P. SZOTA, S. MRÓZ, A. STEFANIK, K. LABER, R. MOLA

ISSN 0543-5846
METABK 60(1-2) 36-38 (2021)
UDC – UDK 669.721:539.417:620.16: 620.193.086.3:518.1=111

THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE BACKWARD EXTRUSION PROCESS WITH A ROTATIONAL DIE OF AZ31 ALLOY

Received – Primljeno: 2020-07-07
Accepted – Prihvaćeno: 2020-10-07
Original Scientific Paper – Izvorni znanstveni rad

In this work theoretical and experimental analysis of the backward extrusion with a rotary die of the AZ31 alloy has been performed. The modification of the classical extrusion was based on the use of a rotary die. The results of theoretical research have confirmed that the use of the modified backward extrusion causes the appearance of shear stress in deformed material, which could affects the activation of additional mechanisms of deformation. The numerical modelling of the rotating extrusion of AZ31 alloy has been conducted by using the computer program Forge®. The experimental tests were carried out in the conditions of the STD 810 torsion plastometer using newly designed tools.

Keywords: Mg alloys, backward extrusion, shear stress, physical modelling, numerical analysis

INTRODUCTION

A growing increasing interest in lightweight structural materials, characterised with high strength while maintaining good plastic properties and low specific weight, can be observed nowadays. The processes of Mg alloys metal forming are of specific nature, and their proper practical implementation in industrial applications is often very difficult. An improvement of the properties of metals being deformed can be achieved, among others, by means of structure refinement by means of the Severe Plastic Deformation (SPD) methods. Numerous metal forming processes, with a significantly differing course, can be considered as the SPD methods, however, the application of severe deformations to materials in precisely determined conditions is what they have in common [1-4]. The works [5-7] demonstrate that application of the accumulation of backward extrusion results in high refinement of Mg alloys structure and increase of their strength. However, in the work [7], a new backward extrusion method using a rotary tool is presented. Quoted work demonstrates that an application of a rotary tool (a die in this case) results in decreasing the extrusion force as compared to the process without rotation and increasing of the deformation intensity in the AZ80 alloy being extruded, as compared to the typical backward extrusion process. The work did not analyse the impact of a rotary tool application on the tangential stress values which leads to the formation of shear bands giving rise to the activation of deformation mechanisms resulting in the refinement of the structure of the material being deformed.

P. Szota (piotr.szota@pcz.pl), S. Mróz, A. Stefanik, K. Laber, Częstochowa University of Technology, Poland
R. Mola, Kielce University of Technology, Poland

RESEARCH SCOPE AND OBJECTIVE

The objective of the study being performed is to determine the impact of a rotary punch application on the flow of metal being deformed and to force the increase of the tangential stress share in the process of backward extrusion. The research was performed on the AZ31 magnesium alloy in as extruded condition. Numerical modelling of the extrusion process using the rotary tool was performed for the parameters of an STD810 torsional plastometer. The theoretical research on the possibilities of adapting the equipment to extrusion tests was performed by means of the Forge® application software. The viscous-plastic model of the deformed body, described with the Norton-Hoff principle [8, 9] was used in the numerical computations.

The computer simulations were performed for two variants: variant I, representing a typical backward extrusion process, and its modification using the rotary punch (variant II). In the theoretical research an input element with a diameter (d) 5 mm and height (h) 5 mm was used resulting in the ratio d/h = 1. The punch displacement speed for both variants was identical and amounted to 4 mm/s, whereas the rotational speed of the punch for variant II was 60 rpm. The temperature of the feedstock and tools was 400 °C. The friction coefficient value, assumed in the computations, was 0,13 [10]. The curves of flow stress for the AZ31 alloy being analysed were determined experimentally, by means of the hot compression test [11].

The shape and dimensions of the tools were designed in such a manner that they correspond to the dimensions of the sample used in plastometric tests with use of the STD810 plastometer (Figure 1). In the first

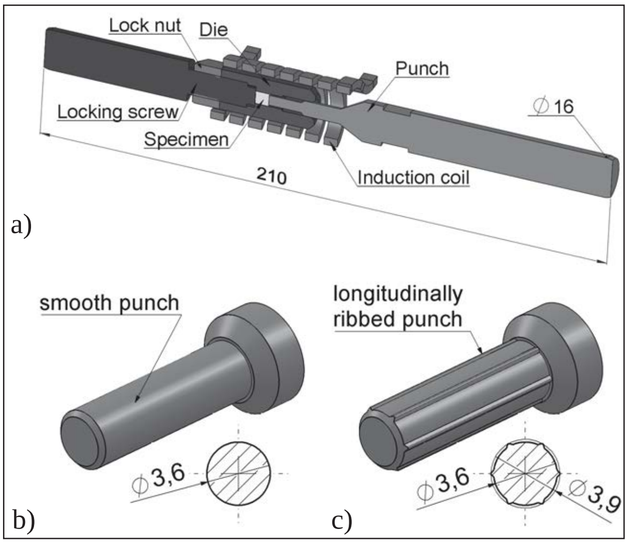


Figure 1 Scheme of assembling dies and specimen used in a computer simulations - a), shape of punches used in variants I - b), shape of ribbed punches used in variants II - c).

variant, a typical punch was used with a circular cross-section and chamfered face surface (Figure 1b), while in the second variant, six longitudinal ribs were formed around the perimeter of the punch (Figure 1c) in order to force the material torsion.

ANALYSIS OF THE NUMERICAL MODELLING RESULTS

The theoretical research conducted it possible to determine the impact of the punch rotation applied on the possibility of die stamping torsion. Thus, in the first research stage, an analysis of metal flow for both variants of the backward extrusion process was performed (Figure 2).

The distribution of velocity vectors obtained for the conventional backward extrusion is typical for such process (Figure 2a). The flow vectors in the cylindrical part of the die stamping are oriented in parallel and, at the same time, opposite to the punch movement direction. However, in the lower part of the die stamping (the bottom part), the vectors are oriented perpendicularly and in the direction of the punch movement. An entirely different character of plastic flow was obtained for variant II in which the rotation of the moving punch was additionally introduced (Figure 2b). The metal on the entire height of the cylindrical die stamping displaces circumferentially, more intensively in relation to the axial direction of the die stamping. Such distribution of flow velocity vectors leads to an increase of tangential stress percentage during deformation, as compared to conventional extrusion.

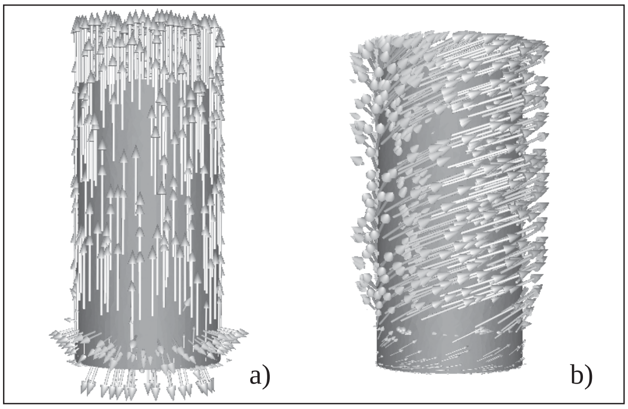


Figure 2 Distribution of velocity vectors: a) variant I - the backward extrusion, b) variant II - the backward extrusion with a rotary punch.

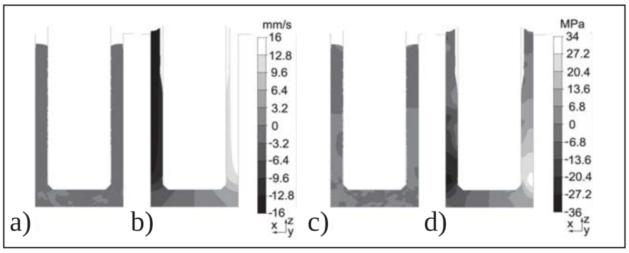


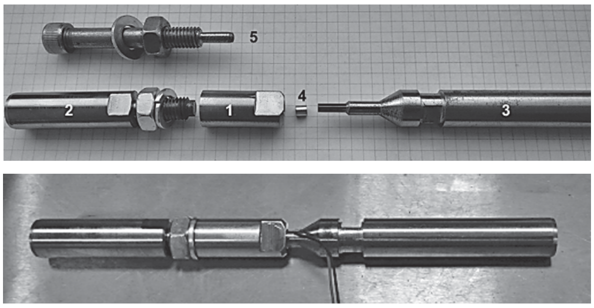
Figure 3 Results of numerical modelling of the backward extrusion - distribution of: a) v_x variant I, b) v_x variant II, c) τ_{zx} variant I, d) τ_{zx} variant II, (v_x - flow component, τ_{zx} - tangential stress).

Within the frameworks of the research, distribution of the transverse flow velocity component v_x of the die stamping was determined for both variants of the extrusion process (Figures 3a and 3b). In the conventional backward extrusion process, metal flowing in the circumferential direction of the die stamping does not virtually occur on its whole cross-section. The application of the rotary punch disturbs the distribution of the transverse velocity component v_x, typical for the backward extrusion process, the metal on the whole height of the cylindrical part and, most importantly, also on the wall cross-section, begins to flow intensely in the circumferential direction of the die stamping, while the values obtained for all walls of the die stamping differ by sign, which testifies for the rotation in the same direction in relation to the symmetry axis of the die stamping.

The analysis of the tangential stress shown in Figures 3c and 3d demonstrated that, in variant I, the values of the τ_{zx} component on the whole cross-section of the die stamping are low, and differ by sign in relation to the horizontal axis of the die stamping cylindrical part. However, for the variant II, the intended effect was achieved, resulting from an additional deformation (torsion, Figure 3d) of the die stamping; apart from flowing towards the height, the entire volume of the cylindrical part walls is torsioned. The change of flow nature, as compared to the conventional process, resulted in the additional tangential stress to occur, which is particularly evident in that part of the die stamping being in contact with the rotating punch (the areas of wall with a greater thickness). Therefore, it can be concluded that the introduction of the punch rotation into the conventional backward extrusion process results in the additional tangential stress.

ANALYSIS OF THE PHYSICAL MODELLING RESULTS

Within frameworks of experimental investigations, physical modelling of backward extrusion of AZ31 al-



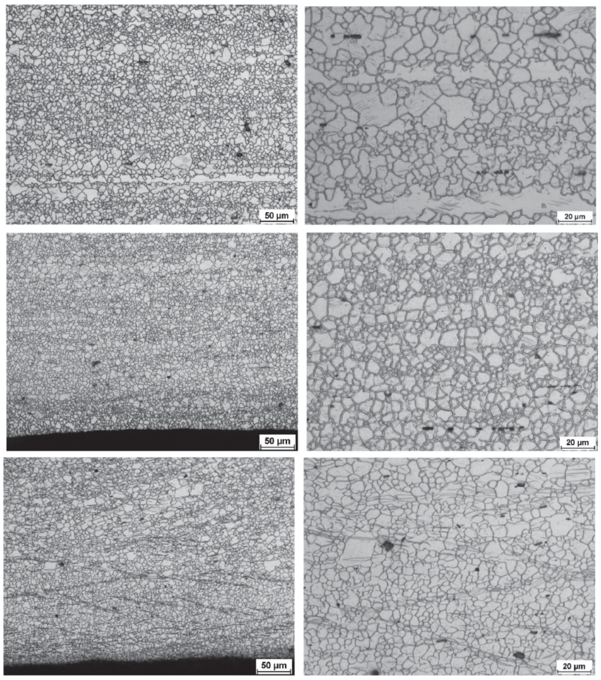
a) b)

Figure 4 Experimental test of a backward extrusion: a) tool kit to the test - 1) die, 2) locking screw at the bottom of the die, 3) punch, 4) specimen ∅5 x 5 mm, 5) ejector, b) assembly of tool kit with the sample inside.

loy samples were performed in the STD810 torsional plastometer. The tests were carried out for two variants and parameters as in the theoretical research. The tests required a special tools (Figure 4).

Figure 4a illustrates the tool kit for tests, and Figure 4b shows the tool kit assembled with the specimen inside the die. A thermocouple was connected to the punch for temperature measurement. The AZ31 alloy specimen was heated inductively up to 400 °C, by a controlled heating of the die and punch. The test consisted of heating for 60 s, soaking for 60 s, deformation for 1 s and cooling for 60 s. The punch displacement speed was 4 mm/s for both variants. In the variant 2, the punch rotation at 60 rpm was additionally introduced.

Figure 5 presents the microstructure of individual specimens in a longitudinal cross-section. The feedstock (Figure 5a) is characterised with band structure and non-uniform grain size. The specimens after extrusion according to variant 1 (Figure 5b) exhibit the band structure of finer grains as compared to the feedstock material. For variant 2 (Figure 5c), a considerable grain refinement is evident together with the occurrence of characteristic bands arranged at some angle to the axis of specimen. It indicates that shear bands were created as a result of intense localised deformation. Within the areas of the bands, fine sub-grains were found which proves the occurrence of dynamic recrystallisation.



a) b) c)

Figure 5 The microstructure of feedstock - a), a sample after backward extrusion - b), a sample after a rotation backward extrusion - c).

SUMMARY

Based on the theoretical and experimental investigations carried out it was found that the introduction of the punch rotation into the conventional process of backward extrusion results in increasing the share of tangential stress during the deformation which leads to the activation of additional deformation mechanisms resulting in creation of shear bands. Such deformation scheme fosters significant refinement, particularly in Mg alloys, which was confirmed in the micro structure analysis.

REFERENCES

[1] V. Ruslan, T. Langdon, Principles of equal - channel angular pressing as a processing tool for grain refinement, Progress in Materials Science 51 (2006) 7, 881-981.

[2] S. Roy, S. Subodh, S. Kumar, K. Chattopadhyay, Accumulative roll bonding of aluminum alloys 2219/5086 laminates: Microstructural evolution and tensile properties, Materials and Design 36 (2012), 529-539.

[3] A. Wierzba, S. Mróz, P. Szota, A. Stefanik, R. Mola, The influence of the asymmetric ARB process on the properties of Al-Mg-Al multi-layer sheets, Archives of Metallurgy and Materials 60 (2015) 4, 2821-2825.

[4] F. Grosman, Z. Cyganek, The research of rolling process with cyclic change of the strain path, Steel Research International 79 (2008), 453-458.

[5] S. Fatemi-Varzaneh, Z. H. Abbas, Accumulative back extrusion (ABE) processing as a novel bulk deformation method, Materials Science and Engineering A 504 (2009), 104-106.

[6] G. Faraji, H, Jafarzadeh, J. Hong-Joo, M. Mosavi, H. S. Kim. Numerical and experimental investigation of the deformation behavior during the accumulative back extrusion of an AZ91 magnesium alloy, Materials and Design 35 (2012), 251-258.

[7] Ch. Aryan, A. Hanzaki, S. Fatemi-Varzaneh, Microstructure and Mechanical Properties of an AZ91 Magnesium Alloy Processed Through Backward Extrusion. Archives of Metallurgy and Materials, 63 (2018) 1, 149-157.

[8] F. Norton, Creep of steel at high temperature, New York, McGraw Hill, 1929.

[9] N. Hoff, The analysis of structures, based on the minimal principles and the principle of virtual displacements, New York, Wiley, 1956.

[10] A. Gontarz, A. Dziubińska, Ł. Okoń. Determination of Friction Coefficients at Elevated Temperatures for some Al, Mg and Ti Alloys. Archives of Metallurgy and Materials 56 (2011) 2, 379-384.

[11] P. Szota, S. Mróz, A. Stefanik, R. Mola, Analysis of the AZ31 magnesium alloy bars rolling process in modified stretching passes, Materialwissenschaft und Werkstofftechnik 3 (2015) 46, 285-293.

Note: The professional translator for English language is LINGUA LAB, Kraków, Poland.