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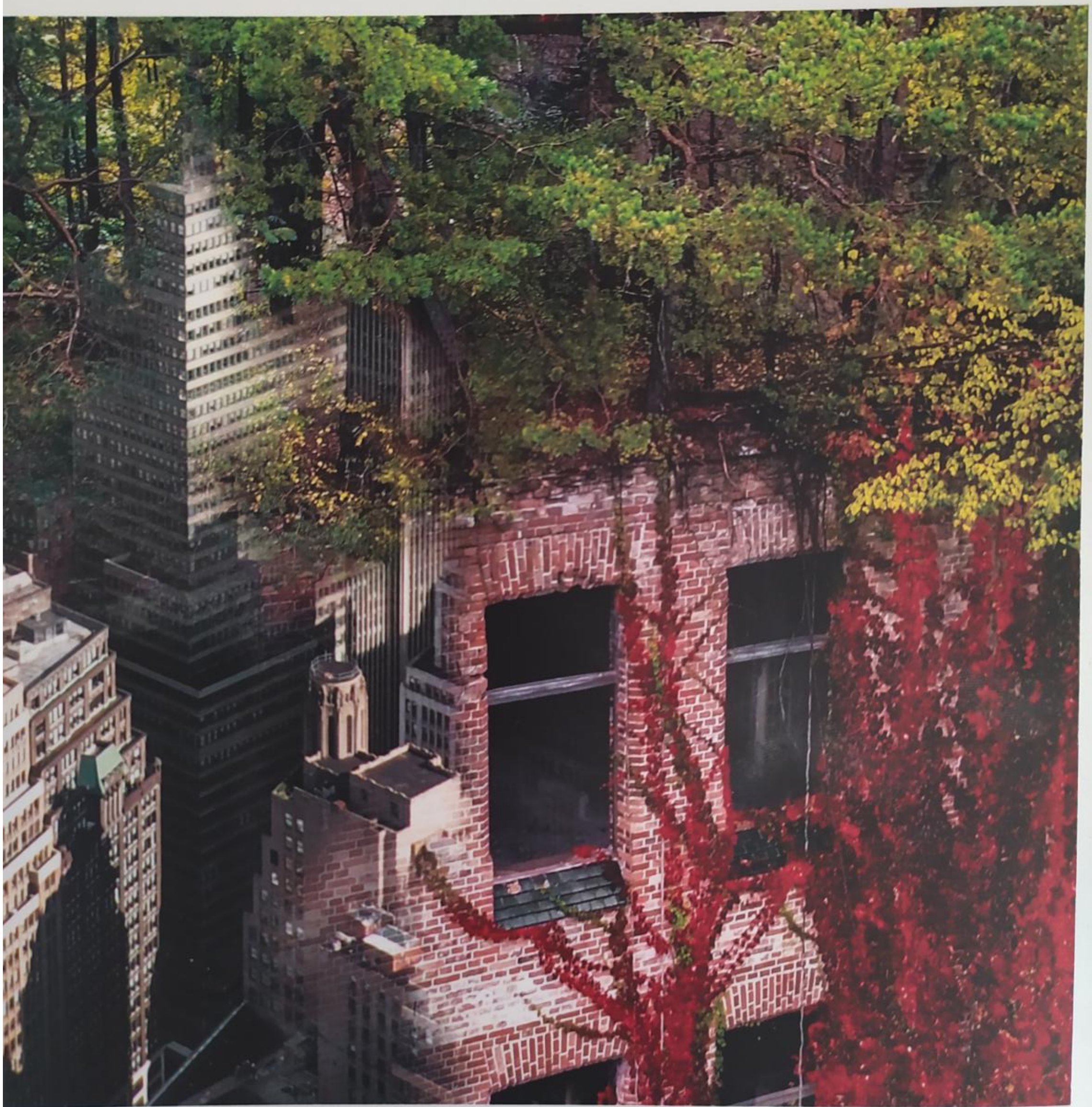

SCIENCE IN THE AGE OF GLOBALIZATION

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Polish-Japanese Joint Research on a Multifunctional Titanium Alloy Gum Metal

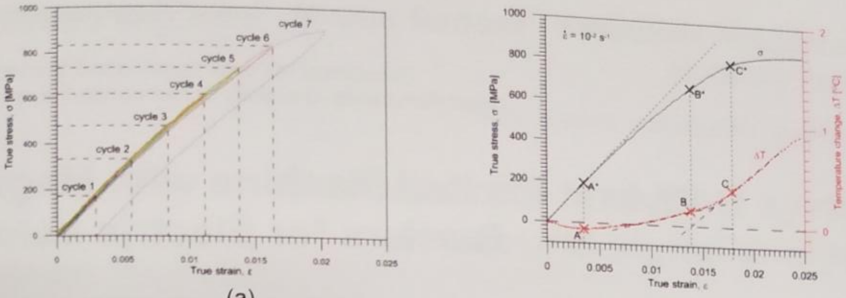
Titanium alloys are well known for high specific strength (material's strength/density ratio) and excellent corrosion resistance when compared to other metals. They have paved their way towards implant applications such as total hip replacement thanks to excellent biocompatibility and good fatigue performance. However, Young's modulus of conventional titanium alloys, which is even over six times higher than a Young's modulus of cortical bone, poses a significant drawback. The mismatch in elastic properties between the implant and the bone can lead to so-called stress-shield effect, which results in a gradual loss of the bone density and fracture at the bone/implant interphase. Thus, the development of titanium based materials with low Young's modulus for biomedical applications has been of particular interest in recent decades. One of them, called Gum Metal, is a relatively new β-type titanium alloy. The alloy was developed at Toyota Central Research & Development Laboratories in Japan at the beginning of the 21st century [1]. Gum Metal is fundamentally composed of Ti_3 (Ta, Nb, V) + (Zr, Hf, O). The superior performance of Gum Metal includes a relatively low Young modulus (around 60 GPa), large recoverable strain (around 2%), high strength (around 1000 MPa) and Invar and Elinvar-like thermal performance [1, 2]. This set of outstanding properties is caused by activity of unconventional deformation mechanisms in Gum Metal, which have been recently discussed in several publications. It was found that a local lattice distortion around oxygen atoms, named nanodomains, which is an intermediate phase between the β phase and the α" martensite, is responsible for the large recoverable deformation of the Gum Metal.

The presented research aims at investigation of mutual correlation between mechanical and thermal characteristics, called thermomechanical couplings, of Gum Metal under selected loadings. The temperature changes determined during the deformation of the alloy serve to look into thermodynamic nature of its unconventional deformation mechanisms [3]. To this end, an experimental set-up combining a testing machine with an infrared system was used. Cyclic loading of Gum Metal with an incremental strain step was performed in order to determine the mechanically recoverable deformation. Stress vs. strain curves of Gum Metal under cyclic tension at a strain rate of $10^{-2}s^{-1}$ with a strain step of around 0.003 are presented in Fig. 1a. The results indicate the large nonlinear recoverable deformation of the alloy. The limit of recoverable deformation of Gum Metal is presented in cycle 5 and equals around 0.014. Stress and temperature change vs. strain curves of Gum Metal under monotonic tension at a strain rate of 10^{-2} s^{-1} are shown in Fig. 1b. Selected stages of the deformation correlated to the critical temperature change values of the alloy are marked:

1) limit of purely elastic deformation of Gum Metal (A*) determined based on Lord Kelvin's formula and corresponds to maximal drop of temperature (A);

2) limit of recoverable deformation of Gum Metal (B*) related to a moderate growth of temperature (B);

3) onset of dominant plastic deformation of Gum Metal (C*) correlated to faster growth of temperature starting in point (C).



(a) (b)

Fig. 1. (a) True stress vs. true strain curves for Gum Metal under cyclic tension at strain rate of $10^{-2}s^{-1}$ cycles 1-7; (b) Stress and temperature change vs. strain curves of Gum Metal under monotonic tension at a strain rate of 10^{-2} s^{-1}.

To conclude, the analysis of Gum Metal thermomechanical behavior under tension served for investigation of thermodynamic nature of deformation mechanisms active during loading of the alloy. The limit of purely elastic deformation of Gum Metal corresponding to maximal drop of temperature was determined. The unconventional deformation mechanisms active during large recoverable deformation of Gum Metal were found to be of dissipative nature. The onset of dominant plastic deformation of Gum Metal was accompanied by a faster growth of temperature.

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Karol Golasiński is a PhD candidate at the Institute of Fundamental Technological Research, Polish Academy of Sciences. His scientific interests embrace mechanics and characterization of superelastic materials in particular multifunctional, smart titanium based alloys. His PhD dissertation entitled "Analysis of thermomechanical couplings in Gum Metal under selected loadings" is planned to be defended shortly. He coauthored 10 research articles published in international journals listed by SJR.