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Aspects regarding the quality of drawn parts

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Abstract. This paper analyzes the fact that the parts obtained through drawing processes are characterized by a quality resulting from the interaction of two factors: the technological system and the processing process. All these three elements are influenced by a multitude of factors, which will be analyzed. Furthermore, an analysis of the thickness accuracy of an A3K steel strip mirrored in obtaining the thickness frequency histogram will be presented, as this represented a factor influencing the drawing force in the production of small cylindrical parts.

1. Introduction

The quality of the drawn parts refers to their manufacturing quality. First of all, a quality piece must be characterized by the physical continuity of the material and meet the purposes for which it was designed and manufactured. This manufacturing quality of the drawn parts results from the interaction between the components of the technological system and the parameters of the cold plastic deformation processing process. Their quality is imposed by the mechanical and physicochemical characteristics of the semi-finished material, respectively of the finished product and is reflected in the roughness of the surfaces, the precision of the relative position of the surfaces, the precision of the shape of these surfaces, the dimensional precision of the piece and last but not least the absence of cracks or breaks.

2. Analysis of the factors determining the quality of a piece processed by drawing

The influence of the characteristics of the semi-finished material is noted by the following aspects:

a) The nature of the metallic material, which can be ferrous (steels) or non-ferrous (copper and copper alloys (simple brass, argentan), aluminum and aluminum alloys, zinc);
b) The type of semi-finished product, which can be cut from sheet metal in the form of individuals that present different configurations depending on the shape of the drawn piece or slitted from sheet metal in the form of a band, which can be intact or with cuts (notched, with perforation of the intermediate bridge, with perforation of the intermediate bridge and marginal cut);
c) The shape of the semi-finished product, which can initially be flat or hollow, when it is desired to continue the deformation through subsequent operations, with the aim of increasing the height of the part while decreasing its circumference;
d) The delivery status of the semi-finished product, which can be soft (annealed) or with different degrees of hardening (1/4 hard, ½ hard, hard), some non-ferrous alloys can be hardened and aged naturally or artificially [5].
e) In the case of steel semi-finished products, the carbon content, possible alloying elements, and accompanying elements resulting from the elaboration are important. Thus, with the increase in carbon content, there is an increase in mechanical characteristics (resistance, hardness) and

a decrease in plasticity (elongation, necking). Alloying elements must be kept within certain limits as they determine the decrease in plasticity, which will lead to a decrease in the degree of plastic deformation. Any non-metallic inclusions have negative effects, as they are sources of crack initiation. Accompanying elements resulting from the elaboration (oxygen, nitrogen, sulfur, phosphorus) must be at the minimum permissible values, as they worsen plasticity. It is recommended to use calmed steels, In the conditions of using a minimum percentage of silicon.

f) The metallographic structure needs to be fine and uniform, to favor the attainment of uniform deformations. Ferrite and ferrite-pearlitic structures are preferred [4].
g) It is advisable for the sheets intended for drawing to be subjected to the cold rolling process with sexto rolling mills or with more cylinders (which ensure a reduction in thickness of 2%) with the aim of avoiding the appearance of surface cracks.
h) In the case of drawings with a high degree of deformation, it is necessary to meet the following conditions:
   - Yield limits and tensile strength to be small, and elongation at break and relative elongation to be increased;
   - The difference between the breaking strength limit and the yield limit to be appreciable or the ratio between the breaking strength and the yield limit to be small;
   - in the specialized literature there are calculation relations that allow the calculation of the yield limit depending on the carbon content and the relative degree of compression deformation or depending on the content of alloying elements [11].
i) A high degree of drawing will lead to the hardening of the material, which means an increase in mechanical characteristics (elasticity, tensile strength limit) and a decrease in corrosion resistance and electrical conductivity. The increase in mechanical characteristics is given by the fact that this accentuated cold plastic deformation determines a grinding of the crystalline grains.
j) The reduction of residual stresses in the drawing part is achieved by applying a stress-relieving annealing treatment at the end of processing, without affecting the hardness and strength characteristics [6]. It is important disposal these stresses from the material of the part, as they negatively influence the accuracy of the part over time

The roughness of the surfaces of the drawn piece is influenced by the following aspects:

a) A good quality of the surfaces of the semi-finished product will be reflected in the quality of the surfaces of the piece;
b) A roughness with small values of the surfaces of the active elements, as well as the retaining ring will positively influence that of the piece and will lead to the application of a higher degree of deformation [5];
c) Any impurities (hard oxides) on the active surface of the drawing die will worsen the roughness of the piece because they will generate scratches;
d) The nature of the lubricant, liquid or solid, mixed or not with graphite or molybdenum disulfide is chosen depending on the nature of the material subjected to processing and influences both the roughness of the surfaces of the piece and the level of tensions and deformations that arise from the material [1];
e) Coatings (galvanized sheet, tinned sheet) lead to the improvement of the quality of the surfaces of the drawn piece [3].

The precision of the relative position of the surfaces is influenced by the following aspects:

a) In the case of pieces obtained by successive drawing from the band, the precision of the relative position of the active elements, the die and the punch, is very important. Also, the precision with which the band is positioned in the die for each of the successive drawings from which the piece is obtained is also important [7].

b) In the drawing of individual semi-finished products, especially in the case of obtaining pieces with complex configurations, an important factor on the precision of the relative position of the surfaces is the number of successive drawing operations;
c) A determining factor in obtaining a good precision of the relative position of the surfaces is the existence of calibration operations [3].

The precision of the shape of the surfaces is influenced by the following aspects:

a) Considering that the shape of the piece results from copying the shapes of the active elements, the precision of the die elements and especially the punch becomes important ([5], [11]);
b) The value of the retaining force, keeping it throughout the process of transforming the flat semi-finished product into a drawn piece, as well as the uniformity of its application influences the precision of the shape of the finished product. The appearance of wrinkles in the wall of the piece is generated by the formation of undulations in the flange area, which arise when the retaining pressure is below the optimal value. These wrinkles are formed at the edge of the piece and under the conditions in which the retaining force is not applied until the ending of the process.
c) The more uniform the plastic deformations along the contour of the drawn piece, the smaller the shape deviations of the surfaces, especially in the case of rectangular or square boxes;
d) The residual stresses in the resulting piece influence the precision of the shape and can be eliminated by applying a stress relieving annealing treatment;
e) Shape deviations both in longitudinal section and transversely have as source the anisotropy of the material [11];
f) The elastic springback, which is specific to any drawn piece, is much larger in the case of pieces without a flange than those with a flange and increases with the diameter of the semi-finished product [5]. The elastic springback is influenced by the ratio between plastic and elastic deformations that occur in the piece during the deformation process [2]. The rigidity of the piece attenuates this phenomenon of springback.

Dimensional accuracy is influenced by the following aspects:

a) The dimensional accuracy of the die and the punch;
b) The precision of the relative position of the active elements [5];
c) The value of the clearance between the punch and the die and the uniformity of its distribution on the circumference of the piece; the dimensional accuracy is better for small clearance values.
d) The degree of wear of the active elements, which is related to the durability of the die; thus, in the case of a higher durability and the permissible degree of wear is higher, to the detriment of the dimensional accuracy of the finished piece.
e) The precision of the thickness of the semi-finished product, which must correspond to the highest class (C);
f) The dimensional accuracy of the semi-finished product, especially in the case of boxes or complex pieces;
g) The precision with which the semi-finished product is positioned in the die;
h) The number of successive operations necessary to obtain the piece; a large number of these operations decrease both, the dimensional accuracy and that of the relative position of the surfaces ([7], [11]).
i) The nature of the lubricant used, liquid or solid, applied directly to the metal surface or on a lubricant carrier layer, on the surface of the retaining ring or the active plate and the semi-finished product; the dimensional accuracy increases as the friction between the punch and the semi-finished product is reduced.
j) The anisotropy of the semi-finished material; the more the material has properties close in any direction, the deformations will be more uniform and the dimensional accuracy will thus be favored.

k) The delivery status of the semi-finished material; a semi-finished product in an annealing state presents a better plasticity, which leads to an increased dimensional accuracy.
l) The value of the retaining pressure and the uniformity with which it is applied to the flange of the semi-finished product; the maximum precision results in the case of applying the optimal size of the retaining pressure [3].
m) The calibration operation improves the dimensional accuracy;
n) The precision of the working stroke of the slider influences the precision of the height of the drawn piece [8]

Therefore, the closer the shape, relative position of the surfaces, effective dimensions of the drawn piece are to those prescribed in the execution drawing, it means that the finished product is of quality. However, if the dimensions, precision or roughness are appropriate, but the material has fissures, cracks or fractures, then the quality of the piece is compromised.
The physical continuity of the material of the drawn piece is influenced by the following aspects:

a) The metallographic structure of the material of the drawn piece; the finer the grain structure metallography, the higher the mechanical resistance [4]; a coarseness grain favors the appearance of cracks.
b) An accentuated hardening of the material during the deformation process can lead to the appearance of cracks;
c) Choosing too small values of the punch radius leads to a state of tensions and deformations at bending too large, which can determine a significant thinning of the material, a considerable hardening and finally the appearance of cracks or breaks at the base of the piece [3];
d) Adopting too high working speeds, as well as its variation during deformation determines a significant embrittlement of the material, an aspect that leads to the appearance of cracks [8];
e) The use of drawing forces larger than those that the wall of the piece can take when the semi-finished product is pulled into the drawing plate by the punch. The high values of the drawing force that can lead to the breaking of the pieces can be caused by improper lubrication, a too high degree of drawing, a retaining pressure above the optimal value, or a low plasticity of the material subjected to deformation [11].

3. Case study

From the multitude of factors presented that influence the quality of a drawn piece, a study was conducted on the influence of the precision of the semi-finished product’s thickness on the drawing and retaining forces in the case of processing small cylindrical pieces from recooked steel A3k sheet strips of 0.4mm thickness. The A3k-Galfinband strip for drawing is calmed with aluminum, has a carbon content of 0.05%, 0.02% silicon, 0.012 phosphorus, 0.013% sulfur and 0.26% manganese. Following the tensile test, the following values of the tensile strength limit, yield limit and elongation were recorded: R_m = 359N/mm2, $R_{p\,0.2}$ =270 N/mm2, A_{80} = 36.6% ([14], [15]).
The dimensions of the active elements, the values of the drawing forces obtained from the simulation of the deformation process with the help of the MARC-Mentat 2003 software [13] and those recorded experimentally are presented in tab. 1. The radius of the punch was 2mm and that of the die/drawing plate was 2.5mm. The clearance between active elements, measured radially, was 0.24mm.

Tab. 1 Experimental conditions and results obtained in the drawing of A3k pieces

Nr exp	Punch	Die	j/2 [mm]	D_{semif} [mm]	h [mm]	m	$F_{measurement}$ [daN]	$F_{simulation}$ [daN]	$Q_{measurement}$ [daN]	$Q_{simulation}$ [daN]
	d_p [mm]	d_m [mm]								
1.	5.52	6	0.24	11	4	0.56	168.89	107,4	0,0	0,0
2.	8.02	8.5	0.24	17	4.1	0.57	245.84	184,9	25,1	20,9
3.	10.52	11	0.24	17	4.5	0.65	296.47	133,8	7,7	6,4

To see what is the influence of the precision of the semi-finished product's thickness, the frequency histogram of the thickness was constructed [12]. For this, the thicknesses were measured using a micrometer with a comparator with a precision of 0.002mm. Tab. 2 includes the observed thickness values x_i and the frequency of their appearance in the string of measured values, m_i.
The amplitude of the series of measurements is calculated ([9], [10]):

$$R = x_{max} - x_{min} = 0{,}101\text{mm}. \quad (1)$$

With the help of Sturges' relation, the number of classes/intervals of equal size is determined:

$$k = 1 + 3{,}322 \cdot \log n, \quad (2)$$

where n – the number of measurements, equal to 45. The result is k=6,49.
The amplitude of the class is determined by the relation:

$$a = R/k. \quad (3)$$

An amplitude of 0.015mm results.
With all these data obtained by measurement and calculation, tab.3 of the frequency of thickness values was constructed, in which were noted: x_{ci} – the average values of the class limits; f_i – the absolute frequency of the class; p_i – the relative frequency of the class.

Tab. 2 The measured values of the thickness of the A3k strip and their frequencies of appearance in the series of measurements

	ths., x_i	Frec., m_i	ths., x_i	Frec., m_i	ths., x_i	Frec., m_i	ths., x_i	Frec., m_i	ths., x_i	Frec., m_i	ths., x_i	Frec., m_i	ths., x_i	Frec., m_i
1.	0,404	2	0,419	1	0,438	2	0,451	1	0,468	1	0,486	1	0,499	1
2.	0,405	1	0,420	3	0,440	2	0,453	2	0,477	1	0,492	1	0,505	1
3.	0,406	2	0,421	1	0,441	3	0,456	1						
4.	0,409	2	0,424	3	0,445	1	0,458	1						
5.	0,410	1	0,425	2	0,448	1	0,463	1						
6.	0,417	1	0,429	4										
7.	0,418	1												
	f_i	10		14		9		6		2		2		2

Tab. 3 The frequency table of thickness values, for the A3k strip

Nr. Class, C_i	Class interval		X_{ci}	f_i	p_i	$\Sigma\, p_i$
	from	to				
1	0.404	0.419	0.4115	10	0.2222	0.2222
2	0.419	0.434	0.4265	14	0.3111	0.5333
3	0.434	0.449	0.4415	9	0.2000	0.7333
4	0.449	0.464	0.4565	6	0.1333	0.8667
5	0.464	0.479	0.4715	2	0.0444	0.9111
6	0.479	0.494	0.4865	2	0.0444	0.9556
7	0.494	0.509	0.5015	2	0.0444	1.0000

The following statistical parameters were determined ([9], [10]):

a) the average value, which characterizes the central tendency of concentration of values,

$$\bar{x} = C + \frac{\sum_{i=1}^{k}(x_{ci} - C) \cdot f_i}{n}, \quad (4)$$

where: C – the thickness value with maximum frequency. It was obtained $\bar{x} = 0.4382$.

b) the dispersion σ, estimated with the S index calculated with Bessel's relation, which shows the tendency of scattering of thickness values compared to the central value $\bar{x}$

$$S^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{k} (x_i - \overline{x})^2 \cdot m_i, S = \sqrt{S^2}. \quad (5)$$

The result was S = 0,028.

From the documentation of the company that supplied the A3k material [15] it results that the thickness of the strip is 0.4±0.05mm.

Using the database provided by tab.3 and the fact that ths_{min} = 0.35mm and ths_{max} = 0.45mm, the frequency histogram was constructed in fig.1.

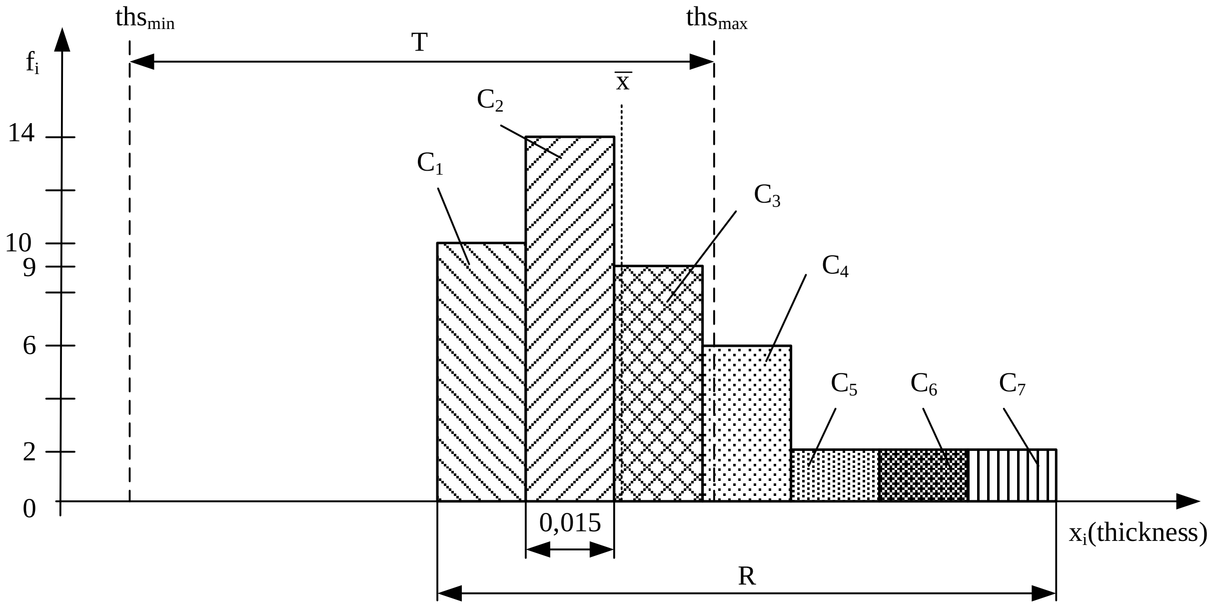

Fig.1 Histogram of the frequencies of the thickness of the A3K strip

Analyzing the obtained representation results in the following observations:

- the position of the maximum in the context of the histogram approaches the form "form with a left-sided notch" ([9]);
- the highest frequencies are the measured values that are close to the average value;
- positioning the tolerance field towards the left end of the histogram leads to the conclusion that the adjustment of the sheet rolling process was made towards the maximum thickness value. Because the amplitude is included only halfway in the tolerance field demonstrates the need to increase the precision of the sheet rolling process, which should lead to a relationship of the form R ⊂ T. The value of S confirms a relatively large scattering of the measured values.

4. Conclusions

From the analysis of the multitude of factors that influence the quality of the drawn pieces, it results that it is necessary to determine some optimal values of these, which is possible using software that allows a modeling of the drawing process, as close to reality as possible. The variations of the physical thickness of the strip influence the values of the drawing coefficient with impact on the drawing force, the retaining force, which will influence the dimensional accuracy, that of the shape, as well as the relative position of the surfaces. The proof of this fact is highlighted in tab.1, where differences are observed between the values of the drawing force and the retaining force obtained from the calculation with the relations from the specialized literature compared to those measured during the experiments.

In the future, it is planned to continue the study for other types of materials and other values of the clearance between the active elements.

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