CHARACTERIZATION OF DAMAGE EVOLUTION SUPPORTED BY ESPI EXPERIMENTAL ANALYSIS

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Abstract: The problem investigated in the present work concerns the damage evolution in elastic-plastic materials subjected to cyclic loading. The modeling of damage mechanisms is supported by Electronic Speckle Pattern Interferometry (ESPI) apparatus using coherent laser light. Such a study can help better understanding of the damage and failure mechanism of modern structural materials for practical engineering problems.

Key words: damage mechanisms, void growth, optical methods

1. INTRODUCTION

The process of the fatigue damage development and structural degradation is of local nature. Using the opportunities offered by the novel experimental techniques, it is possible to identify physical phenomena and to describe the mechanisms of degradation and fatigue damage development in modern structural materials. Their identification involves usage of damage detection methods, both destructive and non-destructive to evaluate material behaviour under different loads (Kowalewski et al., 2008). ESPI is a widely used technique to measure full-field deformation on surfaces of many kinds of objects. As a result of scattering of beam light on the sample surface, the interference of secondary waves occurs and the speckle interferogram is created. Their location and intensity change during the deformation of the sample surface, as a result of the applied loading conditions. Through the subtraction process of the speckle interferograms (before and after loading up to the selected levels), correlation fringes are obtained (Fig.1). Having them, a phase map can be generated. Final full-field stress and strain phase maps are created as the result of mathematical operations. One can indicate the ESPI as very promising non-contact method for displacement measurement.

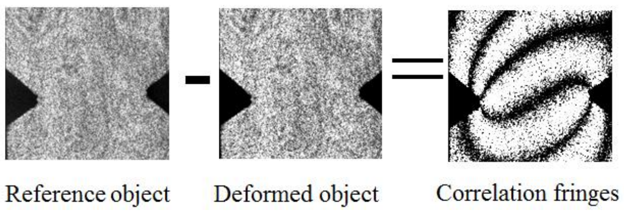

Fig. 1. Conceptual schema: speckles effect.

The shielding effect on fatigue crack growth at constant amplitude loading and during the application of overloads has been investigated using ESPI by Vasco-Olmo et al., (2016). The analysis of the plastic processes that governs crack propagation was analysed using ESPI method by Ferretti et al., (2011). However, its usage in the study of fatigue damage mechanisms has not been explored extensively. Therefore in this study, ESPI was applied to investigate these issues. The nucleation, growth and coalescence of micro-voids is the primary damage process in metals undergoing ductile fracture. The phenomenological based model proposed by Gurson (1977) developed further by Needleman and Tvergaard (1984) (GNT model) has been most frequently used. On the other hand, an extension of the Gurson model is proposed by Nahshon and Hutchinson (2008) that incorporates damage growth under low triaxiality straining for shear-dominated states.

2. EXPERIMENTAL RESULTS

Nowadays, ESPI method seems to be very attractive in capturing a damage development. A typical example of its application for elaboration of strain distribution map is presented in Fig. 2. It shows the results for nickel alloys tested under fatigue conditions. The figure shows strain distributions for different stages of the fatigue process.

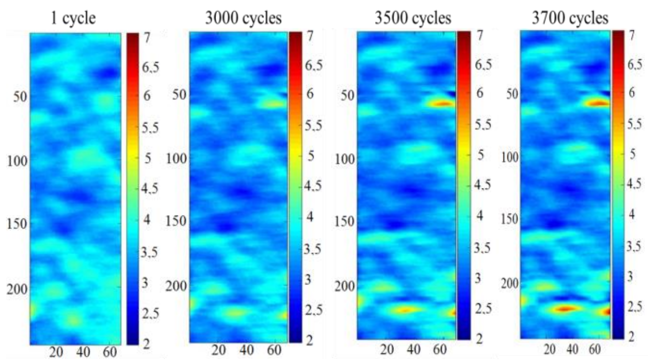

Fig. 2. Strain distribution map on the plane specimen surface using ESPI

The development of fatigue damage in materials takes place around various drawbacks, mainly in the form of voids formed in manufacturing processes such as casting. Besides of density and distribution of defects in the volume of tested spacemen, the specimen size, and location of individual defects are important factors of fatigue damage initiation and its further development.

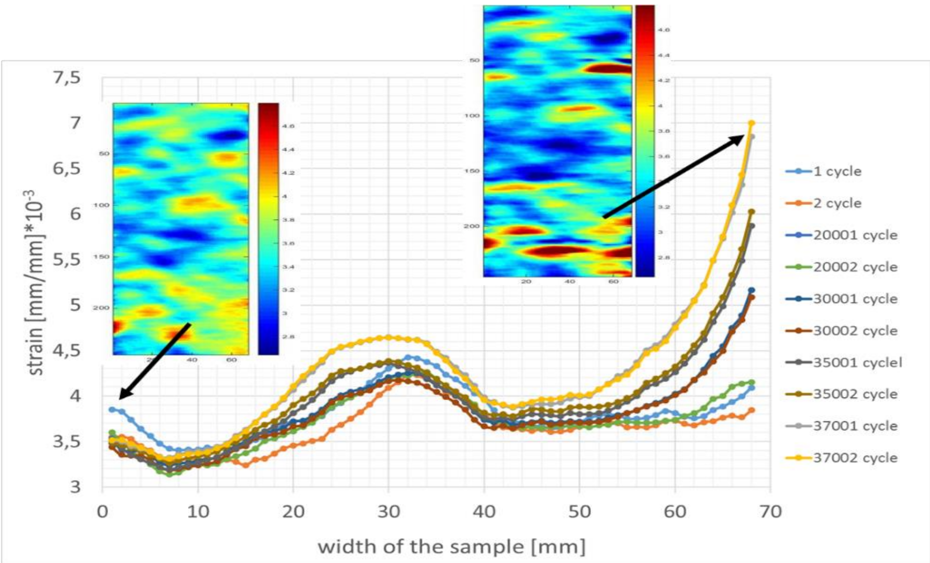

Fig. 6. The lateral profiles of cross-sectional strain changes of maximum values

3. CHARACTERIZATION OF DAMAGE EVOLUTION

The Gurson-Tvergaard-Needleman (GNT) model has been used to develop description of the different damage processes. The evolution of the void volume fraction is divided into a growth part and a part due to nucleation of voids

$$\dot{f} = \dot{f}_{Growth} + \dot{f}_{Nucl} \tag{1}$$

The growth part takes the classical form

$$\dot{f}_{Growth} = (1-f)\mathrm{tr}\dot{\varepsilon}^{p} \tag{2}$$

The void nucleation rate is expressed as

$$\dot{f}_{Nucl} \ = A_n \dot{p} \tag{3}$$

where A_n is the strain rate controlled nucleation rate. A form for the nucleation rate A_n proposed by Chu and Needleman (1980) is expressed as a Gaussian function

$$A_n = \frac{f_N}{s_N\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{p-\varepsilon_N}{s_N}\right)^2\right) \tag{4}$$

where ε_N is the mean value of strain, f_N the corresponding volume fraction and s_N the standard deviation.
The GNT model assumes a yield condition in the form:

$$\Phi = \frac{\sigma_{eq}^2}{\sigma_0^2} + 2q_1 f_* \cosh\left(\frac{1}{2} q_2 \frac{\sigma_{kk}}{\sigma_0}\right) - 1 - q_1^2 f_*^2 \tag{5}$$

Here σ_0 is the yielding stress, while the constants q_1 and q_2 are additional material parameters. The associated flow rule is given in the following form

$$\dot{\varepsilon}_{ij}^{p} = \dot{\lambda}\frac{\partial\Phi}{\partial\sigma_{ij}} \tag{6}$$

where $\dot{\lambda}$ is the plastic multiplier.

Based on experimental micromechanics analysis, the effective properties of elastic-plastic solids with numerous analysis is predicted.The lateral profiles of cross-sectional strain changes of maximum values is shown in Fig.3. Results will serve to verify and calibrate the mathematical description.

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