MECHANICAL ANISOTROPY OF GUM METAL ANALYZED BY ULTRASONIC MEASUREMENTS AND DIGITAL IMAGE CORRELATION

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1. Abstract

Experimental investigation of mechanical anisotropy in a multifunctional beta titanium alloy Gum Metal under compression is reported. Non-destructive and destructive techniques were used to analyze unique mechanical behavior of the alloy. Structural characterization showed a strong <110> texture of Gum Metal, which is a result of cold-swaging applied during its fabrication [1]. Due to this kind of texture Gum Metal can be treated as transversally isotropic solid. Ultrasonic measurements determined elastic constants with high accuracy. A significant difference between Young's moduli of the alloy calculated for parallel and perpendicular directions to the alloy swaging direction was demonstrated. Compression of Gum Metal cube samples with two orientations was conducted on a testing machine. Two perpendicular walls of each sample were monitored by two visible range cameras during the deformation process for further 2-dimensional digital image correlation (DIC) analysis. Strong mechanical anisotropy of Gum Metal was confirmed by a detailed analysis of the stress vs. strain curves and strain distributions.

2. Material and specimens- determination of Gum Metal elastic constants using ultrasonic test

Elastic constants and Young's moduli of the Gum Metal were determined using a non-destructive approach based on measurements of ultrasonic wave propagation. For the measurements of ultrasonic velocities in the sample the pulse-echo contact technique was used [2]. In order to determine all five independent elements of the elastic constants matrix for transversally isotropic solid at least five different values of velocities of ultrasonic waves propagating in different directions and/or with different polarizations must be measured in the material. For this purpose, two samples, denoted as U1 and U2, were cut out from the pre-machined Gum Metal rod in the way shown in Fig. 1. Sample U2 was cut out from the rod at an angle of 45° to the axis 3.

Figure 1: Configuration and orientation of the samples cut out from a Gum Metal rod for ultrasonic test.

Based on the established elastic constants, the Young's moduli of the Gum Metal in cold-swaging direction (3) E_3 = 60.7 GPa and in perpendicular direction (1 or 2) $E_{1/2}$ = 68.5 GPa were calculated. The obtained results are listed in Table 1.

Relation to direction of swaging	Parallel	Perpendicular
Young's modulus [GPa]	60.7	68.5

Table 1: Young's moduli of polycrystalline Gum Metal in relation to its technological texture.

Different values of the Young moduli in two perpendicular directions indicate considerable elastic anisotropy of the Gum Metal. For the compression Gum Metal cuboidal samples with sizes of ≈2.85 mm x 2.85 mm x 3.55 mm were cut out from the Gum Metal cold-swaged bar using electro-erosion machining.

3. Mechanical anisotropy of Gum Metal under compression

A scheme of the experiment set-up used for evaluation of mechanical anisotropy in Gum Metal under compressive loading along (II) and perpendicular (⊥) to its technological texture is shown in Fig. 2a, whereas force vs. crosshead displacement curves obtained from a testing machine is presented in Fig. 2b. In the case of the Gum Metal loading perpendicular to the swaging axis, the maximal force and stress demonstrated higher values around yielding in comparison to loading of the sample cut off along the swaging (Fig. 2b).

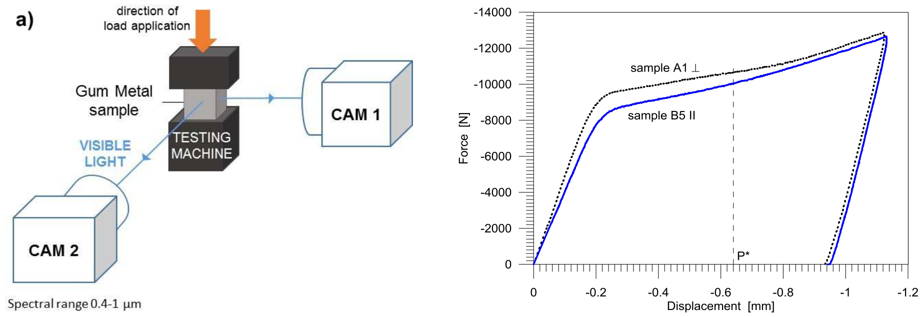

Figure 2: a) Scheme showing Gum Metal sample under compression monitored by two cameras; b) Force vs. crosshead displacement curves for the compression along (II) and perpendicular (⊥) to swaging axis.

Tendency to grow for the values of stresses related to yield limit noticed in Fig. 2b was also observed on the stress-strain curves, calculated by DIC algorithm [3] setting a virtual extensometer with 3 mm gauge length. However, a significant discrepancy between the strains for both curves was observed (Fig. 3a). Strain distributions E_{yy} determined for an advanced plastic deformation stage, denoted by "P" in Fig. 2b, for two perpendicular walls of two loading orientations are shown in Fig. 3b. The average strain discrepancy was mainly caused by shear deformation in the case of loading in perpendicular direction, as observed by camera CAM 2 for sample A1.

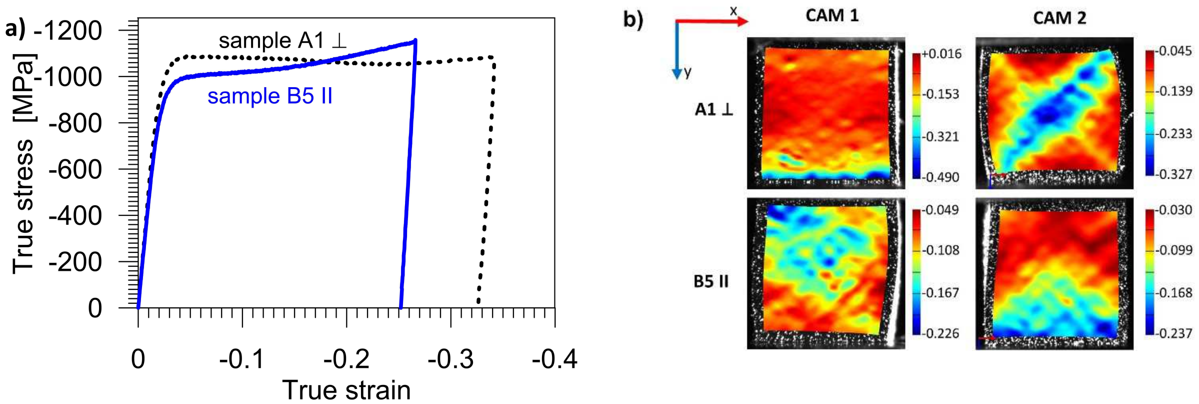

Figure 3: a) Stress vs. strain curves and b) strain distributions (E_{yy}) for Gum Metal under compression along (II) and perpendicular (⊥) to its <110> texture observed by two cameras (CAM 1 and CAM 2).

Such a significant difference between the deformation behavior of Gum Metal under compression along and perpendicular to the swaging direction and its <110> texture, confirmed its strong anisotropy.

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