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A NON-CONTACT REAL-TIME STRAIN MEASURMENT FOR SHORT UNIAXIAL CYCLIC TEST OF STEEL BY DIGITAL IMAGE CORRELATION METHOD

BEZKONTAKTNÍ MĚŘENÍ DEFORMAČÍ ODEZVY OCELI BĚHEM ZKRÁCENÉ ZKOUŠKY NÍZKOCYKLOVÉ ÚNAVY POMOCÍ METODY DIGITÁLNÍ KORELACE OBRAZU

Abstract

A non-contact real-time strain measurement based on the Digital Image Correlation Method (DICM), has been successfully established for cyclic/fatigue tests of steel. It allows recording of the evolution of strain during the short fatigue life of the steel under test. A frequency of 10 Hz for strain data acquisition was reached. This made it possible to perform strain-range-controlled fatigue tests on the specimen (class 11 523). The success of this method would facilitate performing various types of fatigue tests on different kinds of material and would allow gaining better insight and understanding of their fatigue and failure behaviour.

Abstrakt

Bezkontaktní měření deformační odezvy pomocí metody digitální korelace obrazu bylo úspěšně zavedeno pro oblast únavy oceli. Tato metoda umožňuje snímat průběh deformace během krátkého testu nízkocyklové únavy. Snímání průběhu deformace bylo provedeno s frekvencí 10 Hz. Toto umožnilo provedení testu únavy s řízeným rozsahem deformace na ocelovém zkušebním vzorku (materiál 11 523). Úspěšnost této metody by umožnila provádění různých únavových testů pro rozmanitou oblast materiálů a mohla by umožnit lepší náhled a porozumění jejich únavového a poruchového chování.

1 INTRODUCTION

Strain gauges and extensometers have served as conventional strain measurement tools in most mechanical experiments. Their use in cyclic/fatigue tests could meet some difficulties. For example, strain gauges could not be used if fatigue life of the gauges was shorter than that of the material tested. For relatively soft materials such as polymers, the knives of the extensometer could cause local damage (even with protective film) and thus the obtained fatigue life could be much shorter than that of a specimen with a smooth surface. Fatigue tests can be carried out under load (stress)-controlled or deformation (strain)-controlled modes. In most cases, the local strain values are not directly measured or carefully monitored during the entire test procedure. Availability of an effective non-contact strain measurement method becomes increasingly necessary to gain more insight into the fatigue behaviour of various materials.

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2 THEORY OF DIGITAL CORRELATION METHOD

The Digital 3D-Correlation System Q-400 used in this work is an optical instrument for full field, non contact and three-dimensional measurement of deformations and strains on components and materials. The system uses two high resolution digital cameras to record surface changes of the object under investigation while loaded or moved. The recorded images are analysed and compared by a special correlation technique which allows the determination of the object contour as well as the surface displacements with high local resolution.

Images, taken before and after deformation of an object, represent the positions of the object at these two moments of time. To retrieve the in-plane displacements at a certain point of interest on the object, a small subset surrounding this point in the reference image (taken before displacement) is selected to match the similar subset area in the target image (taken after displacement). This procedure is called digital image correlation. The correlation algorithm based on the tracking of grey value pattern in small local neighbourhoods. Is G(x, y) the grey value of a pixel with the coordinate x and y inside of the subset or facet the correlation algorithm minimized the sum [1], [3]:

$$C = \sum_i (G_t(x_{t,} y_t) - G(x_t, y_t))^2 \tag{1}$$

$$(G_t(x_{t,} y_t) = g_0 + g_1 G(x_{t,} y_t) \tag{2}$$

$$x_1 = a_0 + a_1 x + a_2 y + a_3 xy \tag{3}$$

$$y_2 = a_4 + a_5 x + a_6 y + a_7 xy \tag{4}$$

where:

$G_t(x_t, y_t), G(x_t, y_t)$ – grey values of each pixel in the reference and target images,

C – correlation coefficient [-],

x, y – coordinate inside of the subset [m],

a_i – affine transmission [-],

g_i – illumination parameters [-]

However, in the practical application of 3D image correlation techniques some basic conditions have to be observed. As example, the calibration of the cameras has essential influence on the performance of the complete system.

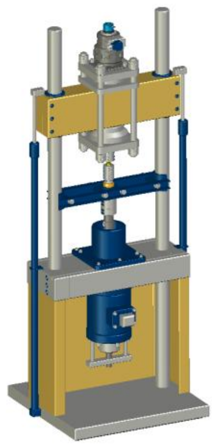
3 SAMPLE TESTS RESULTS

The uniaxial test of the solid specimen, showed in Fig. 1a, was performed by modified testing machine. The laboratory testing machine is based on the frame INOVA 200 ZUZ. This testing machine consist of two pillar fixed in the bottom and top cross beam. There are two hydraulic motors. The top cross beam carries a rotation hydraulic motor, which can stress the test sample by torque up to 300 Nm. The bottom cross beam contains a build in linear hydraulic motor, which enables stressing of the test sample by axial tensile (or pressure) force up to 200 kN. The test sample is fixed from the top in rotation jaws, while from bottom is specimen fixed in measuring jaws. The rotation jaw is connected with rotation hydraulic motor and makes impossible axial shifting of the sample. Bottom (measured) jaws is connected with linear hydraulic motor and makes impossible rotation of the test sample. Control and data acquisition is realized by own software developed in NI LabVIEW Real – Time. The model of testing machine is in Fig. 1b. For details see [2].

The specimen was sprayed due to creation of the subset containing little facet elements (Fig. 3). Then a digital image correlation process determines the shift and/or rotation and distortion of little facet elements determined in the reference image. A strain-range-controlled uniaxial cyclic test was carried out with strain range of 0.3% and mean strain of 0% (Fig. 2). Due to the fact that extensometer hid the part of the specimen surface, the strain measured by DCIM was evaluated at the closest points to the extensometer´s knives (Fig. 3a). Due to the required time for digital image processing, the sampling frequency of the current correlation system is not as high (the sampling frequency of digital cameras was 10 Hz) as that by using the traditional strain gauge or extensometer (100 Hz). Firstly, the main task of this work was focused on capturing the sampling frequency of the extensometer by the help of DICM. Due to the fact of the low hardware capacity, this was successfully done for the time range from 45s to 51,5s of the experimental data of strain-range-controlled cyclic test (Fig. 4). Secondly, we verified the possibility of data capturing with regard to strain gradient. The strain values between the extensometer’s knifes are evaluated as average strain values (Eq. 5) from the experimental data acquired by extensometer. On the contrary, the DICM is able to capture the strain gradient at the observed area of the specimen (Fig. 3b).

$$\varepsilon_x = \frac{\Delta L}{L} = \frac{\Delta x_1 - \Delta x_2}{L} \tag{5}$$

a)



b)

Fig. 1 (a) Solid specimen made of steel (class 11 523); (b) the laboratory testing machine

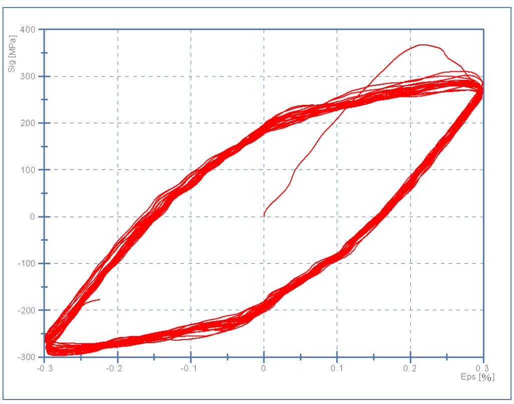


Fig. 2 Experimental data of strain-range-controlled data: stress-strain loops of 25 cycles

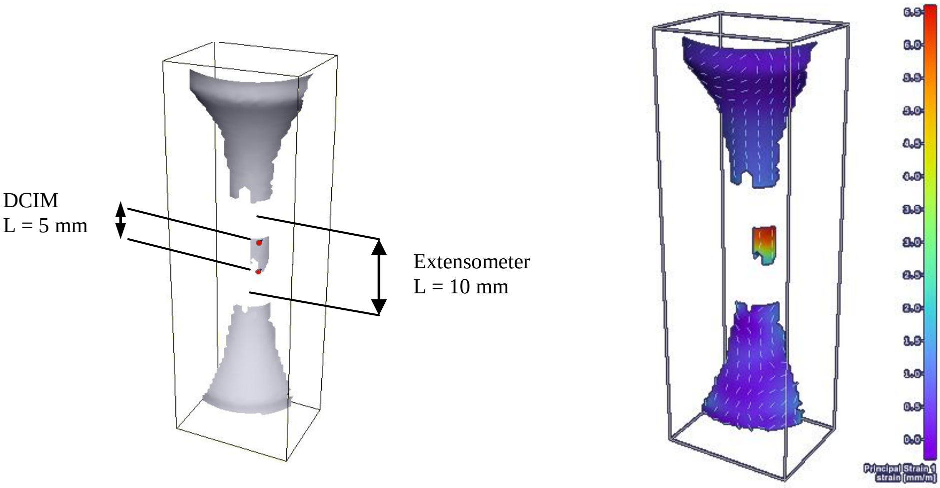


Fig. 3 (a) Contour of the specimen evaluated by DCIM; (b) Strain gradient evaluated by DCIM

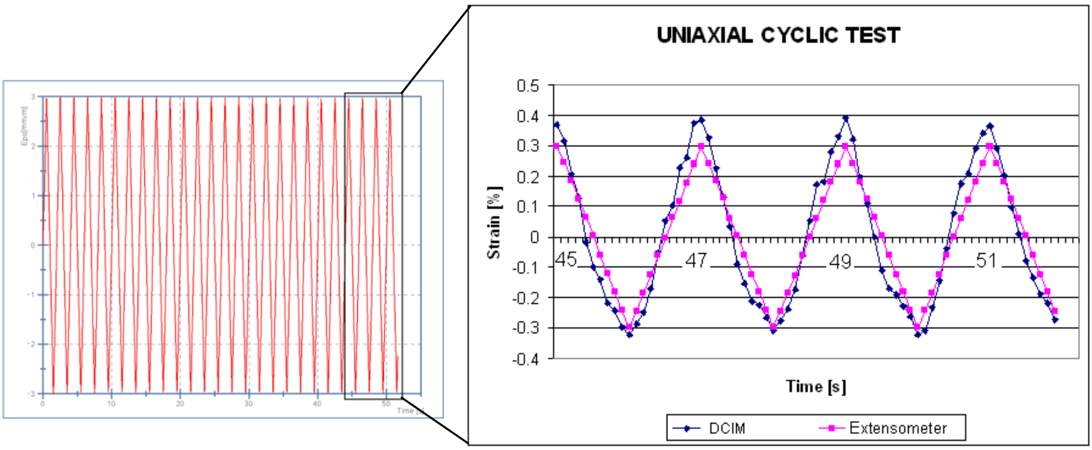


Fig. 4 Sampling frequency range measured by DCIM and extensometer

3 CONCLUSIONS

A non-contact real-time strain measurement based on the digital image correlation technique has been established. Currently, the system can measure strains with an accuracy of 0.01% and a frequency of 10 Hz for strain data acquisition. During our measurement the strain accuracy 0.1 % was achieved due to the lower focal length (17mm) of the camera lenses [1]. The capability of the system has been verified through the strain-range-controlled cyclic uniaxial test.

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