

EVALUATING CUP WALL THICKNESS DISTRIBUTION IN MULTI-STAGE DEEP DRAWING VIA NON-CONTACT MEASUREMENT¹ Miroslav TOMÁŠ, ¹ Marek BUBER*¹ *Technical University of Košice, Faculty of Mechanical Engineering, Department of Automotive Production, Košice, Slovakia, EU, miroslav.tomas@tuke.sk, marek.buber@tuke.sk*<https://doi.org/10.37904/metal.2026.5275>**Abstract**

This study investigates wall thickness variations during the multi-stage deep drawing of bearing housings under industrial-experimental conditions. The paper outlines a methodology for evaluating both material formability and wall thickness distribution within the drawn components. KOHAL 240 cold-rolled steel sheet (DC03 drawing quality), nominal thickness of 2mm served as the experimental material. To analyze material flow and thinning behavior, thickness was monitored across three drawing stages. Measurement accuracy was validated by comparing two distinct approaches: conventional manual measurement using a point-contact micrometer and advanced non-contact optical scanning via the GOM Scan 1 and Zeiss ScanPort systems. The resulting data, presented through comparative graphical analysis, demonstrate a high degree of correlation between the optical and manual methods. Observed deviations remained within acceptable tolerances, confirming the reliability of non-contact scanning for monitoring complex forming processes.

Keywords: deep drawing, bearing-housing, thickness change, 3D scanning

1. INTRODUCTION

Among sheet-metal forming operations, deep drawing represents one of the most complex deformation process in terms of the mechanical deformation modes involved, particularly when considering its anisotropic character. The complexity of the deep-drawing process is further intensified by the fact that, throughout the real operation from the blank to the final cup, different mechanical deformation modes act on the same regions of the material. Thus, mentioned results in localized deformation in specific regions of the cup wall. [1,2].

In real deep-drawing operations, the uniformity of the final cup-wall thickness is influenced by the different stress and strain modes active in various regions of the wall throughout the drawing process. Consequently, the wall thickness of the drawn cup exhibits variations along the cup curvilinear when compared with the initial sheet thickness: $a \geq a_0$ when deep-drawing (tangential stress) prevails (flange) or $a \leq a_0$ when single- or bi-axial stretching prevails (radii, cup wall); where a_0 stands as initial sheet thickness and a stands as actual sheet thickness. [3,4]

The situation regarding wall-thickness evolution during cup drawing is further complicated by the anisotropy in their mechanical and plastic properties. As a result, the deep-drawing process itself becomes anisotropic, showing a directional dependence of the cup-wall thickness relative to the sheet-rolling direction [1,3].

Nowadays advanced measurement instruments and techniques to ensure product quality assurance are implemented in factories. By employing specialized tools such as 3D scanners and dedicated post-processing software, physical parts can be accurately converted into digital CAD models [5,6,7]. Through the application of triangulation principles that transform 2D digital images into spatial coordinates, photogrammetric algorithms can accurately reconstruct an object's surface as a dimensionally faithful 3D digital model [8,9].

The aim of this article is to compare thickness changes during a three-stage deep drawing process, as evaluated by manual measurement using a micrometer and by a modern scanning method with subsequent analysis in specialized software.

2. MATERIALS AND METHODOLOGY OF EXPERIMENT

The investigation of wall thickness changes was conducted on a stamped bearing housing component. The production process consists of three drawing operations (**Figure 1**) and two subsequent calibration operations. In the first drawing stage, a cylindrical cup with a flat bottom is formed. The second stage involves reverse drawing, during which the flange and rim are shaped. In the third stage, the cup diameter is reduced, while the flange and rim are calibrated [10]. A plastic foil made of linear polyethylene (LPE, JK 283 815 100 710) with a thickness of 0.015 mm was used as a lubricant during production.

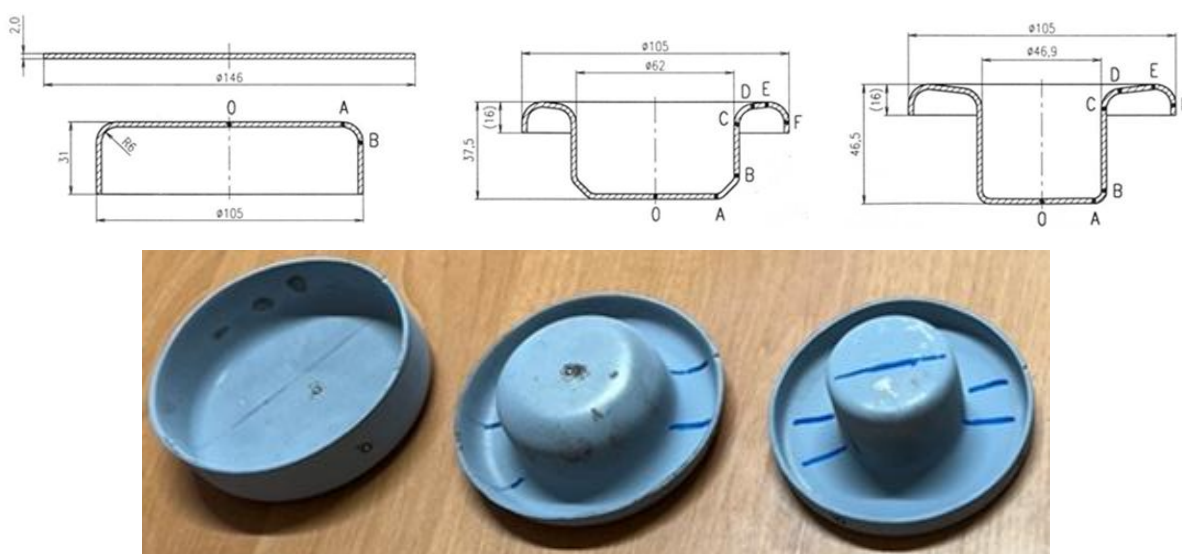


Figure 1 The technological process of bearing housing production

As part of a production experiment, a KOHAL 240 cold-rolled deep-drawing steel sheet with a nominal thickness of $a_0 = 2.0$ mm was examined. The material formability of the examined sheet was evaluated by following tests: mechanical properties by ISO 6892-1), normal anisotropy by ISO 10113, strain-hardening exponent by ISO 10250. A deep drawing test according to Schmidt determined limit drawing ratio $m_m = 0.462$. Chemical composition of KOHAL 240 is presented in **Table 1**, while mechanical properties and anisotropy parameters are summarized in **Table 2**.

Table 1 Chemical composition of KOHAL 240 (wt %)

C	Mn	Si	P	S	Al	Cu	Ni	Cr	O ₂	N ₂
0.054	0.19	0.02	0.014	0.016	0.053	0.031	0.014	0.021	0.0166	0.0045

Table 2 Mechanical properties and anisotropy parameters of KOHAL 240

Smer	R _{P0.2} (MPa)	R _m (MPa)	A ₈₀ (%)	PR _{P0.2} (%)	PR _m (%)	PA ₈₀ (%)	r (-)	r _m (-)	Δr (-)	n (-)	n _m (-)	Δn (-)
0°	156	300	45.8				1.71	1.37	0.68	0.243	0.241	0.007
45°	171	314	40.4	10	5	-12.0	1.03			0.237		
90°	158	301	46.5	2	0	1.5	1.71			0.247		

2.1 Measuring by micrometer

Wall thickness changes during individual drawing operations were measured using a micrometer with point-contact tips and an accuracy of 0.01 mm, mounted in a stand. The thickness of each stamped part was measured at locations indicated in Figure 1 for each drawing stage. An imaginary cutting plane passing through the center of the stamped part, along which the thickness measurements were taken, was oriented at 0°, 45°, and 90° relative to the rolling direction.

To facilitate access to the measurement locations, the part was sectioned using a hacksaw at a distance of 5 mm from the imaginary cutting plane. The positions of the measurement points were determined using a flexible ruler with 1 mm divisions. The points were marked at 3 mm intervals along the specified directions using a marker, with the origin of the ruler aligned with the center of the part.

2.2 Scanning by optical scanner GOM Scan1

The wall thickness of the parts was assessed using a non-contact optical 3D scanning method. For this purpose, a GOM Scan 1 structured-light scanner with a measuring volume of MV 400 was used (**Figure 2**). Scanner was mounted on ScanPort arm. Three-dimensional surface models were subsequently generated in ZEISS Inspect Pro software. According to the instrument specification and ISO 10360 performance criteria, the system provides a dimensional accuracy of 0.02 mm and can capture approximately 6 million points within a scanning field of 400 × 250 mm.



Figure 2 Scanning with GOM Scan 1 scanner setup with rotary table and ScanPort

Prior to scanning, the samples were mounted on a motorized rotary table and positioned at the optimal working distance from the scanner. To ensure correct spatial alignment and sufficient overlap between consecutively captured frames, retro-reflective reference markers were applied to the surface of each cup. For complete geometric coverage, 20 scans were acquired from both the inner and outer surfaces in angles between scanner and rotary table of 20° and 70°. The rotary table rotating in 36° increments between individual scans.

3. RESULTS AND DISCUSSION

Based on the measured mechanical properties, the evaluated deep-drawing criteria, and the limiting drawing ratio, it can be concluded that the KOHAL 240 sheet is a typical deep-drawing steel of the EDDQ-S grade. The anisotropy of the strain-hardening exponent (Δn) is negligible, with a value of 0.007. In contrast, the plastic strain ratio (r) exhibits pronounced anisotropy, with a minimum in the 45° direction and maxima in the 0° and 90° directions relative to the rolling direction. The 45° direction is also the most unfavorable in terms of yield strength, tensile strength, and elongation.

The wall thickness variation curves for the stamped parts in this direction, obtained using both measurement methods, are presented in **Figures 3-5**. The blue curve represents the initial thickness (2 mm), the green curve corresponds to measurements obtained using the ZEISS Inspect software, and the red curve represents manual measurements performed with a micrometer. The thickness values obtained from ZEISS Inspect are further evaluated, and their deviations from the manually measured values are analyzed.

The wall thickness distribution of the stamped part after the first drawing operation (drawing coefficient $m_1 = 0.719$) exhibits a profile typical of cylindrical cups with a flat bottom produced by deep drawing from a flange. As shown in **Figure 3**, no significant change in thickness is observed in the region preceding zone A (bottom of the cup). In zone A (the transition radius between the bottom and the cup wall), a reduction in thickness occurs, with a minimum value of 1.885 ± 0.01 mm. The difference between the scanner-based and micrometer measurements is more pronounced at the edge of the part, where a deviation of 0.08 mm is observed (purple-shaded region).

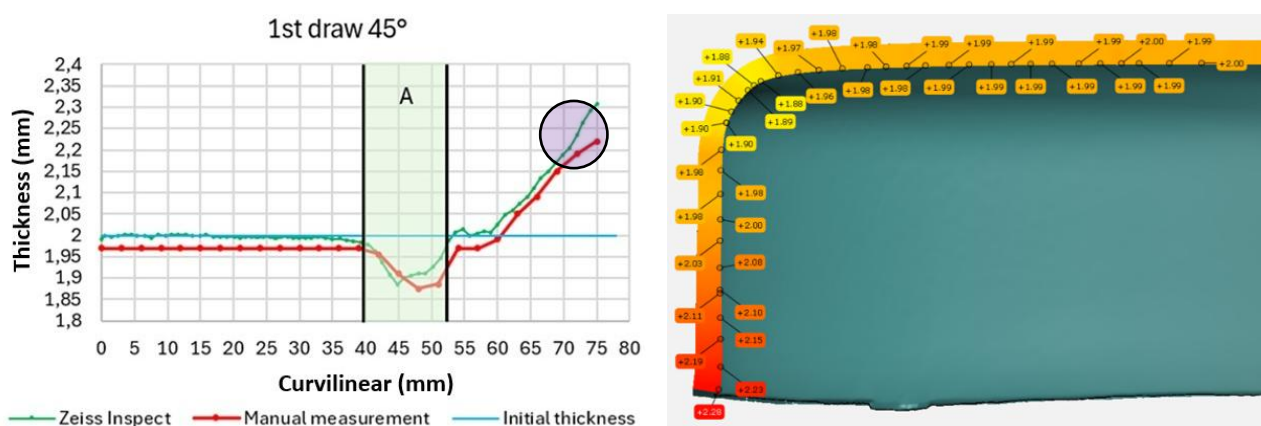


Figure 3 Wall thickness variation of the bearing housing part after the 1st draw

Table 3 Thickness of the 1st sample measured by different methods

Measurement method		Minimal thickness zone A (mm)
Manual measurement 45°		1.875
Zeiss Inspect	0°	1.881
	45°	1.885
	90°	1.907

During the second drawing operation the stamped part is formed in the reverse direction, resulting in the creation of a flange and a rim. Different regions of the part undergo varying degrees of thinning and work hardening. In addition to the thickness variation curves, several local maxima can be observed in individual zones of the stamped part. As shown in **Figure 4**, three main zones (A, B, and C) are identified. In the bottom region of the part 0–B, the material thickness decreases from the initial 2 mm (blank) to an average of 1.85 ± 0.01 mm. In zone B (the transition radius between the bottom and the wall), the most pronounced thinning occurs, with a minimum thickness of 1.734 ± 0.01 mm. In zone A (wall region), the average thickness is 1.78 mm. In the region between zones A and C (transition between the wall and the flange), the thickness increases to 2.09 ± 0.01 mm. In this region, a more pronounced discrepancy between the two measurement methods is also observed, with differences of up to 0.07 mm (purple-shaded region). In zone C (flange), the thickness is 2.062 ± 0.01 mm, while in the rim region beyond zone C, the maximum thickness reaches 2.25 ± 0.01 mm.

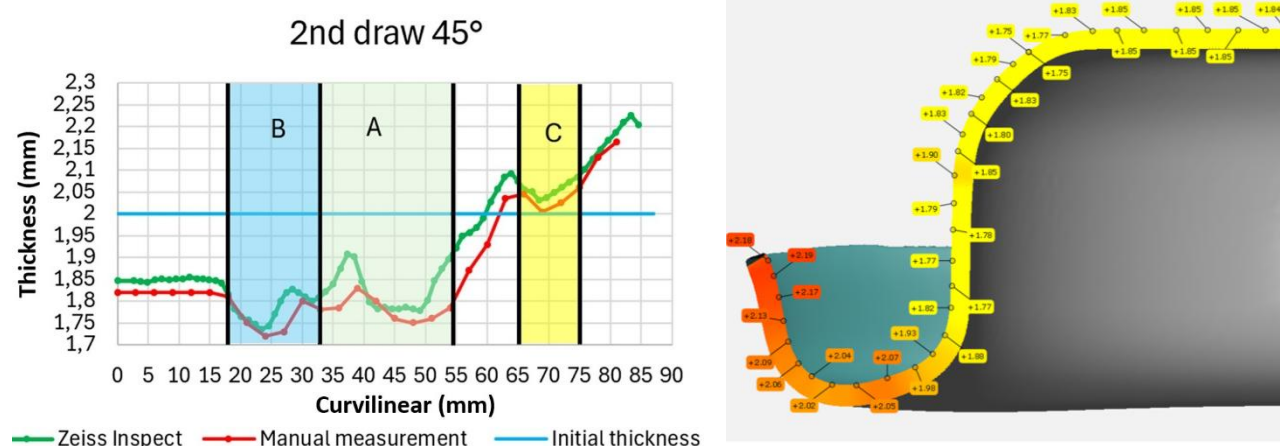
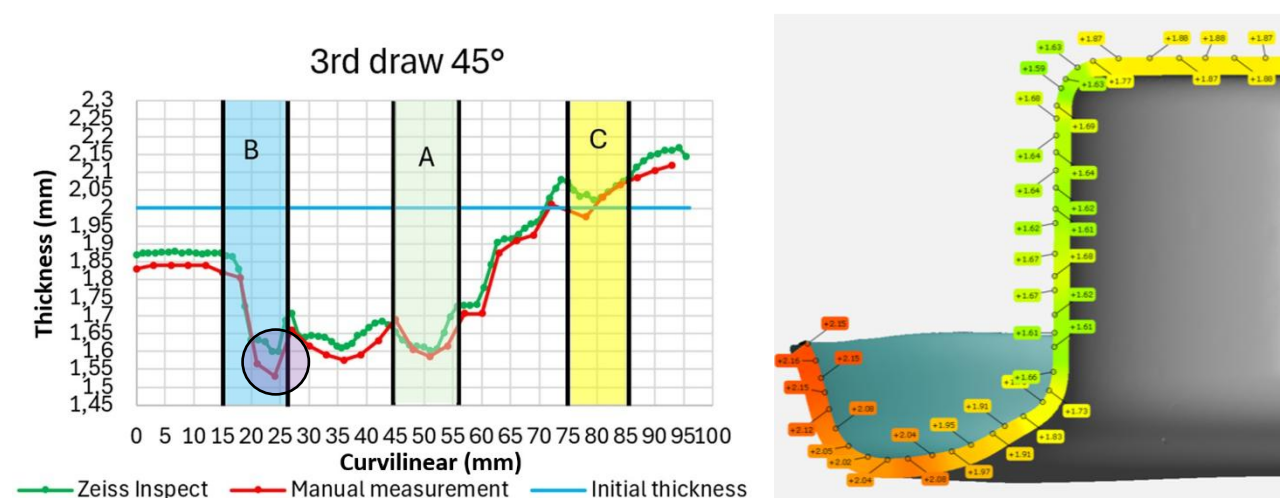


Table 4 Thickness of the 2nd sample measured by different methods

Measurement method		Minimal thickness (mm)		
		zone A	zone B	zone C
Manual measurement 45°		1.75	1.72	2.00
Zeiss Inspect	0°	1.781	1.741	2.045
	45°	1.778	1.734	2.031
	90°	1.774	1.746	2.037

In the third drawing operation (**Figure 5**), during cup reduction and flange calibration, the thickness variation profile does not change significantly compared to the previous stage. In the region 0–B (bottom of the part), no change in thickness is observed relative to the previous drawing step. In zone B (the radius between the bottom and the wall of the part), a change in thickness is observed compared to the previous stage, with an average increase of 0.18 ± 0.01 mm. The largest discrepancy between scanner-based and micrometer measurements is also found in this region (purple-shaded area).



In the region between zones B and A (wall of the part). the thickness decreases by an average of 0.09 mm. which is associated with changes in the height of the cylindrical wall. In zone A (transition between the wall and the flange). a further reduction in thickness is observed due to continued geometric changes in the part. In the region between zones A and C (flange) and in zone C (rim). no significant thickness variations are observed. Overall. thickness measurements across the entire cross-section show no substantial deviations. except in the region between zones A and C. where scanner-based measurements indicate values approximately 0.08 mm higher than those obtained using the micrometer.

Table 5 Thickness of the 3rd sample measured by different methods

Measurement method		Minimal thickness (mm)		
		zone A	zone B	zone C
Manual measurement 45°		1.585	1.530	1.975
Zeiss Inspect	0°	1.657	1.610	2.032
	45°	1.603	1.600	2.022
	90°	1.593	1.602	2.029

By comparing the accuracy of contact micrometer measurements and non-contact scanner measurements. it can be stated that the contact micrometer provides higher thickness measurement accuracy. in the range of ± 0.005 mm. However. the accuracy of determining the measurement position relative to the center of the stamped part must also be considered. with an uncertainty of ± 0.5 mm.

In contrast. non-contact measurements using the ScanPort system enable thickness evaluation with high spatial resolution of the measured points. with positional accuracy ranging from 0.0005 to 0.035 mm. depending on point cloud triangulation during conversion to STL format. The overall accuracy of scanner-based measurements also depends on the selected measuring volume. which is determined by the number of scanned points.

4. CONCLUSIONS

Based on the experimental research conducted. the following conclusions can be drawn:

- The change in the wall thickness in the first drawing stage is typical for cylindrical parts with a flat bottom deep-drawn from a flange. The greatest thinning was measured at the bottom to wall radius.
- The change in the wall thickness in the second stage (reverse drawing) shows several local minima: 1st local minimum at the transition from the bottom to the cylindrical wall (critical point of the housing). 2nd local minimum in the cylindrical wall of the part (its position corresponds to the maximum thinning of the thickness from the first stage – in this part of the housing. the inheritance of thickness changes from the first stage of drawing is evident). 3rd local minimum at the flange to rim radius.
- The course of the thickness change in the third draw is analogous to the course of the change in the thickness change in the second draw but shifts to lower values. The minimum thickness was found at the bottom to wall radius of the housing (critical point of the part).
- The directional dependence of thickness changes correlates with the normal anisotropy coefficient – the most unfavorable direction on the part in terms of thickness changes is the direction of the significant minimum value of the normal anisotropy coefficient.

Measuring material thickness using a 3D scanner offers more comprehensive and surface-representative data compared to a micrometer. as it enables analysis of the entire object rather than only local measurement points. A significant advantage is the non-contact nature of the measurement. which eliminates the risk of material deformation and increases accuracy. especially for thin-walled or soft samples. Through 3D scanning. it is possible to obtain a detailed thickness distribution map and to identify local deviations. inhomogeneities.

and manufacturing defects that point-based micrometer measurements may fail to detect. In addition, a 3D scanner allows digital data archiving, repeated analyses, and integration into CAD/CAE systems, thereby substantially improving the efficiency of quality control and research processes.

ACKNOWLEDGMENTS

This work was supported by the projects: VEGA 1/0238/23 “Implementation of CAx systems and virtual engineering techniques in the redesign of car-body parts for deformation zones”; VEGA 1/0609/25 “Research and development of methodologies for the assessment of strains of sheet metal and manufacturability of the car components in a virtual environment”; and KEGA 024TUKE-4/2025 “Hybrid education of students for the current needs of the automotive industry”.

REFERENCES

- [1] POLLÁK. L. Anisotropy and deep drawability of steel sheets. Bratislava: ALFA. 1978.
- [2] KOREČEK. D., SOLFRONK. P., SOBOTKA. J. Analysis of TRIP Steel HCT690 Deformation Behaviour for Prediction of the Deformation Process and Spring-Back of the Material via Numerical Simulation. Materials 2024. 17. 535. <https://doi.org/10.3390/ma17030535>.
- [3] POLLÁK. L. Normal anisotropy as a deep-drawability criterion of steel sheets. International Sheet Metal Review. 1999. spring. p. 84.
- [4] HOSFORD. W.F.; CADDELL. R.M. Metal Forming: Mechanics and Metallurgy; 4th ed.; Cambridge University Press: Cambridge. UK. 2014.
- [5] VALERGA PUERTA. A.P., JIMENEZ-RODRIGUEZ. R.A., FERNANDEZ-VIDAL. S., FERNANDEZ VIDAL. S.R. Photogrammetry as an engineering design tool. In: ALEXANDRU. C., JALIU. C., COMȘIT. M. (eds.) Product Design. IntechOpen. 2020. DOI: [10.5772/intechopen.92998](https://doi.org/10.5772/intechopen.92998).
- [6] GHOBAKHLOO. M. Industry 4.0. digitization. and opp9869. DOI: 10.1016/j.jclepr ortunities for sustainability. Journal of Cleaner Production. 2020. vol. 252. p. 11 o.2019.119869.
- [7] VALENÇA. J., JÚLIO. E.N.B.S., ARAÚJO. H.J. Applications of photogrammetry to structural assessment. Experimental Techniques. 2012. vol. 36. no. 5. pp. 71–81. DOI: 10.1111/j.1747-1567.2011.00731.x.
- [8] KLIMECKA-TATAR. D., KRYNKE. M. Reverse engineering tools-3D scanning-as support for precise quality control in automated special processes. Procedia Comput. Sci. 2025. 253. 1933–1942.
- [9] REKAS. A., KACZMAREK. T., WIECZOROWSKI. M., GAPIŃSKI. B., JAKUBOWICZ. M., GROCHALSKI. K., KUCHARSKI. D. & MARCINIAK-PODSADNA. L. Analysis of Tool Geometry for the Stamping Process of Large-Size Car Body Components Using a 3D Optical Measurement System. Materials. 14(24). 2021. 7608. <https://doi.org/10.3390/ma14247608>.
- [10] TOMÁŠ. M. Contribution to the study of plastic deformation processes in the deep drawing of complex axisymmetric cup shapes Dissertation. Košice: Faculty of Mechanical Engineering. 2000.