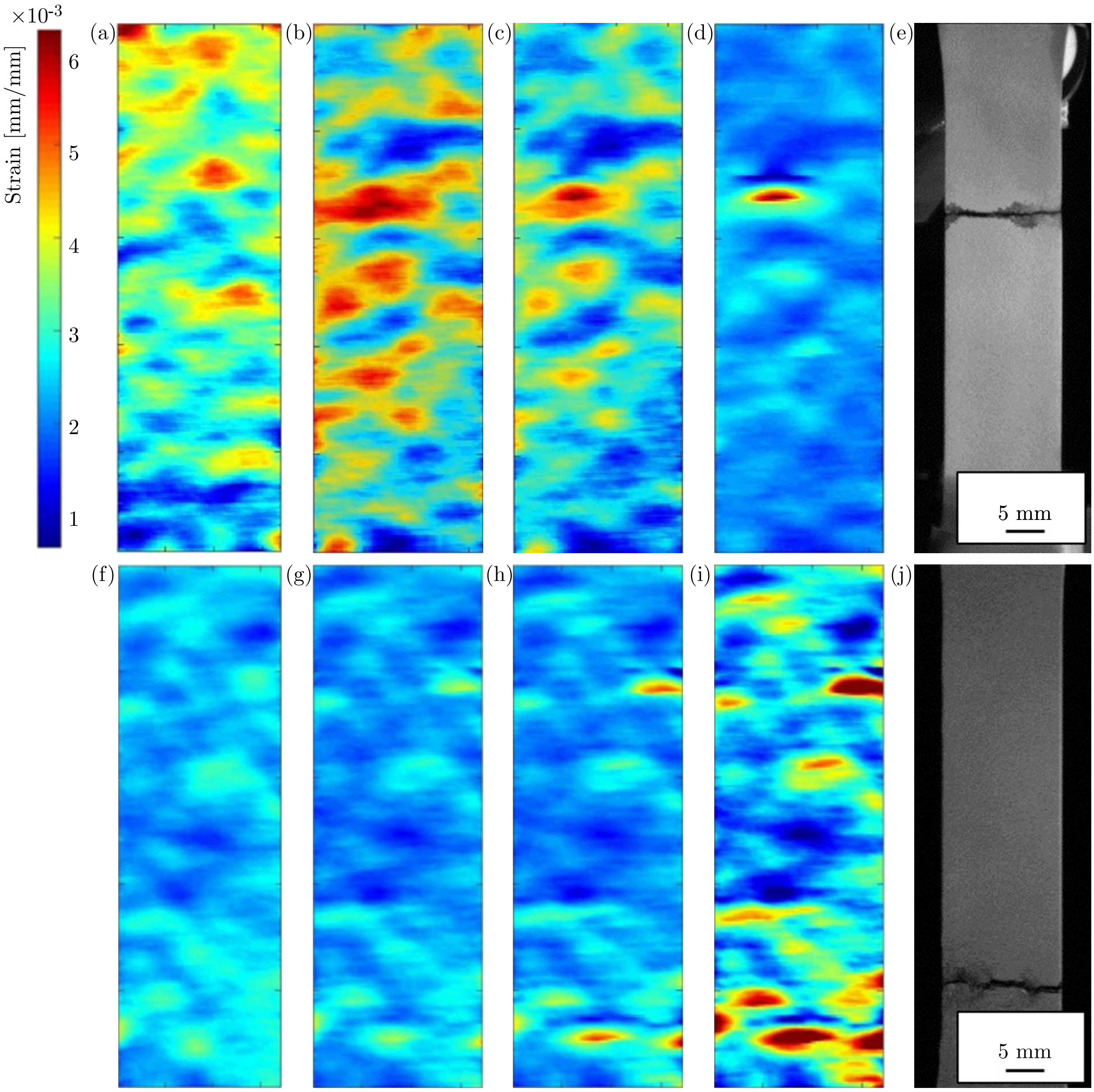

Fig. 3. ESPI measurements performed for the stress amplitude equal to 600 MPa: (a) – 1 cycle, (b) – 30 000 cycles (c) – 60 000 cycles, (d) – 65 000 cycles, (e) – failed specimen after 66 509 cycle, and for the stress amplitude equal to 400 MPa: (f) – 1 cycle, (g) – 20 000 cycles, (h) – 100 000 cycles, (i) – 500 000 cycles, (j) – failed specimen after 536 949 cycle

The fatigue damage development was simultaneously monitored using the ESPI technique.

Selected ESPI measurements for stress amplitudes of 600 MPa and 400 MPa after the selected number of cycles up to the specimen fracture are presented in Fig. 3. The specific areas of higher strain accumulation were presented in form of strain distribution maps using dark red colour. It should be highlighted that the areas with relatively high strain accumulation were found just after the first cycle for both strain amplitudes (Figs. 3a and 3f). The fatigue damage development in subsequent cycles (Figs. 3b-d and Figs. 3g-i) led to a significant increase in strain accumulation in different areas of coated MAR 247 specimens. Such strain accumulation enabled further prediction of potential crack initiation areas which were in fact followed by specimens fracture in these areas (Figs. 3e and 3j).

The analysis of the representative strain distribution map of the aluminized MAR 247 specimen subjected to stress amplitude equal to 400 MPa reveal two regions of potential crack initiation, one at the top and one at the bottom area of the specimen surface (Fig. 4a). Such a strain distribution was captured 5 000 cycles before the specimen failure after 536 949 cycles (Fig. 4b). The enlarged fracture area of the specimen presented by using the optical microscope exposes a transgranular fracture mode (Fig. 4c), which is typical for nickel-based superalloys subjected to fatigue (Ma *et al.*, 2020). One should mention that the cross-sectional view of the bottom area with localized strain accumulation revealed crack occurrence initiated from the coating (Fig. 4d). It was concluded that the crack occurrence in the area of strain localization confirmed the effectiveness of the ESPI method for precise monitoring of the fatigue behaviour of coarse-grained materials. Although the ESPI technique is not limited to a certain kind of materials, its effectiveness to monitor damage development during fatigue is definitely higher for coarse-grained and composite materials. In the authors, previous study, the ESPI measurements of fine-grained X10CrMoVNb9-1 steel did not enable to monitor the fatigue damage development properly (Kopec *et al.*, 2021). It should be mentioned, however, that the microstructure itself will not affect the quality of the results. The main factors influencing the quality are surface preparation and effective fringe pattern application (Zhang *et al.*, 2014).

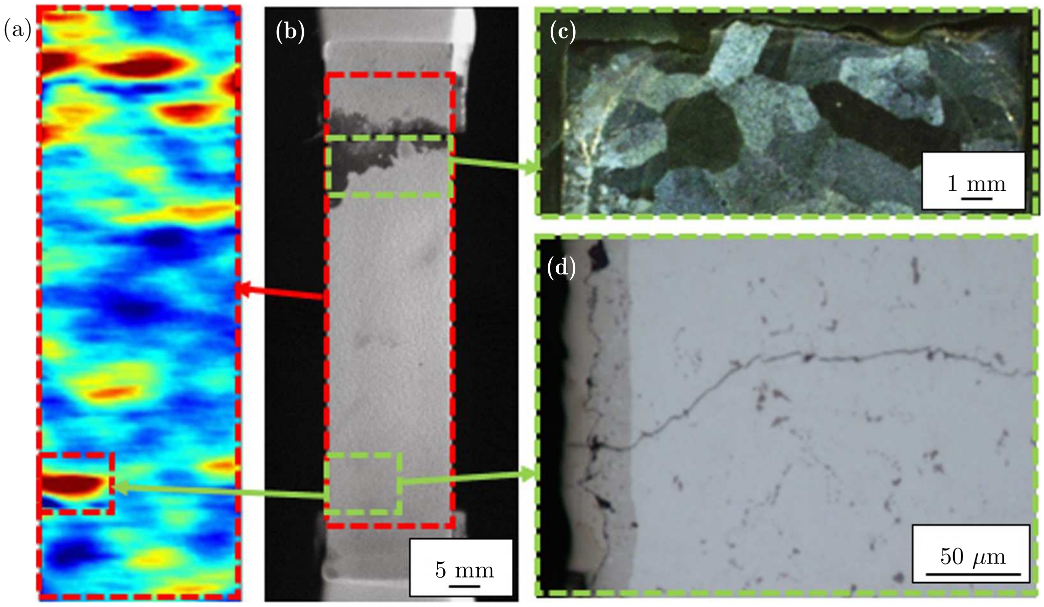

Fig. 4. (a) Strain localisation on the specimen surface approx. 5000 cycles before failure, (b) fractured specimen in testing machine grips, (c) enlarged fractured area revealing the transgranular fracture mode, (d) cross-sectional view of the area with localized stress concentration characterized by the visible crack initiated from the coating

4. Conclusions

The ESPI method offers a wide range of possibilities including assessment of the fatigue damage degree based on the identification of strain accumulation areas around structural or geometric notches, i.e. regions where damage was initiated and subsequently developed. The conducted research has confirmed the suitability of such a optical method for identification of the starting point of coating crack caused by cyclic variable loads. Based on the location of the maximum deformation and its value at this point, occurring after a certain number of cycles, the fatigue life of the layer could be estimated as the number of cycles to the crack appearance.

Acknowledgments

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