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Aspects Regarding the Quality of Deep-Drawn Parts – Part Two

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Abstract. In a previous study, it was argued that parts meeting quality requirements and obtained through a deep drawing process exhibit this 'quality' feature as a result of the interaction between two main factors: the technological system and the forming process itself. To demonstrate these interdependencies, three dies were designed and used to analyze how variations in the thickness of A3K steel strips affect the quality of the formed parts.
The present paper continues this research by examining two additional types of rolled strips: one made of deep-drawing steel and the other of brass. Thickness frequency histograms were constructed, as variations in strip thickness are known to influence both the drawing and holding forces during the manufacturing of small cylindrical parts, thereby impacting the factors that define manufacturing quality.

1. Introduction

A deep-drawn part is considered to be of 'high quality' if, after the manufacturing process, it fulfills the intended function for which it was originally designed and subsequently produced. Manufacturing quality implies that the part exhibits continuity of the metal grain structure, dimensional accuracy, surface shape accuracy, correct relative positioning of surfaces, surface smoothness, as well as the mechanical and physico-chemical properties of the processed material ([1]).

This manufacturing quality is the result of the interaction between the technological system and the deep drawing deformation process. The technological system influences quality through various factors, including the type of press, the die design, the type and shape of the blank, the feeding method, and the handling of finished parts and scrap.

The deep drawing process, in turn, impacts quality through its parameters: part geometry, drawing force, blank holder pressure, type of lubricant used, drawing ratio, process speeds, displacements, strains, stresses, degree of work hardening, and elastic springback ([3], [8]).

2. Case study

Since investments were made in the manufacturing of the three dies ([5], [9]), experiments were also conducted using two additional types of strip-shaped blanks: one slit from deep-drawing steel sheet A5 and the other from brass sheet CuZn30-O. In a previous study, the processed blank was a strip made of deep-drawing steel A3K.

Among the various factors mentioned above that influence the quality of a deep-drawn part, this study focused on the effect of blank thickness accuracy on the drawing and blank holding forces during the forming of small cylindrical parts from both types of strips, each having a thickness of 0.4 mm.

2.1. *The deep-drawing steel strip A5* is aluminum-killed and has a chemical composition of 0.015% carbon, 0.26% manganese, 0.018% phosphorus, 0.01% silicon, and 0.013% sulfur ([12], [13]).

The material was subjected to tensile testing, yielding the following properties: ultimate tensile strength Rm = 312 N/mm², yield strength $Rp_{0.2}$ = 220 N/mm², and elongation A_{80} = 43.5% ([12], [13]).

The forming process involved intentional wall thinning of the part, with a clearance of 0.24 mm between the punch and the die insert. The punches used had a radius of 2 mm, while the active die plates had a radius of 2.5 mm.

Table 1 presents the values of the active element diameters, the heights of the drawn parts, as well as the experimentally measured and numerically simulated drawing and blank holding forces, obtained using the MARC-Mentat 2003 simulation software [11].

Tab. 1 Experimental Conditions and Results Obtained from Deep Drawing of A5 Steel Strip Parts

Nr exp	The Punch	The drawing die insert	j/2 [mm]	D_{blank} [mm]	h [mm]	m	$F_{measured}$ [daN]	$F_{simulated}$ [daN]	$Q_{measured}$ [daN]	$Q_{simulated}$ [daN]
	d_p [mm]	d_m [mm]								
1.	5.52	6	0.24	11	4,2	0.56	173,8	101,5	0,0	0,0
2.	8.02	8.5	0.24	17	4.1	0.61	236.4	162,9	25,15	21,3
3.	10.52	11	0.24	17	4	0.65	273.7	130,4	7,78	6,01

The influence of blank thickness accuracy on the final part quality is determined by constructing the thickness frequency histogram of the strip material [10]. As a result, it was necessary to measure the strip thicknesses using a micrometer with a dial comparator, offering a precision of 0.002 mm. Table 2 presents the measured thickness values, denoted as x_i, and their corresponding frequencies in the measurement set, denoted as m_i.

The range of the measured values is calculated using the following relation ([6], [7]):

$$R = x_{max} - x_{min} = 0{,}054 \text{mm}. \quad (1)$$

The number of equally sized classes (intervals) is determined using Sturges' formula:

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

where n = 31 is the number of measurements, resulting in k = 5.9543.

The class width (amplitude) is calculated using the following relation:

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

Tab. 2 The measured values of the A5 strip thickness and their corresponding frequencies in the series of these values

	Thickness, x_i	Frequency, m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i
1.	0,401	1	0,409	1	0,415	2	0,423	1	0,428	3	0,436	2
2.	0,402	1	0,410	1	0,417	1	0,425	3	0,430	4	0,440	2
3.	0,405	1	0,412	1	0,419	2	0,426	3	0,435	1	0,455	1
	TotalFreq	3		3		5		7		8		5

The calculation yields a class width of 0.009 mm.

Based on the data obtained through measurement and calculation, Table 3 was constructed as a frequency table of the thickness values, where the following were noted: p_i – the relative frequency of the class; f_i – the absolute frequency of the class; x_{ci} – the mean value of the class limits. It should be noted that:

$$p_i = \frac{f_i}{n}. \quad (4)$$

Tab. 3 Frequency Table of Thickness Values for the A5 Steel Strip

Class Number	Class Interval from	Class Interval to	x_{ci}	f_i	p_i	Σp_i
1	0.401	0.410	0.4055	4	0.1290	0,1290
2	0.410	0.419	0.4145	5	0.612	0.2903
3	0.419	0.428	0.4235	9	0.2903	0.5806
4	0.428	0.437	0.4325	10	0.3225	0.9032
5	0.437	0.446	0.4415	2	0.0645	0.9032
6	0.446	0.455	0.4505	1	0.0322	1

The following statistical parameters were determined ([6], [7]):

a) The mean value, which characterizes the central tendency of the data,

$$\bar{x} = g + \frac{\sum_{i=1}^{k}(x_{ci}-g)\cdot f_i}{n}, \quad (5)$$

where: g is the modal value (i.e., the thickness with the highest frequency). The result was x̄ = 0.42 mm.

b) The variance σ, estimated using Bessel's corrected standard deviation (S), which indicates the dispersion of the thickness values around the mean $\bar{x}$

$$S^2 = \frac{1}{n-1}\cdot \sum_{i=1}^{k}(x_i - \bar{x})^2 \cdot m_i, unde\ S = \sqrt{S^2}. \quad (6)$$

The calculated value was S = 0.012 mm.

According to the documentation provided by the supplier of the A5 material ([12], [13]), the strip thickness is specified as 0.4 ± 0.05 mm.

Using the dataset from Table 3 and the fact that g_{max} = 0.45 mm and g_{min} = 0.35 mm, a frequency histogram was constructed for the A5 deep-drawing steel strip, as shown in Figure 1 (C_i represents the class number from Table 3).

The analysis of this graph leads to the following observations:

- The increasing and decreasing trend of the values, with a relatively central position of the maximum, indicates that the histogram corresponds to a 'positively skewed' distribution shape ([6]).
- The values with the highest frequencies are close to the mean, highlighting a tendency for the data to cluster around the average.
- The positioning of the histogram relative to the tolerance field (T) shows that the rolling process favored thickness values closer to the upper tolerance limit. Additionally, it can be observed that the amplitude falls within the tolerance range but is slightly shifted to the right, which makes it necessary to increase the precision of the rolling process to ensure the relationship R ⊂ T is satisfied.

2.2. *The brass deep-drawing strip* contains 70% copper, 0.1% iron, 0.05% manganese, 0.05% lead, 0.02% aluminum, and 0.05% tin ([12], [13]).

Tensile testing of the material yielded the following parameters: ultimate tensile strength Rm = 295 N/mm² and elongation A_{80} = 45% ([12], [13]).

As with the steel parts, the brass parts were also formed with intentional wall thinning, maintaining a clearance of 0.24 mm between the punch and the drawing die insert. The punches had a radius of 2 mm, while the active die plates featured a radius of 2.5 mm.

Table 4 presents the dimensional characteristics of the active tooling elements, the heights of the drawn parts, as well as the force values that occurred during the process, determined both experimentally and through simulation using the MARC-Mentat 2003 software [11].

To construct the frequency histogram of the brass strip thickness [10], it is necessary to gather the data shown in Table 5, which includes the measured thickness values, x_i and their corresponding frequencies m_i within the data series."

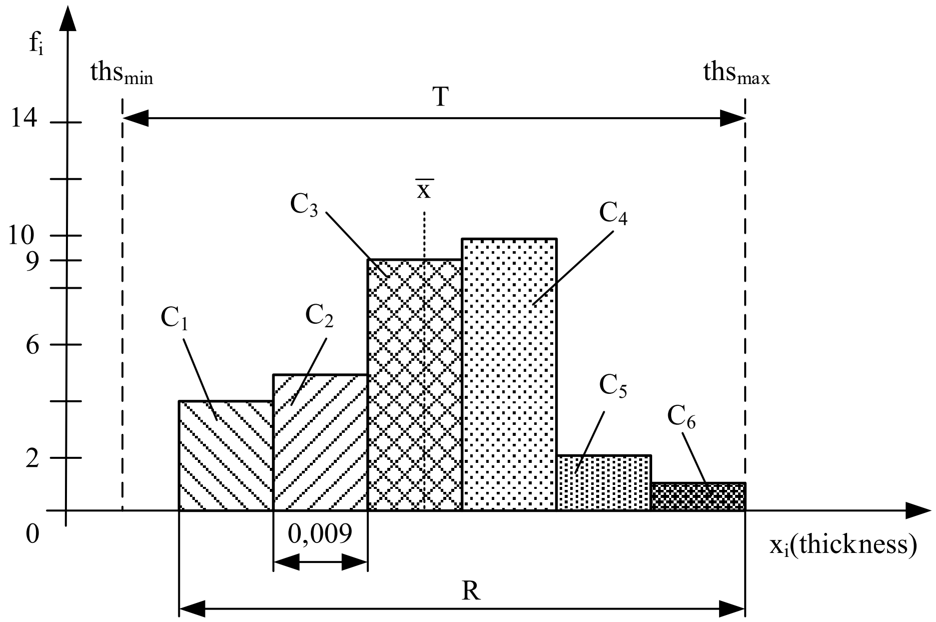

Fig.1 Thickness Frequency Histogram of the A5 Deep-Drawing Steel Strip

Tab. 4 The measured values of the CuZn30-O strip thickness and their corresponding frequencies in the series of these values

Nr exp	The Punch	The drawing die insert	j/2 [mm]	D_{semif} [mm]	h [mm]	m	$F_{measured}$ [daN]	$F_{simulated}$ [daN]	$Q_{measured}$ [daN]	$Q_{simulated}$ [daN]
	d_p [mm]	d_m [mm]								
1.	5.52	6	0.24	11	4,3	0.56	149,04	132,2	0,0	0,0
2.	8.02	8.5	0.24	17	4.1	0.61	183.61	179,9	25,15	22,1
3.	10.52	11	0.24	17	4,5	0.65	245.84	193,2	7,78	6,83

Using Equation (1), the range of the data series was determined as R = 0.056. Using Equation (2), the number of equally sized classes/intervals was determined as k = 6. Using Equation (3), the class width was calculated as A = 0.009. Based on all these measurement and calculation results, Table 6 was constructed as a frequency table of the thickness values for the brass strip.

Tab. 5 Valori Frequency Table of Thickness Values for the CuZn30-O Steel Strip

	Thickness, x_i	Frequency, m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i	Thick., x_i	Freq., m_i
1.	0,395	1	0,405	2	0,413	1	0,420	1	0,428	1	0,439	1
2.	0,398	1	0,408	1	0,415	2	0,421	1	0,431	1	0,445	1
3.	0,401	2	0,409	1	0,416	2	0,425	2	0,433	1	0,448	1
4.	0,402	1	0,411	2	0,418	2	0,427	2	0,435	1	0,451	1
	Total Freq.	5		6		7		6		4		4

Tab. 6 Frequency Table of Thickness Values for the A5 Steel Strip

Class Number	Class Interval		x_{ci}	f_i	p_i	$\Sigma\ p_i$
	from	to				
1	0.395	0.404	0.3995	5	0.1563	0.1563
2	0.404	0.413	0.4085	6	0.1875	0.3438
3	0.413	0.422	0.4175	9	0.2813	0.6250
4	0.422	0.431	0.4265	5	0.1563	0.7813
5	0.431	0.440	0.4355	4	0.1250	0.9063
6	0,440	0,449	0.4445	2	0.0625	0.9688
7	0.449	0.458	0.4535	1	0.0313	1

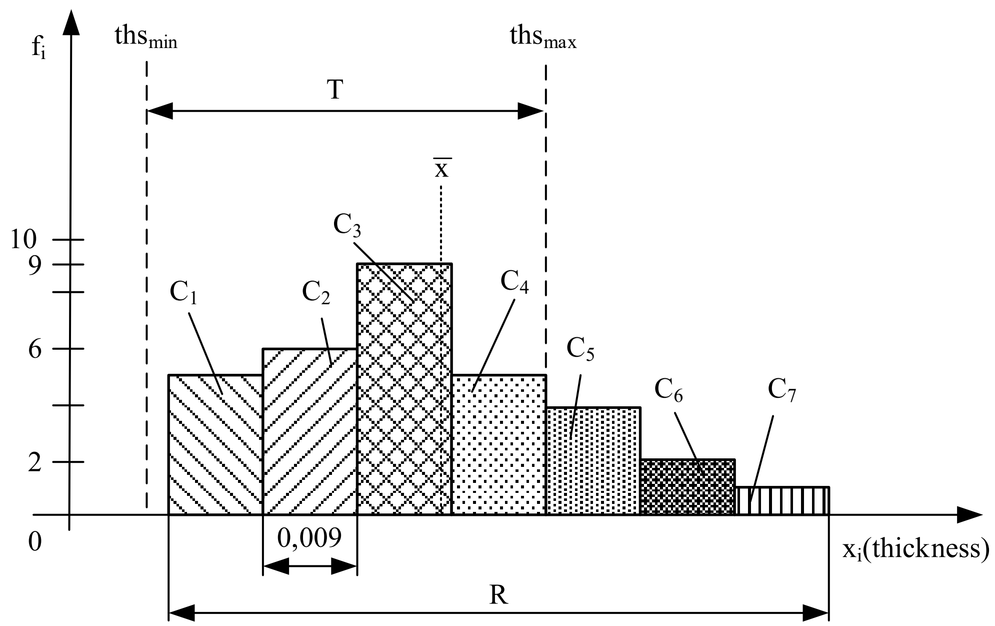

Fig.2 Thickness Frequency Histogram of the CuZn30-O Deep-Drawing Steel Strip

Using Equation (5), the mean value was calculated as $\bar{x} = 0.4195$.
Using Equation (6), the standard deviation index S was calculated as S = 0.0146.

Given that the nominal strip thickness is 0.4 ± 0.05 mm [12], and based on the data from Table 6, the frequency histogram for the brass strip was constructed and is shown in Figure 2.
The conclusions drawn from the analysis of this histogram are as follows:

- The position of the peak relative to the values on the left and right indicates a „positively skewed„ distribution;
- The measured values with the highest frequencies are close to the mean value;
- The overlap between the tolerance field and the histogram suggests that the rolling process resulted in strip thicknesses closer to the upper permissible limit. The fact that only approximately 60% of the histogram's range lies within the tolerance field highlights the need to improve the precision of the rolling process for the sheet metal from which the strips were slit, in order to meet the condition $R \subset T$. The spread of the measured values is consistent with the calculated standard deviation index S."

3. Conclusions

In this study and its first part, it has been shown that the concept of „manufacturing quality„ is extremely complex, as it results from the overlap of multiple influencing factors:

- One of them is the result of the interaction between the technological system and the deep drawing deformation process;
- Another stems from the direct action of factors such as dimensional accuracy, form and position precision, and surface finish quality.

Achieving product quality—that is, fulfilling the functional purpose for which the part was designed—is most efficiently done by optimizing the influence of each of these factors. This can be achieved through the use of simulation software capable of modeling the deep drawing process under conditions as close to reality as possible.
The importance of studying the influence of physical strip thickness variations on final product quality has been demonstrated through the observed changes in the drawing coefficient, which directly affects both the drawing and blank-holding forces. These, in turn, influence dimensional precision, form accuracy, and the relative positioning of surfaces.
From all the tables corresponding to the three material types, which include the dimensions of the active tooling elements, differences can be seen between the forces obtained through simulation and those measured experimentally. These differences are caused by strip thickness variations of 0.05–0.1 mm, which influence the thinning coefficient, as well as by imperfections in the material microstructure (inhomogeneities, structural defects), which affect the mechanical properties ([2], [4]).
Future research will focus on studying the influence of the clearance between active tooling elements on the quality of deep-drawn parts, using the same types of materials.

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