The influence of relative rolling reduction of sheet metal on the changes of deep drawing forces in multi drawing steps for cylindrical drawpiece without collar made from EN AW-1050A aluminium

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Abstract. The paper presents experimental results of investigations on deep drawing process of cylindrical drawpieces without collar in four drawing steps (single draw and three redraws). The research involved the use of EN AW-1050A aluminium blanks with diameter D = 66 mm. The material was prepared by rolling with different relative rolling reductions (z = 5%; 10%; 15% and 20%, respectively) at rolling mill *DUO-100* and blanking process. In investigations of deep drawing, experimental force waveforms as the function of displacement for different relative rolling reductions of sheet metal made from aluminium were obtained.

1 Introduction

The indirect application of the drawing force during each draw is a characteristic of all deep drawing processes. The force necessary to cause deformation is not applied directly to the deformation zone, but to the punch which transmits it to the bottom of the cylindrical drawpiece, and then it is transmitted by the cup walls to the deformation zone [1].

Cold deep drawing of cylindrical drawpieces made from aluminium and aluminium alloys and the design of the tooling have been reported in some studies [2-8]. Those covered both experimental and computer modeling investigations. Moshksar et al. [2] examined the effect of the punch and die profile radii on the drawing load and formability of aluminum sheet metal. Based on the experimental data obtained, the maximum punch force for aluminium cup drawing is proposed. Chałupczak et al. [3] discussed the influence of cold work ratio of EN-AW 1050A aluminium on selected parameters in deep drawing. In their studies, they highlights that more than 12 % cold work ratio of tested aluminum sheets improve the quality of drawing. By means of both numerical simulation (LS-DYNA3D) and experiment, using two typical parts in aircraft made from 2B06 aluminium alloy (China brand), Lang et al. [4] proposed optimization of the key parameters of hydromechanical deep drawing process. Dwivedi et al. [5] presented a review on the deep drawing parameters and identified directions for future research of process. They presented result of study formed the successful aluminium alloys (AA 1200) cup by conical die. Tenner et al. [6] numerically and experimentally analyzed dry deep drawing process of AA 6014 aluminium. In paper [7], Hattali et al. showed recent technological advances of sheet metal forming processes. Fischer et al. [8] proposed system and control algorithm which are able to determine the part quality based on the draw-in directly after the first drawing step for kitchen sink.

The paper presents experimental results for deep drawing process of cylindrical drawpieces without collar made from EN-AW-1050A in four drawing steps. The investigations aimed to determine impact of the relative rolling reduction of sheet metal on the changes of forces. The degree of deformation of material was defined as the relative rolling reduction *z* [9]. The relative rolling reduction *z* was given by formula [9]:

$$z = \frac{s_0 - s_1}{s_0} 100\% \tag{1}$$

where:

s_0 – thickness of material (sheet) before deformation,
s_1 – thickness of material (sheet) after deformation.

2 Methodology

The material for experimental investigations of deep drawing were EN AW-1050A aluminium blanks whose diameter is 66 mm (*D*) and thickness are s_0 = 1 mm; 0.95 mm; 0.90 mm; 0.85 mm and 0.80 mm (which corresponded to relative thickness s_0/D = 0.0151; 0.0144; 0.0136; 0.0129 and 0.0121, respectively).

First, a belts of sheet with thickness s_0 = 1 mm, width b_s = 72 mm and length l_s = 300 mm were rolled with different relative rolling reductions (*z* = 0%; 5%; 10%; 15% and 20%, respectively). The cold longitudinal rolling process was conducted at laboratory rolling mill *DUO-100*. The rolling mill has two mill rolls at diameter equals 102 mm. The relative rolling reduction of sheet *z* = 0% denotes deformation for starting material without rolling. Next, the blanking process was performed at the *ZD 100* testing machine with the blanking die. *ZD100* testing machine was modified by LABORTECH firm. The machine is compliant with metrological requirements for Class 1 and was calibrated as per PN-EN ISO 7500-1:2005. Finally, the deep drawing process was conducted at a special stand which included the following:

– A laboratory press-forming die for deep drawing of cylindrical drawpiece equipped with replaceable dies and punches. Figure 1 shows diagram of the main parts of the tool and table 1 presents dimensions of punches and dies used in investigations (where d_s denotes the diameter of the punch, d_m – the diameter of the die, r_s – the radius of the punch and r_m – the radius of the die, respectively);
– LabTest5.20SP1 testing machine (LABORTECH firm) with 20 kN force. Machine was calibrated by PN-EN ISO 7500-1:2005 and meets the metrological requirements for class 0.5;
– A computer stand with Test&Motion software (LABORTECH) to measure forces and displacements.

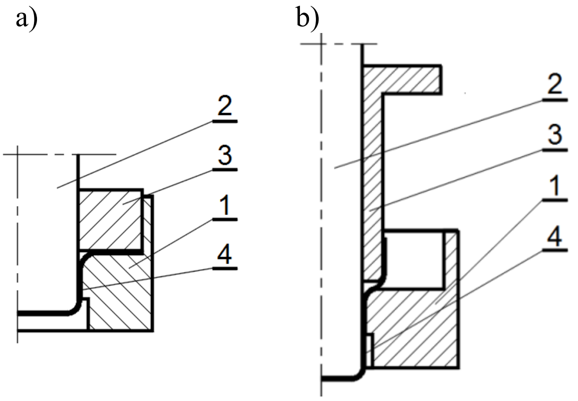


Figure 1. Diagrams of the main parts of deep drawing tools used in investigations: a) tooling for single drawing (where 1- die, 2 – punch, 3 – blank-holder, 4 – drawpiece); b) tooling for redrawing (where 1- die, 2 – punch, 3 – pilot sleeve, 4 – drawpiece).

Figure 1 shows a schematic setup of two drawing steps: first draw and first redraw. The first draw produces cylindrical drawpiece from a flat blank. During each redraw the diameter of the cup is decreased while its height is increased. In experimental investigations, the blank-holder for first drawing was used, because the condition $\frac{s_0}{D} \leq 0.02$ from literature [10] has been met.

Table 1. Dimensions of punches and dies used in investigations (mm)

	Drawing	*First redrawing*	*Second redrawing*	*Third redrawing*
$\mathbf{d_s}$	35.5	26.5	21.5	17.5
$\mathbf{d_m}$	38	29	24	20
$\mathbf{r_s}$	5	3	3	3
$\mathbf{r_m}$	5	3	3	3

EN AW-1050A aluminum was selected as the testing material in these investigations due to its good formability and wide applications in industry [11,12]. The mechanical properties of the material were determined by static tensile testing [13]. Tensile test was conducted on LabTest5.20SP1 testing machine. The stress characteristics were given as a function of the relative strain $\Delta l/l_0$ (where Δl denotes the punch displacement and l_0 – initial length of the measuring part of the sample, respectively) for different relative rolling reductions of material (*z)* after rolling (figure 2).

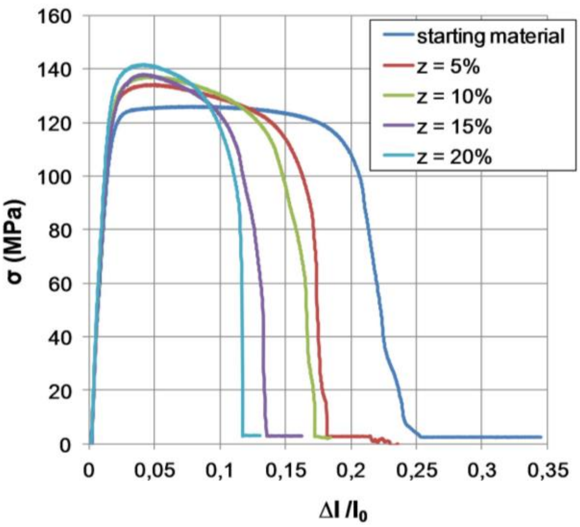


Figure 2. Stress vs. relative dispacement $\Delta l/l_0$ obtained for samples made from EN-AW 1050A aluminium for different relative rolling reductions *z* in tensile test.

The mechanical properties of material were defined by tensile strength R_m and percentage elongation after fracture *A*. The effect of the relative rolling reductions *z* on tensile strength R_m obtained for samples made from EN-AW 1050A aluminium is shown in figure 3. The data shown in figure 3 suggest that the relative rolling reductions have a considerable influence on the values of tensile strength R_m calculated on the basis of the static tensile test. As can be seen from figure 3, an increase in the relative rolling reduction *z* from 0% to 20% causes an increment in the tensile strength R_m of material. The values of R_m obtained for ratios *z* = 0% (starting material without rolling), *z* = 5%, *z* = 10%, *z* = 15% and *z* = 20% were: 126 MPa; 134 MPa; 137 MPa; 138% and 142 MPa, respectively. The relative increase in the tensile strength R_m for the specimens at *z* = 0% (material before deformations) and *z* = 20% was approx. 13 %.

The effect of the relative rolling reduction *z* on percentage elongation after fracture *A* obtained for samples made from EN-AW 1050A aluminium is shown in figure 4. The values of *A* obtained for relative rolling reductions *z* = 0% (starting material without rolling), *z* = 5%, *z* = 10%, *z* = 15% and *z* = 20% were 18.3 %; 14.8 %; 13.6 %; 10.2 % and 7.4 %, respectively. The percentage elongation after fracture *A* decreased as the ratio *z* rose.

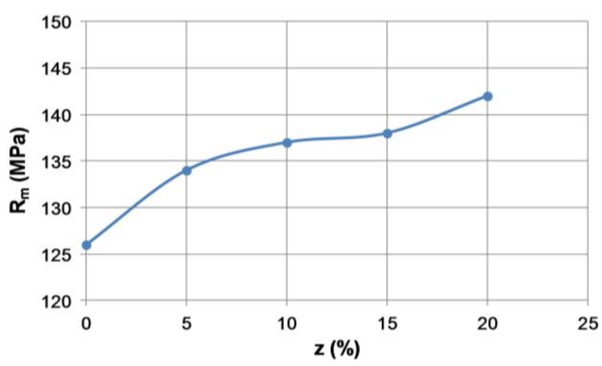


Figure 3. The effect of the relative rolling reduction of material z on tensile strength R_m for samples made from EN-AW 1050A aluminium.

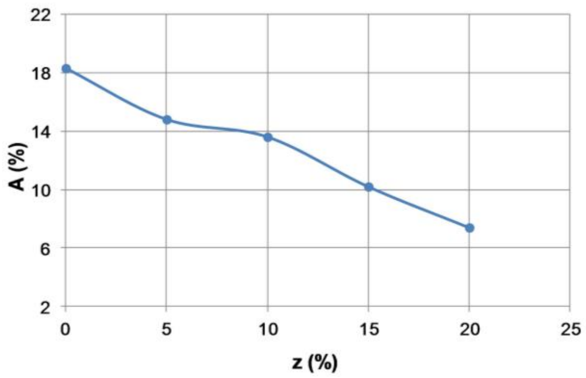


Figure 4. The effect of the relative rolling reduction of material z on percentage elongation after fracture A for samples made from EN-AW 1050A aluminium.

The results indicate that change of mechanical properties (increase of tensile strength R_m and decrease of the percentage elongation after fracture A) of samples made from EN-AW 1050A is related to strain hardening of material after cold deformation (longitudinal rolling).

3 Results and analysis

In the experimental investigations, cylindrical drawpieces in four drawing steps were formed. For the assumed coefficients of deep drawing successful tests were conducted (table 2).

Table 2. Total coefficients of deep drawing assumed in investigations for four drawing steps

m_1	m_2	m_3	m_4
0.57	0.76	0.82	0.83

In table 2, total coefficients of deep drawing (m_n) for each drawing step is given by a formula (2) [10]:

$$m_{1..n} = \frac{d_n}{d_{n-1}} \qquad (2)$$

where:

d_n – diameter of drawpiece (in the middle of thickness) i.e., for drawing d_n equals d_1 as a diameter of drawpiece obtained for first step of drawing, (mm)

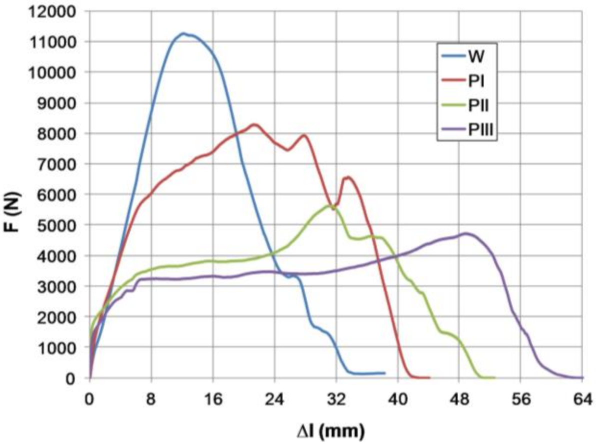
d_{n-1} – a diameter of initial material i.e., for drawing d_0 equals D as a diameter of the blank and for redrawing d_{n-1} is diameter of drawpiece (in the middle of thickness) from previous drawing step (mm).

Examples of cylindrical drawpieces at $d_4 = 19^{\pm 0.1}$ mm and $h_4/d_4 = 2.54 \div 2.81$ (where d_4 denotes a diameter of drawpiece in the middle of thickness for third redrawing and h_4 denotes minimum height of drawpiece for third redrawing) obtained in last step (at coefficient of third redrawing - $m_4 = 0.83$) of experimental investigations are presented in figure 5.

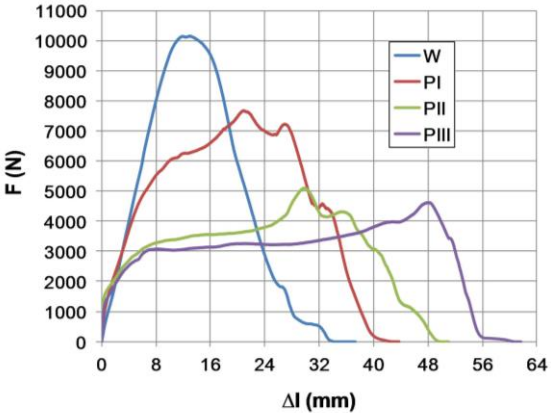
The investigations produced force profiles in deep drawing of EN-AW 1050A aluminum drawpieces for different relative rolling reductions of sheets (figure 6). Force waveforms as the function of displacement for different drawing steps and the relative rolling reductions of sheet metal made from aluminium were very similar in character.

Figure 5. Examples of cylindrical drawpiece without collar made from EN-AW 1050A aluminium at coefficient of deep drawing m_4 = 0.83 with different wall thickness obtained in experiment.

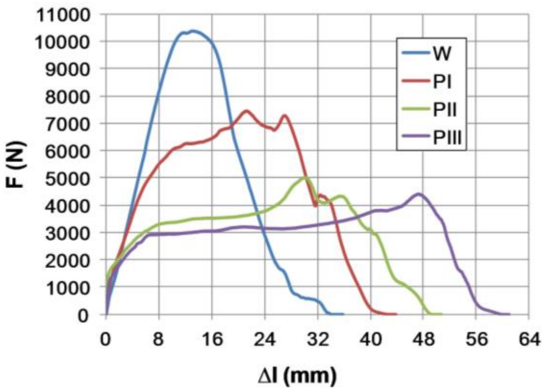
a)



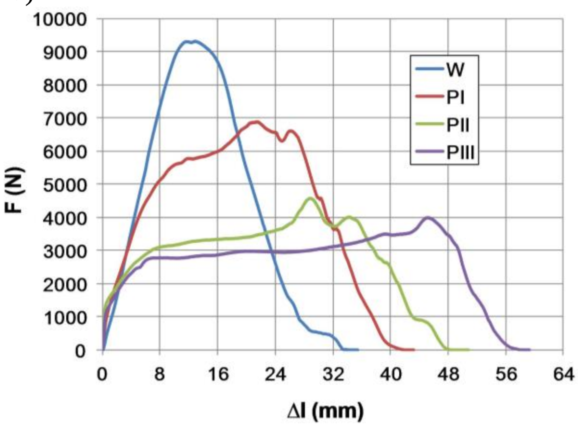
b)



c)



d)



e)

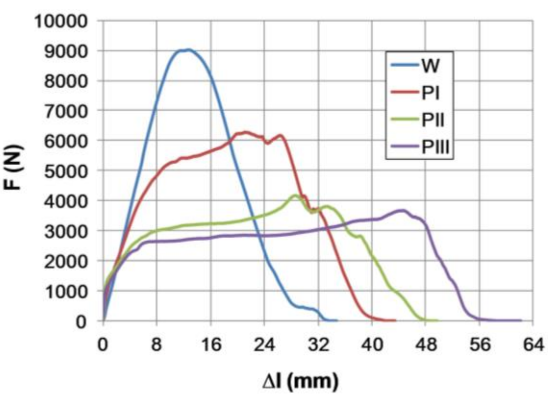


Figure 6. The force (*F*) vs. displacement (Δl) obtained for different relative rolling reductions of aluminium sheets in deep drawing process of cylindrical drawpieces without collar in four drawing steps (where: W - single drawing, PI – first redrawing, PII – second redrawing, PIII - third redrawing):

a) starting material at s_0 = 1 mm
b) z = 5% at s_0 = 0.95 mm,
c) z = 10% at s_0 = 0.90 mm,
d) z = 15% at s_0 = 0.85 mm,
e) z = 20% at s_0 = 0.80 mm.

Investigations have revealed that during deep drawing process, the maximum values of force change depending on the displacement of the punch -Δl (or height of drawpiece) for subsequent drawing steps (figures 6). Displacement of the punch -Δl_1 at which forces obtain maximum values in relation to the total distance -Δl during deep drawing were: $\Delta l_1/\Delta l$ = 0.3÷0.45 for first drawing (*W*), $\Delta l_1/\Delta l$ = 0.5÷0.6 for first redrawing (*PI*) and second redrawing (*PII*) and $\Delta l_1/\Delta l$ = 0.7÷0.8 for third redrawing (*PIII*), respectively. This analysis confirmed the study conclusions regarding changes of deep drawing forces in multi drawing steps for cylindrical drawpieces without collar made from DC01 steel, Cu-ETP copper, CuZn37 brass and EN-AW1050A aluminum for relative rolling reductions z = 0%; 12% and 24% [3].

4 Conclusions

The following conclusions were drawn from investigations into deep drawing of EN-AW 1050A aluminium drawpieces for different relative rolling reductions of sheets:

1. It was possible to conduct deep drawing of aluminium cylindrical drawpieces in four drawing steps without intermediate annealing for assumed total coefficients of deep drawing (m_n), both for small and high relative rolling reduction of sheet. It is confirmed by successfully performed tests for drawpieces with a large slenderness at z = 0% and z = 20%.
2. Force waveforms as the function of displacement for different drawing steps and relative rolling reductions of sheet metal made from aluminium were very similar in character.
3. The relative rolling reduction of sheet have a considerable influence on the values of tensile strength R_m and the percentage elongation after fracture *A*. An increase in the relative rolling reduction *z* from 0% to 20% causes an increment in the tensile strength R_m of material. The percentage elongation after fracture *A* decreased as the ratio *z* rose.

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