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VARIATION OF TENSILE CHARACTERISTIC AND MECHANICAL PARAMETERS OF POWER ENGINEERING STEELS DUE TO CYCLIC LOADING

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ABSTRACT

This paper presents experimental results of tests carried out at room temperature on power engineering steels: P91 (X10CrMoVNb9-1), 10H2M (11CrMo9-10) using thin-walled tubular specimens under biaxial stress state. The loading programme comprised two different types of deformation obtained by monotonic tension and torsional cycles. The values of axial strain and cyclic shear strain amplitude were small and did not exceed 1%. In the case of both materials tested, a significant reduction of the axial stress was achieved. It was even equal to 90% for the 10H2M steel.

INTRODUCTION

Much research effort is focused on the development of technological processes and new effective methods of production. One of the goals of this paper is to recognize possible ways leading to reduction of forces during manufacturing of semi-finished products, which makes it possible to extend the lifetime of machinery elements. Korbel and Bochniak (2001, 2004) proposed the use of the twisting moment during extrusion, forging or rolling. This method, named KOBO, has enabled significant reduction of the forces applied during production. The complex forging process was found to enable plastic forming of metal using smaller forces and to give a high-quality product characterized by a homogeneous structure with good geometry. Filling the die cavity when the metal was forged using reversible torsion in the closed dies required application of less than half the load needed when similar filling was obtained in the process of conventional forging, Fig.1. The new forging method was successfully used to produce bevel gears from structural steel (Bochniak et al. 2006). In this case, more than a fourfold reduction of the force of forging was achieved in comparison with the force required using the conventional method. Cyclic rotation was also used to modify the extrusion process of lead bars (Kong and Hodgson 2000). The average load under these conditions was significantly reduced (up to 25%) in comparison to the simple extrusion process with no die rotation. The authors developed a constitutive model based on the experimental results for softening due to cyclic torsion and the elementary plasticity theory for monotonic extrusion. They have shown that the model is accurate in predicting the extrusion force; however, it requires further development to include the effects of die geometrical parameters and deformation conditions. The common feature of the previously discussed modifications of technological processes is connected to an essential reduction of force due to its combination with cyclic loading. A high deformation, even at a very low temperature, to control dynamic recrystallisation processes and to convert a highly fragmented shear banding substructure into an extremely fine grain structure is another important advantage of the KOBO method (Korbel and Bochniak 2004).

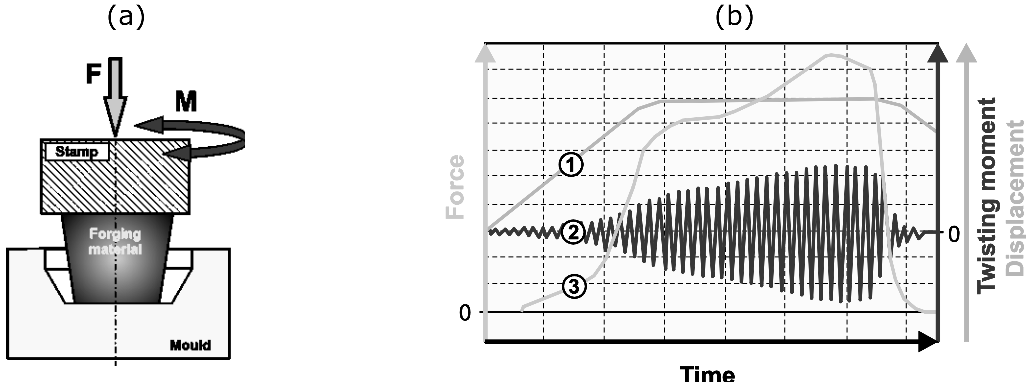

Fig. 1 Scheme of forging process modified using the KOBO method (a), and variation of the parameters during the process (b); 1 – stamp displacement, 2 – twisting moment, 3 – forging force (Bochniak et al., 2006)

Although the method is efficient, variation of the material characteristics has not been sufficiently analysed. Better knowledge of this subject is important for both industrial and research groups, since it may improve selected manufacturing processes and the numerical simulation by taking into account new effects observed in materials. Therefore, it was decided in this paper to investigate how the amplitude of torsion cycles influences the axial stress–axial strain characteristic of power engineering steels. A significant difference of this research in comparison to previous papers is related to the levels of magnitude of the cyclic strain amplitude. In all our experiments it was less than 1%. The experimental results for other materials tested in the similar way were presented earlier by Kowalewski and Szymczak (2009, 2010, 2011, 2012).

PROPERTIES OF MATERIALS AND EXPERIMENTAL PROCEDURE

Two different kinds of steel commonly applied in polish power plant industry were chosen, i.e.: X10CrMoVNb9-1 (P91 according to Polish Standard) and 11CrMo9-10 (10H2M according to Polish Standard). Chemical compositions and initial mechanical parameters were shown in Tab. 1 and Tab. 2, respectively.

The microstructures of both tested steels were obtained using an optical microscope. As it is shown both materials represent the ferritic structure consisting carbides arranged on borders and inside the grains, Fig. 2.

All tests were strain controlled and performed at room temperature under biaxial stress state using tubular thin-walled specimens. Variations of stress/strain components were measured using electro-resistance tensometers attached in the middle section of the specimens. The materials were investigated under two types of complex loading: monotonic tension combined simultaneously with torsion-reverse-torsion cycles at constant strain amplitude and the same loading combination with a step increasing strain amplitude of cycles.

Table 1 Chemical composition of steels

P91									
C	Mn	Nb	P	S	Cr	Ni	Mo	V	Cu
0.08 0.12	0.50 0.80	0.06 0.10	Max 0.02	Max 0.015	8.00 9.00	max 0.40	0.85 1.05	0.18 0.25	Max 0.25
10H2M									
C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu
0,11	0,50	0,30	0,025	0,017	2,50	0,25	0,92	0,019	0,066

Table 2 Mechanical parameters of materials

P91					10H2M			
Young's modulus [MPa]	Elastic limit [MPa]	Yield point [MPa]	Ultimate tensile strength [MPa]		Young's modulus [MPa]	Elastic limit [MPa]	Yield point [MPa]	Ultimate tensile strength [MPa]
218 781	270	400			195 134	331	380	557

(a) (b)

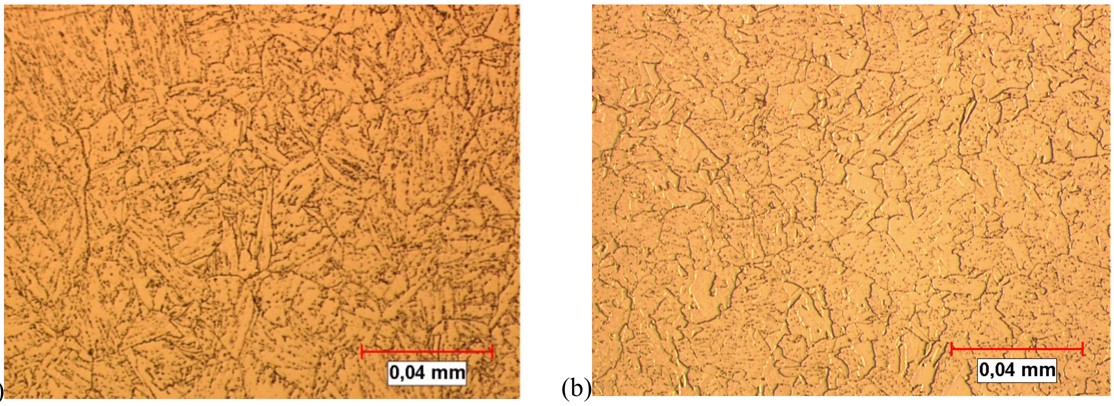

Fig. 2 Microstructure of: (a) P91 steel; (b) 10H2M steel; magnification 500×

EXPERIMENTAL RESULTS

The strain controlled loading programmes consisted two signals, i.e. axial strain monotonically increasing and shear strain cyclically changing, Fig. 3. Determination of material behaviour under different parameters of cyclic loading superimposed on tension was investigated. An analysis of the axial and shear stress components variation versus time, Fig. 4, exhibited effects of hardening and softening, respectively.

A comparison of stress-strain characteristic determined without cyclic loading and those obtained with assistance of cyclic torsion shows a lowering of axial stress, Fig. 5. The effect increased significantly with the increase of torsion cycles amplitude, and achieved the level of 400MPa for the highest amplitude considered. In terms of typical mechanical parameters the effect can be measured by essential drop of yield point and proportional limit from 500MPa to 150MPa and from 400MPa to 100MPa, respectively, for the amplitude equal to ±0.7%,

Fig.5a,b. It should be emphasised, however, that the reduction of these parameters was not permanent, and it vanished after termination of the torsion cycles. It was identified on the basis of the initial yield surface evolution (Kowalewski & Szymczak 2010).

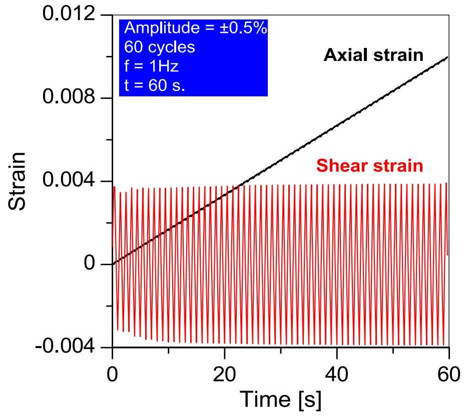

Fig. 3 Loading programme

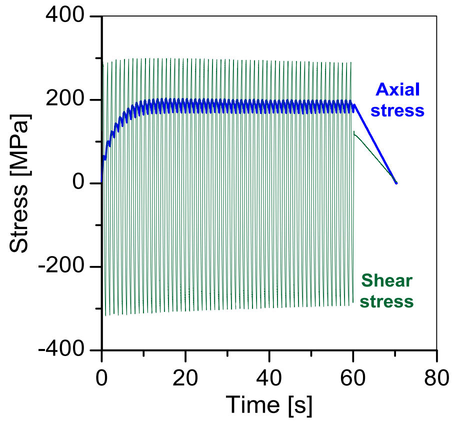

Fig. 4 Stress responses into the loading programme shown in Fig. 3

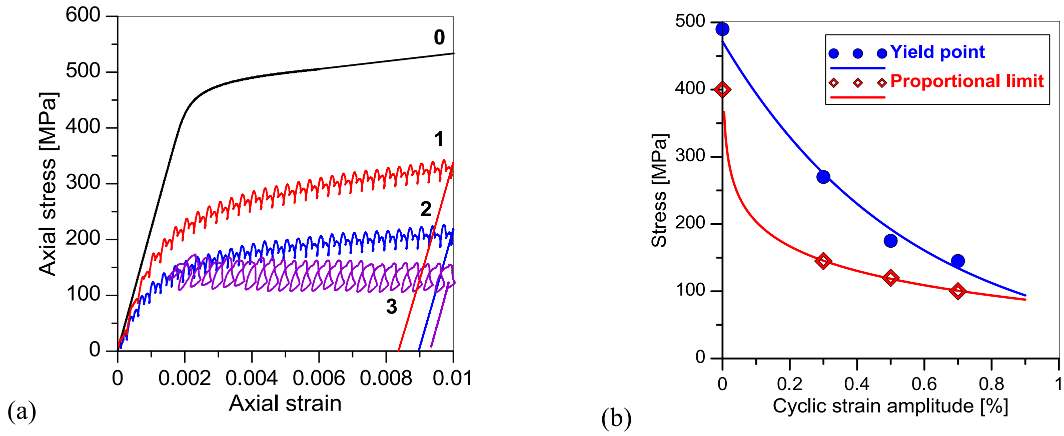

Fig. 5 Variations of: (a) stress-strain characteristic (0); (b) mechanical parameters, due to torsion-reverse-torsion cycles for amplitude equal to ±0.3% (1), ±0.5% (2), ±0.7% (3), frequency 0.5Hz (material: P91 steel)

The experimental programme also contained tests evaluating variation of tensile curves due to torsion-reverse-torsion cycles delayed with respect to the tensile load. The results for the P91 steel are presented in Figs 6-8. It is clearly seen, that a drastic axial force drop is related to the assistance of cyclic loading. The axial stress decreased (370 MPa) directly after the torsion cycles were switched on. Similar effect was earlier observed for the 2024 aluminium alloy (Kowalewski & Szymczak 2007).

The effect was also obtained for the 10H2M steel tested in this research. In this case a reduction of axial stress was also spectacular and attained the level higher than 400 MPa, Fig.9, for the cyclic strain amplitude of ±0.8%.

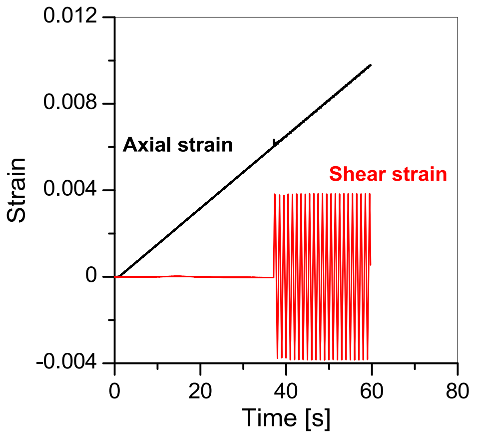

Fig. 6 Loading programme: frequency 1Hz, amplitude ±0.4%, retardation time 36s

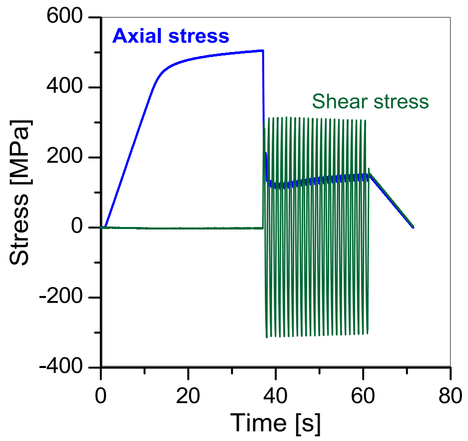

Fig.7 Variations of stress components versus time during loading programme shown in Fig. 6 (material: P91 steel)

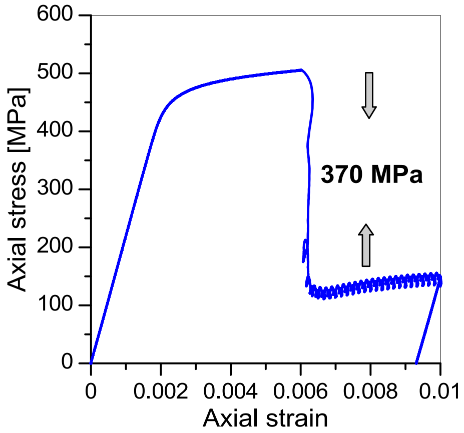

Fig. 8 Tensile characteristic obtained during deformation along the loading path presented in Fig. 6 (material: P91 steel)

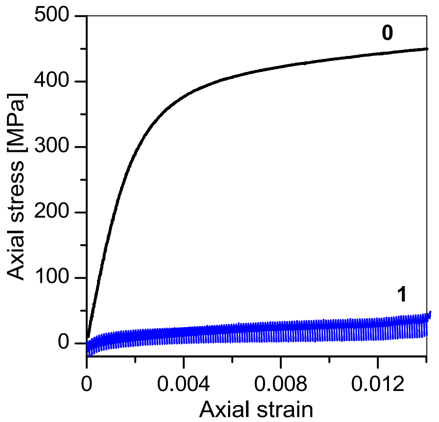

Fig. 9 Comparison of a part of standard tensile characteristic (0) with curve obtained at presence of torsion cycles (1), amplitude ±0.8%, frequency 1Hz (material: 10H2M steel)

Although the reduction of axial stress was very clear, no useful method to determine the optimal cyclic strain amplitude has been developed as yet. Therefore, the loading programme shown in Fig.10a was applied. The stress responses into this programme are presented in Fig.10b. A comparison of the conventional tensile characteristic with similar curve determined while the torsion cycles were applied shows a gradual decrease of the axial stress when the shear strain amplitude increases. It attained the level of 400 MPa what was almost equivalent to the unloaded state in the tensile direction for the highest strain amplitude considered, Fig. 11.

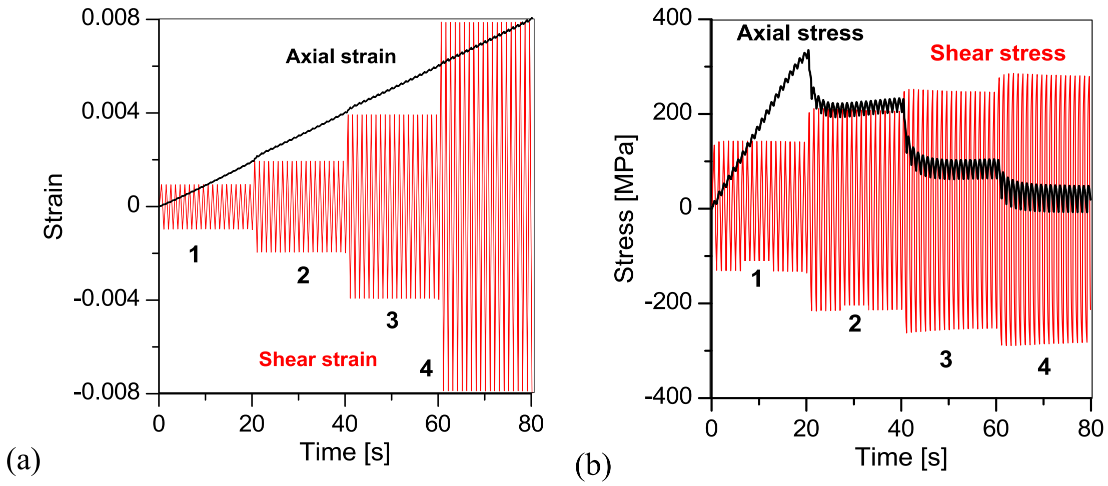

Fig. 10 Variations of stress/strain components: (a) loading programme for cyclic strain amplitude equal to: (1) ±0.1%, (2) ±0.2%, (3) ±0.4%, (4) ±0.8%; (b) stress response into deformation along loading presented in (a) (material: 10H2M steel)

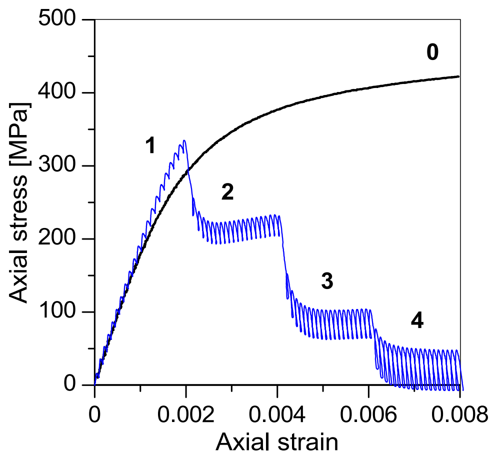

Fig. 11 Comparison of tensile characteristic (0) with curve obtained using the step loading programme presented in Fig. 10a (material: 10H2M steel)

In further analysis another type of loading programme was elaborated in order to check whether the same effects might be observed using different type of cycles. It consisted asymmetrical torsion cycles superimposed on the monotonic deformation, Fig. 12a. The stress responses into the strain controlled programme are presented in Fig.12b. The results concerning this kind of loading exhibited almost the same tendency as those achieved using the combination of the symmetrical torsion cycles and monotonic tension, i.e. the axial stress decreased with the increase of torsion cycles amplitude, Fig.13. It has to be noticed however, that the reduction of the stress level at the first three loading blocks was greater than that observed during deformation enforced by the loading programme shown in Fig.10a.

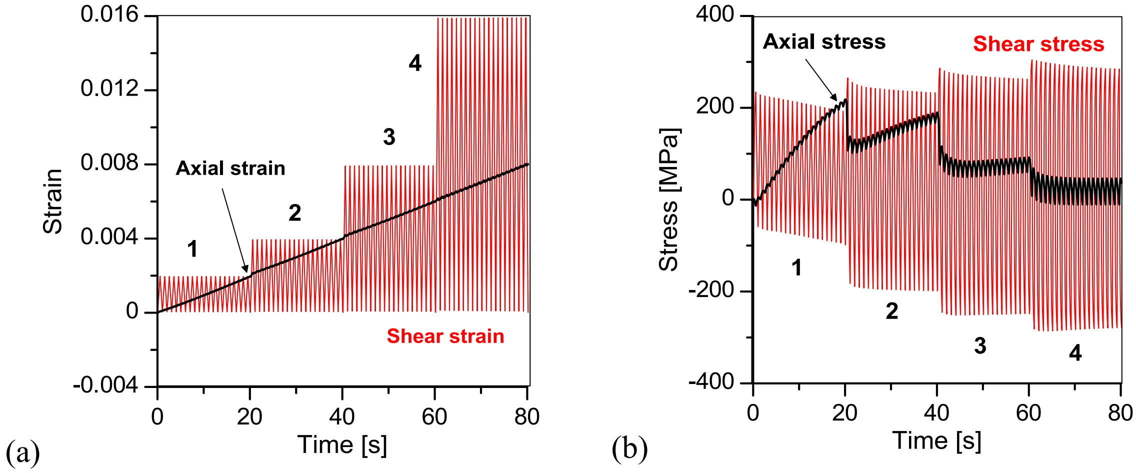

Fig. 12 Loading programme (a), cyclic strain amplitudes: (1) ±0.1%, (2) ±0.2%, (3) ±0.4%, (4) ±0.8%; (b) stress response into deformation along the loading path presented in (a) (material: 10H2M steel)

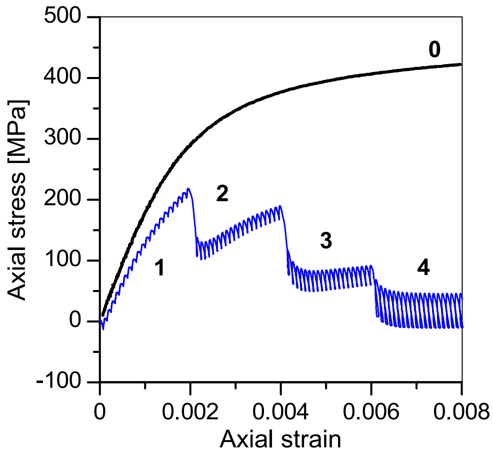

Fig. 13 Comparison of: tensile characteristic (0) with curve obtained using loading sequence presented in Fig. 12a (material: 10H2M steel)

Besides of an influence of the cyclic strain amplitude on the monotonic tension, effects of cyclic loading frequency were also investigated at wide range of magnitudes, i.e. from 0.005Hz to 15Hz. Investigations were carried out only for the 10H2M steel and their results are illustrated in Fig. 14. Figures 14a and 14b show, respectively, the comparison of the part of conventional tensile curve and characteristics determined on the basis of tensile tests assisted by torsion cycles of frequency within the ranges from 0.005Hz to 0.5Hz and from 1Hz to 15Hz.

In the case of tensile curves presented in Fig.14a, obtained under torsion cycles activated, the magnitude of cyclic strain amplitude was equal to 0.4%, whereas for those shown in Fig. 14b – 0.1%. The results presented in both diagrams of Fig. 14 enable to conclude that identification of optimal values of strain amplitude and frequency is not trivial and requires further investigations. It is clearly seen that material sensitivity into frequency variation of torsion cycles becomes much higher if cyclic strain amplitude is greater. On the other hand it is worth to notice that if the cyclic strain amplitude is to small, the material can be almost insensitive to the cyclic loading frequency changes, Fig. 14b.

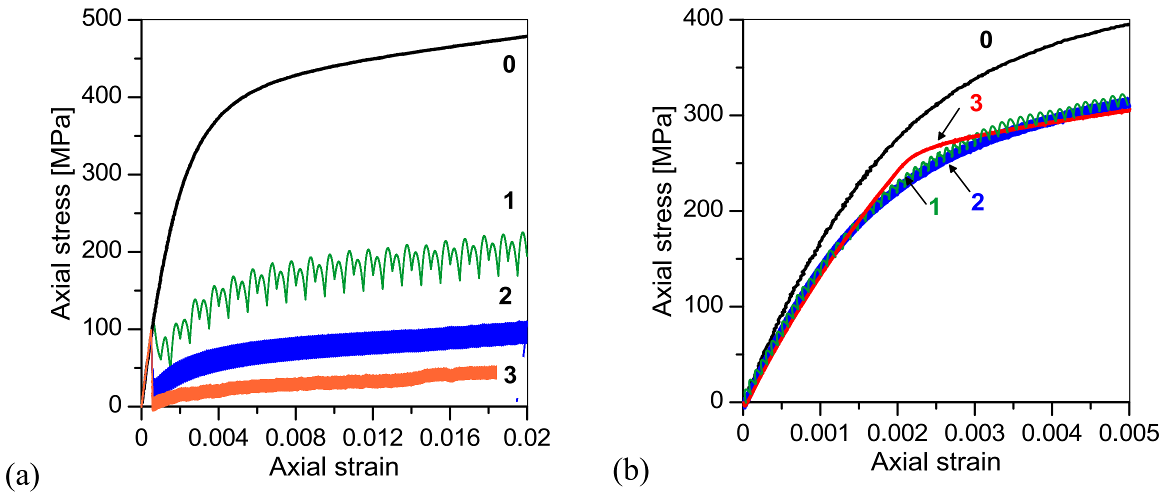

Fig. 14 An influence of frequency of torsion cycles on tensile curve of the 10H2M steel for: (a) strain amplitude of ±0.4% and frequency equal to: 1-0.005Hz, 2-0.05Hz, 3-0.5Hz; (b) strain amplitude of ±0.1% and frequency equal to: 1-1Hz, 2-5Hz, 3-15Hz.

CONCLUSIONS

An analysis of experimental results enabled to formulate the following remarks:

(a) reduction of tensile stress depends strongly on the amplitude and frequency of torsional loading but it is independent on the mean value of cyclic loading,

(b) an increase of the amplitude of cyclic loading leads to gradual lowering of the axial stress,

(c) asymmetrical step-increased torsional cycles caused similar effect as that observed under symmetrical torsion cycles,

(d) an influence of frequency of torsion cycles on tensile curve was discovered; it plays important role especially for the magnitudes within the range from 0.005Hz to 0.5Hz.

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