EXPERIMENTAL STUDIES OF COMBINED EXTRUSION OF PARTS MADE OF ENAW-1050A ALLOY

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Abstract

The paper presents the results from experimental studies of the combined extrusion of parts made of ENAW-1050A alloy. The studies were divided into three stages depending on the relative strain value of the material extruded in forward direction, ε_1: 0.77, 0.69 and 0.59. For each value of the relative strain ε_1, different values of relative strain of material extruded in backward direction were used, ε_2: 0.36, 0.46 and 0.58. On this basis, the influence was determined of the relative strain level in the material extruded in forward and backward directions on the die impact value. It was demonstrated that the values of die impact in the combined extrusion increase with the levels of relative strain of material extruded in forward and backward directions. For combined extrusion, the impact forces are smaller than during the forming of the extrusions in two procedures where in the first procedure, the cylindrical part is extruded in forward direction, and in the other procedure, the sleeve part is extruded in the backward direction. Combined extrusion reduces the effort necessary to manufacture a product and the cost of manufacturing the tools whose durability is additionally enhanced due to lower values of exerted impact.

Keywords: aluminum, combined extrusion.

1. INTRODUCTION

In recent years, aluminium and its alloys have become widely applied materials in a number of sectors. Their excellent mechanical properties and low specific mass are deciding factors for designers in aeronautics, aerospace and automotive industries [1,2,3]. Technological advancement of the last decade has allowed manufacturers to use these materials in car subassemblies [4]. Extensive research is being conducted on designing aluminium-based materials with contemplated qualities and on developing new metal forming technologies or improving existing ones [5,6,7]. The results of the research and new solutions found are becoming crucial to industry.

One of the technologies used in manufacturing products from non-ferrous metals is extrusion. Three basic techniques are used: forward, reverse and combination. The combination extrusion combines forward and backward types. The diagram of the combined extrusion is shown in **Fig. 1.**

From among a body of literature, the most comprehensive and detailed reports on extrusion can be found in [8,9]. The available literature offers analytical solutions, experimental research findings, and recommendations for process design, all relating to forward and backward extrusion only [10,11]. As the literature on combination extrusion is scarce, it has been deemed necessary to undertake studies on the subject, focusing on the analysis of impact forces acting in the combination extrusion process.

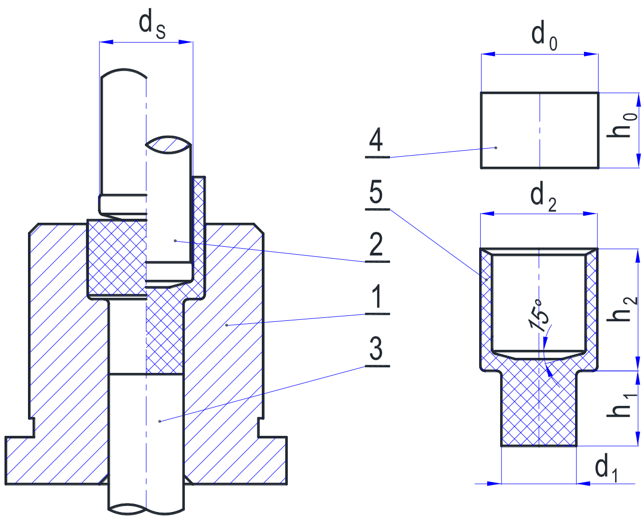

Fig.1 The scheme of combined extrusion of aluminium stampings using conical punch:
1 – die; 2 – flat-conical punch; 3 – ejector; 4 – billet; 5 – die stamping.

2. METHODS AND TEST RESULTS

The objective of this study is to perform experiments relating to combination extrusion of aluminium parts for varied values of relative deformation in forward and backward directions. The experimental studies of the combination extrusion process were conducted on the test unit composed of a ZD 100 testing machine with 1 MN impact, combination extrusion tool, and a computer station for measuring forces and displacement in plastic forming POM 16. The combination extrusion die set was developed based on the backward extrusion die. The test unit was modernized to suit the contemplated needs by designing and manufacturing punch retainers, die holders, punches, die inserts, ejectors, columns and guide sleeves. These changes allowed producing extrusions with a sleeve-cylinder shape. As the slug for the combination extrusion process, aluminium discs A1 99.5% (ENAW-1050A) were used, softened, with external diameter d_0=24.95mm and height h_0=16mm. **Table 1** shows the mechanical properties of the feedstock used in the tests. The material properties were determined based on the results of the static tensile test conducted to PN-EN 10002-1+AC1 [12].

Table 1 Aluminum A1 99,5% (ENAW-1050A) properties.

Material	$R_{0,2}$ [MPa]	R_m [MPa]	A [%]	$A_{11,3}$ [%]	Z [%]
A1 99,5%	24	82	46	34	86

The experimental studies were carried out for flat die inserts, with punches with bullet-shaped nose and the punch front part inclination angle of 15°. The dimensions of the extrusions were the following:

- for the upper part of the extrusion formed in backward direction, external diameter d_2=25mm=const, while internal diameters (punch diameter) d_s=15, 17, and 19mm,
- diameters of the bottom part of the extrusion formed in forward direction are d_1=12, 14 and 16mm, respectively.

The assumed dimensions of the input material and extrusions allowed obtaining the following degrees of relative deformations:

- consecutively for the backward extrusion

$$\varepsilon_2 = d_S^2/d_0^2 = 0.36;\ 0.46;\ 0.58 \qquad (1)$$

- for forward extrusion

$\varepsilon_1=(d_0^2-d_1^2)/d_0^2=0.77;\ 0.69;\ 0.59.$ (2)

The increase in the relative deformation ε_2 in the backward direction reduced the thickness of the extrusion sleeve part, whereas the decrease in deformation ε_1 led to the increase in the cylindrical part of the extrusion in the forward direction. It was assumed that the maximum height of the cylindrical part of the extrusion formed in forward extrusion was h_1 = 14mm due to the design of the test die. This value restricted further movement of the material in the forward direction because of the ejector used in the tests.

The tests began for the flat insert with constant relative deformation ε_1=0.77=const (d_1=12mm) in the forward direction. The use of flat-conical punches (15°) with varied diameters of the working parts allowed obtaining various values of relative deformations in the backward direction, ε_2=0.36; 0.46; 0.58. The tests were conducted with no lubrication applied. **Figure 2** shows the plots of the impact applied by the punch as a function of displacement.

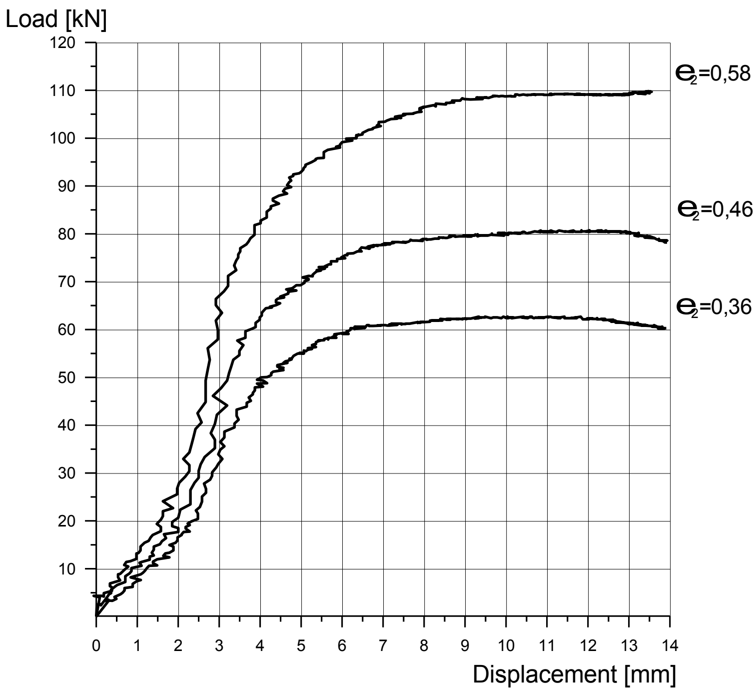

Fig. 2 The stress of the punch as a function of displacement during combined extrusion for different degrees of backward deformation ε_2 and constant value of forward extrusion ε_1=0,77 (d_1=12mm).

The traces of forces shown in **figs. 3** and **figs. 4** were plotted for different relative deformations ε_1 in the forward direction. In fig. 3, the deformation value was taken to be ε_1=0.69 (d_1=14mm), with ε_1=0.59 (d_1=16mm) in fig. 4, which was possible owing to increased diameter of the die insert d_1 from ø12 mm to ø14mm and ø16mm, respectively.

The extrusion process was conducted for the punch displacement s=14mm. The final displacement measurement was made using a dial indicator, whose plunger moved perpendicularly to the bottom surface of the upper die plate. This allowed the measurement of the end part of the punch displacement to an accuracy of 0.01mm. Ending the process earlier was associated with reaching the ejector by the material moving in the forward direction, which caused a rapid rise in impact values. From this moment the extrusion process would be conducted as backward extrusion.

The analysis of forces presented in figs. 2, 3 and 4 indicates that in the first stage of the combination extrusion process, a rapid gain in the values of impact occurs as a function of the punch displacement. Then, the forces become stable. For ε_2=0.36, in the final stage of the process, the forces decrease irrespective of the value of relative deformation ε_1 in the forward direction. It is also obvious that the drop in the punch impact force at the final stage is higher for lower values of relative deformations ε_1 in the forward direction (fig. 3 and fig. 4, ε_2=0.36). For ε_2=0.58 in the final stage of the extrusion process, a rise in the impact forces is observed for relative deformation ε_1=0.77 and ε_1=0.69.

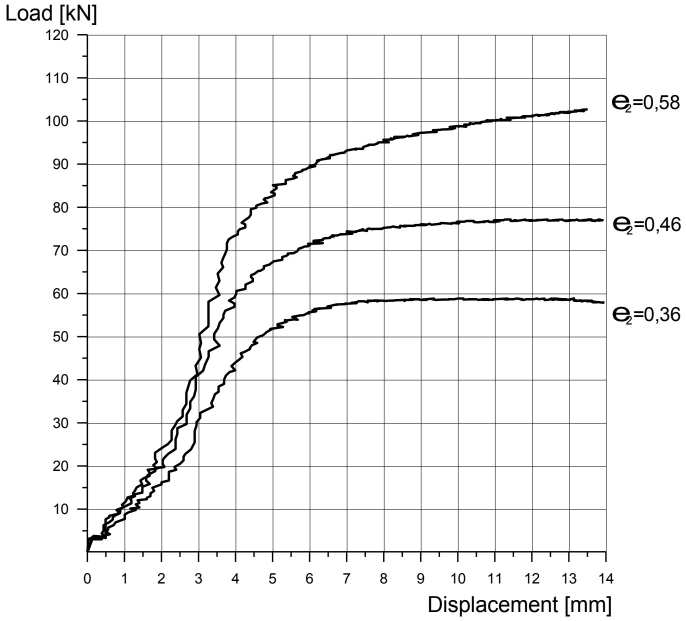

Fig. 3 The stress of the punch as a function of displacement during combined extrusion for different degrees of backward deformation ε_2 and constant value of forward extrusion ε_1=0,69 (d_1=14mm).

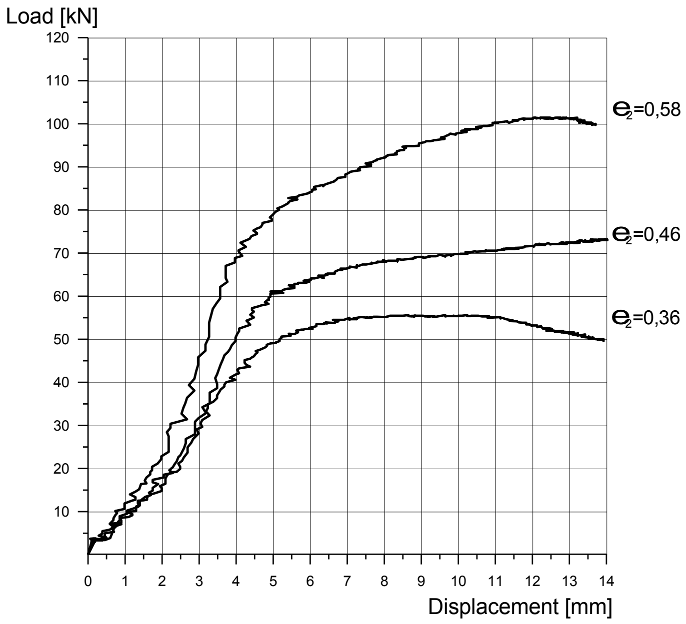

Fig. 4 The stress of the punch as a function of displacement during combined extrusion for different degrees of backward deformation ε_2 and constant value of forward extrusion ε_1=0,59 (d_1=16mm).

In combination extrusion, the increased relative deformation ε_2 in the backward direction leads to the increase in impact force values. For ε_1=0.77 and ε_2=0.36 (fig. 2), maximum impact force value is 62kN. Increased relative deformation ε_2 in the backward direction causes the values of the forces to rise by 30% (for ε_2=0.46) and 76% (for ε_2=0.58). Increased impact force values result from greater hardening of the material.

In combination extrusion, a significant influence on the value of impact forces at the same relative deformation ε_2 in the backward direction is exerted by deformation ε_1 in the forward direction. For ε_2=0.46=const and ε_1=0.59, the maximum impact force is 73kN (fig. 4). Increasing the relative deformation ε_1 from 0.59 to 0.69 and 0.77 at ε_2=0.46=const results in the increase in the maximum impact force of 6% (fig. 3) and 11% (fig. 2).

CONCLUSION

The following conclusions can be drawn based on the findings from the tests conducted on aluminium parts extruded in combination extrusion. The increase in relative deformation ε_2 in the backward direction causes higher impact forces. The increase in diameter d_1 of the die insert and thus reducing relative deformation ε_1 in the forward direction causes reduction in the impact forces for the same values of relative deformations ε_2. Note that the results from the experimental studies presented here showed the advantages of the combination extrusion process relative to forward and backward extrusion processes, as well as expanded the knowledge of the combination extrusion process. Forming of products in combination extrusion eliminates the need to conduct two operations, where the cylindrical part of the extrusion is made in the forward extrusion process and the sleeve part of the extrusion is made in the backward extrusion process. Combination extrusion reduces the cost and effort necessary to manufacture the tools and has a significant positive influence on the durability of the tooling.

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