FEM stress state analysis on springback reduction methods: variable blank holder force and stake bead

Victor L. Silveira[ab], Olavo C. Haase[a], Pedro M. A. Stemler[a], Ricardo A. M. Viana[a] and Alisson S. Duarte[ab*]

[a] Sixpro Virtual&Practical Process, Rua Funchal, 308-lj13, Belo Horizonte, MG31340-230, Brazil
[b] Universidade Federal de Minas Gerais, Av. Pres. Antônio Carlos, 6627, Belo Horizonte, MG31270-901, Brazil
*alisson@sixpro.pro

Abstract. The sheet metal forming process is characterized by elasto-plastic strains. Therefore, after removing the stamped part from the dies, it presents the springback phenomena. The present paper analyzes the adoption of a springback reduction methods in a hat bending forming process, *i.e*, the use of variable blank holder force (VBHF) and stake bead (SB). Based on a Finite Element Method (FEM) stress state analysis, springback magnitudes were correlated to the stress moment in the hat shape side wall. Both springback reduction methods, VBHF and SB, were well described and its practical and economic use in the industry discussed. The FEM stress state anlaysis showed a great correlation to the springback phenomena.

1. Introduction

All sheet metal forming process in which a certain amount of deformation by bending occurs presents an inhomogeneous deformation distribution over the sheet thickness [1]. During the unloading, a removal of the part from the dies, the workpiece shows a change of shape due to the elasto-plastic behavior in order to release the internal tensions developed during the forming, reaching a new equilibrium condition. This dimensional change of the formed part compared to die's shape is so-called springback (SPBK) [2].

For die design purposes, it is essential to consider the springback phenomena [3] by the fact that afterwards the stamped geometry becomes different from the die shape. Therefore, dies should be designed in attention to the springback compensation and/or include elements that reduces stresses that causes it, avoiding a final unusable or unsuitable part. By means of numerical simulation, knowing the blank behavior after unloading provides the possibility of making changes previously to real production. However, predicting material behavior is not a trivial task, since that the geometry changes after springback depends on many factors, *i.e.*, material properties, die shape and dimension, forming conditions, sheet thickness and sector angle [4;5].

In a stamping process the sheet undergoes a deformation process characterized by bending and unbending until it reaches the desired part geometry. With this, the material is subjected to cyclic stresses, which leads it to present different behaviours for each deformation path. This behaviour of the materials was studied by Johann Bauschinger [6]. A method developed by Yoshida-Uemori takes into account this change of behaviour in the material, depending on how it is requested during the deformation. According to the literature, the use of this model guarantees better results when compared to the experimental results [7].

With respect to tooling geometry, some authors have studied aspects that have more influence on the final springback. According to Cho and Moon [8], the punch corner radius and the punch-die clearance lead to almost a linear change in the springback amount. On the subject of process forming conditions, some parameters that influence springback results are punch velocity and blank holder force.

Regarding sheet metal forming application, the increasing automotive industry need for mass reduction due to greater fuel efficiency in vehicles have led to the replacement of classic materials with High Strength Steels (HSS). These materials have the advantage of providing higher strength to weight ratios for structural parts. However, the more resistant the material, the greater the springback. Hence making the design and adjust of the process significantly more complicated, this is one of the factors that has limited the widespread acceptance of these steels in the industrial marketplace [9].

An alternative to facilitate the study and analysis of springback would be the use of computer-aided engineering (CAE), one of the most useful tools to aid in the prediction of springback [10]. With this, it is possible to obtain from the simulation the blank behavior during the forming process, thus being possible to verify the occurrence of problems such as cracks, wrinkles and insufficient stretching. Depending on the software's capabilities, it is possible to get more complex analysis extracted from the process, such as thickness reduction, elastic recovery and plastic deformation.

Considering the difficulty on the springback prediction of stamped parts and its compensation by means of die shape, it is important to study methods that helps reducing it in forming processes. In order to study it, the Hat Shape Bending (scheme in Figure 1) was chosen to be used in this paper as a basis to obtain the springback dependence on blank holder force and the use of specific die elements. So therefore, the present paper evaluates the influence of specific forces conditions applied by the blank holder in springback, providing an explanation based on a side wall stress state analysis. In addition, VBHF and SB solutions were analyzed and described by means of the simulated stress state.
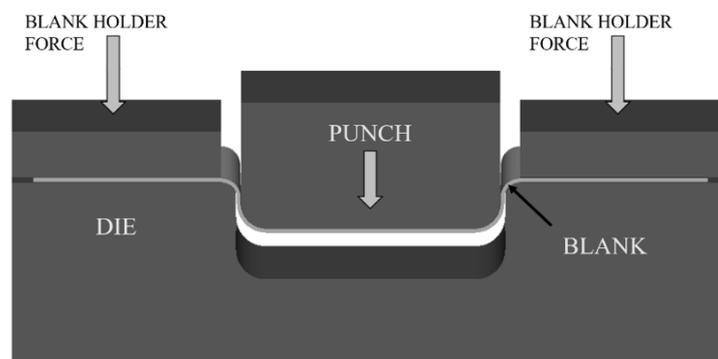

Figure 1. Hat Shape Bending scheme.

2. Methodology

Four simulations were conducted in the software PAM-STAMP [11], which is based on the Finite Element Method and has been validated in Lefebvre's paper [12]. The first three simulations were performed using the same FE model, shown in Figure 2 (a), but with different BHF conditions. The blank holder forces were set to approach different forming conditions. A 40 kN (relative low) and a 120 (relative high) BHF were tested. A third condition for a variable BHF was used. The BHF variation as a function of the flanging steel displacement is shown in Figure 3. This analysis, using constraint and variables BHF, is similar to other authors experiments [13], and tooling dimensions were specific designed for the simulation analysis in this paper. The fourth, and last, simulation was performed for a different FE model (Figure 2 (b)), which includes a stake bead geometry (SB). The stake bead was placed 50 mm away from the adaptor, and has a 37,2 mm length, 10 mm height, and 3 mm forming radius. The BHF used in this case was equal to 40 kN, the same used in the first simulation. Figure 2 (b) and 2 (c) show the blank dimensioning for the simulations using Standard Hat Shape bending and Hat Bending with Stake Bead, respectively.
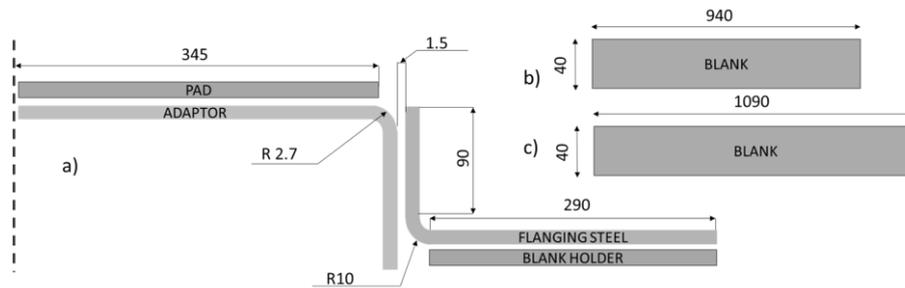
Figure 2. (a) Forming scheme with symmetry plane; blank top view of (b) Standard Hat Shape Bending and (c) Hat Shape Bending with Stake Bead.
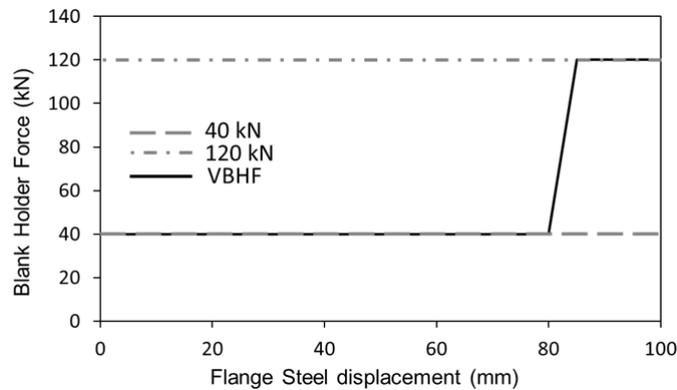
**Figure 3.** Blank holder force behaviour during flanging steel displacement for the simulations performed.

For the first three simulations, the initial blank was discretized in 78 square elements, and for the simulation with stake bead, the initial blank was discretized in 114 square elements. The PAM-STAMP provides an automatic remesh criteria based on the tools' smallest radii, which was used. This method adoption guarantees a more accurate calculation and saves simulation time. Figure 4 shows the wireframe before and after the forming process for both FE model, Standard Hat Shape Bending and Hat Shape Bending with Stake Bead geometry.
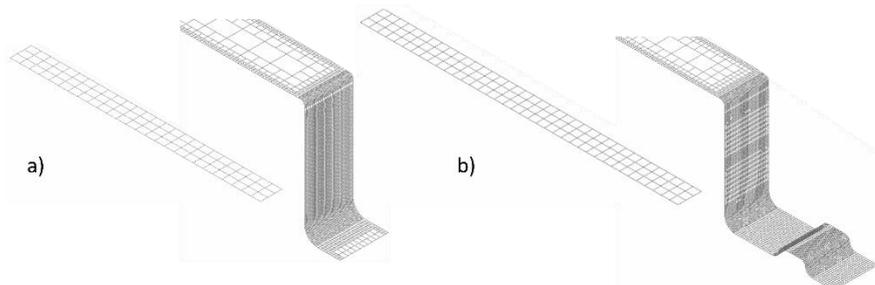
Figure 4. Mesh wireframe: (a) before and (b) after the process for Standard HSB, and (c) before and (d) after for the HSB with Stake Bead geometry.

Due to the natural symmetry of the process, only half of the geometry was necessary to be simulated, decreasing the required number of elements and the simulation time. The forming process occurs when the blank holder presses the blank against the flanging steel and both tools start to move downwards,

forcing the blank to be deformed and forming the hat shape side wall. At the same time, the pad is used for holding the blank against the adaptor, avoiding buckling. The forming movement sequence can be seen at the Figure 5.
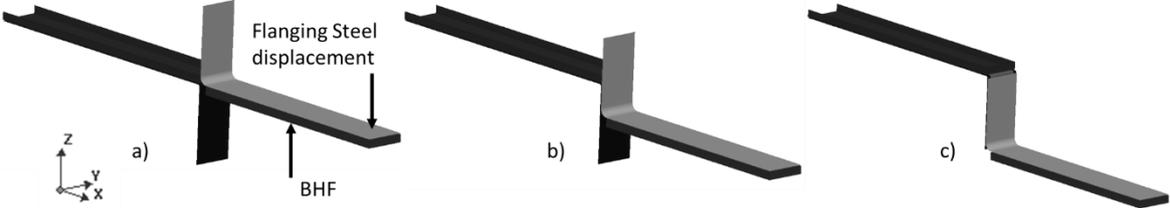
Figure 5. Schematics of flanging steel positioning: (a) initial, (b) intermediary; and (c) final.

The FE setup considered a 0.12 friction coefficient between the surfaces. This value is suggested by PAM-STAMP for cold forming process. From the authors experience obtained with many simulations previously performed, this friction coefficient value validates well the simulation compared to the real manufacturing. A 1.3 mm DP980 was used, and Figure 6 shows the material flow curve. The Hill 48 model was used to represent the material behavior. Furthermore, the material was considered as isotropic.
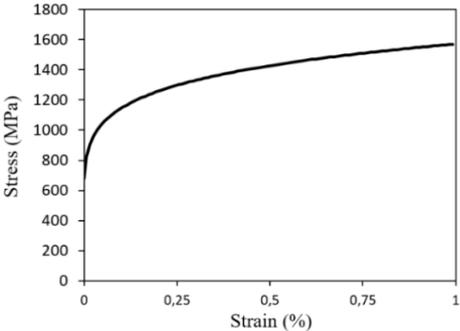

Figure 6. DP980 1.3 mm flow stress curve [Pam-Stamp, v17.5].

3. Results and discussions

The springback results for the first three simulations performed, using Standard Hat Bending Shape, are shown in Figure 7. In Figure 8, the simulated springback result for and Hat Bending with Stake Bead is presented in comparison to the VBHF.
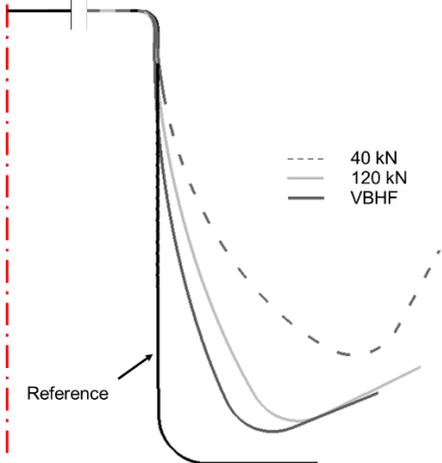
Figure 7. Simulated springback results for 40 kN BHF, 120 kN BHF and VBHF.
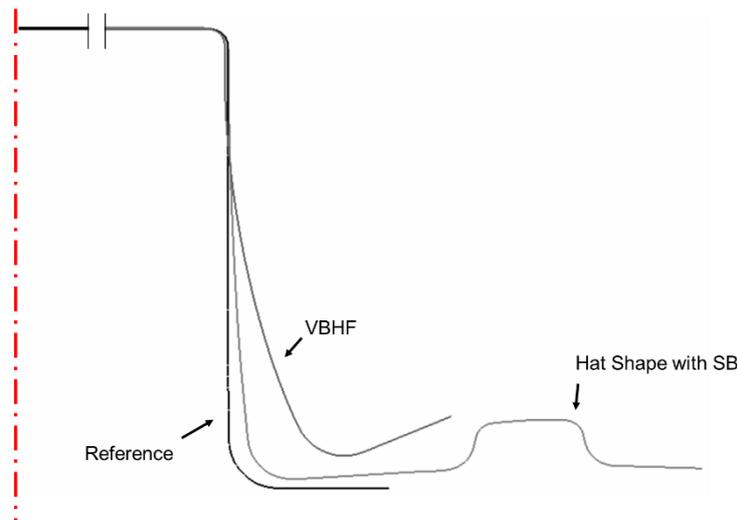
**Figure 8.** Simulated springback results for VBHF and Stake Bead cases.

A nonlinear deformation is characteristics of the process, introducing a large amount of elastic strain in the blank material, and is nonhomogeneous along the sheet thickness. This elastic energy is stored in the blank until the unloading moment, when it is released. This energy releasing is responsible for the springback, in which the blank is trying to reach a new equilibrium position [14].

From the results in Figure 7, among all three different cases of blank holder force used in the Standard Hat Shape bending, the VBHF case has provided the lower springback result. It can be explained by the side wall stresses behavior during the forming process. The initial relative low BHF, for the VBHF, facilitates the forming of side wall by decreasing the blank flow restriction. At the end of the process, there is a sudden BHF increasing, which causes a stretching on the side wall. This action stretches the side wall, minimizing the resultant moment of the intern stresses caused by the bending and unbending during the forming process. Therefore, it decreases the need of a geometry changing to find a new equilibrium position, as also visualized by Gang Liu [13]. This explanation is valid for the Stake Bead as well. In the end of the process, when the blank touches the SB, it increases the blank restriction, which causes stretching on the side wall. As similar to the VBHF case, the stretching on the side wall reduces the internal moment in the sheet thickness.

A detailed side wall stress analysis was conducted for the four simulated cases. The chosen point in Figure 9 was taken for obtaining longitudinal stresses as the flanging steel displaces. Figure 10 summarizes the side wall stress analysis. At a 70 mm displacement (Figure 9 (a)), the 120 kN BHF condition results in lower difference between the longitudinal stress for lower and upper fibers when compared to the 40 kN BHF and VBHF cases. It represents a lower moment on the wall thickness, and therefore it indicates a smaller springback tendency. However, at the end of the process (90 and 100 mm displacement), the BHF increasing for the VBHF condition results in a concentrated side wall stretching, therefore reducing the compressive longitudinal stress in the lower fiber, reducing the moment in the wall thickness. As a consequence, the springback is reduced for the VBHF condition, as previously shown in Figure 7. For the stake bead case, the moment was taken at 70, 96 and 100 mm flanging steel displacement, in attention to the sheet forming over the stake bead.
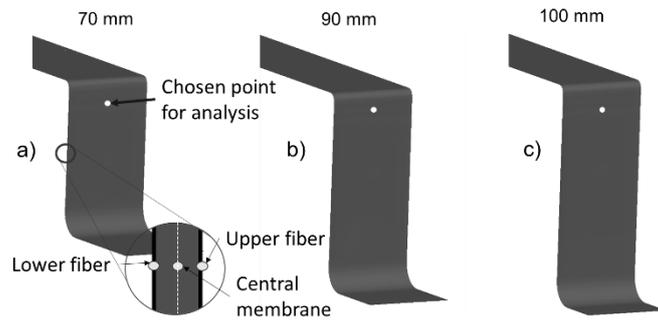
Figure 9. Chosen point for stress analysis when the flanging steel displacement is: (a) 70 mm; (b) 90 mm; and (c) 100 mm.
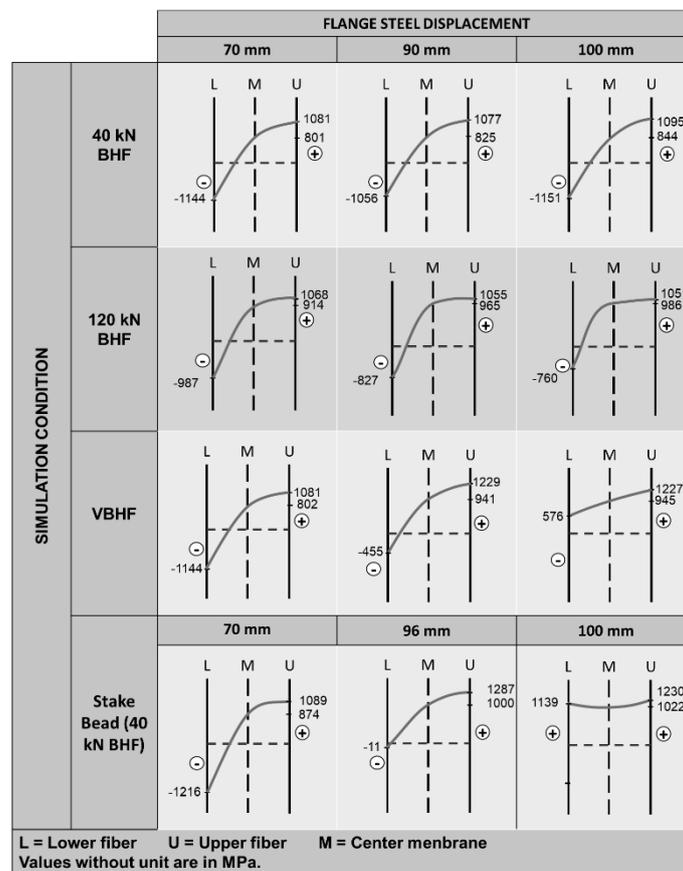
Figure 10. Stress distribution over blank thickness, in the central membrane, lower and upper surfaces.

Based on the analysis in Figure 10, the Hat Shape Bending with Stake Bead has presented the lower internal moment after forming, compared to all other simulations performed. This affirmation is in agreement with the result shown in Figure 8. Comparing only 40 and 120 kN BHF conditions, the final moment in the side wall thickness, for the chosen point (Figure 9), trended to be lower for a higher BHF.

The moment trend in the side wall thickness during the process for all cases, represented by the longitudinal stress difference between lower and upper fibers, is shown in the Figure 11. The final moment magnitude may be correlated to the springback magnitude for each condition.
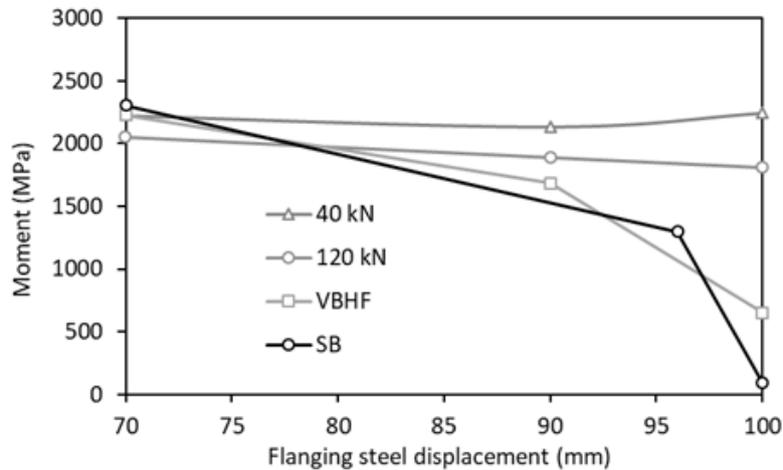
Figure 11. Graphic "Moment vs Flanging Steel Displacement".

Other authors performed studies related to the present subject and have also found that VBHF presents great springback results, such as Hassan [15], Kitayama [10] and Gunnarsson [16]. However, to the best application of this method it is necessary to find an optimized BHF condition, that is, to find an optimized lower force, high force and the transition time between those forces. Choosing rightly the lower force is related to estimate a value high enough to avoid blank wrinkling, but it is difficult to do so. There is not a defined method to estimate the higher force, and choosing high values for this parameter means to take more rupture risks. Defining the transition time between the lower force and the high force is related to an analysis on the strain level in the formed side wall [17].

According to Schmoeckel [1], the springback final result is connected to the BHF applied at the end of the process. Some experimental tests were conducted with different blank holder forces behaviour during a forming process. It could be concluded that better springback results were obtained in those experiments in which a higher force was applied, therefore a stretching condition, in the end of the process. The difference between the experimental results obtained by Schmoeckel was in the strain condition along with the side wall formed in each part. Some of them have undergone a higher stretching longer than others, thus modifying the final strain condition.

A factor to be considered when using a VBHF is its application feasibility. For this purpose, a forming system in which it is possible to variate the BHF during tools displacement is necessary, which is not a common device in the press in general due to the high investment necessary. Typically, the press load system has its action pneumatically, by spring action or by nitrogen pad.

When using stake bead geometry, it was possible to decrease the springback, however, there are disadvantages when using this method. It is necessary more material to form the part, since the surface to be formed is bigger due to the SB geometry addition. In other words, the blank needs to be larger. When comparing this method to the Variable Blank Holder Force method, the costs increasing is not due to the need of a servo press cushion, but due to the necessity of more material for forming process.

4. Conclusions

The tensile moment analysis in the side wall thickness presented a valuable methodology for springback studies, providing great correlation with the springback magnitude.

Different BHF's resulted in different springback shapes. Compared to constant BHF's, VBHF has presented a better springback result in the part formed by Hat Shape Bending process, based on the Finite Elements Method. In addition, the use of Stake Bead has improved the springback reducing compared to the VBHF condition.

It is possible to affirm that VBHF and Stake Bead methods are a viable alternative to reduce springback. Those methods depend on the press capabilities, for VBHF cases, or on the blank size increasing, for Stake Bead cases.

References

[1] Schmoeckel, D., & Beth, M. (1993). Springback reduction in draw-bending process of sheet metals. *CIRP Annals-Manufacturing Technology*, *42*(1), 339-342.

[2] Narasimhan, N., & Lovell, M. (1999). Predicting springback in sheet metal forming: an explicit to implicit sequential solution procedure. *Finite elements in analysis and design*, *33*(1), 29-42.

[3] Samuel, M. (2000). Experimental and numerical prediction of springback and side wall curl in U-bendings of anisotropic sheet metals. *Journal of Materials Processing Technology*, *105*(3), 382-393.

[4] Panthi, S. K., Ramakrishnan, N., Ahmed, M., Singh, S. S., & Goel, M. D. (2010). Finite element analysis of sheet metal bending process to predict the springback. *Materials & Design*, *31*(2), 657-662.

[5] Lima, V., Haase, O., Stemler, P., Viana, R., Duarte, A. (2017). Springback dependence on blank holder force. *37th SENAFOR. SIXPRO Virtual and Practical Process. 11p.*

[6] Toros, S. (2016). Parameters Determination of Yoshida Uemori Model Through Optimization Process of Cyclic Tension-Compression Test and V-Bending Springback. *Latin American Journal of Solids and Structures*, *13*(10), 1893-1911.

[7] Ghaei, Abbas. (2010). "Modeling Springback in Stamped Automotive Structures". Electronic Theses and Dissertations. Paper 188p

[8] Cho, J. R., Moon, S. J., Moon, Y. H., & Kang, S. S. (2003). Finite element investigation on spring-back characteristics in sheet metal U-bending process. *Journal of Materials Processing Technology*, *141*(1), 109-116.

[9] Gomes, C., Onipede, O., & Lovell, M. (2005). Investigation of springback in high strength anisotropic steels. *Journal of Materials Processing Technology*, *159*(1), 91-98.

[10] Kitayama, S., Huang, S., & Yamazaki, K. (2013). Optimization of variable blank holder force trajectory for springback reduction via sequential approximate optimization with radial basis function network. *Structural and Multidisciplinary Optimization*, *47*(2), 289-300.

[11] ESI Group. Pam-Stamp, version 2017.0. Paris, France (2017). 1 CD-ROM.

[12] Lefebvre, D., Haug, E., & Hatt, F. (1994). Industrial applications of computer simulation in stamping. *Journal of materials processing technology*, *46*(3-4), 351-389.

[13] Liu, G., Lin, Z., Xu, W., & Bao, Y. (2002). Variable blankholder force in U-shaped part forming for eliminating springback error. *Journal of Materials Processing Technology*, *120*(1), 259-264.

[14] R.G. Davies, J. Appl. Metalwork 3 (1984) 120.

[15] ul Hassan, H., Maqbool, F., Güner, A., Hartmaier, A., Khalifa, N. B., & Tekkaya, A. E. (2016). Springback prediction and reduction in deep drawing under influence of unloading modulus degradation. *International Journal of Material Forming*, *9*(5), 619-633.

[16] Gunnarsson, L., & Schedin, E. (2001). Improving the properties of exterior body panels in automobiles using variable blank holder force. *Journal of Materials Processing Technology*, *114*(2), 168-173.

[17] Jiang, C., Han, X., Liu, G. R., & Li, G. Y. (2007). The optimization of the variable binder force in U-shaped forming with uncertain friction coefficient. *Journal of Materials Processing Technology*, *182*(1), 262-267.