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Experimental Stress Analysis

STRAIN MEASUREMENT IN RATCHETING TEST AND PREDICTION BY FEM

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Abstrakt: Intensive experimental research of cyclic plasticity at the last three decades increases the knowlidge in the area of cyclic creep (ratcheting). The effect occurs under load controlled testing upon yield limit with nonzero mean stress value. Ratcheting depends mainly on the value of mean stress but also on the nonproportionality of loading quantities. There are presented three methods suitable for cyclic plastic strain measurement during low-cycle fatigue testing in this paper. The deformations in realized tests of 11523 and 11600 steels were observed by extensometer, by digital image correlation method and by strain gauges. Results from FE simulations of realized tests show good correlation with experimental results.

1. Introduction

There are used the same testing machines for the investigation of stress-strain material behavior as for low-cycle fatigue research in the area of cyclic plasticity. It is well known that the tubular specimen is the most popular for the purpose. Easy evaluation from the stress state point of view and possibility of precise strain measurement at the exterior surface are its main features. Extensometers and strain gauges are mostly used. Fatigue testing under load control with nonzero mean load value can lead to the accumulation of a strain component called ratcheting. The both measurement methods mentioned above have a restriction in critical strain value therefore it is necessary to find other method for accurate ratcheting strain measurement.

2. Description of experiments

For identification of material parameters in following FE simulations, there was realized a set of low-cycle fatigue tests of specimen made from 11523 (Fe52C) and 11600 (Fe60-3) steels at the CVUT in Prague. The specimens were subjected to tension-compression and tension-compression/torsion on the test machine MTS 858 MiniBionix [1].

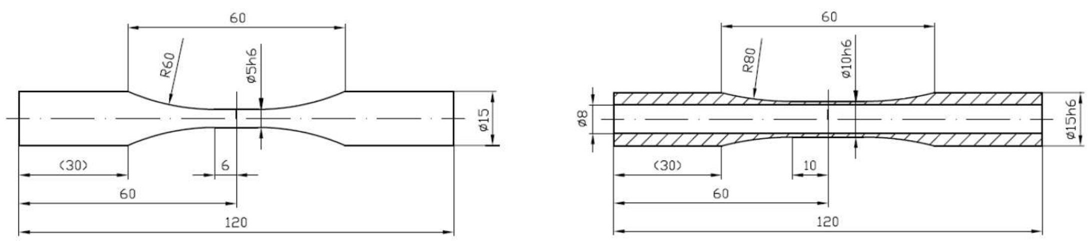

Figure 1: *Testing Specimen for ratcheting tests: uniaxial (left), multiaxial (right)*

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All tests including ratcheting were realized under load control. Three deformation measurement methods were applied in chosen tests: either measurement by extensometer or measurement by strain gauges for 11600 steel and measurement by extensometer and/or digital image correlation method for 11523 steel.

2.1. Measurement by extensometer

In those cases, where the ratcheting was expected in axial direction, the extensometer MTS 634.31F-24 with the 10 mm gauge length was mounted on the cylindrical part of the specimen and applied for strain measurement (Figure 2). The sample of data record gained for two sequences with different mean stress value is shown at the Figure 3. The sampling rate of 20Hz was used for that record, whereas load frequency was 0,5Hz.

Figure 2: *Extensometer application*

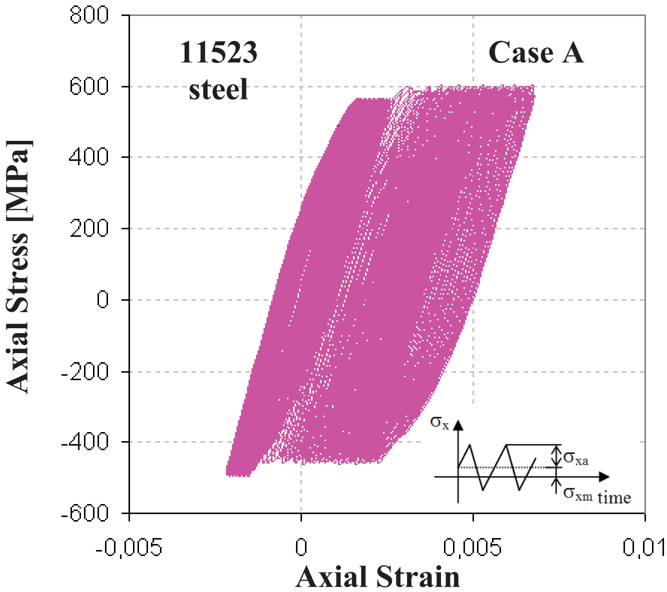

Figure 3: *Stress strain curve from the uniaxial test*

The hydraulic motor of the test machine, including lines (hoses, pipelines), has eigenfrequencies, which can affect a realized test in the resonance region [2]. The dynamic features of the hydraulic circuit significantly affect the time courses of the controlled variables mainly in initial cycles. The hydraulic features as hydraulic capacity and acceleration resistance influence the quality of load control.

2.2. Measurement by digital image correlation method (DICM)

The digital image correlation method is relatively young optical method based on photogrammetry principles [3]. The correlation algorithm is based on the tracking of grey value pattern on the two successive digital pictures. Using the only one digital camera two dimensional displacement field on the investigated surface can be observed. For 3D displacement measurement it is necessary to focus two CCD cameras to the specimen from two different directions. In our case the digital correlation system Dantec Dynamics Q400 with camera resolution of 1,4MPx and cold light system HILIS was used. The measurement records were evaluated by software Vic3D. Different results of the DICM and the measurement by extensometer are evident from the Figure 5. The strain contours displayed at the Figure 4 warn before parasitic bending, which cannot be disclosed by extensometer.

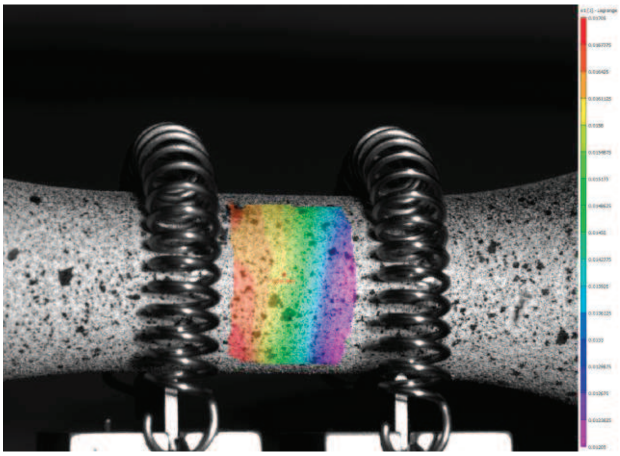

Figure 4: Axial strain measured by DICM

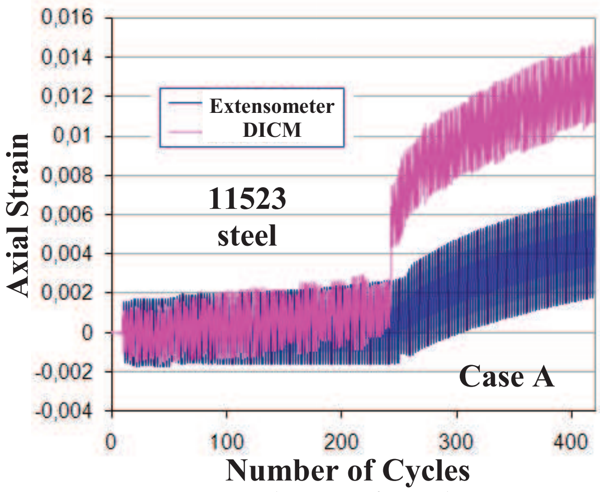

Figure 5: *Accumulation of axial strain*

2.3. Measurement by strain gauges

Under tension-compression/torsion loading it is important to measure axial and shear strain component on the surface of the tubular specimen. For this purpose the multiaxial extensometer is often used. Because of absence of the equipment two strain gauges rosette HBM RY3x3/120 were glued on the specimen. As a sample, results from the multiaxial ratcheting test with loading path corresponding to the loading of the point on surface subjected to rolling contact [3], which was obtained by the symmetric tension/compression and by mean torsion, are presented at the Figure 6. The case with axial stress magnitude of 490MPa and shear stress magnitude of 160 MPa was realised for 11600 steel. As the consequence of the cyclic torsion of the specimen the increase of the shear deformation in one direction occurs cycle by cycle (Figure 7).

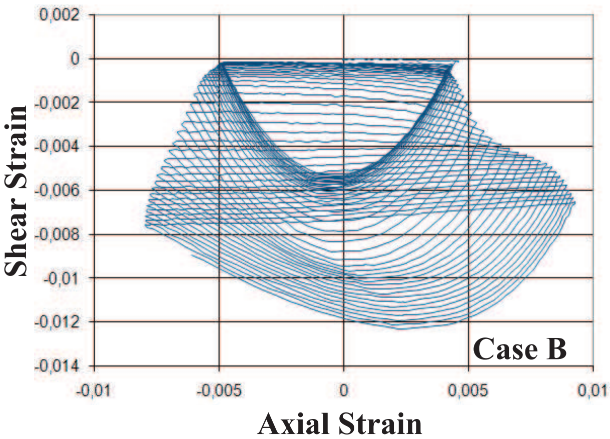

Figure 6: *Strain response from multiaxial test*

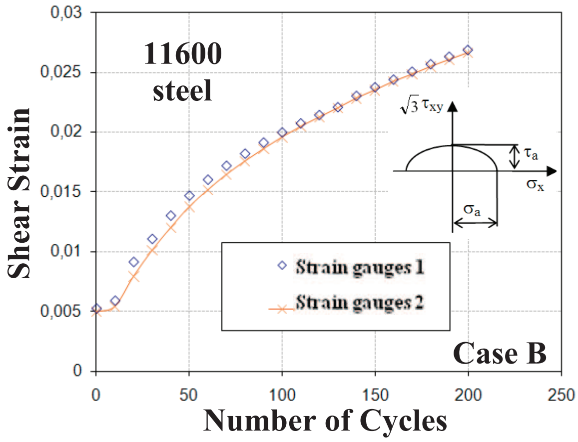

Figure 7: *Accumulation of shear strain*

The investigated steel 11600 embodies almost elastic behavior in initial cycles followed by strong cyclic softening, which is intensified by nonproportional loading.

3. Simulations

It was observed by many authors, that cyclic plasticity models included in commercial FE software are not able to describe mechanical ratcheting correctly. The AbdelKarim-Ohno cyclic plasticity model [5] was considered for prediction of ratcheting strain for case A using

FE method (Figure 8). The newer material model was implemented into the FE code by an improvement of a user subroutine [6]. Constitutive equations and material parameters of the material model are stated in the table 1. More details about the cyclic plasticity model and a way of its calibration were published elsewhere [6].

Von Mises yield criterion $$\bar{f} = \sqrt{\frac{3}{2}(\boldsymbol{s}-\boldsymbol{a}):(\boldsymbol{s}-\boldsymbol{a})} - \sigma_Y = 0\ ,$$ where $\boldsymbol{s}$ is the deviatoric part of stress tensor $\boldsymbol{\sigma}$, $\boldsymbol{a}$ is the deviatoric part of back-stress $\boldsymbol{\alpha}$ and σ_Y is the initial size of the yield surface. The AbdelKarim-Ohno kinematic hardening rule $$\boldsymbol{a} = \sum_{i=1}^{M} \boldsymbol{a}_i\ ,\quad d\boldsymbol{a}_i = \frac{2}{3} C_i d\boldsymbol{\varepsilon}_p - \mu_i \gamma_i \boldsymbol{a}_i\, dp - \gamma_i H(f_i) \langle d\lambda_i \rangle \boldsymbol{a}_i\ ,$$ where $f_i = \frac{3}{2}\boldsymbol{a}_i : \boldsymbol{a}_i - \left(\frac{C_i}{\gamma_i}\right)^2$ and $d\lambda_i = d\boldsymbol{\varepsilon}_p : \frac{\boldsymbol{a}_i}{C_i/\gamma_i} - \mu_i dp$.
σ_Y=200MPa, E=200000MPa, ν=0.3, μ_i=0.15 for all i $C_{1\text{-}6}$=82840,58580,18300,10720,7680,3300MPa, $\gamma_{1\text{-}6}$=2000,1000,500,200,100,2

Table 1: *Constitutive equations and material parameters of AbdelKarim-Ohno model*

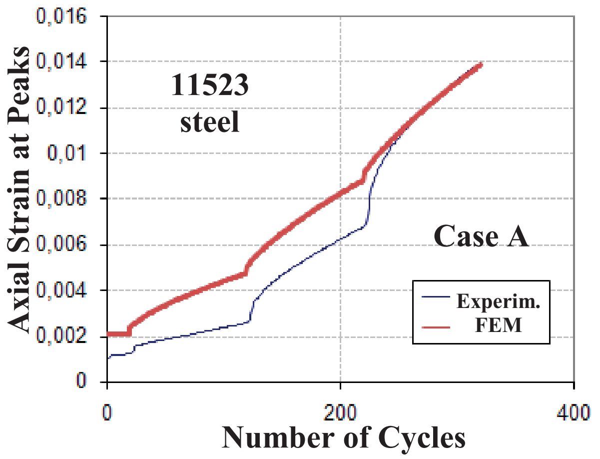

Figure 8: *Comparison of experiment and prediction*

4. Conclusions

Extensometers and strain gauges are mostly used methods for deformation measurement in fatigue testing. The both measurement methods have a restriction in critical strain value therefore a new method for accurate ratcheting strain measurement was tested. The digital image correlation method is the adept for experimental analysis in the large strain regime. This method makes possible to involve bending strain measurement, which can occur during any test with axial load. Used three methods for strain measurement during LCF testing have individual disadvantages. Practically, the easiest solution is the extensometer usage, but for the combination of tension-compression and torsion special extensometer or strain gauges rosette is necessary. All tests will be simulated by FEM in a future paper.

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