HIGH ELASTO-PLASTIC PROPERTIES OF NEW TITANIUM ALLOY GUM METAL IN WIDE SPECTRA OF THE STRAIN RATES

E. Pieczyska[1], K. Golasiński[1], M. Staszczak[1], M. Maj[1], T. Furuta[2] and S. Kuramoto[3]

[1] *Institute of Fundamental Technological Research, Polish Academy of Sciences*
Pawińskiego 5 B, 02-106 Warsaw, Poland
e-mail: epiecz@ippt.pan.pl

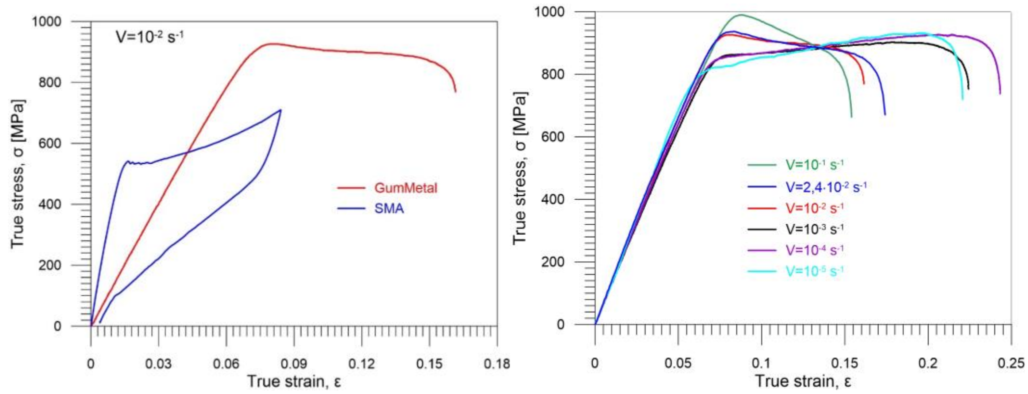
[2] *Toyota Central Research & Development Laboratories, Inc.,*
Nagakute, Aichi, 480-1192, Japan
e-mail: e0646@mosk.tytlabs.co.jp

[3] *Department of Mechanical Engineering, College of Engineering*
Ibaraki University; 4-12-1, Nakanarusawa, Hitachi, 316-8511
e-mail: kuramoto@mx.ibaraki.ac.jp

Abstract: Results of investigation of mechanical properties and the related temperature changes in a β-Ti alloy, Gum Metal, subjected to tension in a wide spectrum of the strain rates are presented. The stress-strain curves have been obtained by MTS testing machine while fast and sensitive infrared camera Phoenix Flir Co. allowed estimating temperature changes accompanying the specimen deformation process. The obtained mechanical curves confirm an ultra-low elastic modulus and high strength of Gum Metal. The yield point was estimated with high accuracy basing on the thermoelastic effect measured by the advanced infrared technique. Furthermore, it was observed that the stress-strain characteristics change from hardening to softening beyond the Yield point depending on the strain rate applied.

1. Mechanical properties of Gum Metal in tension until rupture - influence of strain rate

A comparison of stress vs. strain curves for the titanium alloy called Gum Metal until the specimen rupture and TiNi shape memory alloy pseudoelastic characteristics is presented in Fig. 1a, whereas influence of strain rate on the mechanical characteristics in Fig. 1b.



a) b)

Figure 1. Comparison of stress vs. strain curves: a) Gum Metal titanium alloy until rupture and TiNi shape memory alloy, b) Gum Metal subjected to tension at various strain rates (Pieczyska *et al.* 2015).

Looking at Fig. 1 b one can notice that the stress-strain characteristics change from hardening to softening beyond the Yield point depending on the strain rate applied in the test. For lower strain rates: $10^{-5}s^{-1}$, $10^{-4}s^{-1}$ and $10^{-3}s^{-1}$ hardening of the alloy during the further deformation is observed, whereas for higher strain rates: $10^{-2}s^{-1}$, $2.4x10^{-2}s^{-1}$ and $10^{-1}s^{-1}$ softening occurs.

2. Investigation of thermomechanical couplings in Gum Metal-Yield Point analysis

Stress and the specimen average temperature vs. strain for Gum Metal subjected to tension till rupture at various strain rates and within various strain ranges are presented in Figure 2. The maximal temperature is observed at higher strains (rupture) and at higher strain rates.

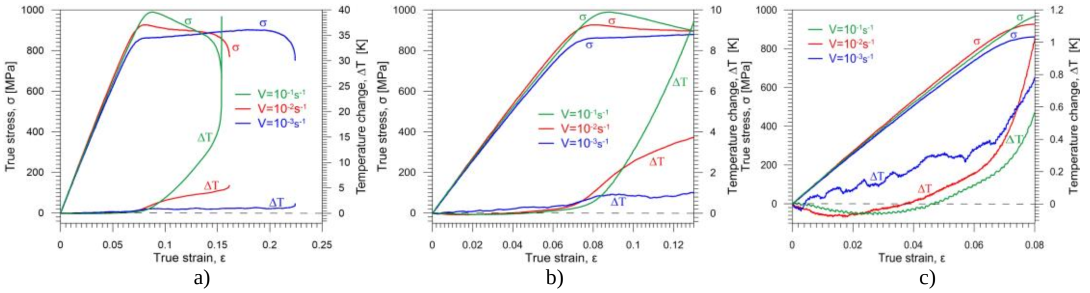


Figure 2. Stress and the specimen average temperature vs. strain curves for Gum Metal subjected to tension at various strain rates within various strain ranges: a) till rupture, b) till strain 0.13, c) till 0.08.

The temperature change of the specimen subjected to adiabatic elastic deformation is called a thermoelastic effect and was described by Lord Kelvin (Thomson, 1853) theory (1):

$$\Delta T_{el} = -\frac{\alpha T \Delta \sigma_s}{c_p \rho} \qquad (1)$$

where α denotes the coefficient of the material linear thermal expansion, T – the specimen absolute initial temperature, $\Delta\sigma_s$ – the isentropic change of stress, c_p – the specific heat at constant pressure, ρ – the material density. Thus, the discrepancy between the linear dependence of the change in temperature vs. stress (≈ strain for small values) or the value of maximal drop in the specimen temperature (for the simplicity) can be used for evaluating a limit of the reversible material deformation with a high accuracy (Pieczyska., 1999). Looking at the mechanical and thermal curves presented in Figure 2 one can see that a maximal drop in the Gum Metal temperature occurs at significantly lower strains values than the limit of the reversible deformation, macroscopically estimated. It means that such a large limit of the alloy reversible deformation stressed as the Gum Metal "super" property (Saito *et. al.*, 2003, Furuta *et al.,* 2013), originates from other deformation mechanisms. These results are different from those observed for other Ti alloys, steel and polymers and will be a subject of our research.

4. Conclusions

Thermomechanical couplings in the new multifunctional titanium alloy Gum Metal subjected to tension at various strain rates confirm its ultra-low elastic modulus and very high strength. The temperature distribution obtained with fast and sensitive infrared camera indicated the alloy Yield point. However, it was noticed that the maximal drop in the temperature obtained for Gum Metal occurs earlier than limit of its reversible deformation.

Acknowledgments

The research has been carried out with the support of the Polish National Centre of Science under Grant No. 2014/13/B/ST8/04280.

References

[1] Saito T, Furuta T, Hwang J.H, Kuramoto S, Nishino K, Suzuki N, Chen R, Yamada A, Ito K, Seno Y, Nonaka T, Ikehata H, Nagasako N, Iwamoto C, Ikuhara Y, Sakuma T, Multifunctional Alloys obtained via a dislocation-free plastic deformation mechanism, *Science* 300, 464-467, 2003.

[2] Furuta T, Kuramoto S, Morris JW, Nagasako N, Withey E and Chrzan DC, The mechanism of strength and deformation in Gum Metal, *Scripta Materialia*, **68**, 767–772, 2013.

[3] Pieczyska EA, Thermoelastic effect in austenitic steel referred to its hardening, *J. Theor. Appl. Mech*., 2, 37, 1999 (Ph.D thesis).

[4] Pieczyska EA, Staszczak M, Golasiński K, May M, Furuta T, Kuramoto S, *Internal report*, 2015.