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A THERMOMECHANICAL ANALYSIS OF HIGH ELASTO-PLASTIC PROPERTIES OF GUM METAL AT VARIOUS STRAIN RATES

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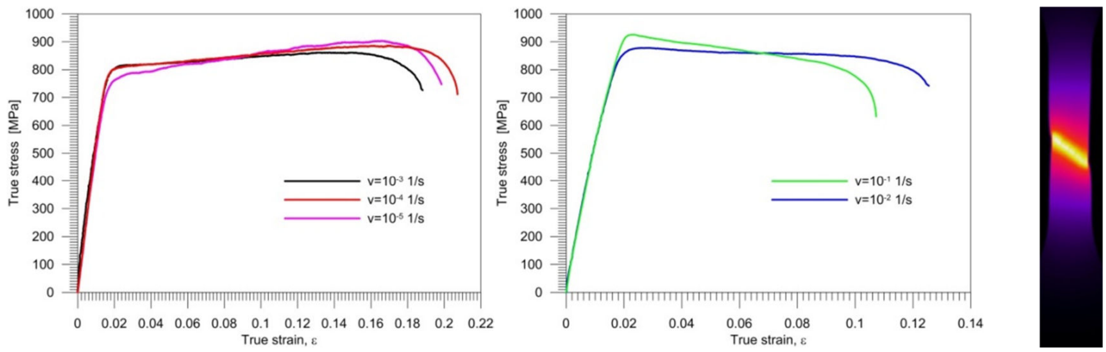
ABSTRACT

Mechanical characteristics obtained by MTS testing machine and digital image correlation (DIC) algorithm as well as the related temperature changes in a new β-Ti alloy - Gum Metal, subjected to tension in a wide spectrum of the strain rates, are presented. The fast and sensitive infrared camera ThermaCam Phoenix allowed estimating temperature changes accompanying the specimen deformation process in contactless manner. The obtained mechanical curves confirm an ultra-low elastic modulus and high strength of Gum Metal. Furthermore, it was presented how the stress-strain characteristics change from hardening to softening depending on the strain rate. The thermoelastic effect, estimated by the IR technique was discussed according to the Gum Metal yield point.

Keywords: gum metal, titanium alloy, tension test, strain rate, thermomechanical coupling.

RESULTS AND CONCLUSIONS

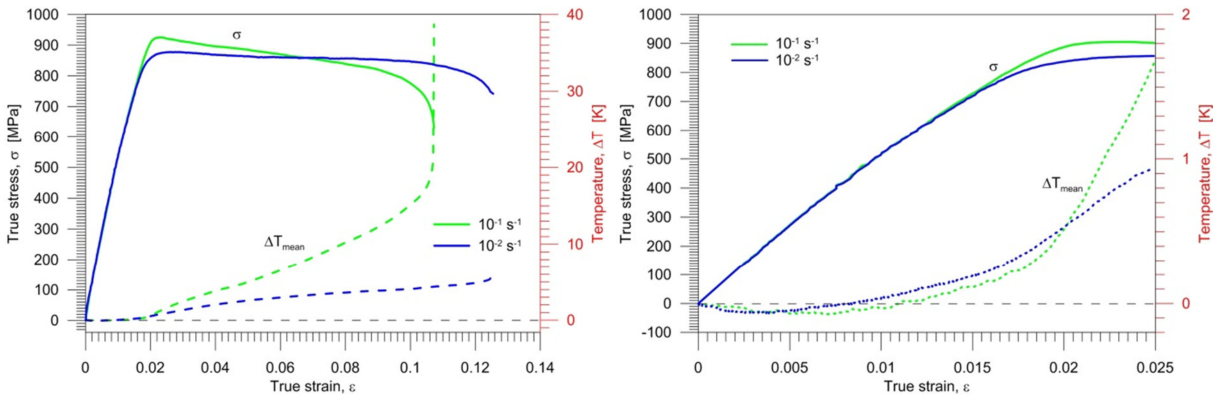
Gum Metal is a new titanium alloy, characterized by high strength and low elastic modulus (Sato et al., 2003; Furuta et al., 2013). The research presented in the paper also demonstrates high strain rate sensitivity of the alloy. At the higher strain rates, significantly higher level of the ultimate strength and lower values of the strain range were recorded (Fig. 1). Furthermore, we have found that at the lower strain rate; $10^{-5}s^{-1}$ and $10^{-4}s^{-1}$, the stress-strain hardening occurs, at the strain rate $10^{-3}s^{-1}$ the curve is almost parallel to the strain axes, whereas at the higher strain rates, i.e. $10^{-2}s^{-1}$ and $10^{-1}s^{-1}$, softening is observed. A comparison of the stress vs. strain curves obtained by DIC analysis demonstrating hardening effect is shown in Fig. 1a, whereas softening effect, in Fig. 1b, respectively.



(a) (b) (c)

Fig. 1 - Comparison of stress vs. strain curves obtained by DIC analysis of Gum Metal subjected to tension until rupture demonstrating: a) hardening effect (strain rates $10^{-5}s^{-1}$, $10^{-4}s^{-1}$ and $10^{-3}s^{-1}$); b) softening effect (strain rates $10^{-2}s^{-1}$ and $10^{-1}s^{-1}$); c) thermogram showing in infrared localized strain, captured just before the specimen rupture

Moreover, the temperature distribution obtained with fast and sensitive infrared camera demonstrates developing of the strain localization, leading to necking and rupture (Fig. 1c).
One of the unique characteristics of Gum Metal reported in the literature (Sato et al., 2003) is a nonlinear elasticity up to the value of ~2%. There is ongoing discussion on the origin of this phenomenon. In order to contribute to this research, we consider also temperature changes accompanying the Gum Metal deformation process and elaborated with high accuracy by using infrared camera. Fig. 2a shows stress and average temperature changes (ΔT_{mean}) vs. strain determined at strain rates of $10^{-2}s^{-1}$ and $10^{-1}s^{-1}$ in the strain range up to rupture, whereas Fig. 2b presents the results obtained within the initial strain range of true strain 0.025.



(a) (b)

Fig. 2 - Comparison of mechanical characteristics and average temperature changes (ΔT_{mean}) obtained during tensile tests at the strain rates $10^{-2}s^{-1}$ and $10^{-1}s^{-1}$ for Gum Metals: a) until rupture; b) up to strain of 0.025

The temperature changes accompanying the solid material deformation within initial loading stage demonstrate thermoelastic effect, i.e. drop in temperature which is usually related to the material yield point (Pieczyska, 1999). It has been noticed within this research that, irrespective of the applied strain rate, the maximal drop in the specimen temperature occurs significantly earlier than limit of its mechanically reversible deformation (Pieczyska et al., 2016). The subsequent increase in the temperature (from strain value less than 0.01) provides dissipative character of the process and cannot be considered as non-linear elasticity. Nevertheless, in order to verify this result the further studies are needed.

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