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Miniature specimen tensile testing of AZ31 alloy processed by ECAP

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ABSTRACT

Purpose: Evaluation of bulk nanomaterials and ultra-fine grain structures consists mostly of metallographic evaluation and hardness measurement. The documentation of mechanical properties by hardness testing only might be very inaccurate due to the measurement error and sensitivity. Moreover the yield stress, ultimate tensile stress an elongation determined by tensile testing are more suitable for description of mechanical properties. This article promotes miniature tensile testing. Although the miniature tensile testing could be commonly used for description of mechanical properties in SPD materials, it is quite unknown.

Design/methodology/approach: In this article the miniature tensile testing was used for determination. of mechanical properties anisotropy in AZ31 alloy processed by ECAP. The verification was performed by comparison of conventional and miniature tensile specimens of the non-deformed bulk material.

Findings: From the experimental procedure and results low material consumption during sampling, sampling and measurement simplicity and possibility to measure the properties in various directions are denoted.

Research limitations/implications: Future detailed investigation of secondary phase particles and dislocation-precipitate interaction should be performed. This investigation was not performed as it requires transmission electron microscopy. Such investigation will be performed only for chosen specimens to confirm discussed hypotheses.

Practical implications: The paper promotes application of miniature tensile testing for determination of mechanical properties in SPD processed materials. Application of this methodology allows determination of mechanical properties from local volume, material save or preformation of several experiments from a single specimen.

Originality/value: The finding might be valuable for researchers in SPD field. The originality of this paper is based on novel methodology and its applicability.

Keywords: Mechanical properties; Miniature tensile testing; Anisotropy; AZ31 alloy

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PROPERTIES

1. Introduction

Fabrication of nano-scale or utrafinegrained materials through methods of severe plastic deformation (SPD) is already decades an interesting topic. Since invention of the first method – equal channel angular pressing (ECAP) [1], several other processing methods [1-11] were developed and wide range of materials was produced and researched [5-19]. The common feature of SPD materials is their heterogeneity and anisotropy [18-23]. While for microstructural analysis the processed material size is sufficient, its dimensions are often not allowing conventional mechanical testing. Therefore, the anisotropy and heterogeneity of mechanical properties are usually determined only from hardness measurement. Recently miniature specimen tensile testing methodology was developed [23-25]. In comparison to the small punch test for this procedure no fit has to be performed and mechanical properties can be determined directly from the test. The sample dimensions allow local testing of processed material (e.g. ECAP sample with 10x10 mm cross-section). Therefore, it can be used for mechanical properties anisotropy measurement. However, it might have wider application.

2. Experimental description

For experimental procedure commercial magnesium alloy AZ31 was used. The billets with dimensions 10 x 10 x 100 mm were processed through the ECAP die with die angle 90°. As the processing is not a concern of this article, other processing parameters are not enlisted. The tensile tests in this article were performed for 1 pass through the ECAP die.

For anisotropy evaluation the sampling was performed in various directions (Fig. 1). The billet was pre-machined in milling centre, and then the specimens were cut with precise saw. The specimens were ground with 800 and 1200 grit SiC paper. After sampling the actual specimen dimensions were measured and recorded in order to avoid thickness and width change after the spraying. At first a continuous layer of white colour was sprayed on the specimen surface, and then a pattern was sprayed with black colour. The white-layer over the specimen surface creates, in combination with black speckles, a fine field of stochastic speckle pattern which provides a grey scale contrast for Digital Image Correlation (DIC) measurements. A stochastic pattern along with the specimen dimensions is depicted in see Fig. 2.

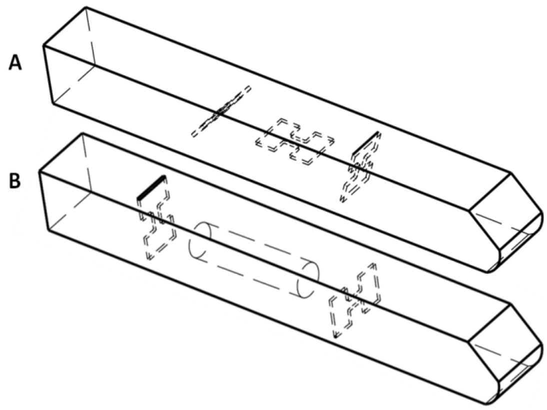

Fig. 1. ECAP billet with sampling scheme. Billet A contains tensile samples in longitudinal direction 45°angle from longitudinal direction and 60° to longitudinal direction. Billet B consists of tensile samples in vertical and lateral dimensions and sample for dilatometry

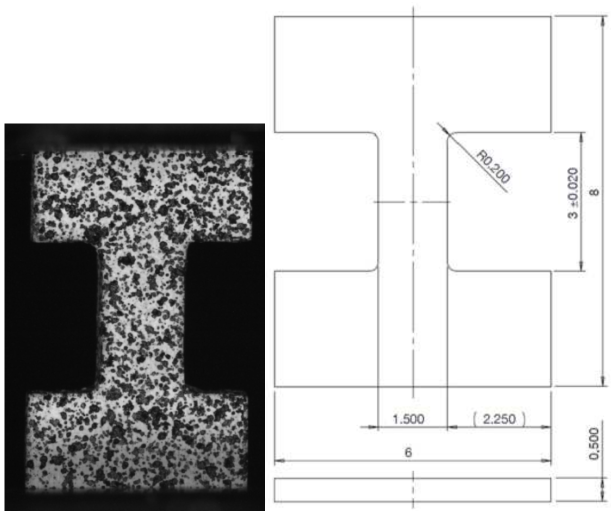

Fig. 2. Specimen with surface pattern and sample geometry

The number and size of speckles depend on an area of interest and on a resolution of CCD camera. All images were captured with 4 megapixel monochromatic camera at a framerate of 5 fps. The measuring volume of 10x8mm was set to cover a focus area of interest which is represented at least by 3mm gauge length of the sample.

As the pulling proceed is measured, the change in the gage length of the sample is computed using digital image correlation technique which accurately provides high precision information about the strain distribution on the specimen surface, see Fig. 3.

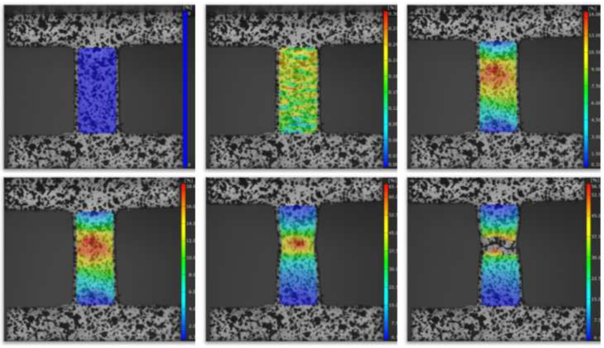

Fig. 3. Example of strain distribution in the specimen during the test

Tests were done in electromechanical electro-mechanical tension and compression testing machine at the room temperature up to a strain rate of 0.0004/s. The setup consists of the mechanical testing machine with 5kN load capacity and DIC system with one camera for 2D measurement, see Fig. 4.

Fig. 4. The test setup for miniaturized tension

The procedure was verified by measurement of conventional and miniature specimen, produced from AZ31 bulk material in a longitudinal direction. Following mechanical properties -elasticity modulus, proof yield strength (Rp0.2, determined at 0,2% elongation offset), ultimate tensile strength (R_m), total elongation (A_3, A_5) and uniform elongation (UA, elongation up to R_m) were determined.

Due to the dimensions of miniature tensile specimen the elongation A_5 was not directly evaluated because of too short gauge length of the sample. Thus the following equation (1) was used for an evaluation of total elongation

$$A_x = \frac{UA_m * L0_x + \left(A_m - A_g UA_m\right) * L0_m}{L0_x} \qquad (1)$$

where A is elongation [-], x is the index specifying gauge length to which are originally measured values are converted and m is for originally measured values with considered gauge length. UA is uniform elongation [-] and L0 represents initial gauge length [mm] with respect to the index.

3. Results

The comparison of conventional and miniature specimen is visible in Fig. 5. Influence of sampling direction is visible in Fig. 6. The mechanical properties are enlisted in Table 1.

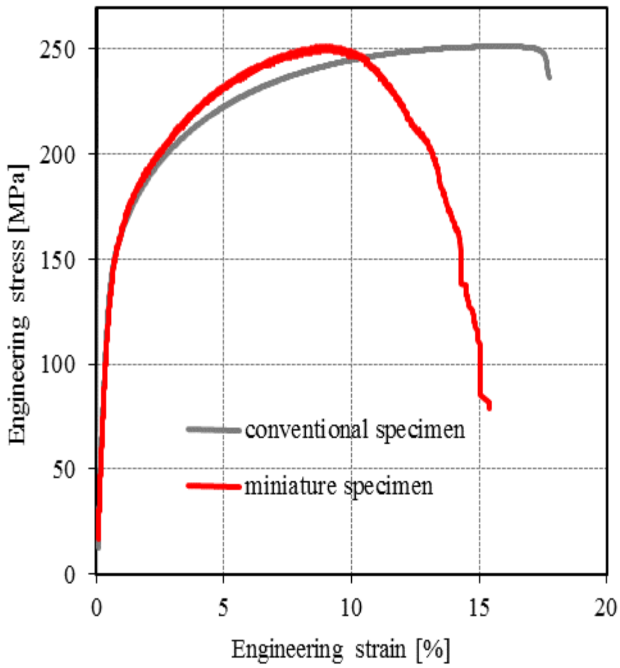

Fig. 5. Stress-strain curves of bulk material – miniature specimen compared to the conventional specimen.

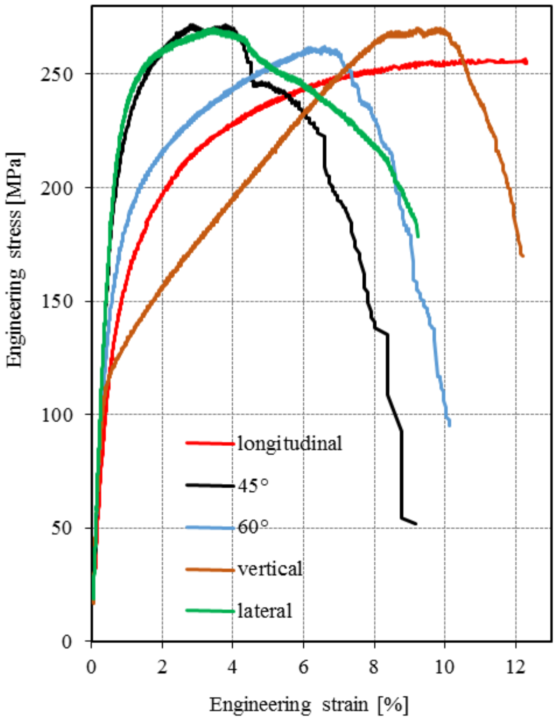

Fig. 6. Stress-strain curves of the miniature tensile specimens in various directions

Table 1.
Mechanical properties of bulk material and ECAP billets. The A_5 value of miniature tensile specimen was calculated according to eq. 1

	material and specimen type	E [GPa]	$R_{p0.2}$ [MPa]	R_m [MPa]	UA [%]	A_5 [%]
bulk	conventional specimen	29,8	150	251	14,5	16,5
bulk	miniature specimen	28,6	149	252	8,2	24,9
ECAP billet	miniature, longitudinal	29,5	133	257	9,6	9,6
ECAP billet	miniature, 45° to longitudinal	38,1	203	271	2,2	14,1
ECAP billet	miniature, 60° to longitudinal	38,4	153	262	5,9	13,0
ECAP billet	miniature, vertical	30,3	116	270	9,1	15,2
ECAP billet	miniature, lateral	38,9	215	270	2,8	19,7

4. Discussion

The conventional specimen and miniature specimen differ mostly in elongation. However both –yield and ultimate tensile strength are in very good agreement. This could be probably attributed to the grain size, morphology and deformation behaviour (hcp lattice) of the bulk material. The miniature tensile tests of ECAP billet clearly confirm the anisotropy of mechanical properties. The lower yield strength was observed in vertical direction. Deacrease of the angle to the longitudinal direction and theoretical slip angle (45°) resulted in a respective increase of the yield strength (from 133 to 203 MPa) in the ECAP billet. This denotes the important possibility of the miniature specimen to map the relation between the die angle and mechanical properties. However similar strengthening is as well visible in the lateral direction, which is quite surprising. For further research the microstructure evaluation can be performed. Due to the miniature specimen dimensions this will be possible from the same billet near the sampling location. Such proceedure - combination of microstructure evaluation of the tensile test results will contribute to deep understanding of the deformation behaviour of SPD materials.

5. Conclusions

The research of miniature tensile testing led to following conclusions:

- The miniature tensile test results are comparable to the conventional tensile test results.
- The elongation is most sensitive to the tensile testing methodology and the specimen design in relation to the microstructure and surface conditions while the strength can be determined very precisely.
- The miniature tensile specimen geometry and sampling methodology allows machining of several specimens from one billet and most importantly sampling in various directions.
- The propose methodology is very useful for anisotropy investigation and mapping of mechanical properties.

According to these conclusions the miniature tensile testing method could be considered as tailor-made for the SPD materials evaluation. The miniature tensile testing of SPD materials should be followed by grain orientation mapping (e.g. by scanning electron microscopy with electron backscatter diffraction detector). The results of microstructure evaluation in combination with miniature tensile testing will contribute to deep understanding of the deformation behaviour of processed material.

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