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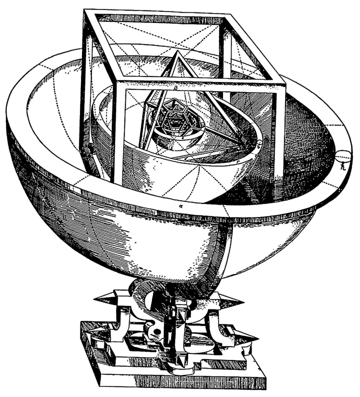

GUM METAL THERMOMECHANICAL PROPERTIES IN INITIAL STAGE OF THE LOADING AND DEFORMATION

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1. Introduction

Investigation of the superior properties of a titanium alloy Gum Metal, caused by an activity of unconventional deformation mechanisms is presented. Gum Metal is a trademark of the *Toyota Central Research & Development Labs, Inc. Co.*, which stands for a class of multifunctional β-Ti alloys. The alloy is characterized by outstanding mechanical properties such as relatively low Young's modulus, large reversible deformation and high strength. These properties are related to the specific chemical composition of the alloy, namely Ti–23Nb–0.7Ta–2Zr–1.2O (at.%), and significant cold-working up to 90% in area reduction. The first paper about the alloy was published in 2003 in Science [1]. The properties, in particular high strength, superelastic-like behavior and good biocompatibility enable various applications, e.g.: in automotive, biomedical, aircraft or fitness industry [2]. Research on the alloy properties and structure has been done in Japan, USA and China [1, 2]. However, a thermodynamic nature of the deformation of Gum Metal has been investigated in IPPT PAN, Warsaw [3, 4]. To this end, a combination of Digital Image Correlation (DIC) and Infrared Thermography (IRT) was used during the alloy loading and deformation [4]. Recently, constitutive models describing the Gum Metal unique behaviors in various loading conditions, including cyclic loading [5] and dynamic strain rates [6], have been also proposed.

2. Experimental details

The setup used in the experiment consisted of a MTS 858 Testing Machine and two cameras working in two different spectral ranges: visible (0.3-1 ηm) Manta G-125B and Infrared (3-5 ηm) ThermaCam Phoenix. Dog bone samples with sizes of gauge part 7 mm x 4 mm were used. The specimens were subjected to tension at 2 strain rates $10^{-2}s^{-1}$ and $10^{-1}s^{-1}$. More details are presented in [4].

3. Results and discussion

The stress σ and mean temperature changes ΔT_{mean} vs. strain ε for the initial stage of tension at strain rate of $10^{-2}s^{-1}$ is presented in Fig. 1, whereas for the strain rate $10^{-1}s^{-1}$ in Fig. 2. In the same figures, strain distributions in the direction of tension ε_y obtained by DIC and temperature distributions found by IRT are shown. It was confirmed that the alloy is characterized by low Young's modulus (~65 GPa), large reversible deformation (~1.6 %), high strength (~1000 MPa).

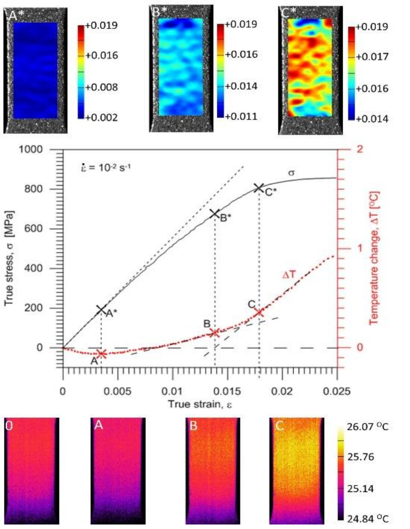

Fig. 1. Stress σ and temperature change (ΔT_{mean}) vs. strain ε obtained for Gum Metal's tension up to 0.025 at strain rate $10^{-2}s^{-1}$

Moreover, the elastic yield limit, corresponding to maximal drop in the specimen temperature (A^*), and limit of mechanically reversible deformation (B^*) have been identified. The limit of the mechanically reversible deformation was determined by an additional experiment composed of incremental loading–unloading tensile cycles with a small strain step (Fig. 3). The increase in the specimen temperature (after a drop due to thermoelastic effect) started from point A and reaches a max. value of 0.9 ºC for lower and 1.7 ºC for higher strain rate. It revealed a dissipative character of the process, probably caused by stress-induced exothermic transformation of α'' nanodomains [4].

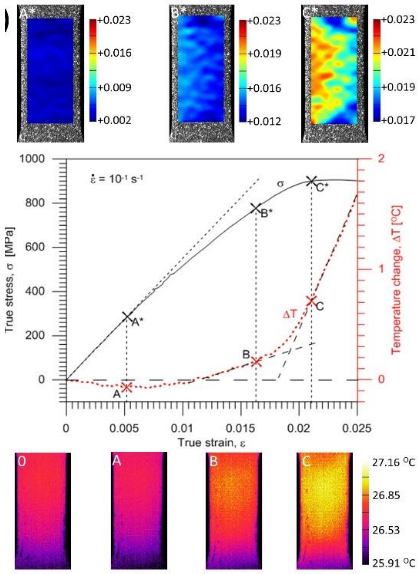

Fig. 2. Stress σ and temperature change ΔT_{mean} vs. strain ε for Gum Metal's tension in the initial deformation range at strain rate of 10^{-1} s^{-1}.

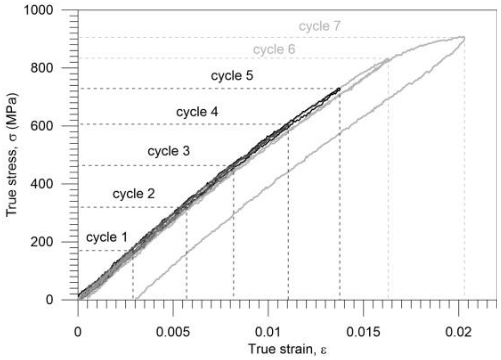

Fig. 3. Stress vs, strain for Gum Metal incremental cyclic loading–unloading

The thermograms marked by 0 denote the temperature distribution before the specimen loading. The marked points A*-A, B*-B, and C*-C denote the stress and temperature corresponding to the Gum Metal's elastic limit, the limit of the mechanically reversible deformation, and the start of almost linear, significantly higher increase in temperature, respectively.

The thermal response in the initial loading range reaches its minimal value (points A-A*) significantly before the end of the nonlinear reversible deformation of Gum Metal (points B-B*) as shown in Fig. 1 and Fig. 2.

Based on the obtained mechanical and thermal characteristics, the subsequent stages for the Gum Metal loading can be distinguished:
0 - A* ; elastic deformation stage, accompanied by drop in temperature, like for other solid materials,
A*-B*; superelastic-like deformation, a dissipative
B* – C* ; yielding and fast growth of temperature.

4. Conclusions

Thermodynamic nature of the long nonlinear recoverable deformation of β-Ti alloy named Gum Metal was studied by using fast infrared camera and digital image correlation experimental techniques.

From the analysis of the obtained mechanical data and the related temperature changes it was found that the maximal drop in the Gum Metal's temperature (thermoelastic effect) occurs at the lower strain when compared to the limit of its mechanically reversible deformation, obtained via subsequent cyclic loading with small step.

The increase in the specimen temperature between the maximal drop and the mechanically reversible stage reveals a dissipative character of the Gum Metal deformation not observed in other solid.

Acknowledgements

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