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EXPERIMENTAL CHARACTERIZATION OF MATERIALS SUBJECTED TO COMBINED LOADINGS PART I: TENSION-TORSION

BY

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Abstract. This paper presents a set of experimental characterizations for materials subjected to different loading paths. The methodology consists in testing circular specimens by tension-torsion combined loadings. Tensile initial loadings are stopped when different values of extension are achieved. Subsequently torsion loads are applied until specimens fails. Experimental results shows that hardness and Young modulus decrease when extension decreases. Subsequent loading by torsion has a significant influence on material final microstructure for each of six cases.

Keywords: complex loading paths; fractographical examination; instrumented indentation tests.

1. Introduction

Materials are subjected to a complex historic of loading and deformation during exploitation. To obtain multiaxial stress states in laboratory conditions different experimental procedures can be applied: biaxial tensile tests (Andruşcă *et al*., 2015a), combined loadings (Andruşcă *et al.*, 2015b) etc.

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Severe plastic deformation represents an effective method to obtain ultrafine grained (UFG) and nanocrystalline materials which consists in combining torsion, tension or/and compression loads (Wang *et al.*, 2014). Experiments under combined axial and torsion loads are used to evaluate ductile failure (Haltom *et al.*, 2013; Graham *et al.*, 2012), to obtain initial and subsequent yield surfaces under different tension-torsion loading paths (Hu *et al.*, 2012), to study inhomogeneous plastic deformations (Khoddam *et al.*, 2014), to study micro-structural evolution of pure copper (Li *et al.*, 2014). Instrumented indentation tests (ISO 14577-1) are used to assess evolution of materials characteristics at several levels of deformation. For materials with ductile behavior one of the most important parameters is the yield stress. Another important feature of combined loadings is represented by the study of rupture mechanisms in combined tension and shear. Failure mechanisms are governed by internal necking mechanism and internal shearing mechanism (Barsoum *et al.*, 2007). The transition from internal necking (tensile load) to internal shear (torsion load) can be connected with the variation range (high to low) of stress triaxiality (Barsoum *et al.*, 2011).

2. Material and Methods

To characterize material behavior are used two approaches: macroscopic (combined loading) and microscopic (SEM analysis and nano-indentation tests). This study is focused on microscopic approach. Two successive different loading paths were performed: initial tension combined with subsequent torsion and initial torsion followed by subsequent tension. In this study experimental procedure of combined loadings assumes the next cycle: tensile preloading-elastic recovery- torsion reloading until break.

Initial loading of circular specimens in the case of combined loading analysed in this paper was tension. Uniaxial tensile test are performed on a universal testing machine Intron 8801. The subsequent loading was torsion. Torsion tests are performed through an attachable device that allows free end torsion. SEM technique is used to analyze failure surfaces and to investigate microstructural changes. From failed circular specimens small disc pieces are cuted near from the vicinity of the rupture zone. On this discs is determined hardness and Young modulus through nano-indentation tests. Material used in this study is S 235 JR structural steel.

3. Results and Discussions

Circular specimens fabricated from S 235 JR are subjected to combined loadings. Initial loading sequence consists in of applying gradual extensions through tensile test. Than specimens are elastic recovered. Finally, the subsequent loading sequence is torsion. For surface failure analysis images were taken of the specimen center by SEM technique at different magnifications (magnitudes ranging from 50X to 1000X). In Fig. 1 is represented specimen location were micrographs are made.

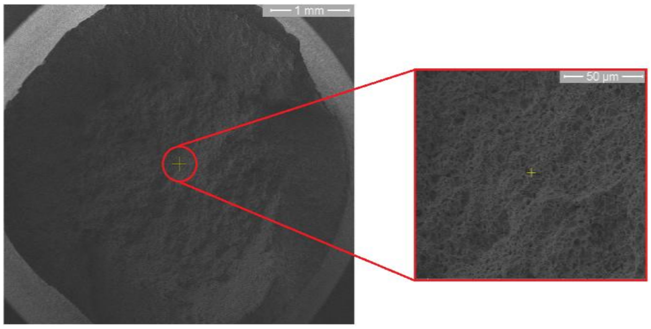
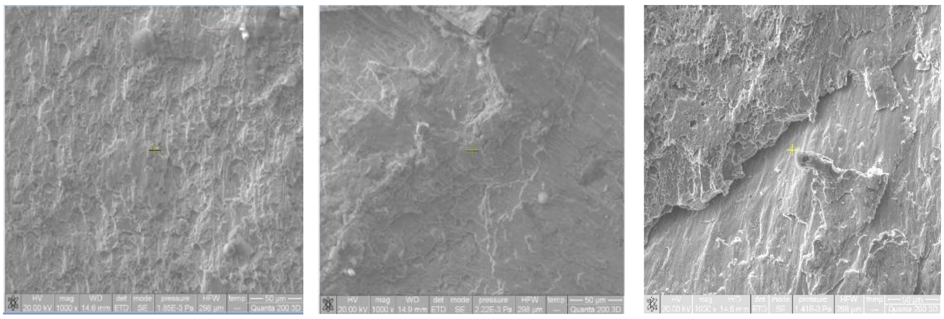


Fig. 1 – Location of micrographs (for all resultant fracture surfaces).

By varying level of extension applied by initial tension different twist angles are necessary to break each specimen. In Fig. 1 is presented a surface failure from a specimen subjected to uniaxial tension test, were necking is present.

In Fig. 2 are illustrated failure modes for three different fracture surfaces corresponding to specimens S_A, S_ C and S_F.



S_A *S_C* *S_F*

Fig. 2 – SEM fractographs for three specimens showing failure mode (1000X).

S_A is the specimen with the highest value of extension and the smallest value of twist angle. Although twist angle value was small it can be observed the influence of subsequent torsion test. Increasing twist angle value for each specimen the influence grows resulting failure modes like in Fig. 2 (S_C and S_F).

Instrumented indentations tests are made in 9 indentation points, on two perpendicular radial direction (Fig. 3) upon disc samples extracted from fractured circular specimens.

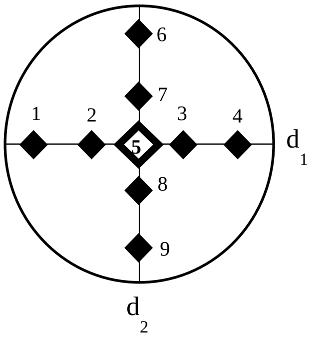


Fig. 3 – Distribution of points where nano-indentation tests were performed on disc samples.

To capture the variation of hardness and Young's modulus on the disc have been traced two perpendicular directions (d_1 and d_2). The point of intersection of the two is the center piece (point 5). Medium values of hardness and Young's modulus for each sample are considered to be representative in illustrating their evolutions.

In Fig. 4 is presented the variation of Young's modulus for six disc pieces cuted form circular specimens.

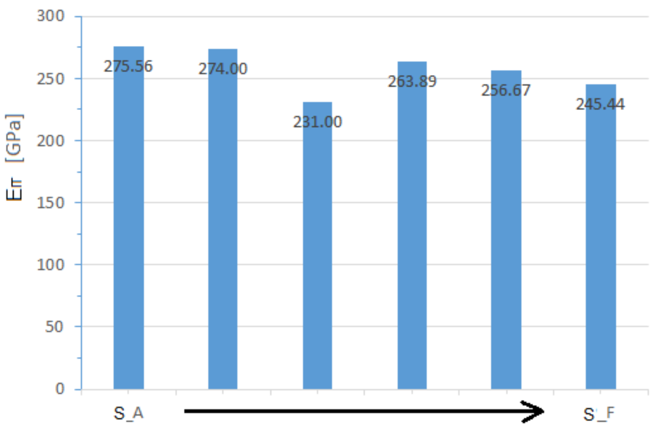


Fig. 4 – Variation of Young's modulus.

Can be observed that maximum values are registered for samples S_A (275.56 GPa) and S_B (274 GPa) and the lowest values are find for S_C (231 GPa) and S_F (245.44 GPa).

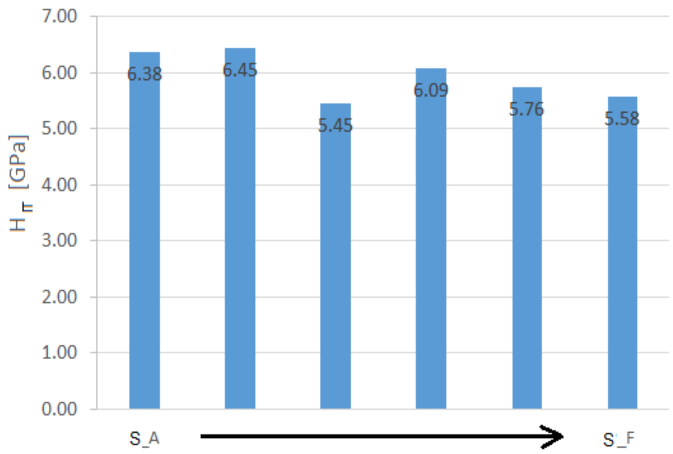


Fig. 5 – Evolution of hardness.

It was found that the higher hardness values (6.38 and 6.45 GPa) are associated with test pieces that have had high levels of extensions applied by initial tensile test (S_B and S_A from Fig. 5). Distribution of the two parameters is not uniform on the perpendicular directions, with higher values outside the disc and lower values inside.

4. Conclusions

This study investigates the influence of complex loading paths on material behavior at microscopic level. Subsequent torsion tests has a major influence on samples final failure previously subjected to tension tests. Hardness and Young modulus, obtained through instrumented indentation tests shows that, excepting sample P_3, they decrease when the level of extension applied by initial tensile test is reduced. Microstructure has a preferred orientation induced by torsion subsequent test. Through the combined loadings can be estimated limit values for the two different stresses (normal and tangential), before material final failure occurs.

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CARACTERIZAREA EXPERIMENTALĂ A MATERIALELOR SUPUSE LA SOLICITĂRI COMBINATE PART I: TRACŢIUNE CU TORSIUNE

(Rezumat)

Această lucrare prezintă studiul evoluţiei microstructurii şi a unor caracteristici ale materialelor supuse la solicitări combinate (tracţiune şi torsiune). Şase epruvete cu secţiune circulară, confecţionate din oţelul structural S235 JR, au fost supuse la un ciclu de testare ce a constat din trei faze - o solicitare iniţială în domeniul elasto-plastic, revenire elastică şi o solicitare subsecventă până la rupere. Testele s-au realizat după cum urmează: iniţial, epruvetele au fost solicitate la tracţiune cu diferite valori ale extensiei, iar subsecvent au fost solicitate la torsiune, până la rupere. Suprafeţele de rupere ale epruvetelor au fost analizate microscopic prin tehnica SEM. Din epruvetele rupte au fost prelevate probe sub formă de disc, pe care s-au efectuat teste de indentare instrumentate. Prin aceste teste s-au determintat valorile durităţii şi modulului Young. S-a constatat că cei doi parametri au o tendinţă descrescătoare, începând cu epruveta care a fost cel mai mult solicitată la tracţiune şi cel mai puţin la torsiune, P_A şi terminând cu epruveta P_F. Suprafeţele de rupere rezultante în urma solicitării combinate arată că influenţa semnificativă asupra microstructurii materialului o are solicitarea subsecventă la torsiune. Se observă o orientare preferenţială a grăunţilor, ghidată de solicitarea la răsucire. Prin solicitarea combinată la tracţiune cu torsiune, se poate aprecia influenţa tensiunilor normale şi tangenţiale asupra cedării materialelor, în vederea estimării valorilor limită corespunzătoare fiecăreia dintre cele două solicitări.