Hybrid SPD process of aluminium 6060 for microforming

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Abstract. The increasing share and expansion of miniature devices requires the mastery of miniature parts production, including metal parts. In metal microforming, due to the conditions of mechanical similarity, the aim is to use materials with the smallest grain. Ultra-fine-grained metals (UFG) fulfill this requirement. These metals can be obtained, inter alia, in SPD processes such as ECAP. The work uses the extension of the SPD based on ECAP with additional metal forming operations necessary to obtain blanks for microforming in the form of a 0.2 mm foil. Three variants of the technological process were performed. This foil was then subjected to a micro-drawing operation aimed at determining the influence of the foil preparation process on the sheet metal microforming process flow.

Introduction

The miniaturization of devices [1], which has been progressing for several decades, imposes the miniaturization of the parts used for their production, which are largely produced by metal forming technology [2]. Reducing the dimensions to about one millimeter causes a change in the dominant physical phenomena. Difficulties in the accurate design of technological processes for miniature parts, combined with the growing demand for them, led to the separation of a relatively new branch of metal forming, which is microforming [3]. This is because of the natural granularity of the polycrystalline materials used [4] and the surface layer treated as an area with a certain thickness, mainly dependent on the structure of the material [5]. The share of both of these features increases as the product becomes smaller, the material of which can no longer be considered uniform throughout its volume. The proposed avoidance of many of the unfavorable scale effects is the concept of using ultrafine grain metals (UFG) [6-8]. Within the presented work, the field of interest was narrowed down to sheet metal microforming processes. As a method of obtaining ultra-fine grain, the ECAP process was adopted on the stand used in previous works [9]. The selected material for the tests is aluminium alloy 6060, which was chosen because of its high (in the group of aluminium alloys) strength properties.

The main purpose of the work was to develop a research method allowing for the assessment of the possibility of using this alloy with the UFG structure obtained by the ECAP method for sheet metal microforming processes. It should be noted that the UFG materials obtained from the ECAP process are in the form of rods that must undergo further deformations [10], so that the final effect is a foil with a UFG structure. The influence of the technological path of preparing foil with a thickness of 0.2 mm made of aluminium alloy 6060 on the possibility of sheet metal microforming was initially examined. The process of free micro-drawing was adopted as the verification process. It was chosen because of the simplicity of implementation, which favours further miniaturization and reduces the number of process parameters in research. Due to the

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difficult formability of the selected material discussed in the literature, it was decided to use heat treatments to improve this feature.

Material Preparation

The extended UFG metal fabrication process with the ECAP main operation was used in the work to prepare 0.2 mm thick 6060 aluminium foil. Three series of material in the form of foil, marked respectively with the symbols CG (material not subjected to ECAP), UFG F (material subjected to ECAP in the delivery condition) and UFG G (material supersaturated before ECAP) were punched with a 4 mm diameter punch. Then, the obtained discs were used to carry out the micro-drawing operation.

The hot-extruded bar PN EN 6060 ø50 was used as the initial material. The bar was divided into billets with dimensions of 8x8x45 mm by milling according to the scheme shown in Fig. 1a. Part of the billets were subjected to supersaturation (annealing for 2 hours at 525°C, cooling in water). These billets were used to prepare a series of UFG G material. Then, a two channel turns mtECAP (2x110°) was performed six times at 150°C. ECAP was performed for a batch of supersaturated material (UFG G) and as delivered (UFG F). The rods obtained in this way were subjected to free upsetting (Fig. 1b) at 150°C, obtaining plates with a thickness of 1 mm. Upsetting was carried out in three subsequent operations with a comparable increase in surface area (~2 times) to enable renewal of lubricating layer. In addition, identical upsetting was applied to the billets that were not subject to the ECAP. The diagram of the upsetting operation is shown in Fig. 1c. The obtained material was mainly subjected to natural ageing, however, the use of elevated temperature in the ECAP and upsetting operations meant that the material stayed in total for almost an hour at a temperature close to 150°C, which could initiate the processes related to artificial ageing.

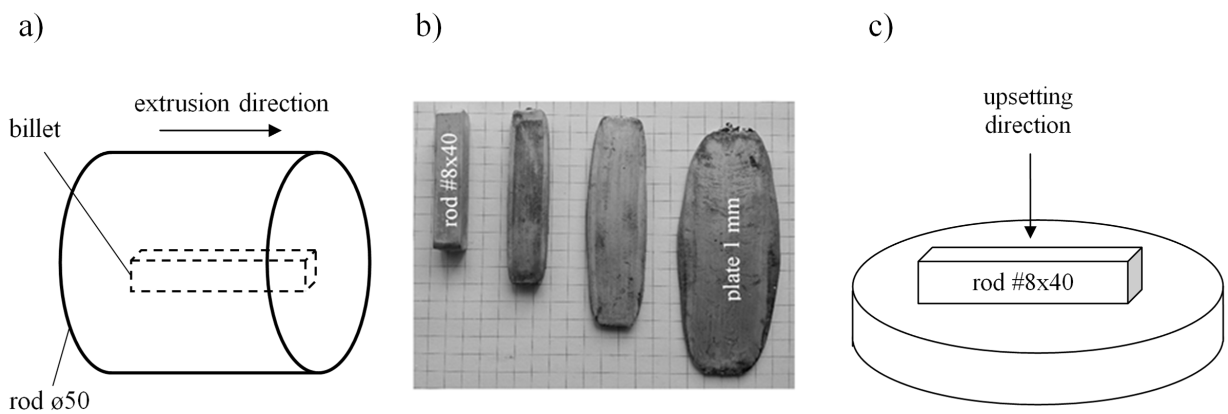


Fig. 1. Scheme of orientation of the taken billets in relation to the ø50 mm rod (a), the result of subsequent upsetting operations at a thickness of ≈ 5, 3 and 1 mm (b) and the scheme of upsetting operations (c).

In the next stage of the process, the obtained plates were cut into 6 mm wide strips, which were rolled to a thickness of 0.2 mm at room temperature to obtain a foil intended for microforming. The method of taking strips from plates are shown in Fig. 2. Full material preparation process is presented in Table 1.

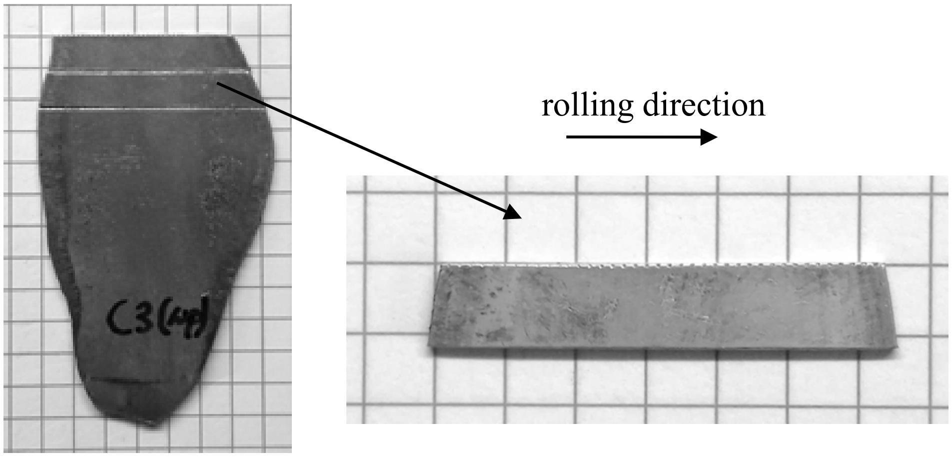


Fig. 2. Preparation of metal strips for the rolling process.

Table 1. Material preparation process (green color mean that operation was performed).

Operation	Cutting from ø50 rod	Supersaturation	mtECAP	Upsetting	Cutting	Rolling
Result	billet (#8x45 mm)	billet (#8x45 mm)	Rod (#8x40 mm)	Plate (1 mm thick)	Strip (6 mm wide)	Foil (0,2 mm thick)
CG	green			green	green	green
UFG F	green		green	green	green	green
UFG G	green	green	green	green	green	green

Material Analysis

In order to verify the effect of supersaturation on the material properties after the ECAP, a uniaxial tensile test for specimen with 10 mm gauge length [9] was performed, in which the yield strength $R_{p0.2}$, tensile strength R_m and elongation A were determined. These parameters were determined for the material immediately after the ECAP process and after additional upsetting. Tensile test for a thin foil was not performed. Fig. 3 presents the obtained results and compares them with the parameters of the material as delivered.

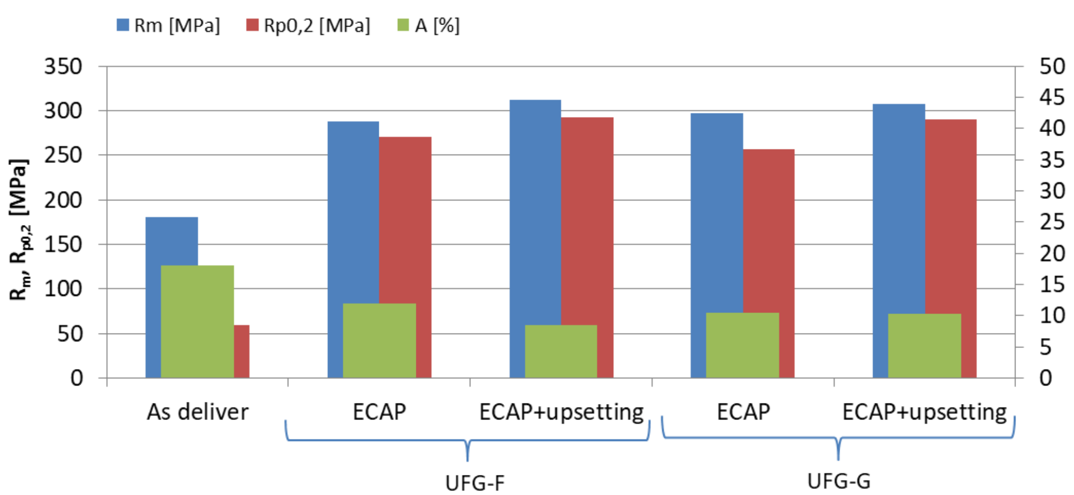


Fig. 3. Comparision of R_m, $R_{p0.2}$ and A for prepared series of material in two stages of the process.

The obtained 0.2 mm foils were subjected to EBSD structural analysis. Fig. 4 shows the corresponding grain size distribution for CG and UFG foil.

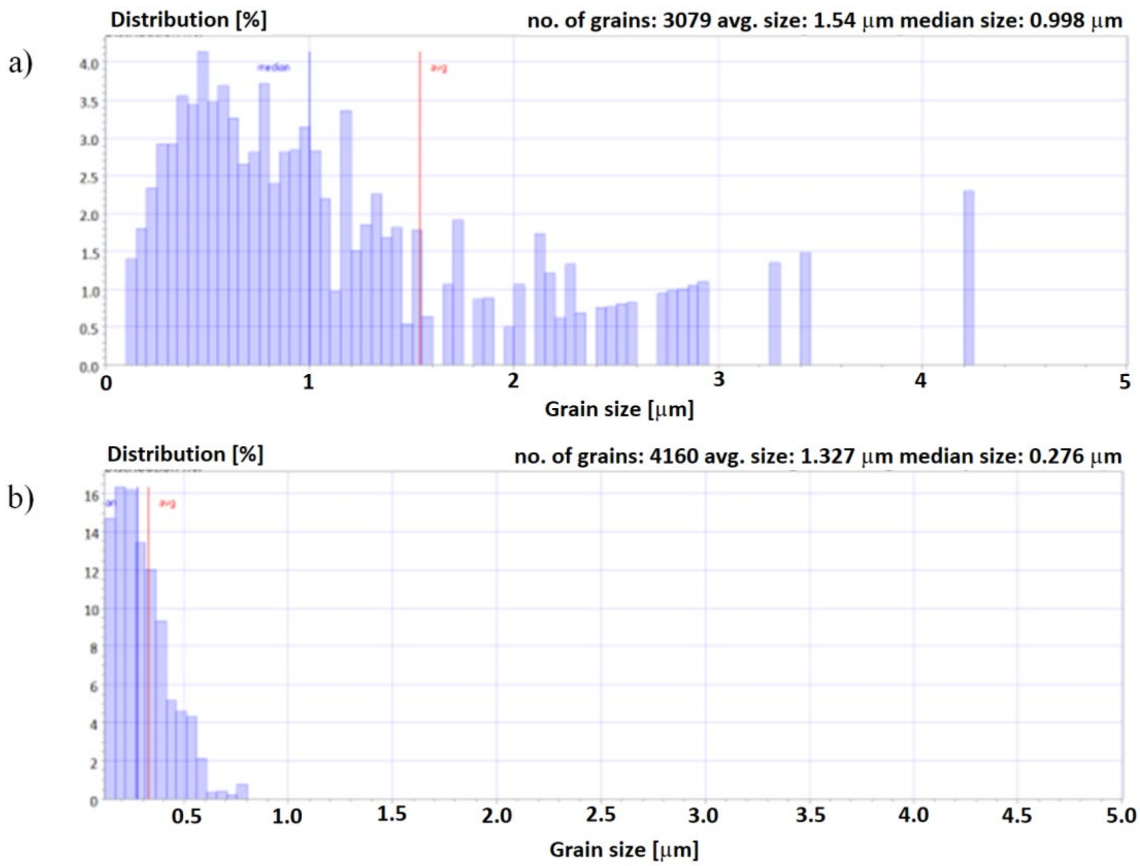


Fig. 4. Grain size distribution of 6060 aluminum foil for CG (a) and UFG-F (b) series.

Collected data indicate a noticeable effect of supersaturation on the properties of the obtained material, however, this effect is different immediately after ECAP and after additional upsetting. The supersaturated material (UFG-G series) shows higher strength and lower plasticity after ECAP compared to the UFG-F series, however, after additional upsetting, this relationship is reversed and the UFG-G series shows lower strength and higher plasticity. This phenomenon may be caused by the influence of increased tamperture occurring during upsetting, which may partially eliminate the strengthening effects. Finally, a positive effect of supersaturation on the formability of the obtained UFG plates was observed.

Structural analysis of foils intended for sheet metal microforming leads to the conclusion that the ECAP process unifies the structure of the material in the entire volume of the obtained foil. The foil made of the CG material is characterized by a much greater grain size variation, despite the fact that the large plastic deformation that took place during subsequent metal forming operations significantly fragmented the grains.

Formability Determination

Formability determination was performed by means of micro-drawing process. Carrying out the drawing process requires a preliminary operation, which is the preparation of the preform. In this case it was a disc with a diameter of 3.8 mm. A micro-blanking process with a blank holder, which in turn required preforms in the form of 10x7x0.2 mm strips. In this process, a precise micro-device placed on the testing machine table was used. The micro-device ensured precise positioning of the tools. The micro-blanking operation was additionally used to analyze the technological variants of CG, UFG-F and UFG-G. The courses of forces were recorded (Fig. 6a), the cut strengths and the fill factors of the graph were determined (Table 2). To reduce the complexity of the tools, free micro-drawing was carried out in the system shown in Fig. 5a, consisting of the same device as for micro-blanking. For this kind of process the drawing ratio should be bigger than 0.55 [1] , and 0.58 was chosen.

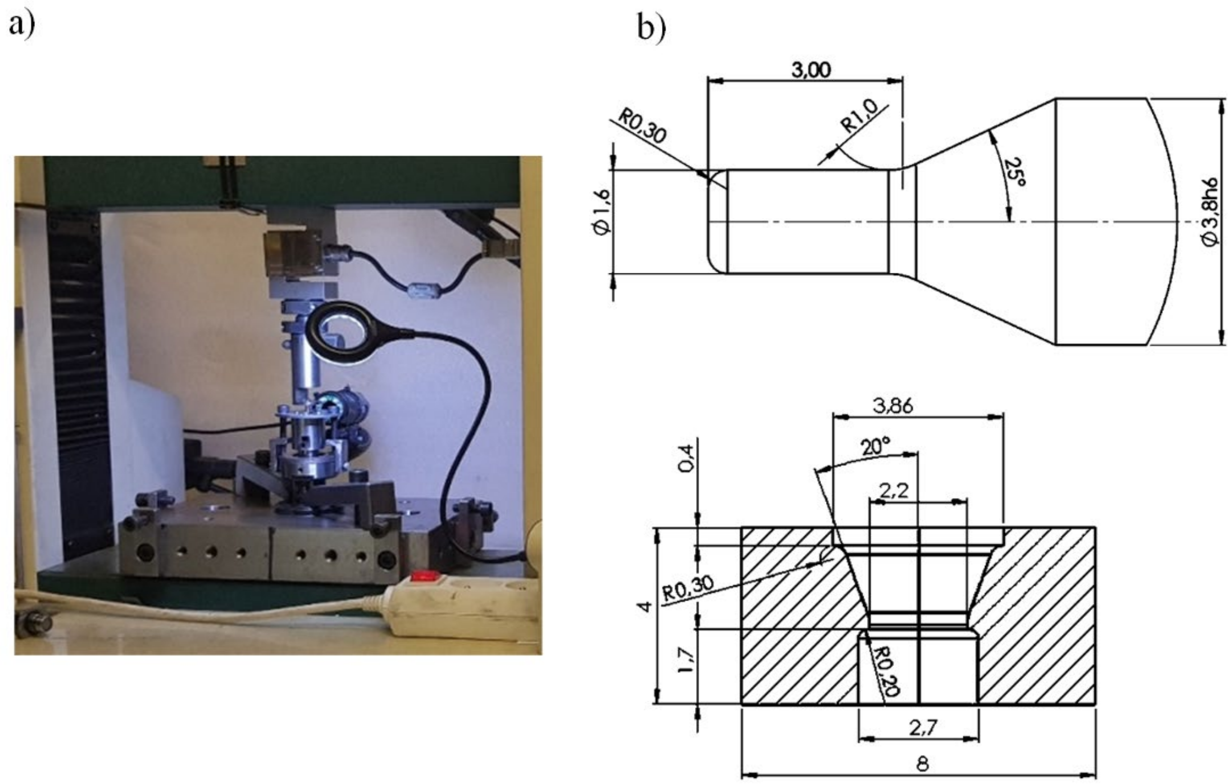
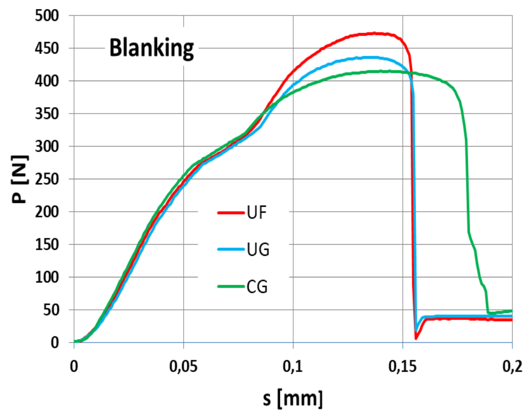


Fig. 5. Setup for micro-drawing (a) and dimensions of the tools used (b).

The dimensions of the tools are shown in Fig. 5b. Lubrication was applied with a lubricant based on MoS2 from the die side and light oil from the punch side. The coefficient of extrusion in the process was 0.54. The following description refers to the force recorded during the process (Fig. 6b).

a)



b)

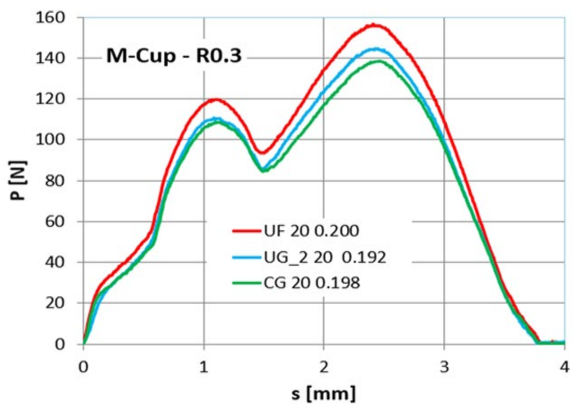


Fig. 6. Course of forces during micro-blanking (a) and micro-drawing (b) of 0.2 mm foil for three series of material.

The disk is placed in the cavity of the matrix (Fig. 5b) enabling its precise positioning. The precisely guided punch presses centrally on the foil, the force of the process increases to the value of the first maximum. After reaching it, the edge of the disc begins to be drawn into the die, sliding on its conical surface. As the punch moves, the force decreases and reaches a minimum value, after which it increases again due to the strengthening of the material and the thickening of the edge of the cup. When the strengthening and thickening of the material is no longer able to compensate for the decreasing perimeter of the edge, the force of the process decreases until its full completion. The threat here is the possible cracking of the bottom, which is the main phenomenon limiting the process.

Table 2. Cut strength R_t and graph fill factor λ for three series of 0.2 mm foil.

	CG	UF	UG
R_t [MPa]	168	185	181
λ	0,67	0,51	0,55

Despite the slightly higher cut strength determined for the material from the UFG-F series, the effect of supersaturation before the ECAP on the blanking process conditions was not observed. An increase in the micro-drawing process force was observed in the case of the UFG-F material. With regard to the CG and UFG-G materials, slight differences in the force course were observed, requiring further research. The shape and appearance of the cups surface (Fig. 7) as well as the size of the lugs indicating the presence of flat anisotropy in the assessment of the image from the light microscope do not indicate significant differences in individual material series.

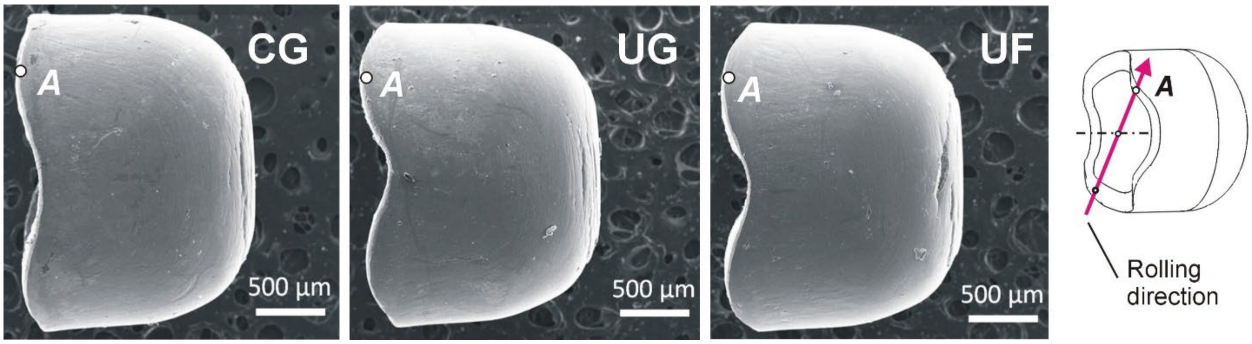


Fig. 7. SEM images of obtained micro cups for three series of material.

Summary

The presented paper proposes a research method for selection of process parameters enabling the use of UFG materials obtained by the ECAP method for use in sheet metal microforming. The applied ECAP has been enriched with the process of obtaining thin foils by initial multiple upsetting with the possibility of increasing the temperature and subsequent multiple rolling at room temperature. The obtained material in the form of a foil with a thickness of 0.2 mm made of aluminium alloy 6060 was then subjected to a micro-drawing operation recognized as a process determining the formability of the prepared materials in the conditions of sheet metal microforming. Necessary to prepare preforms for the micro-drawing process, the micro-blanking process was used to additionally compare the characteristics of foils from different series.

Based on the prepared research, it was found that the obtained material in the form of a foil is characterized by a uniform structure and is consistent throughout its volume without structural defects and cracks. The ECAP process plays a key role in unifying the structure throughout the volume of the foil. Its omission results in a significant decrease in the homogeneity of the material, despite the large deformations to which the material is subjected during upsetting and rolling, which causes significant grain refinement comparable to ECAP.

Despite the noticeable differences in strength properties occurring after the upsetting process for the supersaturated material and the material processed as delivered, no effect of supersaturation of the billets material before the ECAP process on formability was observed in the conditions of the sheet metal microforming.

Some differences in process flow for prepared materials was observed in micro-blanking and micro-drawing (Fig. 6), but for clearly distinguishes the formability there are planed extension of micro-drawing process in the next research.

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