INFLUENCE OF THE STRAIN RATE ON THE MECHANICAL AND STRUCTURE CHARACTERISATION OF GUM METAL

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1. Introduction

Gum Metals is innovative β Ti alloy, characterized by outstanding properties, e.g. : a low value of Young's modulus ≈ 60 GPa (similar to bone), a large range of reversible strain up to 2.5% (10 times higher than other alloys), high strength (>1000 MPa), favorable machining properties, thermal characteristics stable in the range of -200°C to +250°C [1-3]. The unique properties combined to high biocompatibility of the alloy create large application possibilities in biomedical industry, rehabilitation and sport facilities, robotics, automotive and space [4,5]. The goal of the research is to investigate the impact of the strain rate on the mechanical characteristics, the related temperature changes and the microstructure evolution of the Gum Metal samples subjected to compression loading in a wide spectrum of the strain rates.

2. Experimental details

To this end, a quasistatic testing machine MTS as well as Split Hopkinson Pressure Bar (SHPB) system was used [6]. The cylindrical samples 5 x 5 mm were used and the obtained strain rates equaled to $10^{-3}s^{-1}$, $1s^{-1}$, 940 s^{-1}, 1460 s^{-1} and 2200 s^{-1}. The results gained under quasi-static and dynamic loadings confirmed the high sensitivity to the strain rate (Fig. 1).

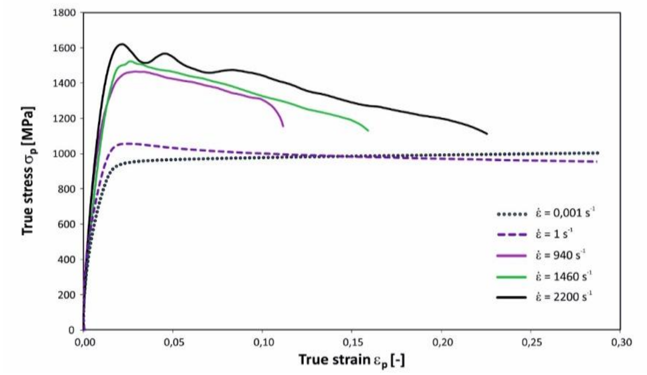

Fig. 1 Stress vs. strain of Gum Metal at 2 quasi-static and 3 dynamic compression loadings [7].

It was found that the elastic-plastic transition during quasi-static compression of the Gum Metal appears at the stress level between 900 MPa and 1000 MPa, whereas under high strain rate loading ~1200 ÷ 1400 MPa, respectively. Moreover, a little strain hardening was observed for the strain rate of 10^{-3} s^{-1}, whereas a significant strain softening is visible for the strain rate of 10^{0} s^{-1} and at the higher strain rates. Furthermore, the temperature change of the Gum Metal sample was estimated by using a fast and sensitive infrared camera. The maximal temperature was estimated for the highest applied strain rate and equals over 200 ºC. Valuable results were also obtained from the structure investigations.

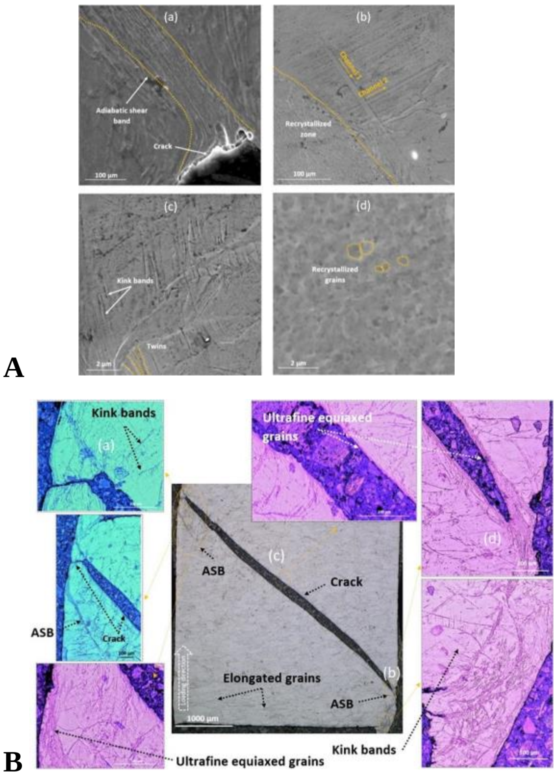

Fig. 2 (A) SEM images of Gum Metal after dynamic testing at the strain rate of 2270 s^{-1} taken in the selected areas (a)-(d) chosen in Fig. 2 (B) [7].

Microstructural deformation mechanisms regulating strain hardening and strain softening were identified. A crack and an adiabatic shear band formed at ~ 45 deg with respect to the loading direction, and widely spaced deformation bands (kink bands) were observed (Fig. 2). Dislocations within the channels intersecting with twins may cause strain hardening while recrystallized grains and kink bands with crystal rotation inside the grains may lead to strain softening [7].

The microstructural features of the Gum Metal samples after the loading and deformation were evaluated using optical microscopy SEM and EBSD techniques. Based on the experimental results, the mechanical responses of the Gum Metal have been described using the modified Johnson–Cook model.

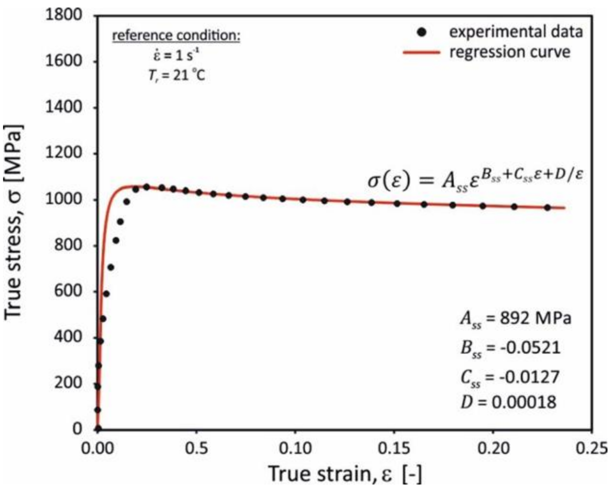

Fig. 3. Fitting the model curve of stress vs. strain to experimental data of Gum Metal under compression at the strain rate of 1 s^{-1} [7].

3. Conclusions

The drowned conclusions are as follows:

1. The mechanical behavior of Gum Metal presented in the stress–strain curves obtained for the alloy tested under monotonic and dynamic loadings revealed a strain-softening effect which intensified with increasing strain rate.
2. The plastic flow stress was observed to increase both for static and dynamic loading conditions with increasing strain rate. In turn, the strain rate sensitivity was seen to decrease with increasing strain rate.
3. Microstructural deformation mechanisms regulating strain hardening and strain softening were identified. A crack and an adiabatic shear band formed at ~ 45 deg with respect to the loading direction, and widely spaced deformation bands (kink bands) were observed. Dislocations within the channels intersecting with twins may cause strain hardening while recrystallized grains and kink bands with crystal rotation inside the grains may lead to strain softening.
4. Good agreement between the experimental and numerical data obtained using the modified Johnson–Cook model was achieved.

Acknowledgements

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