LIGHTS AND SHADOWS IN APPLICATIONS OF DIC AND ESPI FOR DAMAGE EVALUATION OF MATERIALS

Zbigniew L. KOWALEWSKI[1], Mateusz KOPEĆ[1], Adam BRODECKI[1]

[1] Institute of Fundamental Technological Research, ul. Pawinskiego 5B, Warsaw, Poland,

E-mail: zkowalew@ippt.pan.pl

1. Introduction

Indication of a point of crack initiation within the gauge length is practically impossible using the conventional extensometers. Such a problem may be effectively solved by the application of either ESPI (Electronic Speckle Pattern Interferometry) [1] or DIC (Digital Image Correlation) full-field optical methods [2].

This paper presents several attempts to use novel optical techniques for damage evaluation of materials subjected to cyclic loading and its monitoring on specimens made of the power engineering steel. Effectiveness in damage analysis of Digital Image Correlation (DIC) and Electronic Speckle Pattern Interferometry is compared.

2. Methods

DIC is a stereoscopic technique in which two CCD cameras, light sources and computational software are used. In this method, a specimen need to be covered with a special pattern (black dots on a bright background). Such a pattern defines the x and z coordinates which are further used to run the test under the strain control. Origins of the rectangular or square-shaped pattern are directly applied to calculate the displacement/strain. The results obtained are presented in the form of full-field, strain distribution maps. DIC method is mainly used for static measurements in which tensile and compressive behaviour, fracture toughness and the geometrical imperfection effects on mechanical response can be investigated in detail.

ESPI is the holographic interferometry type technique based on the laser beam analysis distracted from the optically rough surface. The specimen surface is captured as an image by the CCD (charge-coupled device) sensor and transferred to a working station. As the first beam illuminates the specimen surface, the reflected beam interferes with the reference beam, and thus, the subtraction process of the speckle interferograms (before and after loading up to the defined levels) is performed and correlation fringes are obtained. The fringes enable to generate a phase map with the distribution of displacement components in each direction, separately. Subsequent mathematical operations under the fixed boundary conditions (measurement area dimensions) and the material parameters (Young's modulus and Poisson's ratio) led to the final full-field stress and strain phase maps. ESPI, although different in terms of operation principles, it is quite similar to DIC optical technique for which also the displacement maps during loading can be obtained. It should be mentioned however, that it is has significantly higher than DIC resolution. More importantly, it is mainly laboratory scale dedicated due to a high vibration sensitivity, that disturbs seriously the results captured.

The paper presents the application of both optical techniques for damage evaluation in plane specimens subjected to cyclic loading.

3. Materials and Specimens

The specimens, Fig. 1, were manufactured using X10CrMoVNb9-1 (P91) polycrystalline steel.

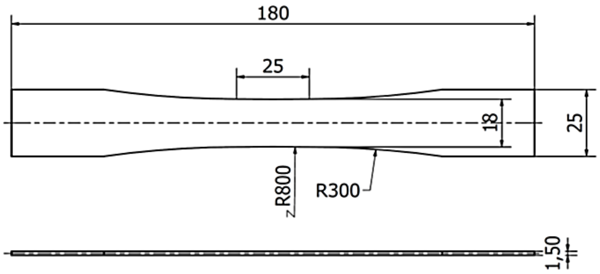

Fig.1. Engineering drawing of the specimen

This is a low carbon, creep-resistant steel, typically used for tubes, plates and structural components in the power plant industry. The content of alloying elements in P91 includes

C (0,2÷0,5%); Mn (0,3÷0,6); Cr (8÷9,5); Mo (0,85÷1,1); V (0,18÷0,25); Ni (< 0,4); Cu (< 0,3); Si (0,08÷0,12); S (< 0,01).

4. Results

In order to check the effectiveness of the ESPI method, all tests were carried out under the same conditions on the plane specimens using also Digital Image Correlation (DIC). Each specimen fractured within 1000 cycles from the crack initiation. It should be highlighted, that the ESPI measurements enabled to observe damage almost close to the specimen fracture only. In order to have broader recognition of this problem, tests were performed for three magnitudes of the stress amplitude equal to 550 MPa, 600 MPa and 630 MPa, however, the same difficulties for optical crack detection were met. Therefore, the selected strain maps for 500 MPa were presented only, Fig. 2.

(a) (b)

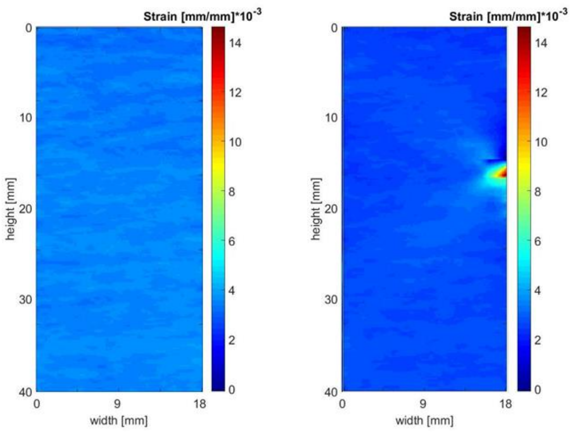

Fig. 1. Comparison of ESPI strain maps for the stress amplitude equal to 500 MPa with the unified scale after: 100 000 cycles (a); 299 207 cycles (b).

In order to check the applicability of the DIC methodology, measurements were performed for the same stress amplitude as that for the ESPI used, i.e. 500 MPa, after a selected number of cycles up to the specimen fracture.

Unlike the ESPI measurements, DIC technique captured a strain localization area after just one cycle (Fig. 3a). The subsequent evolution of fatigue damage to 100 000 cycles enabled to clearly indicate the area of potential crack initiation (Fig.3b) and its development up to specimen fracture (Fig.3c). The effectiveness of the DIC method was further confirmed by performing additional measurements for the stress amplitude equal to 600 MPa, 630 MPa and 640 MPa.

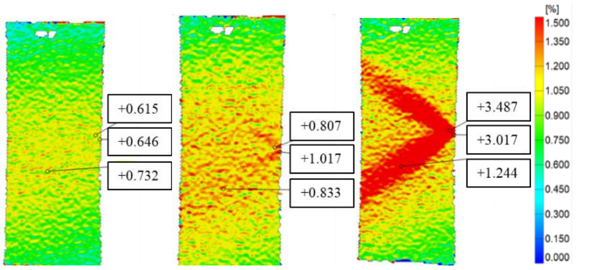

Fig. 2. DIC strain maps for the stress amplitude equal to 500 MPa with unified scale after : 1 cycle (a); 100 000 cycles (b); 301 251 cycles (c).

For each measurement, the area of potential crack initiation was precisely captured after several initial number of fatigue cycles and specimens fractured exactly in this specified region. It should be mentioned however, that the application of the highest values of stress amplitude required a modification of the scale in order to clearly present the strain distribution.

5. Conclusions

Both optical techniques were assessed in terms of their effectiveness in fatigue damage development monitoring. It was found, that DIC enables to monitor the fatigue behaviour and accurately indicates the area of potential failure within the early stage of fatigue damage development.

Contrary to DIC, the application of the ESPI method was not so successful. It also enabled to indicate a location of the potential damage area, however, significantly later than DIC. The main limitation of ESPI usage results from its high sensitivity which procures many difficulties during working with the servo-controlled hydraulic testing machines that introduce high frequency vibrations.

Acknowledgements

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References

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