POLISH ACADEMY OF SCIENCES - MATERIALS SCIENCE COMMITTEE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
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ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY

Conference Proceedings

11th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

The effect of complex strain path on the hot dynamic restoration of silicon bronze CuSi3.5

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In the paper the effect of complex strain path on the flow stress and limit strain of CuSi3.5 silicon bronze is described. It has been found that by strain state control the large increase of limit strain and decrease of equivalent stress in some range of deformation can be obtained and by proper chosen of strain path such phenomena could be practically useful.

1. INTRODUCTION

Besides common knowledge that temperature, strain rate and strain have important effect on the structure and mechanical properties of hot deformed metals and alloys the effect of strain path is much more less known especially for massive processes[1-3]. The effect of strain path for sheet metals forming are very strong, example are FLD, so it is even difficult to use FLD in sheet metal forming processes design without taking into account the strain path. Recently instead of forming limit diagrams the forming limit stress diagrams, independent on strain path, have been applied [4, 5]. But in the case of massive processes the investigation of effect of strain path on the structure and mechanical properties of materials is more complex and difficult. Few experiments concerning the effect of strain path on behavior of metals and alloys in torsion test were performed. The effect of monotonic versus cycling torsion for copper, interstitial free steel in the ferritic and austenite ranges and in strain reversal under torsion for an HSLA steel have been investigated [6-9]. Strain paths similar to those found in cycling torsion are also observed in some industrial processes like: rolling, forging, rotary swaging. The main aim of the paper is to investigated the complex strain path effect on the behavior of silicon bronze.

2. EXPERIMENTAL PROCEDURE

Experiments were conducted by using a plastometer for complex strain paths. The plastometer was design and produced in Engineering Metal Forming Processes Department of Wroclaw University of Technology [10]. The plastometer can be used for monotonic torsion, for cycling torsion with different course of amplitude and during that kind of deformation the specimens can be simultaneously monotonic or cycling straining by tensile or compression. The scheme of plastometer is shown on Fig.1.

The specimens from CuSi3.5 silicon bronze were deformed in the temperature between room and 650 ^{0}C. The temperature was measured by a thermocouple in contact with surface. The specimens were simultaneously monotonic tension with 0,01 s^{-1} and cycling twist with strain rate of 0.1 s^{-1} at different amplitudes ε_{ac}= 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 rotation.

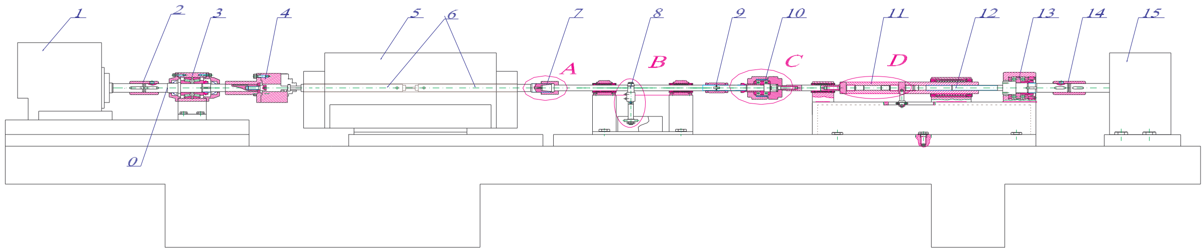

Fig.1. Scheme o f plastometer: 1-asynchronous machine of 13 kW power, 2-sleeve clutch, 3-constant support, 4-swivel head, 5-furnace, 6-sample holder, 7-self-centric clutch, 8-torque sensor, 9-cluch, 10-rotanion head, 11-compresion and tensile sensor, 12-screw mechanism, 13- constant support, 14- sleeve clutch, 15 asynchronous machine of 13 kW power

For precise determination of relation between flow stress and effective strain in the torsion test the FEM and initially assumed work hardening curves should be applied [11]. Taking into account that the main aim of the work is the comparison of flow stress obtained at complex strain path and monotonic strain the classical method of flow stress determination was used.

The precise description of the plastometer is given in the paper [11] in this book. The specimens shown on Fig.2 were used in investigation. The work hardening surface layer caused by mechanical turning was removed by heating of specimens at higher temperature.

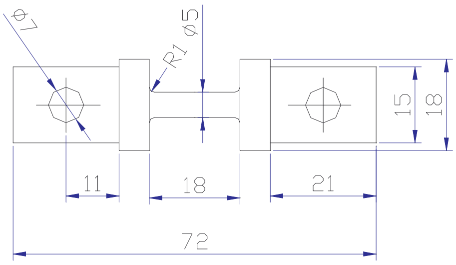

Fig. 2. Scheme of specimens used for complex strain path investigation

The shear stress comes from the torque are given by following relation

$$\tau = \frac{3M_s}{2\pi r_{rz}^3}, \tag{1}$$

and flow stress determined in tensile test by

$$\sigma_1 = \frac{F}{A}, \tag{2}$$

where: F - tensile force, A - cross section of specimen, M_s - torque, r_{rz} - real specimen radius. The equivalent stress comes from simultaneously operating torsion and compression test calculated according to Huber-Misses criterion is given by

$$\sigma_e = \sqrt{\sigma_1^2 + 3\tau^2}\,. \tag{3}$$

The equivalent strain obtained by using above mentioned two kind of tests is as follows

$$\varepsilon_e = \frac{1}{\sqrt{3}}\sqrt{3\varepsilon_1^2 + \gamma^2}, \tag{4}$$

where: ε_1- strain in tensile or compression tests, calculated according to

$$\varepsilon_1 = \ln \frac{l_k}{l_p} , \tag{5}$$

and γ – shear strain determined in torsion test, according to

$$\gamma = \frac{r_{rz}\omega}{l_{rz}} , \tag{6}$$

where: l_p and l_k – initial and final gauge length of tensile specimen respectively, ω - angel of rotation, l_{rz} - real gauge length of specimen,
The strain rate in torsion test is given by

$$\dot{\varepsilon} = \frac{1}{\sqrt{3}} \frac{r_{rz}\dot{\omega}}{l_{rz}} , \tag{7}$$

and in tensile test by

$$\dot{\varepsilon} = \frac{d\varepsilon}{dt} . \tag{8}$$

where: $\dot{\omega}$ - rotational speed
The equivalent strain rate for this test is given by

$$\dot{\varepsilon}_e = \frac{1}{\sqrt{3}} \sqrt{3\dot{\varepsilon}^2 + \dot{\gamma}^2} , \tag{4}$$

3. RESULTS AND DISCUSSION

The effect of application of symmetrical minor cycling torsion with two different amplitudes equal to 0.05 and 0.2 rotation in tensile test on the relation between equivalent stress and strain against monotonic tensile test at ambient temperature is shown on Fig.3. From that figure it can be seen that in the small range of deformation below 0.6 equivalent strain the application of symmetrical minor cycling torsion substantially decreases the equivalent stress in comparison with equivalent stress obtained in monotonic tensile test. The further increase of equivalent strain caused strong increase of equivalent stress, greater for smaller cycling amplitude (ε_{ac}= 0.05) then for higher (ε_{ac}= 0.2).

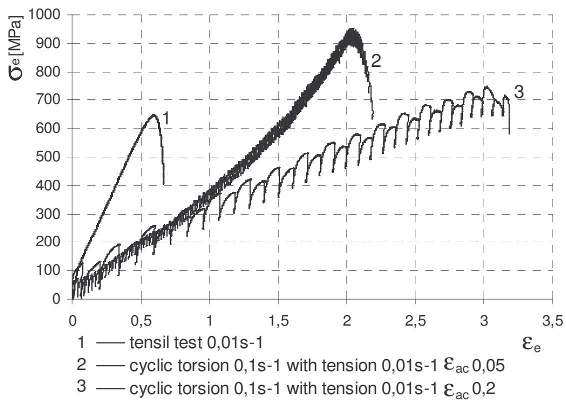

Fig. 3. The effect of application of symmetrical minor cycling torsion with two different amplitudes equal to 0.05 and 0.2 rotation in tensile test on the relation between equivalent stress and strain against monotonic tensile test at ambient temperature

The effect of application of symmetrical minor cycling torsion with two different amplitudes equal to 0.05 and 0.2 rotation in tensile test on the relation between σ_1 and ε_1 at ambient temperature is shown on Fig.4. From that figure it can be seen that the application of symmetrical minor cycling torsion more decrease of the σ_1 then greater amplitude is applied. The results can be interpreted in term of dislocation rearrangements between configuration for monotonic and cyclic straining. The obtained results show that

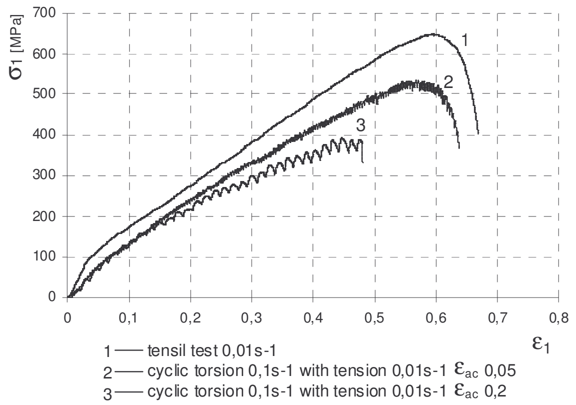

Fig. 4. The effect of symmetrical minor cycling torsion on the relation between σ_1 and ε_1 determined in monotonic tensile deformation at 0,1 s^{-1} at ambient temperature

there is possibility to control equivalent stress and strain by changed of strain path. All above mentioned results need further microstructure investigation for better understand the reason of such behavior of materials under low cycling and monotonic straining.

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