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COMPARATIVE STUDY OF WALL THICKNESS CHANGE AT DEEP DRAWING OF BOX-SHAPED PRODUCT USING FLAT RESTRICTION BARS

In the paper the deep-drawing method using flat restriction bars to restrict plastic flow of sheet material at straight parts of drawing die by increasing of resistance to friction between a blankholder, a die and a blank is presented. Mentioned bars provide enough radial stresses in the drawpiece's flange to prevent the excessive material flow into the drawing die. Parameters of the deep drawing process such as the blankholder force and the restriction bars' normal force, given by filling pressure of gas springs were tested and adjusted to deep drawing of a bathtub model. The wall thickness change was measured by the dial gauge and by photogrammetric method using 3D optical system ARGUS. The experiments were done using the cold rolled steel sheet for enameling KOSMALT 240 with thickness of 0.6 mm. The results of measurements of bathtub wall thickness reduction by using both considered methods showed the same tendency, but there is a difference in values of thickness reduction. The measurements based on the non-contact 3D optical system ARGUS gave the lower values of wall thickness reduction at critical areas of the bathtub model equals of 10.6÷11.7%, compared to ones measured by the dial gauge.

Key words: deep-drawing, box-shaped drawpiece, flat restriction bar, friction, ARGUS system

1. Introduction

When box-shaped products are drawn, the restriction beads at straight walls of drawn parts are used to prevent the excessive material draw-in into the drawing die cavity. The restriction beads provide uniform material plastic flow into drawing die cavity by additional material deformation – bending and unbending. The restriction beads are usually placed on the blankholder and slots are placed opposite onto the drawing die. This technology as well as con-

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structional feature requires enough blank size to provide its function through the deep drawing process and to bring up enough radial stress on drawing die radius as well [1, 2]. The position of the restriction bead, defined by dimension e_1 (Fig. 1) should comply with drawpiece's shape and constructional strength in the area of drawing die radius. When flanged drawpieces are drawn, the restriction beads are placed to the distance beyond the edge of the flange. It requires an additional material, what increases the blank size and gets worse both, the material utilization and the economy of production.

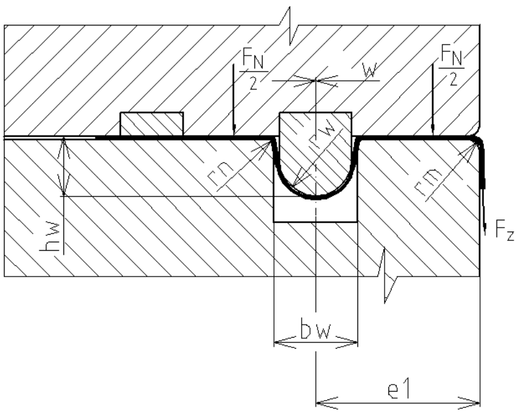

Fig. 1. Forces at deep-drawing with restriction beads

Nowadays, in the forming praxis are used different design concepts of forming dies to control material plastic flow in the flange at deep drawing of complicated drawpieces, such as large automotive panels or stainless steel sinks. Dieffenbacher developed Multi Point Cushion system (Fig. 2) for deep drawing of stainless steel sinks as presented by Pahl [3]. Altan reviewed various practical MPC systems and described using of nitrogen, hydraulic or pneumatic cylinders to apply a constant blank holder force through the press stroke [4]. Doege [5] presented the application of pliable blank holder system allowing to achieve a more homogeneous blank holder pressure. Pliable blank holder system results in a uniform pressure distribution in the flange and improves material plastic flow during deep drawing [5]. The other ways how to control blank holder force summarized Trzepieciński as systems using a multi-segmented flat and tapered blankholders, pulsatory and elastic blankholders as well as intelligent multi input multi output (MIMO) systems with numerically controlled blankholder force [6]. Most of mentioned processes are based on numerical controlling the blank holding force in separated areas of the flange by closed-loop control circuits.

The important parameter after the deep drawing process is the drawpiece's wall thickness change as a result of stress and strain distribution during the deep drawing. The wall thickness change react precisely when parameters of deep drawing such as the blankholder force and the friction are changed and anisotropy of steel sheets is considered as well. Thus, measuring the wall thickness change allows finding out the critical areas at deep drawing. The change of sheet metal thickness is usually measured using the dial gauge with coned flat tips along drawpiece's contour in specified sections. This manual method is not very precise and time consuming. The precision of thickness measurement is increased by the number of measurements [7]. Nowadays, automated measurement systems have been developed, such as the optical system Argus by GOM mbH based on photogrammetry. The Argus is the contact-less measuring system based on optical scanning of deformation grid after drawpieces' plastic deformation. The deformation grid had to be etched onto the blank before its processing. Pictures of the deformed drawpiece with deformation grid have to be taken from different angles. Then, from pictures and recognized coded points, using software image processing are computed 3D coordinates of grid points and computed distances between them. Based on volume constancy law major and minor strains, thickness reduction or critical areas of drawn part are computed [8].

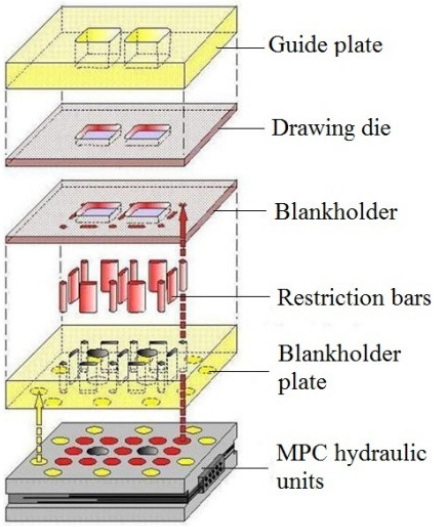

Fig. 2. Design of a drawing die using flat restriction bars (Multi Point Cushion by Dieffenbacher)

The optical measuring system Argus is now established in the forming practice as well. Frącz et al. [9-11] used the Argus system for verification and optimization of the numerical simulation of sheet metal forming process. They have used the system for direct experimental verification of computer simulation results and the selection of boundary conditions in simulations. They have found that this system does not provide acceptable accuracy in the measurement of certain areas of the drawpiece, especially those that include internal, small radii. Slota et al. [12] tested the sensitivity of the Argus system by using a photo or a video camera to take the pictures, using the anti-reflexive spray and comparing the strains computed by the numerical simulation and ones measured by the Argus system. Authors have observed great sensitivity of different factors on the measured values of strains, such as the time of etching, etching process parameters, type of measuring grid, quality of sheet surface in pre-production phase and type of used camera, application of developer, interpolation parameters, different lighting conditions, angles of the camera view and the number of captured pictures in post-production phase.

2. Experimental procedure

The aim of the contribution is to compare results of thickness change measured manually and by optical system Argus. The experimental work has been done on the drawpiece of the bathtub model using the method of deep drawing with flat restriction bars. In the Department of Technologies and Materials Technical University in Košice the drawing die with flat restriction bars has been developed to control material plastic flow at deep drawing of bathtub model drawpiece [13, 14]. The material plastic flow is regulated by changing friction forces between flat restriction bars and the blank as well as the blank and the blankholder. The friction force value is regulated by normal force derived from gas springs placed under the die. Gas springs are placed at the straight sections of the die cavity as it is shown in Figs. 3 and 4. The gas springs (6 and 7) act to the flat restriction bars 4 through the pillars 5 against the blankholder 3, when the blankholder touches down on the blank lying on the restriction bars. Then, the normal forces of gas springs generate the friction forces when the blank is draw-in into the die cavity. The normal forces of gas springs are controlled separately for each gas spring by its filling pressure using the regulation unit 8. The scheme of the control unit and gas springs connections is shown in Fig. 5. The steel sheet KOSMALT 240 with thickness 0.6 mm was used for deep drawing. The properties of the experimental material are shown in Table 1. The polyethylene plastic foil was used as a lubricant.

Table 1. Mechanical properties of the KOSMALT 240 steel sheet with a thickness a_0 of 0.6 mm

Specimen orientation	$R_{p0.2}$ **[MPa]**	R_m **[MPa]**	A_{80} **[%]**	r	r_m	Δr	n	n_m
0°	191	307	40.9	1.52	–	–	0.221	–
45°	195	310	33.4	1.35	1.488	0.275	0.218	0.219
90°	176	305	36.9	1.73	–	–	0.219	–

As it is shown in Fig. 4, the restriction bars are placed from the side of the blank where they did not affect the surface appearance because of possible scratches when material moves through the restriction bars. Note that the blankholder surface must be free of any slots. The gas springs number and position depend on drawpiece's shape (the length of straight wall) and it is shown in Fig. 5. At the gas spring dimensioning we assume the gas spring force F_{BL} must initiate the friction force T_{BL} on unit length of flat restriction bar between the blank and the blankholder as well as the blank and the drawing die, see Fig. 6. Coming out from assumptions presented in the literature [12] the force F_{BL} we can calculate as follows:

$$F_{BL} = \frac{F_{r\max}}{2\mu} = \frac{\sigma_{r\max} \cdot l_{BL} \cdot a_0}{2\mu},$$

where: $\sigma_{r\max}$ – maximum uniform stress of processed steel sheet, l_{BL} – length of flat restriction bar, a_0 – steel sheet thickness, μ – friction coefficient.

Based on the calculation were chosen the gas springs shown in Table 2 connected as it is shown in Fig. 5.

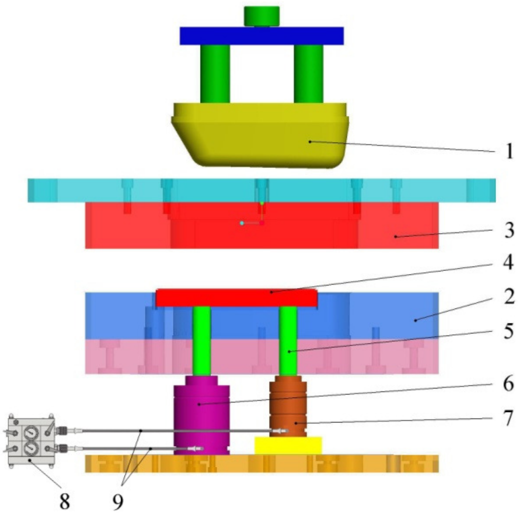

Fig. 3. Parts of experimental drawing die: 1 – punch, 2 – die, 3 – blankholder, 4 – flat restriction bar, 5 – pillar, 6 – gas spring (75 kN), 7 – gas spring (30 kN), 8 – regulation unit, 9 – pressure hose

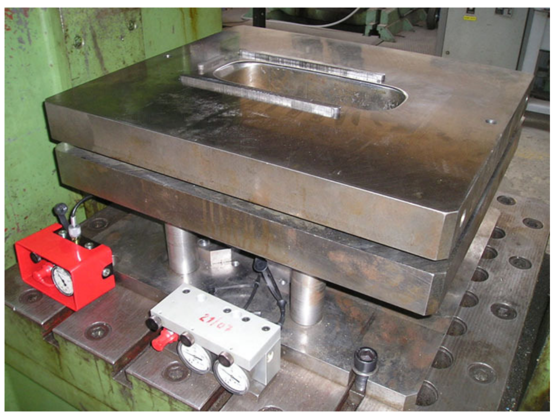

Fig. 4. The drawing die with flat restriction bars

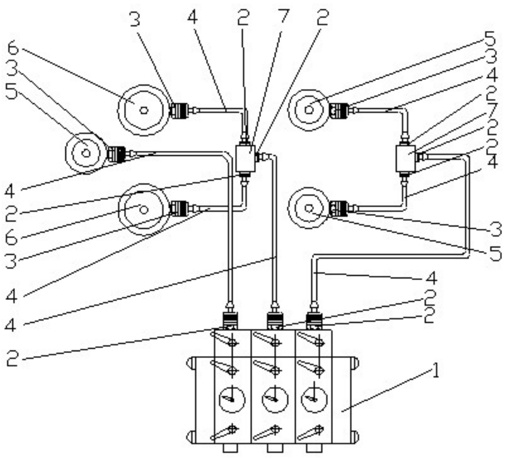

Fig. 5. Scheme of control unit and gas springs connections: 1 – control unit, 2, 3 – connector, 4 – high pressure tube, 5, 6 – gas springs, 7 – T-connector

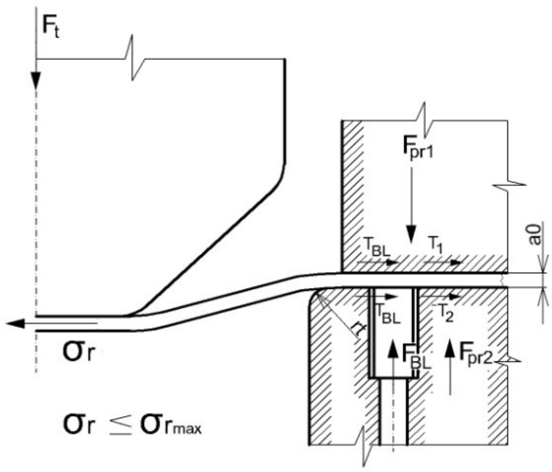

Fig. 6. Forces on contact surfaces at deep drawing with flat restriction bars

Table 2. Gas springs filling pressure

Gas spring	Pressure [bar]	Pressure at stroke [kN]
TPF 3000 x 10 C	85	38
TPF 7500 x 10 C	45	38

At deep drawing with flat restriction bars it is important to set pressure in gas springs to reach the drawpiece without loss of primary (wrinkles under the blankholder), secondary (wrinkles in free walls of drawpiece) and tertiary (fracture) stability. The blankholding force was set to 340 kN due to using the polyethylene plastic foil as lubricant. The gas springs filling pressure was decreased step by step in both pairs of springs (5, 6) from the maximum filling pressure to the values as it is shown in Table 3, when the drawpiece without cracks and wrinkles has been drawn. The research of wall thickness reduction was realized on the drawpiece in longitudinal axis (section A-A) and in the bathtub corner (section B-B) as it is shown in Fig. 7. The section A-A fits to the steel sheet rolling direction 0° and section B-B fits to direction 45° against rolling direction. The wall thickness was measured by the dial gauge with coned flat tips on cut drawpiece in distance of points 5 mm. Thickness reduction was then calculated as relative value of initial a_0 and final a_t sheet thickness: $(a_t - a_0)/a_0 \cdot 100\%$.

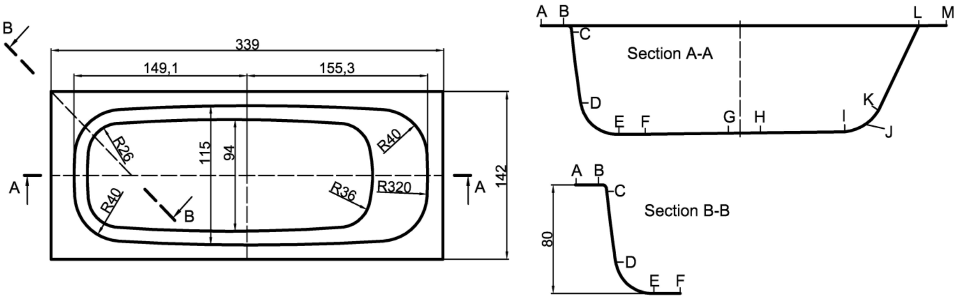

Fig. 7. The sections of the bathtub for measurement of wall thickness reduction

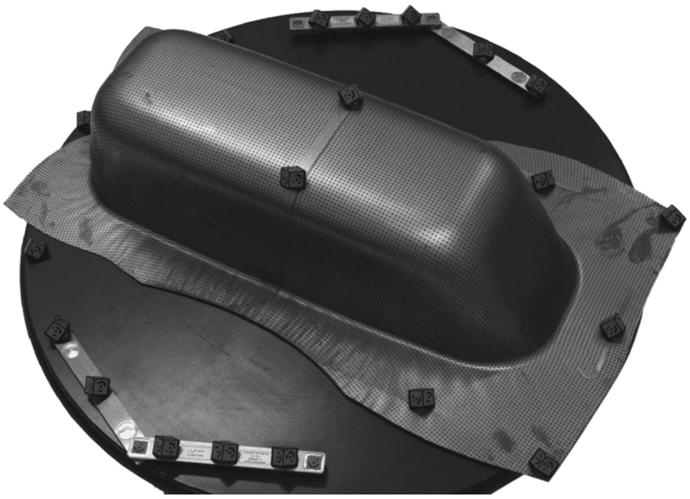

Fig. 8. The bathtub drawpiece with coded points

The other way to measure wall thickness reduction was to use the non-contact optical 3D deformation measuring system Argus. Prior the deformation of the initial blank was etched by electrolytic method using the etching device EU Classic by Östling and the electrolyte. The regular point's pattern was

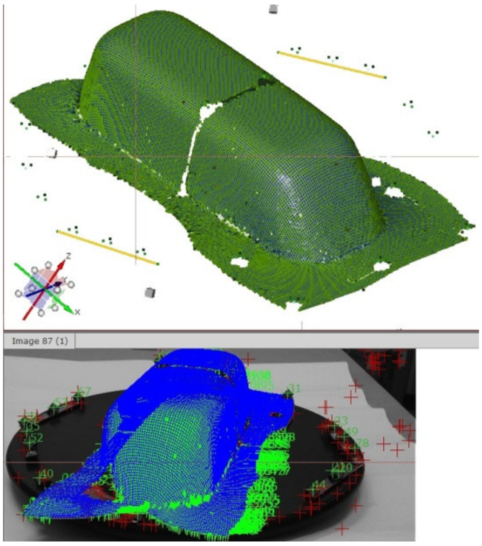

Fig. 9. Grid of identified points

applied to the surface of the blank with point distance 2 mm. After deformation by deep drawing with flat restriction bars, coded point was positioned round the drawpiece and set of pictures of the bathtub of the drawpiece model in several different positions with different views have been recorded using the video camera with 5-megapixel resolution. The bathtub drawpiece with coded points is shown in Fig. 8. Recognized points and grid created at evaluation mode is shown in Fig. 9.

3. Results and discussion

The changes of wall thickness reduction measured in longitudinal section A-A are shown in Fig. 10 and the changes in the section B-B through the bathtub corner are shown in Fig. 11. The values of wall thickness reduction measured by dial gauge with coned flat tips are shown in dashed line. The values of wall thickness reduction measured by optical system Argus are shown in solid line. The values of maximum local thinning measured by dial gauge with coned flat tips have been found as follows:

a) in the section A-A two local thinning are localized in transitional radius of wall to bottom D-E with the value of 23.28% and 20.28%; in transitional radius of slanted wall to bottom I-K is localized the third local thinning with the value of 28.33%,
b) in the section B-B through the corner with orientation 45° to longitudinal bathtub axis the local thinning of 32.94% in transitional radius of wall to bottom D-E was identified.

The values of maximum local thinning measured by optical system Argus have been found as follows:

a) in the section A-A two local thinning are localized in transitional radius of wall to bottom D-E with the value of 11.11% and 15.34%; in transitional radius of slanted wall to bottom I-K the third local thinning with the value of 25.34% is localized,
b) in the section B-B through the corner with orientation 45° to longitudinal bathtub axis the local thinning of 29.10% in transitional radius of wall to bottom D-E was identified.

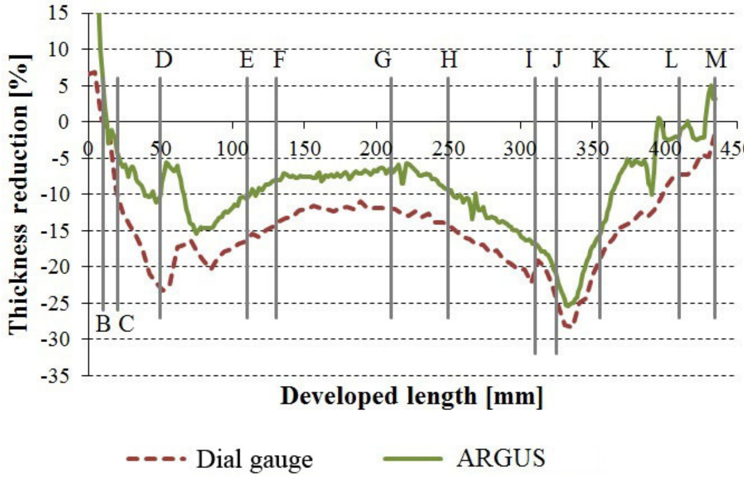

Fig. 10. Comparison of thickness reduction measured by the dial gauge and the non-contact 3D optical system ARGUS, the section A-A

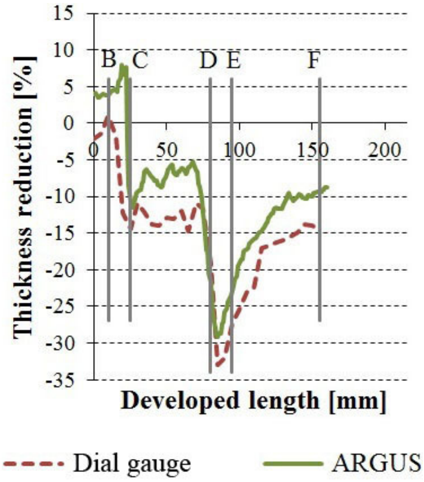

Fig. 11. Comparison of thickness reduction measured by the dial gauge and the non-contact 3D optical system ARGUS, section B-B

Table 3. Comparison of wall thickness reduction measured by the dial gauge and the 3D optical ARGUS system

Wall thickness reduction [%]	**Section A-A**	**Section B-B**
	I-K	**D-E**
Dial gauge	28.33	32.94
ARGUS	25.34	29.10
Difference	-10.6%	-11.7%

The values of maximum local thinning are compared for both methods of measuring in Table 3. If the maximum values of thickness reduction are considered, the non-contact 3D optical system Argus gives the lower values at critical areas of the model of the bathtub drawpiece –10.6% in section A-A and –11.7% in section B-B, comparing to ones measured by dial gauge. The differences of maximum local thinning measured by the optical system Argus are given by two factors: the first one is the quality of the etched deformation grid and the second ones are the appropriate shooting conditions to take pictures of the drawpiece and positioned coded points. Concerning the quality of the etched deformation grid, the regular round point and the high contrast with the surrounded surface are necessary. Thus, the blank surface quality is also the important and the surface must be free of any corrosion, oil, tallow and other defects. The quality of etching is connected with the time of etching, etching process parameters and an appropriate electrolyte. Over-etching or inadequate etching may cause the irregularity of the point, so the optical system identifies even though small, but the incorrect position and dimensions of the point and then differences in the strain calculations may occur. The deformation of the etched grid on the blank surface also shows the initial imperfections as it was found by Frącz et al. [10] when they have investigated the sensitivity of the optical system Argus as well. Concerning the shooting conditions, the most important factors are lighting, aperture and shutter speed, the number of captured pictures taken at shooting, angles of camera view, etc. The aperture and the shutter speed have been chosen to reach the maximum depth of focus. The number of pictures is dependent on the total accuracy of optical measuring of 0.04 pixels as recommended in the literature [8]. The most important factor influenced on the results we consider the lighting conditions, because used fluorescent light is not the most convenient for shooting.

4. Conclusions

Based on the experiments of deep drawing of the model of the bathtub drawpiece and evaluation of thickness reduction measured by the dial gauge and by the non-contact 3D optical system Argus, following outputs can be stated:

1. The experiments verified the method of the deep drawing with flat restriction bars. The controllable gas springs have been used to restrict

the material plastic flow into the drawing die cavity by friction forces between the blank and flat restriction bars generated by normal forces of gas springs. The flat restriction bars have been placed in the straight walls of the drawing die cavity as it is given at the deep drawing with restriction beads.

2. Two methods of wall thickness reduction measurement were compared – measurement of the thickness by the dial gauge and by the non-contact 3D optical system Argus. The results of measurements of bathtub wall thickness reduction showed the same tendency, but there is a difference in values of thickness reduction. Measurements based on the non-contact 3D optical system Argus gives the lower values of wall thickness reduction at critical areas of bathtub model equal of –10.6% in the section A-A and –11.7% in the section B-B, comparing to ones measured by the dial gauge. Some possible reasons have been discussed, as the most important we consider the surface quality of the blank (free of corrosion, oil etc.), the quality of the etched grid and the lighting used at shooting.
3. The more precise method for wall thickness reduction measurement authors consider the contact method using the dial gauge with coned flat tips with measuring realised along contour of draw piece in specified sections, even though the method is considered as not very precise and time consuming. The precision of thickness measurement can be increased by the number of measurements.

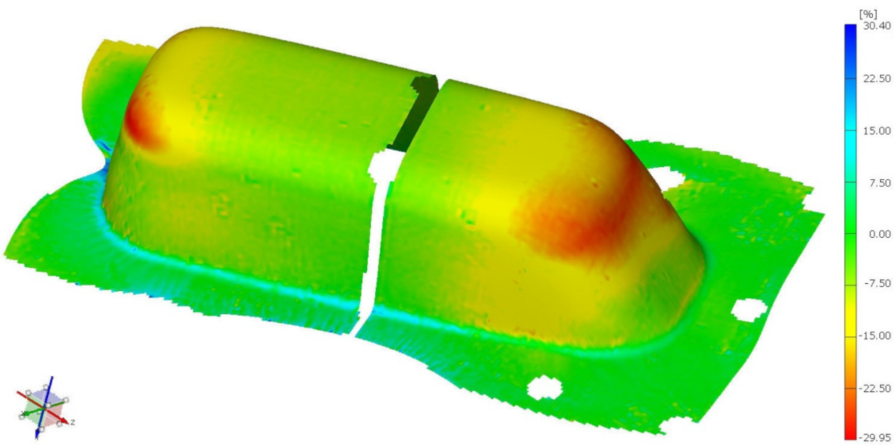

Fig. 12. Thickness reduction of the bathtub drawpiece measured by the non-contact optical system ARGUS

4. The difficulties in measurement of small radii by the optical system Argus as it was presented by Frącz et al. [9] have been proved. The wall thickness reduction on the drawing die radii cannot be measured by the

Argus; the values shown in Fig. 12 are averaged using values of surrounded points.

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BADANIA PORÓWNAWCZE ZMIAN GRUBOŚCI ŚCIANKI WYTŁOCZEK SKRZYNKOWYCH KSZTAŁTOWANYCH ZA POMOCĄ PŁASKICH TRZPIENI DODISKOWYCH

Streszczenie

W pracy przedstawiono metodę głębokiego tłoczenia z wykorzystaniem płaskich trzpieni dociskowych ograniczających płynięcie materiału blachy na płaskich powierzchniach matrycy poprzez zwiększenie oporów tarcia pomiędzy dociskaczem, matrycą i odkształcaną blachą. Wspomniane trzpienie zapewniają wystąpienie dużych naprężeń promieniowych w kołnierzu wytłoczki, zapobiegając nadmiernemu płynięciu materiału do wnętrza matrycy. Parametry procesu głębokiego tłoczenia, takie jak siła docisku oraz normalna siła oporu trzpienia sterowana za pomocą ciśnienia w sprężynach gazowych, były badane i ustawiane podczas modelowania głębokiego tłoczenia wanny. Zmiana grubości ścianki była mierzona za pomocą przyrządu czujnikowego oraz metody fotogrametrycznej z wykorzystaniem systemu optycznego 3D ARGUS. Badania eksperymentalne przeprowadzono dla blachy stalowej zimnowalcowanej do emaliowania KOSMALT 240 o grubości 0,6 mm. Wyniki pomiarów redukcji grubości ścianki wanny za pomocą obydwu rozważanych metod wykazały podobną tendencję, zauważono jednak różnicę w wartości redukcji grubości ścianki. Pomiary przeprowadzone za pomocą systemu ARGUS opartego na bezkontaktowej metodzie optycznej pomiaru wykazały mniejsze wartości grubości blachy w obszarach niebezpiecznych (w zakresie 10,6÷11,7%) w porównaniu z metodami pomiaru za pomocą przyrządu czujnikowego.

Słowa kluczowe: głębokie tłoczenie, wytłoczka prostopadłościenna, płaski trzpień oporowy, tarcie, system ARGUS

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