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Gum Metal mechanical properties investigated by infrared camera and digital image correlation

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Introduction

Gum Metal is a trademark of Toyota Central Research & Development Laboratories, Inc. which stands for a class of multifunctional β-Ti alloys. A specific chemical composition (typically Ti–23Nb–0.7Ta–2Zr–1.2O, at.%) as well as technological processing of the alloy result in fabrication of a material with a set of superior properties. Among them, an ultralow elastic modulus (around 60 GPa), a relatively large range of nonlinear reversible deformation (around 2%) and a high strength (around 1000 MPa) are characteristic for Gum Metal [1]. They are caused by unconventional deformation mechanisms which have been discussed in the literature in the last decades. Peculiar observations of the Gum Metal microstructure embraced significant crystal lattice rotations, nanodisturbances and “giant faults” -localized planar defects carrying very large plastic strains [1]. The mechanism of the nonlinear reversible deformation of Gum Metal is most probably related to the stress-induced growth of orthorhombic α'' phase nanodomains suppressed by added oxygen-induced strain as suggested in [2].

Experimental Results

The goal of this research was to analyze thermomechanical couplings in Gum Metal subjected to tension on a testing machine at strain rates: 10^{-1} s^{-1} and 10^{-2} s^{-1}. During the deformation, changes infrared radiation were measured by a fast and sensitive infrared camera, while displacement changes were monitored by a high resolution visible light camera. The combination of infrared thermography (IRT) and digital image correlation (DIC) applied to monitor the tension of Gum Metal enabled to obtain temperature distributions and strain fields at selected stages of loading. More details of the experimental procedures can be found in [3, 4].

Fig. 1a shows a stress σ and average temperature ΔT vs. strain ε curve of Gum Metal subjected to tension at 10^{-2} s^{-1} and a thermograph as well as a strain field in point A* and A respectively. It was found that the maximal drop in Gum metal temperature (point A*) occurs significantly earlier than the relatively large limit of its mechanically reversible nonlinear deformation. The temperature increase proves a dissipative character of the process also at this stage and is related the deformation-induced growth of α'' partially suppressed by oxygen-added strains.

Fig. 1b shows a comparison of stress σ and average temperature ΔT vs. strain ε curves of Gum Metal subjected to tension at 10^{-1} s^{-1} and 10^{-2} s^{-1} as well as thermographs and strain fields just before rupture. As could be expected the yield strength for the strain rate 10^{-1} s^{-1} is higher than for 10^{-2} s^{-1}. During the plastic deformation, both the strain and temperature distributions demonstrate that at higher strain rates strain localization starts nucleating just after the yield limit leading to the specimen necking and rupture. Macroscopically, it is exhibited as softening of the stress-strain curve in contrast to the strain hardening observed at lower strain rates.

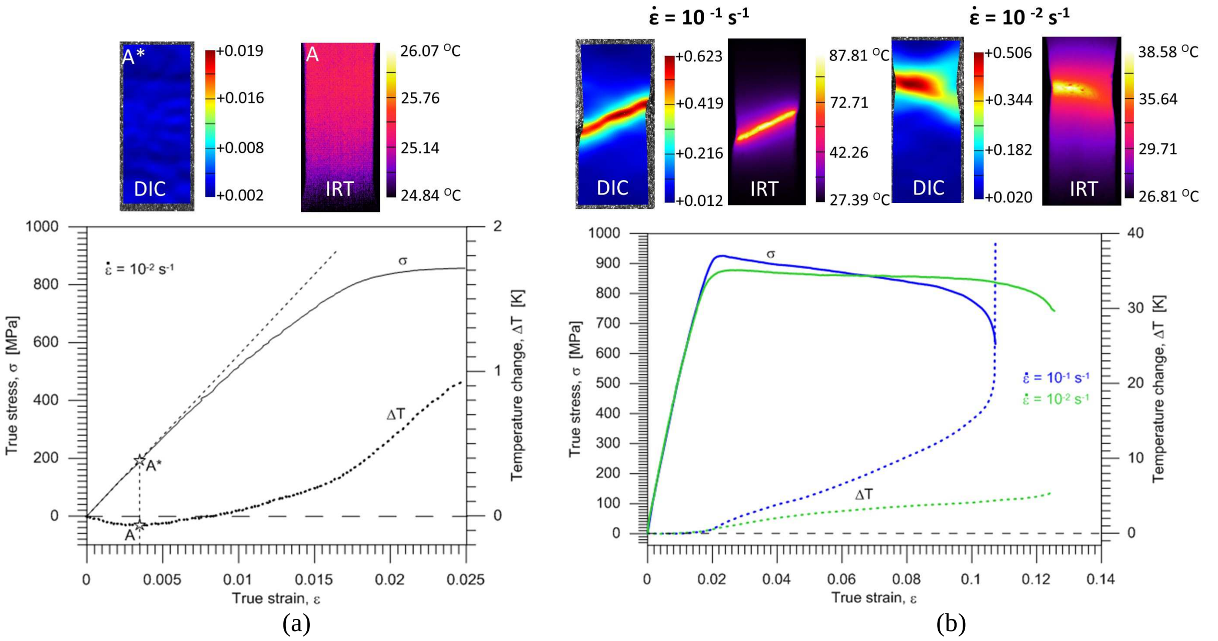

Fig. 1. (a) stress σ and average temperature ΔT vs. strain ε curve of Gum Metal subjected to tension at 10 $^{-2}$ s^{-1} and a thermograph as well as a strain field in point A* and A; (b) comparison of stress σ and average temperature ΔT vs. strain ε curves of Gum Metal subjected to tension at 10 $^{-1}$ s^{-1} and 10 $^{-2}$ s^{-1} as well as thermographs and strain fields just before rupture.

Conclusions

The analysis of thermomechanical couplings in Gum Metal subjected to tension on a testing machine at strain rates: 10 $^{-1}$ s^{-1} and 10 $^{-2}$ s^{-1} with aid of IRT and DIC was conducted. Elastic limit of Gum Metal under tension was determined based on a maximal drop in the specimen average temperature. The nonlinear reversible deformation of the alloy was found to have an exothermic character. The development of plastic deformation of Gum Metal was studied via the evolution of thermographs and strain fields at selected stages of loadings.

Acknowledgments

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