AN INFLUENCE OF CYCLIC TORSION STRAIN AMPLITUDE ON MONOTONIC TENSION OF POWER PLANT STEEL

Tadeusz SZYMCZAK[*], Zbigniew L. KOWALEWSKI[**]

[*]Centre for Material Testing and Mechatronics, Motor Transport Institute, 80 Jagiellonska Street, 03-301 Warsaw
[**] Department for Strength of Materials, Institute of Fundamental Technological Research PAS, 5B Pawinskiego, 02-106 Warsaw

tadeusz.szymczak@its.waw.pl, zkowalew@ippt.pan.pl

Abstract: The paper reports the experimental data of tests on the 10H2M steel, carried out under complex loading being combination of monotonic tension and cyclic torsion. Two types of torsion cycles were applied, i.e.: symmetrical and asymmetrical, having four blocks of different shear strain amplitude within a range from ±0.1% to ±0.8%,. All tests were conducted using the tubular specimens at room temperature. The main aim of the experimental procedure was focused on examination of axial stress variations due to torsion cycles of step increasing strain amplitude. An analysis of the results showed a significant reduction of the tensile stress. This effect became stronger when the torsion strain amplitude was increased and it achieved 85% stress drop at highest strain amplitude considered in comparison to the standard tensile characteristic.

Key words: complex loading, biaxial stress state, stress reduction, tensile stress, shear stress, tubular specimen

1. INTRODUCTION

Great effort of many research groups is focused on modification of metal-forming processes, [eg. 1]. They are looking for elaboration of an effective method for essential reduction of technological forces. As it is presented in the paper [1] such effect can be obtained by the use of a twisting moment during drawing or extrusion. It is also known, that variations of material properties are strongly related to a type of cyclic loading and theirs' parameters. The results of tests on 2024 aluminium alloy [2, 4], exhibited almost 70% reduction of the tensile stress, due to presence of torsion-reverse-torsion cycles having an amplitude below ±1%. Similar effect was also observed for the other materials, i.e.: P91 steel [3, 4] and M1E copper [3, 4].

In this paper we will consider the same issue for the 10H2M steel at hardened and tempered state and will try to find how cyclic loading type and its amplitude may influence the process of monotonic tension.

2. DETAILS OF EXPERIMENTAL PROCEDURE

The 10H2M steel, widely used in the polish power plant industry, was selected for investigations. Firstly, the material was subjected to microstructural inspection in longitudinal and perpendicular directions in order to check its homogeneity degree. Subsequently, the standard tensile test was carried out to find the basic mechanical parameters, i.e. Young's modulus (159 GPa), elastic stress limit (331 MPa), yield stress (380 MPa) and ultimate tensile strength (557 MPa). In the next step the main experimental programme was performed.

All tests were conducted using thin-walled tubular specimens (Fig. 1a) having a length and wall thickness equal to 60mm and 1.5mm, respectively. The specimen geometry was examined by a finite element analysis. The results showed a uniform distribution of the axial stress on the measuring section of specimen, Fig. 1b.

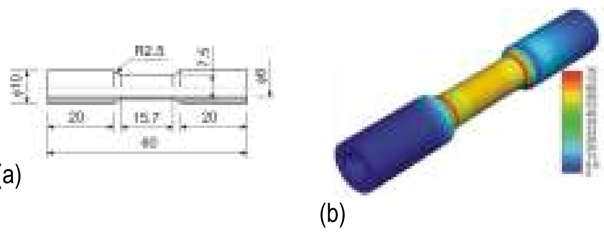


Fig. 1. Specimen: a) dimensions and geometry; b) axial stress distribution

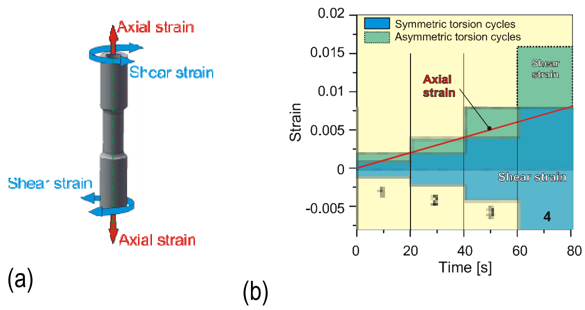


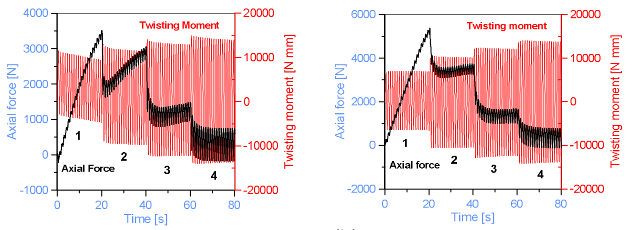
Fig. 2. Loading programme details: a) scheme of loading, b) scheme of control signals variation, numbers 1, 2, 3, 4 correspond to strain amplitude of torsion cycles equal to: ±0.1%, ±0.2%, ±0.4%, ±0.8%, respectively

The specimens were tested at a room temperature, using the Mini-Bionix servo-hydraulic biaxial testing machine enabling to examine a material behaviour under deformation due to tension and torsion, Fig. 2a.

The loading programme (Fig. 2b) contained two strain signals, i.e. a monotonicaly increasing axial strain and cyclicaly changing shear strain - symmetricaly or asymmetricaly. Four levels of cyclic strain amplitude were applied: (1) - ±0.1%, (2) - ±0.2%, (3) - ±0.4%, (4) - ±0.8% at frequency of 1Hz.

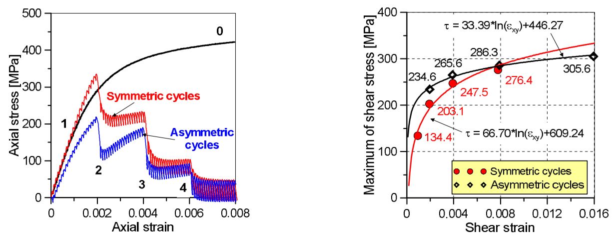
3. RESULTS

Figure 3 presents variations of the axial force and twisting moment observed during the loading programme shown in Fig. 2. It illustrates an increase of twisting moment, at beginning of each block of torsion cycles (Fig. 3a,b). Moreover, a strong coupling between the amplitude of torsion cycles and variations of the tensile force is visible. The axial stress reduction gradually increased with an increase of the cyclic strain amplitude. For the shear strain amplitude equal to: ±0.2%, ±0.4% and ±0.8% it achieved respectively 150MPa, 300MPa and 420MPa in the case of symmetrical cycles, while for the asymmertical ones 220MPa, 320MPa and 420MPa, Fig. 4a. It is worth to emphasise that independently of type of cyclic loading (symmetrical and asymmetrical) the same values of axial stress drop were observed in the last block of cycles, i.e. for the strain amplitude equal to ±0.8%.



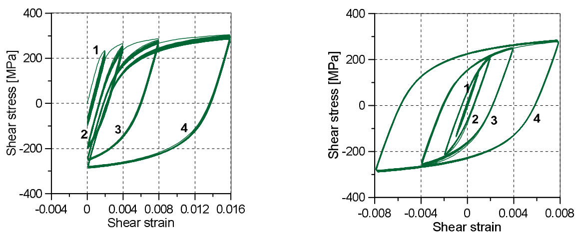
(a) (b)

Fig. 3. Variation of axial force and twisting moment versus time during deformation for the programme containing: (a) asymmetrical torsion cycles, (b) symmetrical torsion cycles



(a) (b)

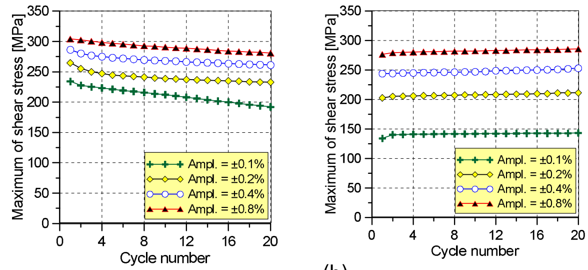
Fig. 4. Comparison of: (a) tensile characteristic (0) to stress-strain curves determined in assistance of torsion cycles (1, 2, 3, 4); (b) variation of the maximum shear stress versus shear strain for various levels of amplitude of symmetrical and asymmetrical torsion cycles



(a) (b)

Fig. 5. Histeresis loop variations due to: (a) asymmetrical cycles, (b) symmetrical cycles

Cyclic behaviour of steel under torsion was analysed on the basis of hysteresis loop variations, Figs. 5, 6. The results exhibited a gradual non-linear increase of the shear stress when amplitude become greater, independently on the type of torsion cycles considered, Fig 4b. An analysis of hysteresis loops at each block identified the softening effect due to asymmetrical torsion cycles (Fig. 5a, 6a). An opposite effect was achieved in the case of symmetrical torsion cycles, Fig. 5b, 6b.
The results also allowed an identification of the ratcheting effect for asymmetrical cycles, Fig. 5a. It increased at each loading block. Looking at the hysteresis loops obtained during symmetrical and asymmetrical torsion cycles it is easy to notice, that for the highest strain amplitude the maximum values of shear stress are the same for both cases.
The microstructural investigations carried out in the mutually perpendicular directions of the tested specimens before and after loading did not identify any significant differences which would be able to explain the stress reduction observed during testing. Therefore, it looks that another technique is required, i.e. such technique which would be able to register “online” any structural variations.



(a) (b)

Fig. 6. Maximum level of shear stress for subsequent cycles in the case of: (a) asymmetrical loading, (b) symmetrical loading

4. SUMMARY

Tensile characteristics of steel can be modified using cyclic torsion. The axial stress lowering was strongly dependent on the strain amplitude of torsion cycles. Both symmetrical and asymmetrical cycles may lead to the same reduction of the tensile stress provided an adequate shear strain amplitude is chosen. In the case of 40H steel it was equal to ±0.8%.

REFERENCES

1. **Korbel A., Bochniak W.** (2004), Refinement and control of the metal structure elements by plastic deformation, *Scripta Materialia*, 51 755–759.
2. **Kowalewski Z.L., Szymczak T.** (2010), On the effects associated with control parameters delay during biaxial cyclic loading of engineering materials, *Materials Science Forum*, 638-642, 3913-3918.
3. **Kowalewski Z.L., Szymczak T.** (2011), Modification of simple deformation processes of metallic materials by means of cyclic loading, *Materials Research Innovations,* 15, 1, 73-76(4), 2011.
4. **Szymczak T., Kowalewski Z.L.** (2012), Variations of mechanical parameters and strain energy dissipated during tension-torsion loading, *Archives of Metallurgy and Materials*, *57 (1), 193*–197.