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Strain gage measurements for accurate yield point determination

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Abstract. In this contribution the experimental program is summarized. The experiments were aimed especially at the accurate yield point determination on specimens made out of structural low carbon ČSN 41 1523.1 steel after normalization annealing (ČSN 411523, ASTM A623-Gr.C). These tests were carried out in the Laboratory of material diagnostics of Institute of Thermomechanics AS CR in Pilsen. Several methods for deformation and force controlled loading and various types (single with one measuring grid, rosette) of strain gages were used for achieved measurements. Likewise, the specimen made from different material batch was tested for comparative purposes. Strain gages were glued on both sides of the specimens for evaluation of coaxial alignment. Reached results are compared with tensile test. All obtained data are evaluated and optimal solution is exported as output. The accurate determination of the yield point is very important for next tests of ratcheting and distortional hardening computation.

Introduction

A loading is often generated by a mutual matter influence in practice. This type of loading corresponds with force controlled loading. The accurate determination of a yield point is important for another loading and for a modeling of accumulation of plastic strains during cyclic plastic loading. Ratcheting is defined as the accumulation of plastic strains during cyclic plastic loading. [1] Modeling this behavior is extremely difficult because any small error in plastic strain during a single cycle will add to become a large error after many cycles. [1] The ratcheting deformation is accumulated continuously with the applied number of cycles, and it may not cease until failure. [2] If these problems are applied on multiaxial loading, a linear area is bounded by a circle shape of allowed stress. If stress amplitude exceeds it and turns back, the nonlinear part becomes linear and the change of border comes up.

Implementation of a stress mean value is important for ratcheting tests. Ratcheting is quantified by plastic deformation increment per cycle. This value corresponds with mean strain in a cycle which is defined by relationship

$$\varepsilon_m = \frac{\varepsilon_{ph} + \varepsilon_{pd}}{2}, \qquad (1)$$

where ε_{ph} is plastic deformation in top of open hysteresis loop and ε_{pd} is plastic deformation in bottom of open hysteresis loop. [3]

Experimental measurement

The tests have been conducted on tubular specimens which were made of structural low carbon ČSN 41 1523.1 (ASTM A623-Gr.C) steel after normalization annealing. The specimen dimensions are given in Fig. 1 and all specimens were loaded in normal direction by electrohydraulic computer controlled testing machine Inova ZUZ 200-1. This type of machine is able to reach maximal force in tension-pressure up to 200 kN and simultaneously the torque moment 1 kNm. The strain gages were using for measurement of deformation – rosettes of type 3/120RY11 with maximal effective bridge excitation voltage 1.5 V and with dimension of measuring grid 0.8 mm and single type LY11-6/120 with excitation 8 V and dimension of grid 6 mm. The yield point was determined as 365 MPa on base of research report concerning tensile test accomplished by workplace Research and Testing Institute Plzeň.

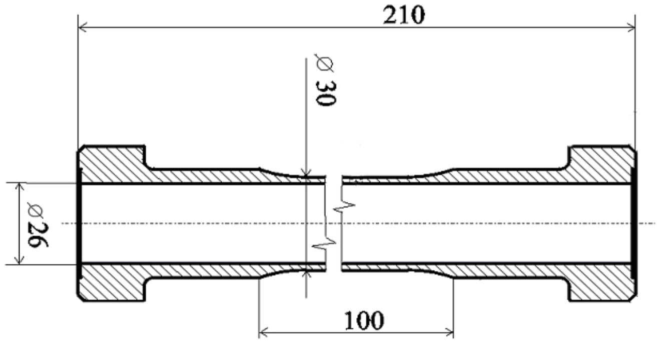

Fig. 1 Testing specimen with dimensions.

The first experiment

The course 0-400 MPa per 1 minute was chosen for the first passing of the yield point. The rosette was used for measurement but it did not hold transition and in time 56.86 second during the deformation about 3000 μm/m the flow of data from sensor broke down. The sample rate was 10 Hz. The results are evaluated in Fig. 2 where 3 deformation courses are shown. The main deformation is tagged as ε 90°. This sensor informs also about deformation in slanting branch as the next course tagged ε 45° and next in the orthogonal orientation to main plane which is tagged ε 0° and due to tensile in main plane the transverse narrowing occurs and therefore this sensor shows the negative values of pressure. It is possible to pursue the linear shape to value of stress 322.57 MPa during deformation 1557.56 μm/m. Afterwards it is evident a tremble occurs behind this value. It can be caused by material relaxation and by atom movement to new positions during slide. Then a big increase of deformation follows during slight growth of stress.

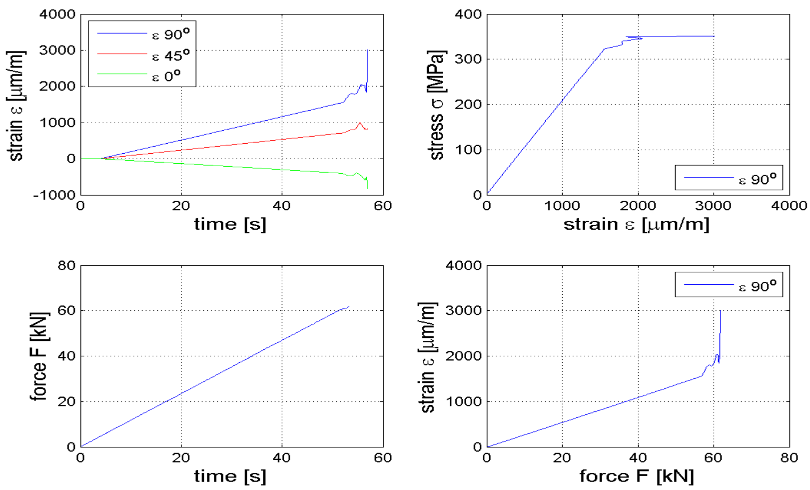

Fig. 2 Results from first test where yield point has value 322.57 MPa.

The second experiment

A new specimen without any loading history was chosen for the second test. But this specimen was from other material batch. The load course was picked as 0-284.2 MPa per 1 minute and subsequently the course was slow down about growth of 2.84 MPa per 2 minutes. The results are presented in Fig. 4. Other batch has very big influence on yield point because it corresponds with stress 283.64 MPa and with strain 1359.9 μm/m. Nonetheless the single gage did not stand whole course and it broke down when it reached the final value 6911 μm/m.

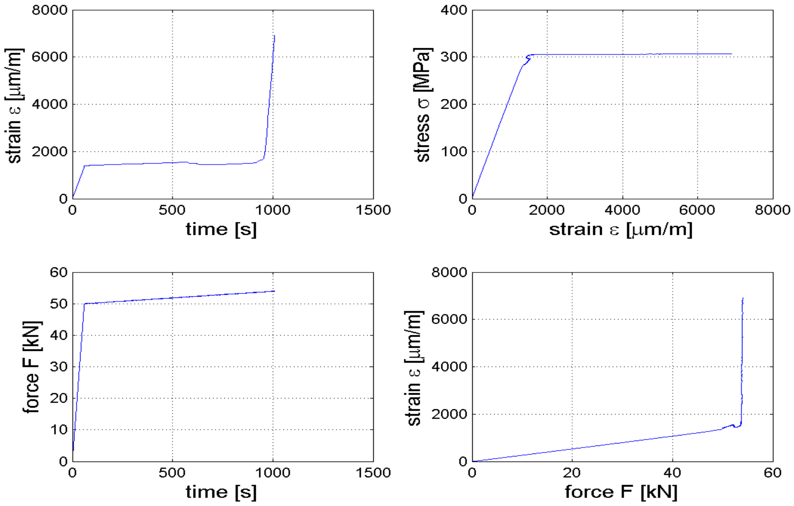

Fig. 4 Results from second test with different loading rate and with different material batch. The yield point corresponds with stress 283.63 MPa.

The third experiment

New specimen from the same batch as in the first experiment was used for this test. The loading speed was 2.84 MPa per 2 minutes in interval from 255 to 284 MPa for detail investigation in this range. The measurement were carried out with single strain gage (marked as ε1) and also with the rosette from other side. New obtained data are displayed in Fig. 5. They indicate that possible small plastic deformation could occur during around 262 MPa and 1200-1250 μm/m. But in this range it is not possible declare anything about strong yield point because a strong deformation did not occur. Difference between sensors of deformation is probably caused by stick way when the specimen axis was not kept exactly, therefore the main orientation was a little bit different.

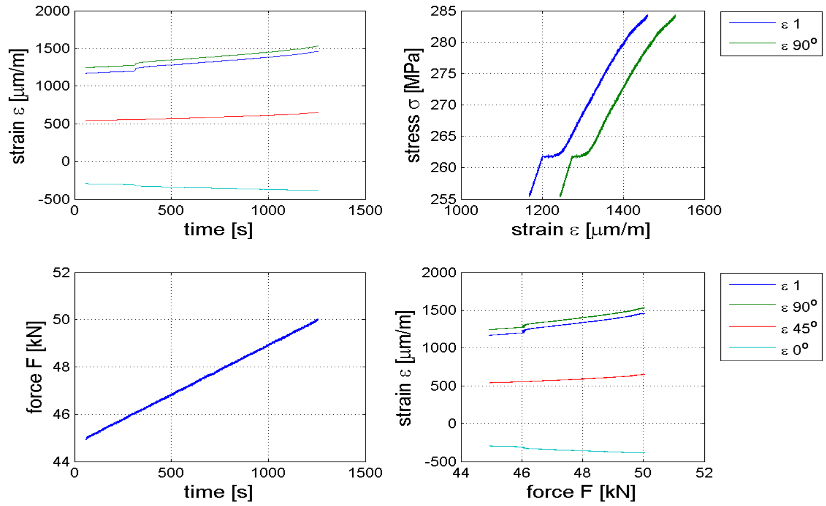

Fig. 5 Results from third test with using rosette and single strain gage. They indicate that possible small plastic deformation could occur around 262 MPa.

The fourth experiment

The fourth experiment was realized with the slowest load approach with loading speed 2.84 MPa per 2 minutes to stress value 297.45 MPa. The new specimen without loading history was used also for this test. Choice of the material batch was controlled and it was kept like in the first and third experiment. The measurements were carried out with single strain gage and also with the rosette from other side. In the Fig. 6 the results are displayed. The linear part ends in the point of deformation 1430 μm/m and stress 290.7 MPa. This result was visually read off from graph. After this value the single strain gage broke down, therefore the output of single gage misses in Fig. 6.

On the other hand the method of three points can be applied on these obtain graph values. When the stress values in the graph are zoomed in, it is possible to find out that the values lay in amplitude range 0.85 MPa due to slow loading speed. Therefore calculated stress from measured force can be compared in the linear part with Hook's rule to determine the elastomer modulus E. Computed values of elastomer modulus are for the first experiment 222.8 GPa, for second 218.2 GPa and for fourth 208.2 GPa. These values are completely in accord with tabular values.

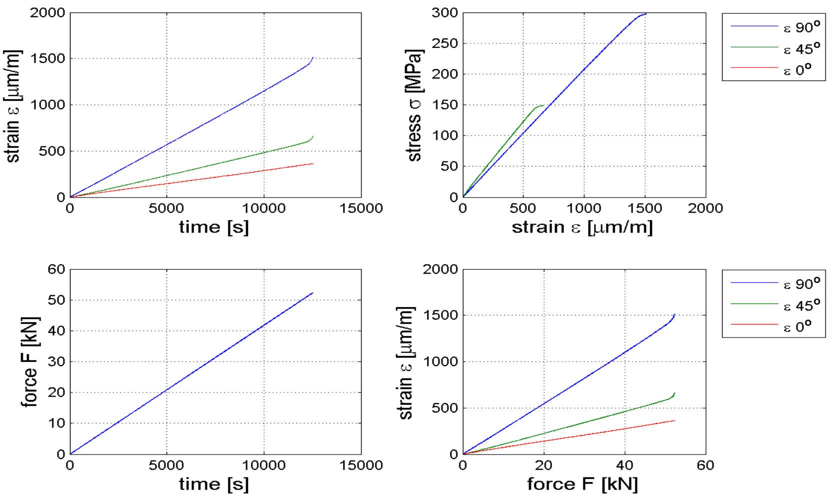

Fig. 6 Results from fourth test with using rosette and single strain gage. Loading speed was 2.84 MPa per 2 minutes to stress value 297.45 MPa. The linear part ends in the point of deformation 1430 μm/m and stress 290.7 MPa.

The fifth experiment

For the fifth test the similar step method as in the case of second part of the first experiment was chosen. The loading was of linear character with loading speed 11.37 MPa per minute. The start of every step was at zero and first loading curve had peak at stress point 250.1 MPa. From peak value the curve has unloading character with same unloading speed up to zero. Next step increment was 2.84 MPa. Single strain gages were glued on both sides of the specimen. Final curves are shown in Fig. 7. If the yield point is exceeded, the permanent deformation occurs how it is evident from Fig. 7. The yield point was determined by optical method as 287.5 MPa for strain 1422 μm/m.

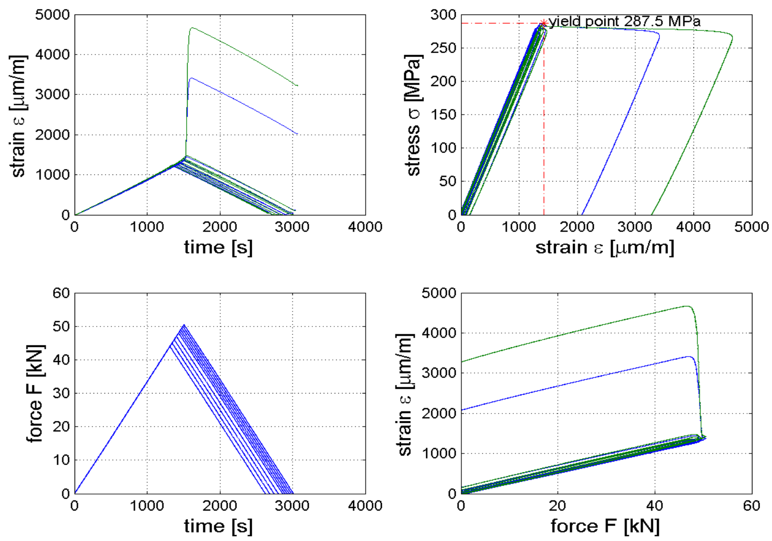

Fig. 7 Results from fifth experiment using step test method and single strain gages on both sides of the specimen. Loading increment was 2.84 MPa. Loading and unloading speed was 11.37 MPa per minutes. The linear part ends in the point of deformation 1422 µm/m and stress 287.5 MPa.

The sixth experiment

The sixth test was the last and for verification the deformation controlled loading was chosen with loading rate 0.5 mm per minute. The evaluation of test is in Fig. 8. The course of loading curve is linear up to value 298.5 MPa for strain 1442 µm/m. Because the loading is only axial, the single strain gages glued on both sides of the specimen were used.

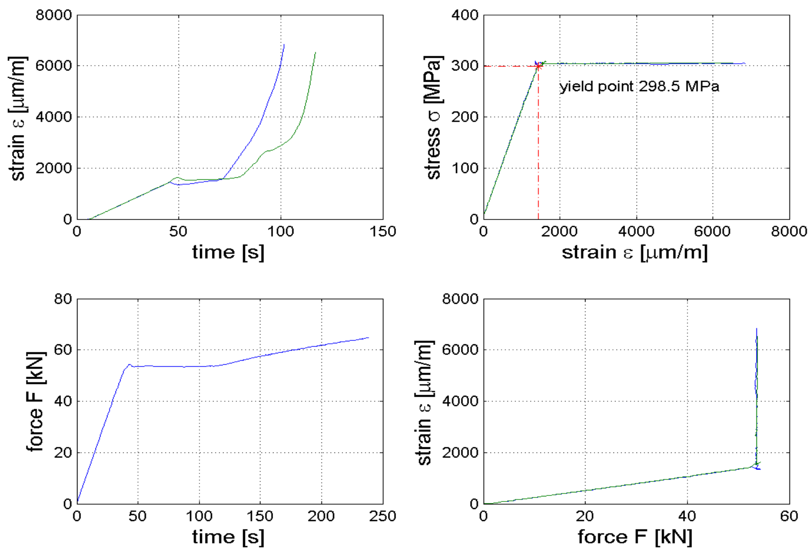

Fig. 8 Output of sixth experiment which was performed by deformation controlled loading with rate 0.5 mm per minute. Loading curve is linear up to 298.5 MPa for strain 1442 µm/m.

Conclusions

This paper informs about obtained knowledge from experimental works on material ČSN 41 1523.1 steel after normalization annealing. These experimental works have initial purposes for ratcheting investigation. How it was shown by experiments although the specimens were of the same type of material, it is necessary to keep the united material batch. The second test indicated that another material batch can differ in value of yield point at about 10 MPa. New specimen without any loading history had to be used due to inception of permanent deformation after yield stress exceeding.

The first experiment was performed with fast loading rate 400 MPa per minute but obtained result indicates that fast loading rate is not suitable for accurate yield point determination. Nevertheless this result is nearing tensile test. Optimal loading and unloading rate was in this case 11.37 MPa per minute or lower. The presented step test in the fifth test is the most suitable for accurate yield point determination. If three the most exact results of yield point (from last three experiments) are taken into consideration the yield point has average value (292.2 ± 1.4 %) MPa.

All results have been obtained by visual method but the method of three points should be better for this application. The result from third experiment is very interesting too because it has revealed potential plastic non-linear behavior could occur behind the 262 MPa.

Last but not least the performed experiments shows some kind of spring effect occurred after yield point exceeding. Deformation decreased with stress growth during this effect. This could be caused by atom position change and by dislocation movements. A size of area depends on loading rate. A very big strain growth occurs after exceeding of this area and strain gages lose the function. Therefore strain gages are sufficient only for the accurate yield point determination but for multiaxial ratcheting investigation would be better biaxial extensometers or non-contact kind of strain measurement.

Acknowledgements

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