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Measurement of Cyclic Creep by Digital Image Correlation Method

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Abstract. This contribution presents a new methodology of cyclic creep investigation based on digital image correlation application. The full-field strain analysis brings the possibility of strain accumulation evaluation on a curved part of standardly used specimen in multiaxial fatigue research. Resulting cyclic creep curves can subsequently serve for evaluation of strain accumulation prediction, what can positively influence future research in cyclic plasticity domain. The new methodology saves amount of material and leads to a shorter experimental time.

Introduction

Digital Image Correlation Method (DICM) is a suitable tool for 3D full-field strain analysis in practice as well as material research [1]. DICM makes possible to measure complete history of strain tensor in examined point of the specimen in a large scale of strains. Thus, it is an appropriate optical method for effective evaluation of fatigue tests. In the previous study [2], DICM was compared with standard uniaxial extensometer to verify its applicability for cyclic creep (ratcheting) strain measurement with acceptable accuracy. Indeed, the power of DICM is in 3D full-field analysis. There is a question, if strain analysis in the part of specimen with increasing cross-section area might be useful.

This paper presents some new results of deformation response on cyclic loading in tubular specimen measured by DICM. The research was conducted within the framework of meetings with students involved in the program for talented students of the Faculty of Mechanical Engineering at VŠB - Technical University of Ostrava.

Experimental setup

Specimens were made of R7T steel, which is commonly used material of railway wheels. All tests were realized on biaxial testing machine LabControl 100kN/1000Nm at the VŠB – TU Ostrava, see Fig. 1. For DIC measurements the Mercury RT® system (2x2.3Mpx@40Hz), provided by Sobriety s.r.o. company, was used. Averaged strains were measured by EPSILON3550 extensometer with 25mm gauge length in order to verify the measured strain response by DICM in the testing part of specimen. An optical contrast coating known as pattern was prepared on each specimen for application of DICM.

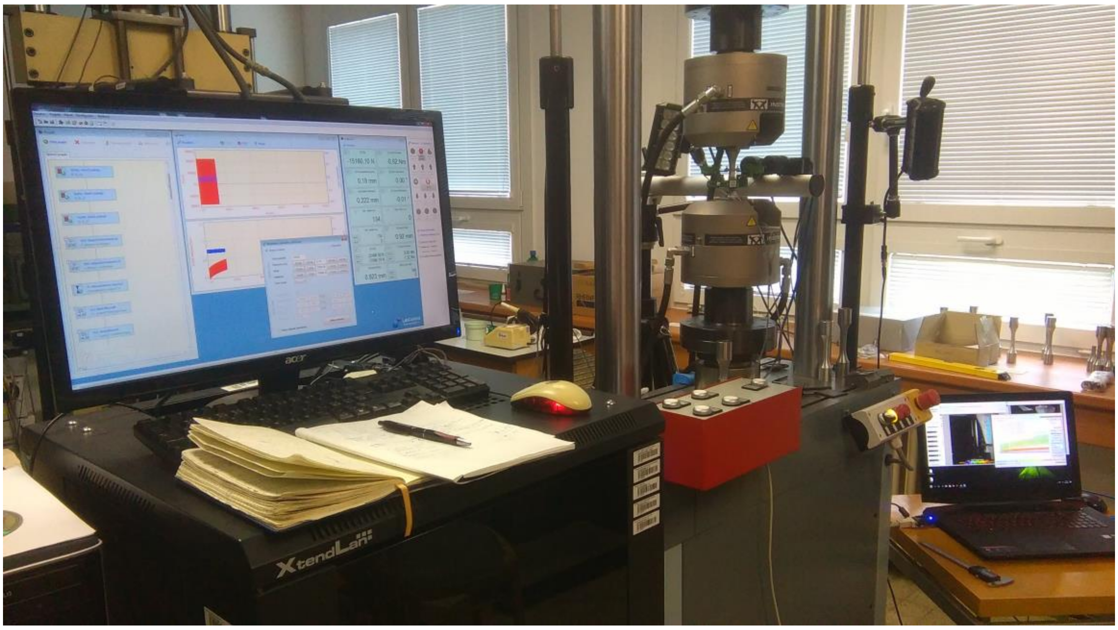

Fig. 1. A photo from realized measurements

The specimen geometry considered for all measurements is shown in the Fig. 2. The tubular specimen with outer diameter 12.5mm and inner diameter 10mm was used. The proportional loading was investigated exclusively in this experimental study. More precisely two stress states were investigated: tension-compression and pure torsion. However, it should be mentioned, that the new methodology is applicable also to other types of loading, including non-proportional cases.

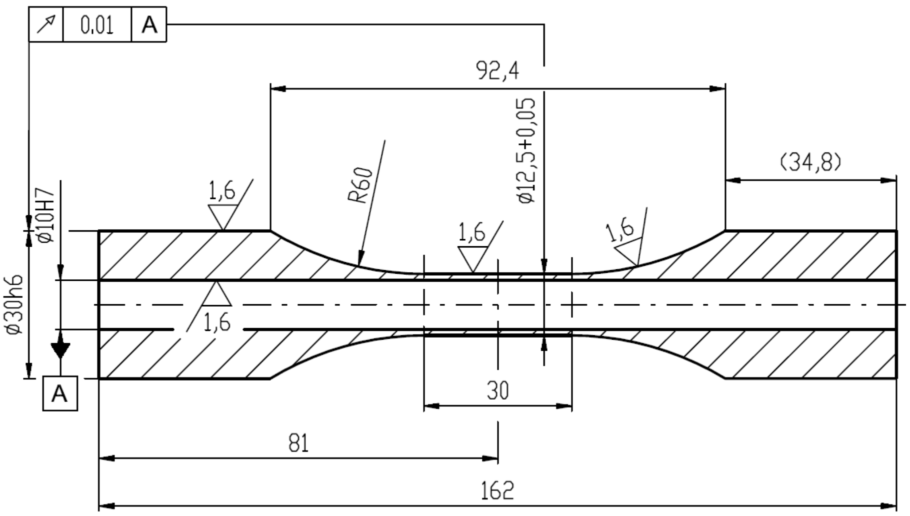

Fig. 2. A scheme of specimen's geometry

Results of cyclic uniaxial tests

First two fatigue tests were realized under uniaxial loading. In order to investigate the stress-strain curve of the material considered, a sequential test was performed under strain control. The comparison of static stress-strain curve with cyclic stress-strain curve is done graphically in the Fig. 3. The reader can observe a cyclic softening behaviour for small strain amplitudes and a cyclic hardening behaviour for higher strain amplitudes.

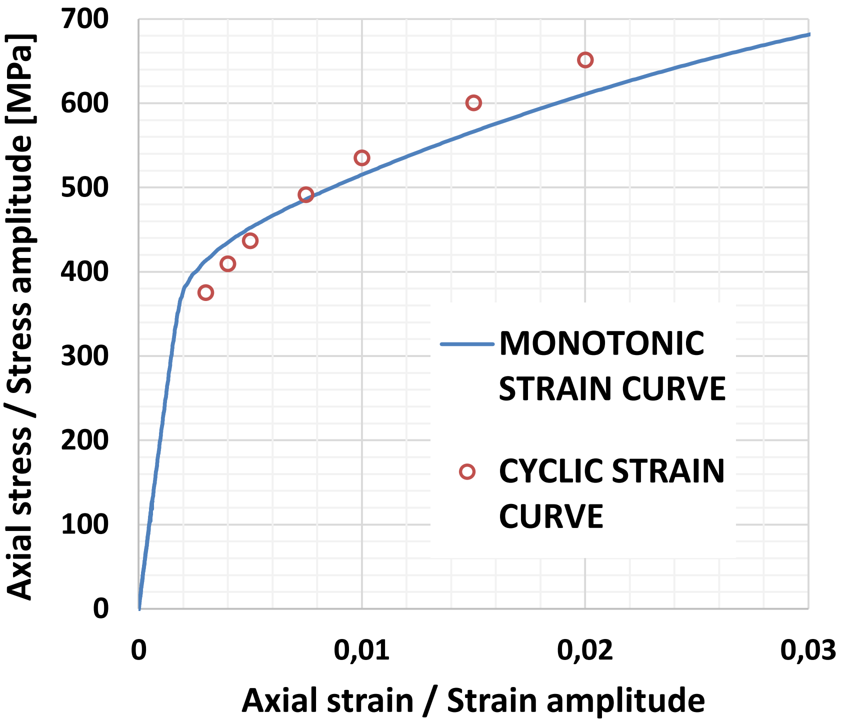

Fig. 3. Stress-strain curves of investigated material obtained from a sequential uniaxial test

The next conducted experiment was done with emphasis on cyclic creep investigation. The harmonic loading with the stress amplitude of 450MPa considering mean stress of 50MPa was applied (frequency 0.1Hz up to 200 cycles, then increased to 0.5Hz). The test was conducted until fracture. Accumulation of total strain is apparent from Fig. 4. Number of cycles to fracture was 1006 cycles. The material shows a ratcheting behaviour with steady state after stabilization of strain response, see Fig. 5.

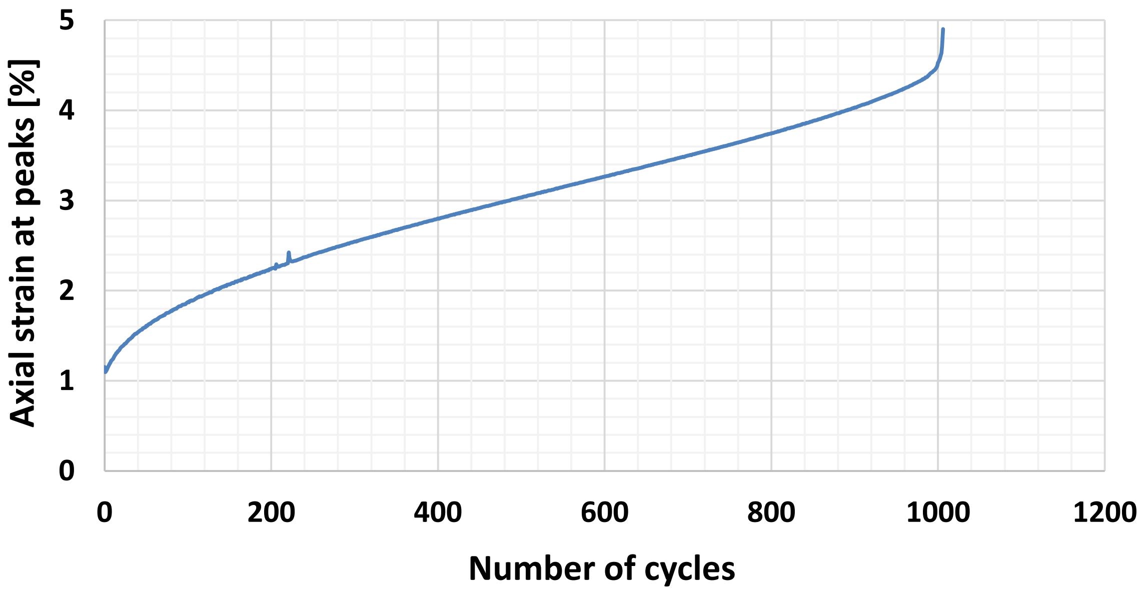

Fig. 4. Uniaxial ratcheting strain measured at peaks as a function of number of cycles

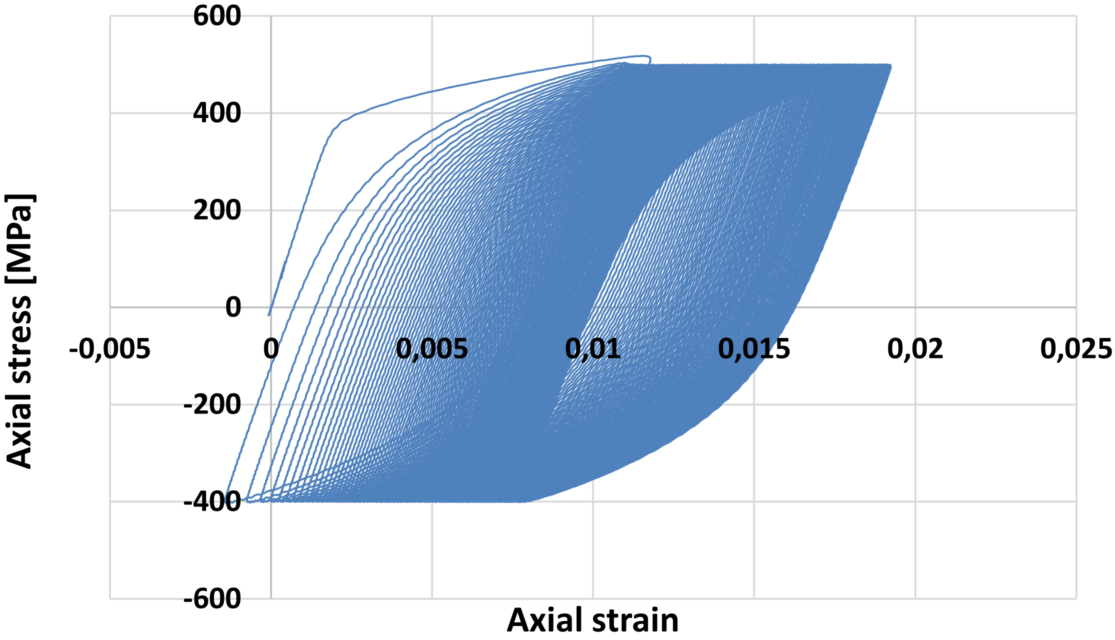

Fig. 5. Stress-strain behaviour of the material in uniaxial ratcheting test

Initial cycles were measured also by DICM. Points selected for evaluation of strains are shown in the Fig. 6 (left). Corresponding uniaxial strain accumulation evaluated at peaks are compared in the graphical form in the Fig. 6 (right). The larger cross-section the less axial strain accumulation was observed as expected.

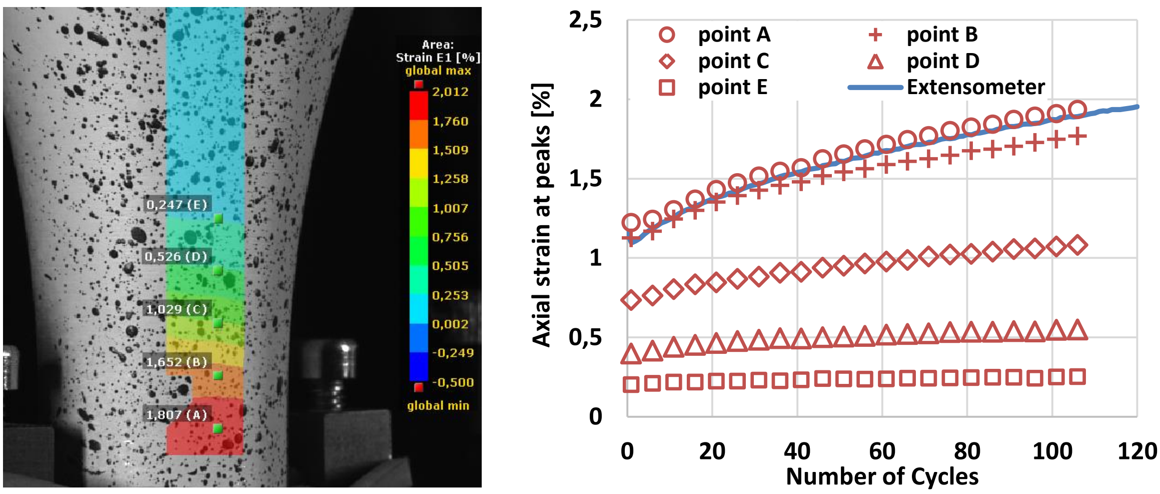

Fig. 6. Contours of first principle strain (left) and axial strain accumulation (right) evaluated from DIC measurement in uniaxial ratcheting test.

Results of cyclic torsion test

The last experiment realized in this study was done in cyclic torsion. The harmonic loading was applied considering shear stress amplitude of 233MPa with mean shear stress of about 30MPa (frequency 0.1Hz up to 322 cycles, then increased to 0.5Hz). The test was realized until fracture. Shear strain accumulation measured by extensometer during the whole test is presented in Fig. 7. Small decrease of shear strain was caused by interruption of the test in order to change the loading frequency. Number of cycles to fracture was 18780 cycles.

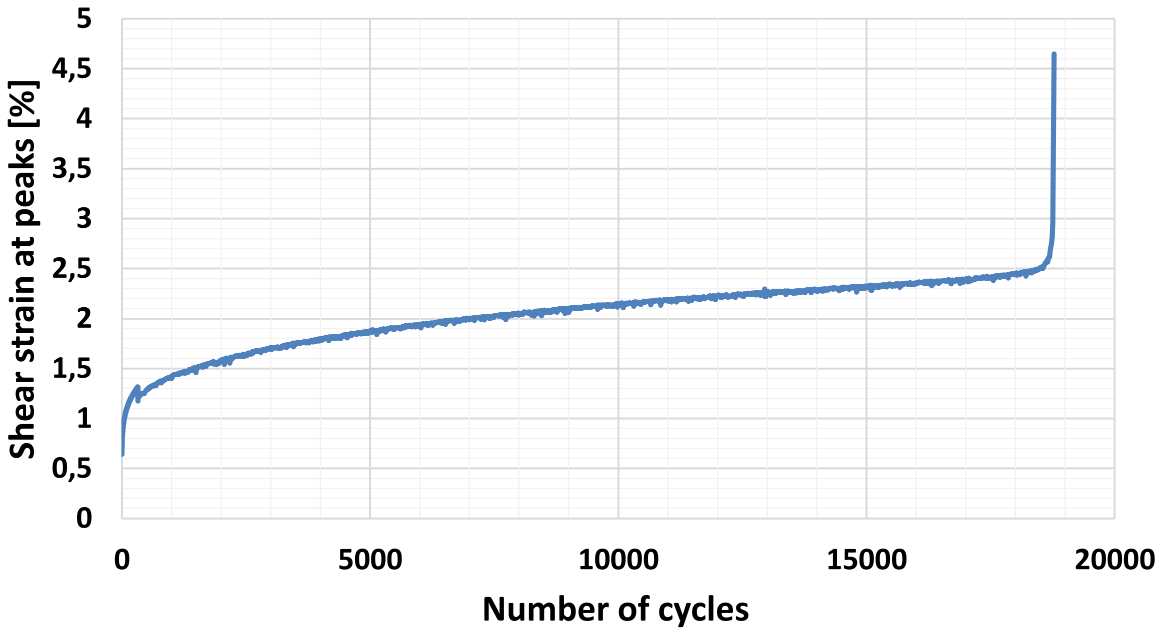

Fig. 7. Shear strain accumulation measured by extensometer in torsional ratcheting test.

Examined material again shows a ratcheting behaviour with steady state after saturation of opened hysteresis loop as can be seen in the Fig. 8, where stress-strain history for selected cycles is presented. Equivalent stress and equivalent strain were evaluated as

$$\sigma_{eqv} = \sqrt{3}\tau, \tag{1}$$

$$\varepsilon_{eqv} = \frac{\gamma}{\sqrt{3}}, \tag{2}$$

where τ and γ are the shear stress and the shear strain respectively. The stabilized behaviour occurs after about 10000 cycles in this case as can be seen in the Fig. 8.

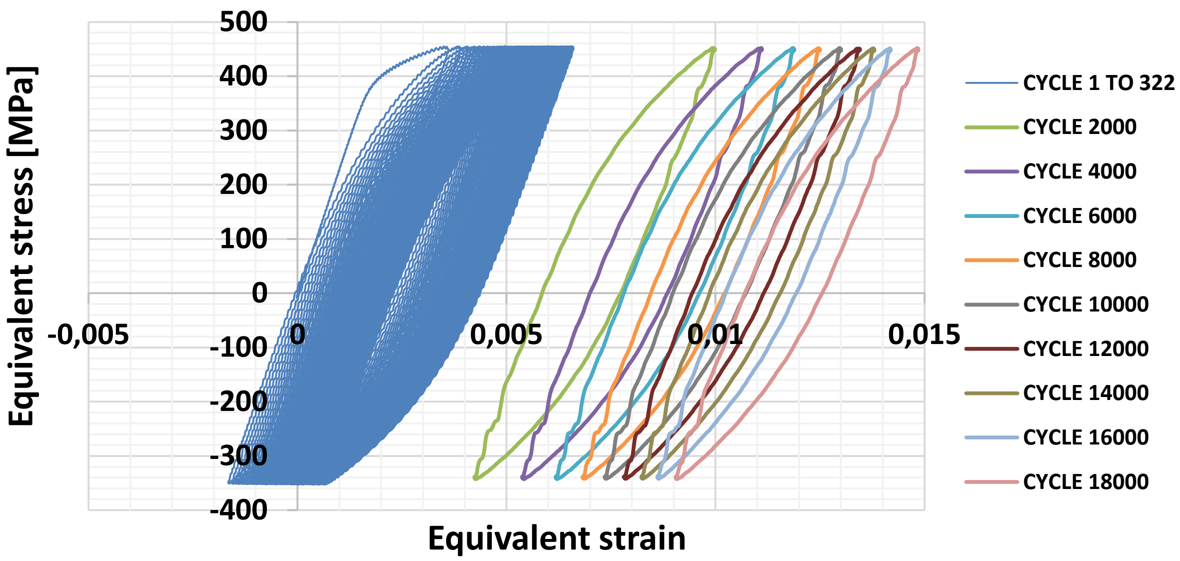

Fig. 8. Stress-strain behaviour of the material in torsional ratcheting test

Shear strains were simultaneously measured in initial cycles by DICM. Evaluation points are shown in the Fig. 9 (left). Shear strain accumulation evaluated at peaks in mentioned points are compared in the Fig. 9 (right). The larger cross-section the less amount of plastic strain can be seen again.

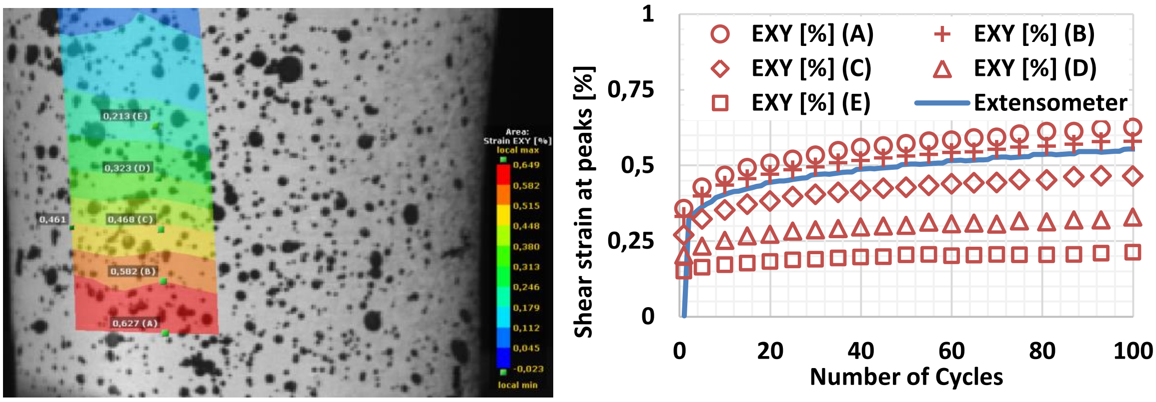

Fig. 9. Contours of shear strain (left) and shear strain accumulation (right) evaluated from DIC measurement in torsional ratcheting test.

Conclusion

As it is clear from presented results (Fig. 6 and Fig. 9), DICM gives comparable results as extensometer for the point A placed in the testing part. The difference is caused by stress concentration in the area close to the border between testing part and the part with curved surface. The stress concentration was obtained in a FE simulation too. The accumulation of plastic deformation is decreasing with increasing cross-sectional area as could be expected. The strain responses at the point E in both cases (uniaxial as well as torsional) show almost plastic shakedown. Obtained experimental data will be used for evaluation of cyclic plasticity models [3,4] developed for accurate ratcheting prediction of metallic materials.

Acknowledgement

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