ICEM/454 Gum metal in compression – investigation of mechanical anisotropy caused by texture

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Experimental investigation of mechanical anisotropy in a multifunctional titanium alloy, characterized by unique properties and named Gum Metal [1- 4], is reported. Structural characterization showed a strong <110> texture of the alloy, which is a result of a cold-swaging process applied during its fabrication [2]. Ultrasonic measurements determined elastic constants with high accuracy and demonstrated a significant difference between Young's moduli of the alloy in parallel and perpendicular direction to the swaging axis. Compression loading performed on a testing machine in both sample orientations and monitored by two CCD cameras for further digital image correlation analysis (DIC) confirmed the Gum Metal strong anisotropy.

Material, experimental methodology and results

In this investigation, Gum Metal with composition Ti–36Nb–2Ta–3Zr–0.3O (in mass%) produced at Fukuoka University was studied. Fabrication route consisted of billet forming from mixed powders of the constituents, sintering, hot forging and cold-swaging for obtaining a β Ti alloy with pronounced texture along the <110> direction. The role of oxygen is very important, since it influences the Gum Metal properties hindering stress-induced phase transformations, specifically in the nonlinear range of initial deformation.

Ultrasonic velocities in the Gum Metal sample were measured using a pulse-echo contact technique. A pre-machined polycrystalline rod submitted for ultrasonic testing exhibited a transversal isotropy around its longitudinal axis. It was proved by the X-ray diffraction results and confirmed by measurements of ultrasonic velocities in all 3 directions of the Gum Metal rod. The Gum Metal cubical samples with sizes of 2.85 mm x 2.85 mm x 3.55 mm were cut out from the alloy cold-swaged bar using electro-erosion machining. The samples were prepared in two orientations; parallel and perpendicular to cold-swaging axis. Subsequently, two perpendicular surfaces of the specimen were uniformly coated by soot and further on tiny drops of white paint were sprayed onto the surface. During the test, the loading force as a function of time was monitored. Simultaneously, sequence of visible range images was recorded from two different perpendicular surfaces. On the basis of the obtained sequences, the strain fields were determined using DIC procedure implemented in ThermoCorr software developed in IPPT PAN [5]. Using the DIC procedure implemented in ThermoCorr software also allowed determining various components of the strain field distribution with a high accuracy and performing selected calculations [6]. Stress vs. strain characteristics of Gum Metal under compression confirmed its outstanding mechanical performance including large nonlinear recoverable deformation, low Young's modulus and ultra-high strength as well as superplasticity. Evolutions of strain fields of Gum Metal sample compressed parallel and perpendicularly to the cold-swaging direction were analyzed. It has been shown that in the case of compression perpendicular direction the strain localization proceeded in two deformation bands, whereas in the case of parallel direction the deformation process was more uniform.

Concluding remarks

Results of experimental investigation of mechanical anisotropy in the β titanium alloy Gum Metal under compression loading with using non-destructive and destructive techniques are reported.

The elastic constants and Young's moduli of Gum Metal determined by ultrasonic technique demonstrated a significant difference between the Young's moduli measured in the cold-swaging and perpendicular directions. The anisotropy was confirmed by the structure investigation.

Structural analysis performed on Gum Metal samples revealed almost pure β phase with a potential trace composition of ω phase (XRD patterns). The microscopic observations showed elongated grains with fiber-like structures and significant misorientation in particular grains (EBSD orientation maps). Texture analysis indicated a pronounced <110> orientation induced during a process of cold swaging.

Significant difference between the Gum Metal stress-strain curves obtained during the compression loading was analyzed by special experimental approach with the strain fields simultaneously from two perpendicular surfaces (walls) on the sample by two CCD cameras. Observations of the evolutions of strain distributions during the deformation processes served to understand macroscopic phenomena caused by anisotropy occurring in Gum Metal under compressive loading.

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References

[1] Saito T, Furuta T, Hwang JH, 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 (2003) Multifunctional Alloys obtained via a dislocation free plastic deformation mechanism. Science 300:464-467

[2] Tane M, Nakano T, Kuramoto S, Hara M, Niinomi M, Takesue N, Yano T, Nakajima H (2013) Low Young's modulus of Ti-Nb-Ta-Zr alloys: cold working and oxygen effects. Acta Mater 61:139-150

[3] E.A. Pieczyska, M. Maj, T. Furuta, S. Kuramoto, in: M. Kleiber et al. (Eds) Advances in Mechanics: Theoretical, Computational and Interdisciplinary, Gum Metal – unique properties and results of initial investigation of a new titanium alloy – extended paper, Taylor & Francis Group, London (2016)

[4] Golasiński K, Pieczyska EA, Staszczak M, Maj M, Furuta T, Kuramoto S (2017) Infrared thermography applied for experimental investigation of thermomechanical couplings in Gum Metal. QIRT J 14:226-233

[5] Nowak M, Maj M (2018) Determination of coupled mechanical and thermal fields using 2D digital image correlation and infrared thermography: Numerical procedures and results. Arch Civ Mech Eng 18:630-644

[6] Pieczyska EA, Maj M, Golasiński KM, Staszczak M, Furuta T, Kuramoto S, Investigation of Gum Metal yielding and strain localization effects basing on infrared thermography and DIC analysis, Manuscript submitted to Experimental Mechanics (under revision).