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Some aspects regarding the equipment and machinery used in sheet metal deep drawing – Part Two

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Abstract. In a previous study, the press and the devices mounted on it were presented, which enabled the determination of the forming force values as well as the blank holder force in the deep drawing of small cylindrical parts made from A3k steel strip. Given this significant material investment, the previously initiated study was continued. Thus, the present paper describes the dies and equipment used, as well as the values of the above-mentioned parameters, but for two other types of materials: brass and deep drawing steel.

1. Introduction

Open-type double-action presses are recommended for use with dies that enable deep drawing of small parts. The components studied in this work were produced using a dynamometric die with quickly interchangeable active elements [2], mounted on a PAI 16 eccentric mechanical press [1]. In the previous study, A3k steel strip was used, while in the present work, results are presented for two other types of sheet material: deep-drawing steel and brass. All blank materials were in strip form, obtained by slitting cold-rolled sheets. These strips had a thickness of 0.4 mm ± 0.05 mm [5] and a width of 22 mm. All parts were cylindrical with a flange, featuring a flat base connected to a vertical wall.

The die was designed and constructed to allow the integration of a dynamometric sensor, which was mounted in the hole of the press table [2]. The blank holding force was applied directly by securing the blank product on the die. The sensor enabled the measurement of both main forces involved in the forming process: the drawing force and the holding force. An inductive displacement transducer [6] was mounted on the press ram. The signals collected from the transducer (indicating horizontal spot deviation) and from the force sensor (indicating vertical spot deviation) were amplified using an electronic strain gauge and transmitted to an oscilloscope for visualization. Thus, the force–displacement diagram (F–h) of the drawing force over the working stroke could be observed on the oscilloscope screen.

2. Case study

Once the active elements were designed ([3], [4]) and manufactured, along with the quick-change die, the dynamometric sensor, and the stand for collecting force and displacement data for the purpose of studying the deformability of A3k blank material, the research was continued using two other types of materials in order to make efficient use of these investments. The ultimate goal is to make an optimal material selection based on the part's shape and intended function, in order to obtain high-quality products.

Regardless of the type of blank material, the deep-drawn parts were formed with intentional thinning of the material thickness, with a clearance of 0.24 mm between the active elements. The punches were designed with a 2 mm fillet radius, and the die plate with a 2.5 mm radius. Following the calibration of the dynamometric sensor, the following equations were obtained for the drawing force F and the blank holding force Q::

$$F = 77{,}647 + 52{,}0613 \cdot U - 0{,}763 \cdot U^2; \quad (1)$$

$$Q = 77{,}647 + 104{,}1226 \cdot \varepsilon - 3{,}052 \cdot \varepsilon^2 , \quad (2)$$

here, ε [µm/m] denotes the strain value read from the electronic strain gauge for different load values F [daN], while U represents the voltage passing through the conductor. Following the calibration of the memory oscilloscope and the electronic strain gauge, it was determined that a strain of 10 µm/m corresponds to a voltage of 20 V. Consequently, the strain was calculated using the following equation:

$$\varepsilon = 0{,}5 \cdot U. \quad (3)$$

2.1. The A5 deep-drawing steel strip is aluminum-killed and contains 0.013% sulfur, 0.018% phosphorus, 0.26% manganese, 0.01% silicon, and 0.015% carbon [5]. The tensile test results showed the following mechanical properties: elongation A_{80} = 43.5%, tensile strength Rm = 312 N/mm², and yield strength $Rp_{0.2}$ = 220 N/mm² [5].
Table 1 presents the values of the punch and die diameters (d_p and d_m), the heights of the deep-drawn parts (h), the clearance between the punch and the die plate (j), the strain (ε), the voltage (U), the drawing coefficient (m), as well as the experimentally determined values of the blank holding force (Q) and the drawing force (F).

Table 1. Experimental conditions and results obtained from the deformation of A5 deep-drawing steel strip

Nr exp	The Punch	The drawing die insert	j/2 [mm]	Q [daN]	ε [µm/m]	U [V]	F [daN]	h [mm]	m
	d_p [mm]	d_m [mm]							
1.	5.52	6	0.24	0	0.0	1.9	173.8	4,2	0.56
2.	8.02	8.5	0.24	25.15	34.6	3.2	236.4	4.1	0.61
3.	10.52	11	0.24	7.78	34.8	4	273.7	4	0.65

The following steps are required to conduct the experiments:

- Mounting the active elements in the die, corresponding to each experiment;
- Applying the lubricant to the surface of the blank product and inserting it into the die;
- Adjusting the punch stroke position to achieve the desired part height;
- Calibrating the electronic strain gauge and the oscilloscope for measurement purposes;
- Applying the force necessary to achieve optimal blank holding pressure;
- Zeroing the electronic strain gauge, followed by initiating the punch stroke and then removing the deep-drawn part from the die;
- Reading the drawing force value, which is recorded on the oscilloscope;
- Measuring the height of the part, as obtained experimentally.

Fig.1 A5 Steel Deep-Drawn Part

The A5 steel parts obtained from the experiments are shown in Fig. 1. Figures 2 and 3 present the blank holding force vs. punch stroke diagrams, captured from the oscilloscope screen, for the first two experiments.

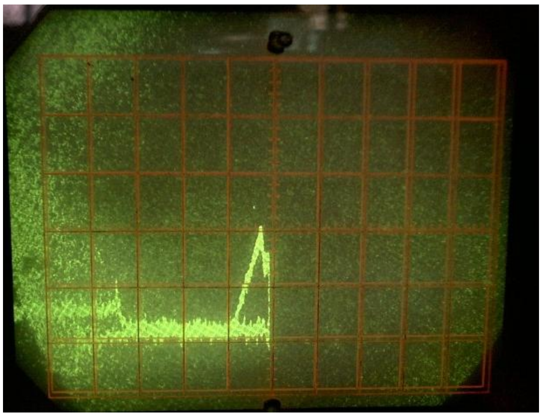


Fig.2 F-h diagram for experiment 1

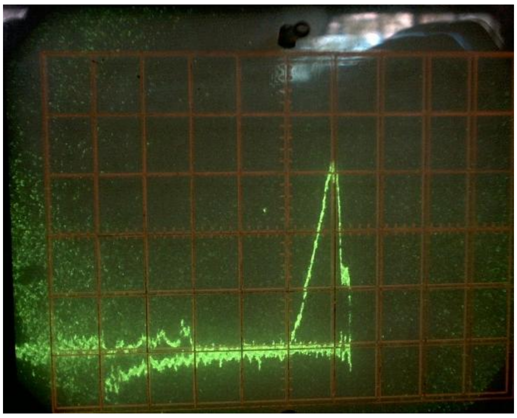


Fig.3 F-h diagram for experiment 2

2.2. The CuZn30-O brass deep-drawing strip contains 0.02% aluminum, 0.05% lead, 0.05% manganese, 0.05% tin, 0.1% iron, and 30% zinc [5]. The tensile test yielded the following results: elongation A_{80} = 45%, tensile strength Rm = 295 N/mm² [5].
Table 2 presents the same parameters as in Table 1, some of which were predetermined, while others were obtained experimentally.

Table 2. Experimental conditions and results obtained from the deformation of CuZn30-O strip

Nr exp	The Punch	The drawing die insert	j/2 [mm]	Q [daN]	ε [µm/m]	U [V]	F [daN]	h [mm]	m
	d_p [mm]	d_m [mm]							
1.	5.52	6	0.24	0	0.0	1.4	149.04	4,3	0.56
2.	8.02	8.5	0.24	25.15	34.6	2.1	183.61	4.1	0.61
3.	10.52	11	0.24	7.78	34.8	3,4	245.84	4,5	0.65

Fig.4 Brass Deep-Drawn Part

The brass parts obtained from the experiments are shown in Fig. 4. Figures 5 and 6 display the drawing force vs. punch stroke diagrams, captured from the oscilloscope screen, for the first two experiments.

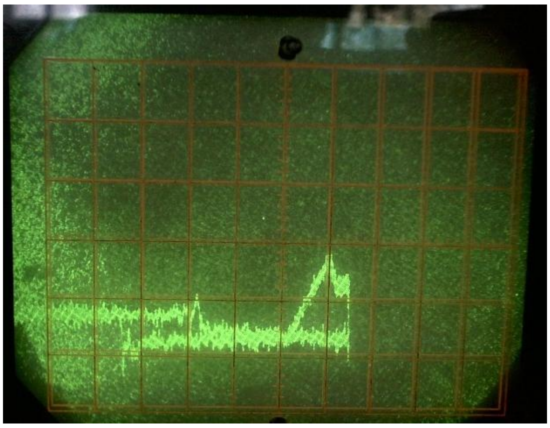


Fig.5 F-h diagram for experiment 1

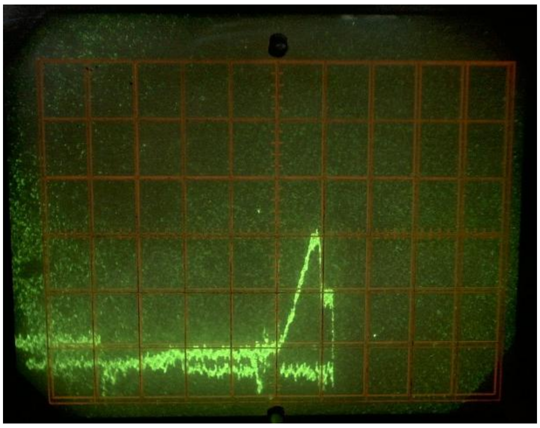


Fig.6 F-h diagram for experiment 2

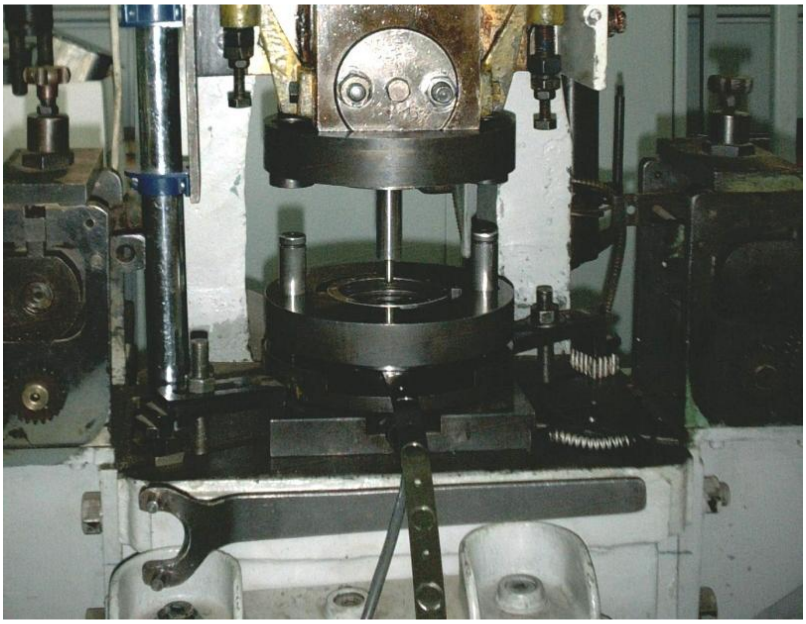
3. Active Tooling Components and Equipment Used

As previously mentioned, the punches are designed with a fillet radius of 2 mm, while the die plates have a radius of 2.5 mm. These components were made from tool steel containing approximately 0.8% carbon and were subsequently subjected to a heat treatment sequence consisting of hardening followed by high-temperature tempering, resulting in hardness values of 50–54 HRC (Rockwell Hardness Scale). The punch diameters, specified in the previous tables, have a tolerance field of $d^{0}_{-0,006}$. Similarly, the diameters of the die plates, also previously mentioned, have a tolerance field of $D_{0}^{+0,009}$.

a) b) c)

Fig. 7 Active Tooling Elements for Deep Drawing – Examples

The contact surfaces of the active elements, which interact with the deforming blank, were ground to a fine finish after heat treatment. The blank holder ring was manufactured from low-alloy tool steel containing 12% chromium. It also underwent hardening and tempering, and measurements showed a hardness of 42–45 HRC.
Figure 7 presents examples of the above-described active components used in the deep drawing process, namely: (a) blank holder ring, (b) die plate, and (c) drawing punch.
Figure 8 illustrates the dynamometric die equipped with quick-change active elements, mounted on the eccentric mechanical press, along with the processed strip blank.



4. Conclusions

This study presented the press, the die with quick-change active elements, and the dynamometric sensor, which were used in the forming of the parts. Together with the measurement stand, these components enabled the analysis of the deep drawing process for small cylindrical parts, as demonstrated by the recorded values of the drawing and blank holding forces, as well as the F–h diagrams.
The experiments were carried out on two different types of materials, with the blank products being in the form of deep-drawing steel strip and brass strip. According to the results of the first two experiments, the parts produced from both materials met the 'manufacturing quality' criterion, namely the preservation of the metal's fiber continuity. The high drawing force values observed in experiment 3 for both materials indicate that the parts fractured during forming.
Future work aims to continue the study of drawability by developing new sets of active elements with varying clearances, in order to assess the influence of this factor on the formability of the materials.

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