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

BY

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Abstract. Combined torsion-axial loading is an experimental procedure that provides information about the elasto-plastic behavior and failure mechanisms of materials. When different values of twist angles are achieved, torsion initial loading of circular specimens is stopped. Subsequently tensile loads are applied until break. Hardness and Young's modulus are determined by instrumented indentation test. These two parameters together with material microstructure changes depends on the ratio between the two types of loadings. Material failure is governed by different mechanisms and is influenced either by predominant action of normal stresses/shear stresses.

Keywords: mechanical testing; combined loadings; SEM analysis; nanoindentation tests; materials failure.

1. Introduction

Investigation of materials behavior subjected to complex loadings presents a major practical interest and is a difficult task. The experimental set-ups developed for performing multiaxial loading tests are very varied. Combined torsion-axial loading can be conducted in static or dynamic

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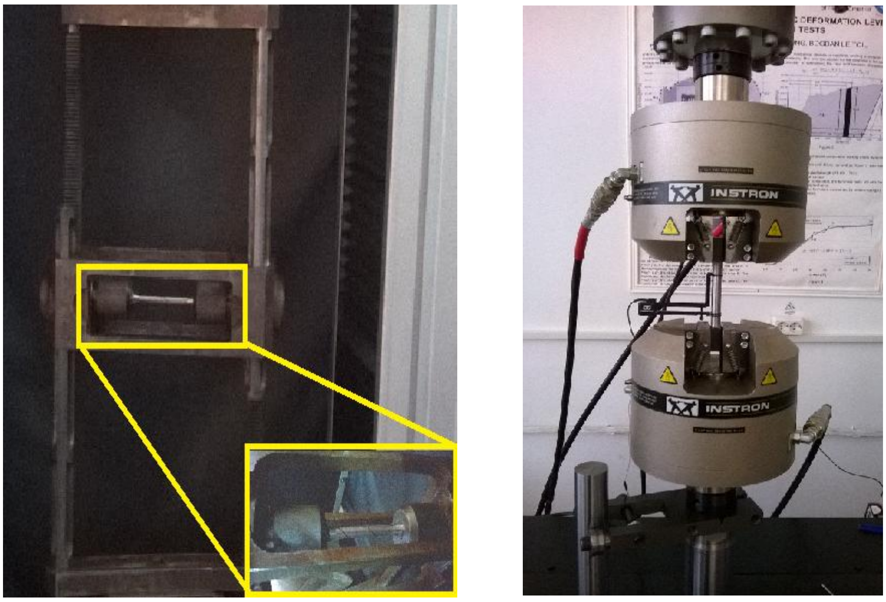
conditions, with tubular or cylindrical specimens. The aims of such researches are to investigate material mechanical behavior, to characterize failure modes, to define adequate constitutive models, etc. Combined loading through torsion and tensile tests is an experimental technique that can be applied to a wide range of materials: steel (Andrușcă *et al.*, 2015; Andrușcă, 2016a; Andrușcă *et al.*, 2016b), pure copper (Li *et al.*, 2014; Wang *et al.*, 2013), polymers (Guitton *et al.*, 2014), composites (Wang *et al.*, 2014) etc. For some metallic materials, through torsion test, large plastic deformations are applied without any change in the sample's shape and size (Guo *et al.*, 2016). Depending on the stress state can be observed different ductile rupture mechanisms that can be identified by a micromechanical study using scanning electron microscopy of the fractured surfaces (Barsoum and Faleskog, 2007). Getting information from nano-indentation experiments (Clausner *et al.*, 2014) or by determining Vickers hardness (Zhang *et al.*, 2011), can be established correlations between different mechanical properties materials and hardness.

2. Material and Methods

Combined torsion and axial loadings have assumed three stages to test circular section specimens made from S 235 JR structural steel: 1) torsion preloading, 2) elastic discharge, 3) tensile reloading until break (Fig. 1).



a *b*

Fig. 1 – Combined loading of specimens with circular cross section:
a – torsion test; *b* – tensile test.

Successive loadings were initiated with torsion tests followed by tensile tests. Torsion tests are performed on a universal testing machine WDW 50 using an attachable device that allows axial displacements of specimens. Pretorsion implied loading specimens with different values of rotation angle. Subsequent tensile tests were conducted on an Instron 8801 Servohydraulic Fatigue Testing System. Reloading of specimens by tensile testing, was made up to breaking. After specimens are broken disc samples have been cut out and they have been subjected to instrumented indentation test. Also, rupture surfaces are investigated to evaluate microstructural changes and failure modes.

3. Results and Discussions

To investigate the material behavior and failure mode, circular specimens fabricated from S 235 JR are subjected to combined torsion-axial loading. When imposed value of twist angle is reached initial test is stopped. The experiment continues with tensile test, with different values of extensions depending on when specimens break. Twist angle and extension values for each specimen are presented in Table 1.

Table 1
Values of Twist Angle and Extension for the Six Specimens

Test parameters	Sample no.					
	S_1	S_2	S_3	S_4	S_5	S_6
φ [°]	1279.55	1031.23	782.94	534.63	286.31	37.99
Δl [mm]	16.83	19.46	16.79	20.96	22	24.4

In Fig. 2 are presented the equipment used for instrumented indentation tests and load-depth curve used to determine H_{IT} and E_{IT}.

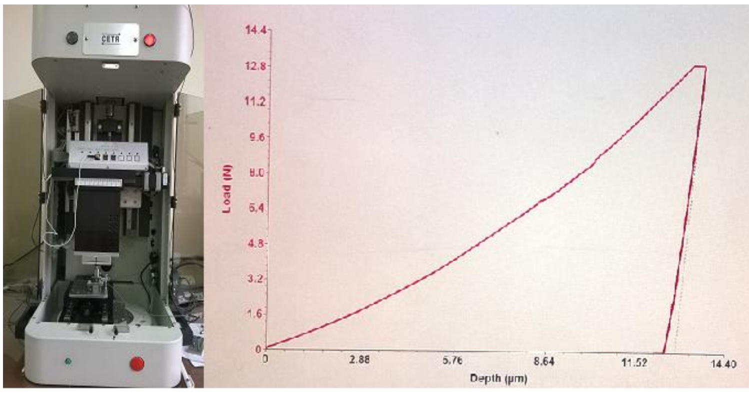


Fig. 2 – Equipment used in nanoindentation tests and load-depth resultant curve.

Fracture surfaces corresponding to four different specimens S_1, S_2, S_4 and S_6 are illustrated in Fig. 3.

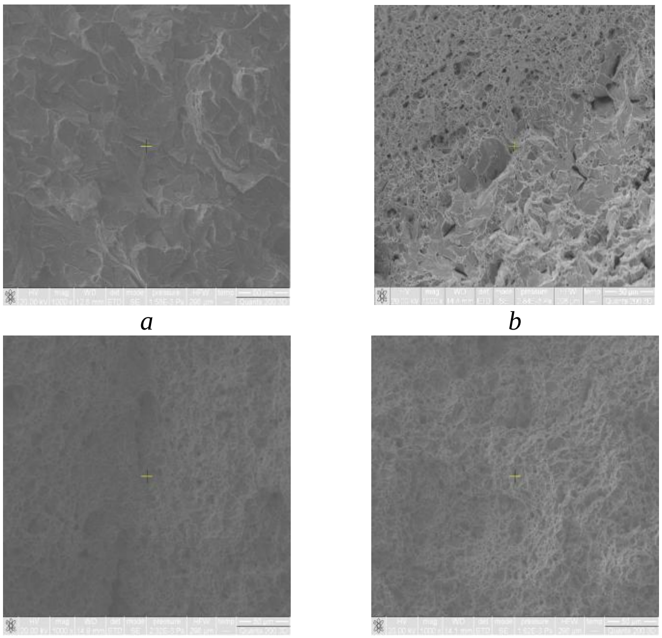


Fig. 3 – SEM fractographs showing the failure modes for S 235 JR:
(*a*) S_1; (*b*) S_2; (*c*) S_4; (*d*) S_6 (magnitude *1000X*).

It was made an average of measured values for each sample to illustrate instrumented hardness and Young's modulus variation. Young's modulus variation is presented in Fig. 4.

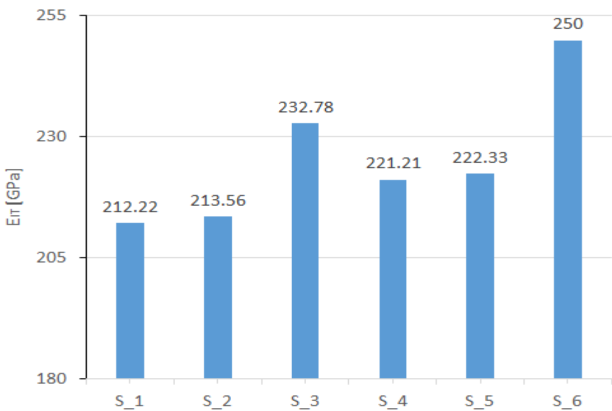


Fig. 4 – Young's modulus variation after torsion-tensile combined loading.

In the case of sample S_1 (φ = 1279.55°) it was found the minimum value of Young's modulus (212.22 GPa). The maximum value was obtained for sample S_1 (φ = 37.99°).

Variation of hardness for the six samples is presented in Fig. 5.

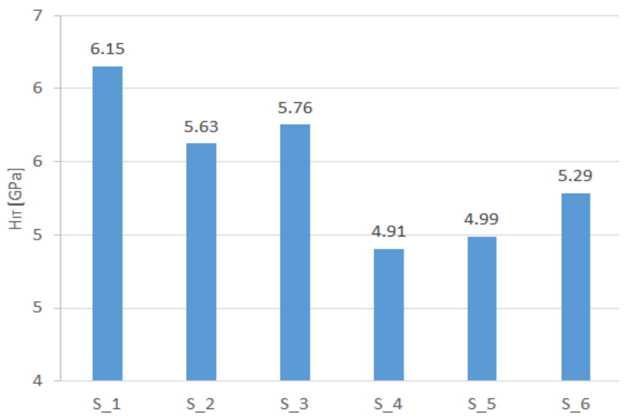


Fig. 5 – Hardness variation after torsion-tensile combined loading.

The higher value of indentation hardness (6.15 GPa) is found for specimen S_1, which has been tested with maximum value of rotational angle. The minimum hardness value is recorded for specimen S_3 (4.91 GPa) which is not the sample with smallest value of twist angle.

4. Conclusions

The present work shows the influence of combined torsion-axial loading on material parameters such as hardness and Young modulus and on failure mechanisms. Young's modulus increases with decreasing of twist angle for specimens subjected to initial torsion and subsequent tensile tests, while hardness presents a decreasing trend. This changes are due to material hardening by initial torsion and subsequent tensile. Study of resulting fracture surfaces showed that material failure occurred in most cases due to tensile load.

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CARACTERIZAREA EXPERIMENTALĂ A MATERIALELOR SUPUSE LA SOLICITĂRI COMBINATE PARTEA A II-A: TORSIUNE CU TRACŢIUNE

(Rezumat)

Solicitarea combinată a organelor de mașini și a elementelor structurale este frecvent întâlnită în aplicațiile inginerești. Cunoașterea comportamentului și a modului de cedare a materialelor cu un istoric complex al încărcărilor și deformațiilor este de o importanță capitală. Solicitarea combinată la torsiune cu tracțiune a epruvetelor cu secțiune circulară oferă informații despre comportamentul la deformații plastice mari şi despre cedarea materialelor solicitate inițial în domeniul elasto-plastic, descărcate elastic și solicitate ulterior până la rupere. În funcție de gradul de încărcare aplicat, prin cele două solicitări (inițială și finală), se poate observa că unele proprietăți mecanice ale materialului suferă modificări. Duritatea și modulul de elasticitate longitudinală, determinate prin teste de nanoindentare, variază ca urmare a ecruisării materialului. Totodată cedarea variază de la un mecanism influențat predominant de tensiunile tangențiale la un mecanism în care influența dominantă o au tensiunile normale. Prin modificarea raportului solicitărilor s-a constatat că există o tranziție între cele două mecanisme de cedare.