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MODELLING OF STAMPING PROCESS OF TITANIUM TAILOR-WELDED BLANKS

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Abstract

In the paper some numerical simulation results of sheet-titanium forming of tailor-welded blanks (TWB) are presented. Forming the spherical caps from the uniform and welded blanks are analysed. Grade 2 and Grade 5 (Ti6Al4V) titanium sheets with thickness of 0.8 mm are examined. A three-dimensional model of the forming process and numerical simulation are performed using the ADINA System v.8.6, based on the finite element method (FEM). An analysis of the mechanical properties and geometrical parameters of the weld and its adjacent zones are based on the experimental studies. Drawability and possibilities of plastic deformation are assessed based on the comparative analysis of the determined plastic strain distributions in the drawpiece material and thickness changes of the cup wall. The preliminary experimental studies confirm correctness of the assumptions in the presented numerical forming process. The results obtained in the numerical simulations show some difficulties occurring in forming of welded blanks and provide important information about the process course. They might be useful in design and optimization of the forming process.

Key words: TWB blanks, sheet-metal forming, FEM modelling, titanium sheet

1. INTRODUCTION

Tailor-Welded Blanks (TWB) become more popular in industrial applications in these sectors where reduction of weight and manufacturing costs are important. They are of particular interest in automotive and aircraft industry where there is the growing demand for shell parts (drawpieces) meeting specific functional properties which include low fuel consumption and sufficient strength of elements responsible for usage safety (Hyrcza-Michalska & Grosman, 2008; Sinke et al., 2010; Schubert et al., 2001).

Reduction of production costs for elements made of TWB blanks results from limitation to material usage and number of required forming operations, and consequently decline in the demand for tools. Application of TWB blanks allows for achieving in one operation drawpieces characterized by mixed strength and functional properties. It also allows for reduction of discards from cutting and blanking, and decrease in number of parts needed to produce component. It is estimated that application of TWB blanks can reduce the number of required parts to 66% and reduce the weight by half (Qiu & Chen, 2007; Babu et al., 2010; Meinders et al., 2000).

Application of welded blanks for products manufactured with use of stamping process requires solving many problems, especially in case of forming hard-to-deform sheets, such as alpha and beta titanium alloys. The presence of the weld (its geometric parameters) of different (generally lower) plasticity compared to the base material and heterogeneity of stamped blank lead to change in material deformation scheme in comparison with the deformations that occur in a homogeneous material. This is due to weld dislocation, whose direction and mag-

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nitude depend on differences in mechanical properties and thickness of welded materials (Hyrcza-Michalska & Grosman, 2008; Babu et al., 2010; Kinsey et al., 2000).

In order to evaluate suitability of welded blanks for the forming processes, it is necessary to carry out several studies, including numerical simulations of the process, that will allow for prediction of sheet behaviour in consecutive stages of the forming process (Ananda at al., 2006; Qiu & Chen, 2007; Meinders et al., 2000; Babu et al., 2010; Rojek, 2007; Hyrcza-Michalska et al., 2010; Lisok & Piela, 2003; 2004; Więckowski et al., 2011; Zimniak & Piela, 2000).

The increase in demand, among others in aircraft industry, for structural elements with specific functional properties leads to a growth of interest in sheet-titanium forming. Generally, titanium Grade 2 sheets have good drawability however produced drawpieces are characterized by low strength. On the other hand titanium Grade 5 sheets have higher strength than titanium Grade 2 sheets and they have low propensity to plastic deformation and this limits their application in forming processes (Adamus, 2010; 2009 a; 2009 b).

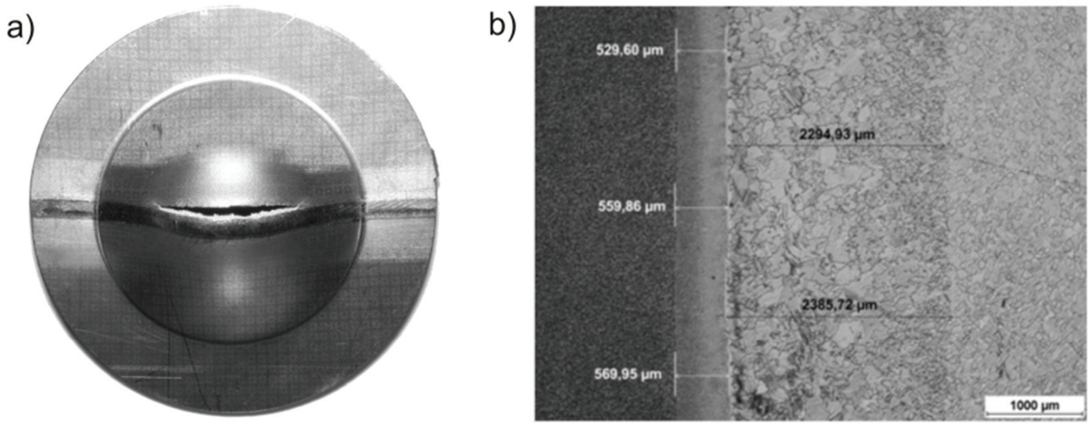

Fig 1. *a) Drawpiece obtained during experimental research, b) microstructure of electron beam welded joint.*

2. GOAL AND SCOPE OF THE WORK

A goal of the paper is evaluation of changes in deformation and displacement scheme of TWB blank material in consecutive stages of the forming process, using numerical simulation and experimental verification of changes in the wall thickness distribution in the drawpiece. In this study the numerical simulation of drawing spherical cap from welded sheets made of titanium Grade 2 and Grade 5 of the same thickness was performed, in order to evaluate its drawability and formability in traditional stamping processes. Additionally calculations for the uniform sheets Grade 2 and Grade 5 were performed. Experimental studies are designed to confirm the validity of the assumptions made in the numerical model of the process (figure 1a).

Grade 2 and Grade 5 materials were joined using electron beam welding (EBW) technology. EBW causes some changes in material microstructure. Analysis of the joint microstructure shows occurrence of 5 zones – from the left: base material – Grade 5, heat affected zone (HAZ) in Grade 5, zone of joint penetration, heat affected zone in Grade 2 and base material - Grade 2. The zone of microstructure changes has a width of less than 3 mm. HAZ in Grade 2 is wider than HAZ in Grade 5. Its width is of ~2282 μm, while width of HAZ in Grade 5 together with zone of joint penetration is of ~553 μm. Titanium Grade 5 has a globular, fine-grained structure. Grains of α phase with separation of β phase on the grain boundaries are visible. Higher magnification shows a change of globular microstructure into lamellar one on the transition of HAZ in Grade 5 into the joint penetration zone. Microstructure of the border zone between the joint penetration and HAZ in Grade 2 is more evolute than the border zone between HAZ in Grade 5 and the joint penetration zone. Microstructure of HAZ in Grade 2 shows big recrystallized grains of α phase. α phase grains with lenticular grains represent the microstructure of base material Grade 2. Rectilinear shape of grain boundaries is typical for recrystallized grains. Microstructure of electron beam welded joint is shown in figure 1b.

3. NUMERICAL MODEL

A three-dimensional model of the stamping process was developed. The model comprises material of the welded blank and the stamping tool consisting of a die, a punch and a blank-holder. FEM geometry model is shown in figure 2.

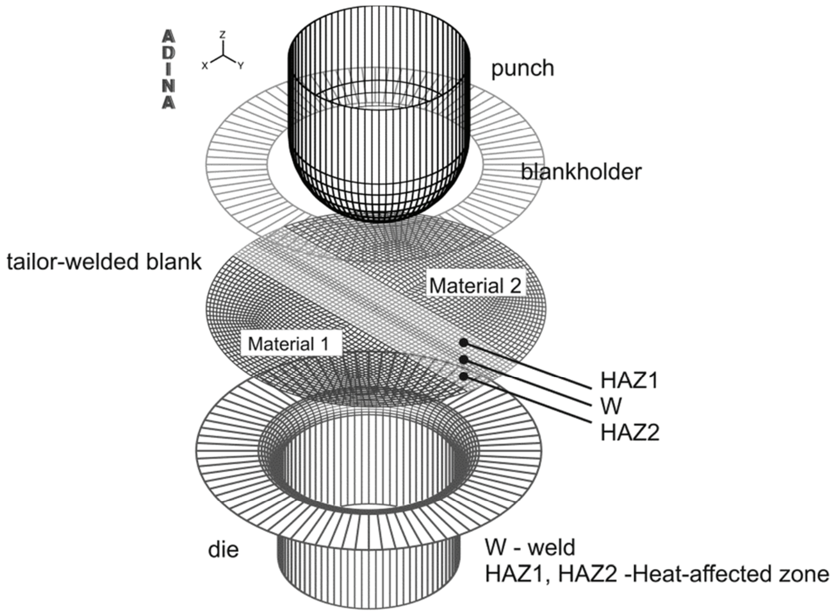

Fig. 2. *A discrete model of the forming process of a spherical cup made of TWB blank with the specified 5-zone model of the welded blank.*

In the calculations all elements corresponding to the tool were assumed to be perfectly rigid and for elements corresponding to the deformed sheet an isotropic elastic-plastic material model was applied (bilinear plastic material model).

Mutual displacement of tool elements against each other was realised by immobilising die and applying the displacement to the punch in the direction of X axis. In the case of the blank-holder its progressive motion was limited by a hold-down force F_d. A proper selection of the blank-holder force prevents wrinkling of the flange material (figure 3), and it also has a significant impact on the distribution of drawpiece wall thickness. An optimal value of the blank-holder force was determined based on the preliminary numerical simulation of the stamping process.

Discretization of the blank material (TWB blanks) for the stamping process, in the form of a disc with diameter d_k = 60 mm, was performed using four-node shell elements of specified thickness.

Modeling of the welded blank material required distinction of appropriate zones and taking into account different material properties in the weld vicinity. In the presented model 5 zones were distinguished: weld zone (W), two heat affected zones (HAZ) located symmetrically on both sides of the weld (HAZ1, HAZ2) and two zones representing base materials (M1, M2) - figure 2.

Measurements of the zones were performed during observation of the weld cross-section structure. In the calculations a constant thickness of the weld and heat-affected zones, which equals to thickness of the welded blanks – 0.8 mm, was assumed. Some important geometric parameters of the model are presented in table 1. In the analysed case the weld was located in the drawpiece centre.

A contact interaction between the tool and the blank material plays an important role in the forming process (Adamus, 2010; 2009 a). In the numerical calculations a friction coefficient $\mu = 0.1$ was set for contact surfaces between the die, blank and blank-holder, where the working surfaces were lubricated, and the friction coefficient $\mu = 0.3$ was set for the contact surface "punch – deformed material (blank)" – without lubrication.

Calculations were performed using the ADINA System v. 8.6, based on FEM, which allows for non-linear description of material hardening and the contact between the tool and the forming blanks.

Table 1. *Parameters assumed in FEM model for the stamping process of TWB blanks.*

Parameter	value
blank diameter d_k	60 mm
clearance between punch and die $l = d_m - d_s$	2 mm
punch radius r_s	16 mm
die fillet radius r_m	4 mm
blank thickness g	0,8 mm
weld width W	1,9 mm
heat-affected zone width $HAZ1$	1,7 mm
heat-affected zone width $HAZ2$	1,0 mm
blank-holder force F_d	3000 N
punch path h_s	20 mm

The mechanical properties, which are required for performing calculations, of base material, heat affected zone and weld zone were determined based on the uniaxial tensile test as well as on the basis of changes in hardness distribution within the weld cross-section. Test specimens were prepared using TIG welding method. The mechanical properties of the material in the weld zone were estimated based on the relationship between the hardness and strength of the material assuming that the material yield stress is in direct proportion to its hardness. The assumed mechanical properties are summarized in table 2.

Table 2. *Experimentally determined material properties of Grade 2 and Grade 5 titanium, weld materials, and HAZ material.*

Material/zone	Tensile strength Rm [MPa]	Yield strength $R_{0,2}$ [MPa]	Young's modulus E [GPa]	Poisson's ratio ν
M1-GRADE 2	316.6	236.8	110	0.37
M2-GRADE 5	1002.4	964.3	110	0.37
HAZ1	442.8	368.3	110	0.37
HAZ2	798.5	747.7	110	0.37
W	518.5	375.0	110	0.37

4. RESULTS

Figure 2 shows the shape of the drawpiece obtained during the numerical simulation of stamping process of TWB blank.

The numerical calculation results of plastic strain ε [-] and thinning of the drawpiece wall as a result of stamping process are shown in figures 4-6. In the case of stamping process of uniform Grade 2 blank it can be observed that the plastic strain distribution in the blank material is uniform and circular (figure 4a), and is accompanied by uniform thinning of the drawpiece wall (figure 4b). In the case of the forming process of uniform Grade 5 blank it is seen that concentration of plastic strains is in a pole of the cup. In this area it is seen a considerable material thinning (figure 5a and 5b).

The numerical simulation of TWB blank forming shows that the weld moves in the direction of Grade 5 material as punch hollows into the deformed blank (figure 6).

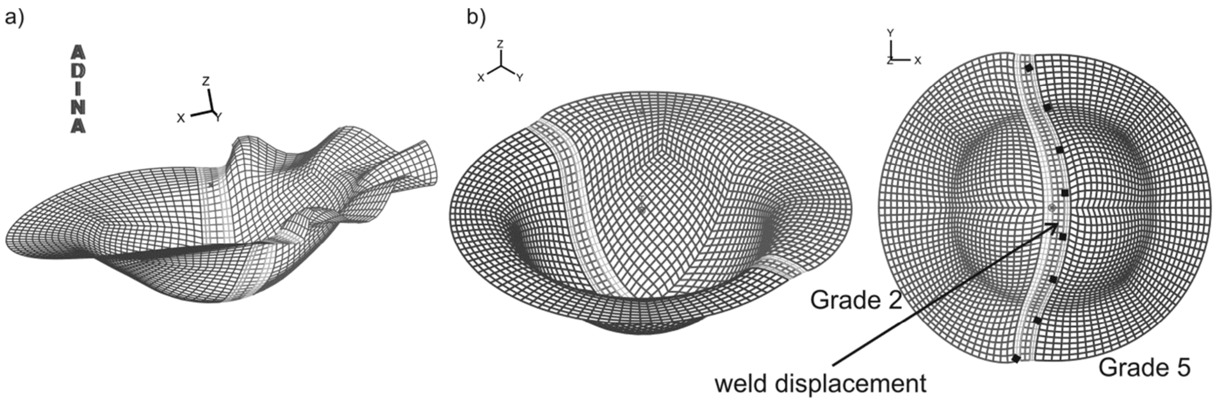

Fig. 3. *The drawpiece shape obtained in numerical simulation of the stamping process of the welded blank a) blank-holder force 1000N, b) blank-holder force 3000N.*

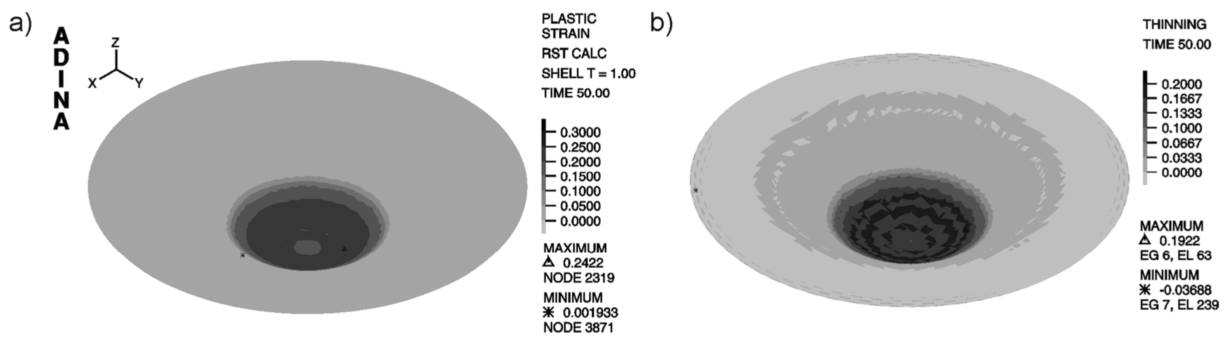

Fig. 4. *Numerical simulation results of stamping process of spherical cup made of Grade 2 blank at the punch penetration of 10 mm: a) plastic strain distribution ε [-], b) material thinning [mm].*

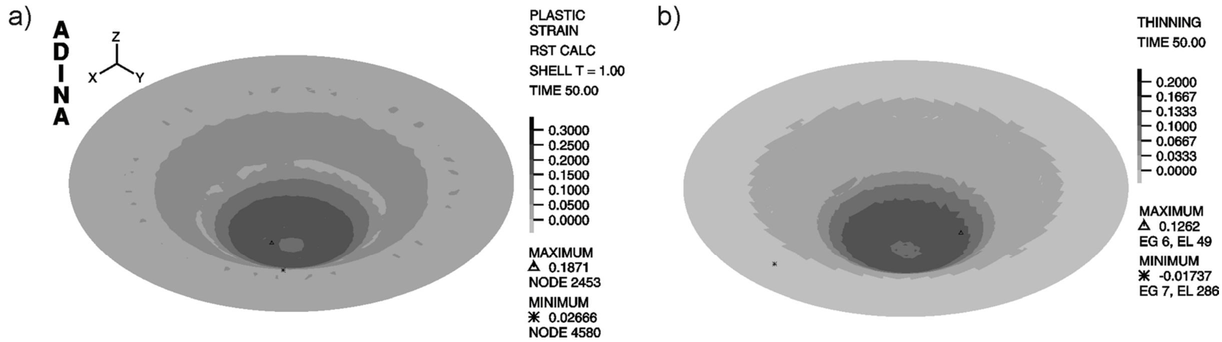

Fig. 5. *Numerical simulation results of stamping process of spherical cup made of Grade5 blank as the punch penetrates the depth of 10 mm: a) distribution of plastic strains ε [-], b) material thinning [mm].*

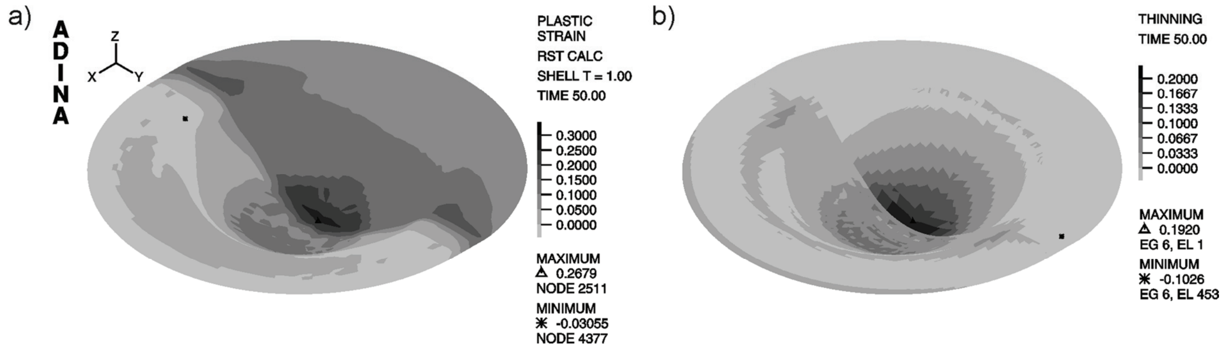

Fig. 6. *Numerical simulation results of stamping process of spherical cap made of welded blank Grade2||Grade5 for punch penetration of 10 mm: a) distribution of plastic strain ε [-], b) material thinning [mm].*

As a result of weld displacement, plastic strains increase in more deformable material and decrease in less deformable material (figure 6a). It should also be noted that in the area near the drawpiece top (on the border between more deformable material and the heat affected zone) there is a local increase in strains and significant thinning of the drawpiece material (figure 6a and 6b). This might indicate that there is a possibility of drawpiece weakening and possible loss of material continuity in this area.

5. SUMMARY

The main goal of the study was to develop a numerical model of stamping process of titanium TWB blanks. The performed simulations (FEM) of the process allow for analysis of deformation introduced into material during forming process and drawability assessment of the welded blanks. In future these studies will be focused on a more accurate description of material mechanical characteristics in the heat affected zones and weld, which will allow for further improvement.

The calculations confirmed experimental results that stamping of titanium welded blanks that are characterized by different strength properties, using rigid tools, is much more difficult than stamping of the uniform blanks. Comparison of strain distribution in the drawpiece made of a homogeneous material with those found in drawpiece made of TWB blanks shows that the presence of weld with different strength properties, introduces irregularity in the strain scheme in the deformed blank. It can be observed that there is limited formability in the zone corresponding to weld and that there is movement of this zone in the direction of less deformable material.

The simulation results show the efficiency of applying numerical calculations to studying stamping processes of TWB blanks. The results provide important information about the process and may be useful for the design and optimization of the process run (selection of appropriate process parameters such as: blank-holder force, lubrication conditions etc.).

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REFERENCES

Adamus J., 2010, The analysis of forming titanium products by cold metalforming, *Monografie nr 174, Wyd. Politechniki Częstochowskiej* (in Polish).

Adamus J., 2009 a, Stamping of the Titanium Sheets. *Key Engineering Materials*, http://www.scientific.net

Adamus J., 2009 b, Theoretical and experimental analysis of the sheet-titanium forming process, *Archives of Metallurgy and Materials*, 54/3.

Ananda D., Chena D.L., Bhole S.D., Andreychuk P., G. Boudreau, 2006, Fatigue behavior of tailor (laser)-welded blanks for automotive applications, *Materials Science and Engineering*, A 420, 199–207.

Babu Veera K., Narayanan Ganesh R., Kumar Saravana G., 2010, An expert system for predicting the deep drawing behavior of tailor welded blanks, *Expert Systems with Applications*, 37.

Hyrcza-Michalska M., Grosman F., 2008, Formability of laser welded blanks, *Proc. Conf. 17th International Scientific And Technical Conference "Design and technology of drawpieces and die stampings", Poznań:INOP* (in Polish).

Hyrcza-Michalska M., Rojek J., Fruitos O., 2010, Numerical simulation of car body elements pressing applying tailor welded blanks – practical verification of results, *Archives of Civil and Mechanical Engineering*, 10/4.

Kinsey B., Liu Z., Cao J., 2004, A novel forming technology for tailor-welded blanks, *Journal of Materials Processing Technology*, 99.

Lisok J., Piela A., 2004, Model of welded joint in the metal charges used for testing pressformability, *Archives of Civil and Mechanical Engineering*, 4/3.

Lisok J., Piela A., 2003, Model złącza spawanego we wsadach do tłoczenia blach „tailored blanks", *Przegląd spawalnictwa*, 6 (in Polish).

Meinders T., van den Berg A., Huetink J., 2000, Deep drawing simulations of Tailored Blanks and experimental verification, *Journal of Materials Processing Technology*, 103.

Qiu X.G., Chen W.L., 2007, The study on numerical simulation of the laser tailor welded blanks stamping, *Journal of Materials Processing Technology*, 187–188.

Rojek J., 2007, Modelling and simulation of complex problems of nonlinear mechanics using the finite and discrete element methods, *Prace IPPT IFTR REPORTS 4* (in Polish).

Schubert E., Klassen M., Zerner C., Walz C., Seplod G., 2001, Light-weight structures produced by laser beam joining for future applications in automobile and aerospace industry, *Journal of Materials Processing Technology*, 115.

Sinke J., Iacono C., Zadpoor A.A., 2010, Tailor made blanks for the aerospace industry, *Int. J. Mater. Form*, 3/1.

Więckowski W., Lacki P., Adamus J., 2011, Numerical simulation of the sheet-metal forming process of tailor-welded blanks (TWBs), *Rudy Metale*, 56/11 (in Polish).

Zimniak Z., Piela A., 2000, Finite element analysis of a tailored blanks stamping process, *Journal of Materials Processing Technology*, 106.

MODELOWANIE PROCESU TŁOCZENIA SPAWANYCH BLACH TYTANOWYCH TYPU TWB

Streszczenie

W artykule przedstawiono wyniki symulacji numerycznych procesu tłoczenia spawanych blach tytanowych typu TWB (Tailor-Welded Blanks). Przeprowadzono analizę kształtowania czaszy kulistej z wsadu spawanego oraz materiałów jednorodnych. Badano blachy tytanowe Grade2 i Grade 5 o grubości 0.8 mm. Przestrzenny model procesu tłoczenia oraz obliczenia numeryczne wykonano przy użyciu programu ADINA v. 8.6, bazującego na metodzie elementów skończonych (MES). Oceny właściwości mechanicznych i parametrów geometrycznych spoiny oraz obszarów jej przyległych dokonano na podstawie badań doświadczalnych. Dokonano oceny tłoczności oraz możliwości kształtowania plastycznego badanych materiałów poprzez analizę porównawczą wyznaczonych rozkładów odkształceń plastycznych w materiale wytłoczek oraz zmiany grubości ścianek wytłoczek. Prowadzone równolegle wstępne badania doświadczalne potwierdziły słuszność przyjętych założeń w zaprezentowanym modelu numerycznym procesu tłoczenia. Uzyskane na drodze symulacji wyniki wskazują na trudności występujące podczas kształtowania blach spawanych oraz dostarczają istotnych informacji o przebiegu procesu, przez co mogą być przydatne na etapie projektowania i optymalizacji procesów tłoczenia.

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