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ANALYSIS OF SPRING-BACK DURING FORMING OF THE ELEMENT MADE OF AMS 5604 STEEL

ANALIZA SPRĘŻYNOWANIA POWROTNEGO PODCZAS KSZTAŁTOWANIA ELEMENTU ZE STALI AMS 5604

Spring-back poses a serious problem during the design of the sheet-metal forming processes due to difficulties in obtaining the correct shape and dimensional accuracy of the stamped elements. Forming with blank preheating is one of the methods of prevention against spring-back effect. However, this solution involves cost increase resulting from the additional operation of material heating and necessity of material protection against oxidation.

In the paper forming of an element made of AMS 5604 steel, which is a part of aircraft engine deflector, has been analysed. The work aimed at determination of the spring-back effect arising during two-time forming on deviation of the basic size of the drawn-part from nominal one. Basing on the numerical analyses an optimum yield point for the deformed material, which assures maximum deviation from the basic size lower than 0.1 mm, has been also determined. Change in the yield point value was obtained thanks to heating up of the blank material before forming.

Keywords: spring-back, sheet-metal forming, numerical simulation, AMS 5604 steel

Zagadnienie sprężynowania powrotnego stanowi istotny problemem przy projektowaniu procesów kształtowania blach na zimno ze względu na trudności z otrzymaniem odpowiedniej dokładności kształtowo-wymiarowej elementów. Jednym ze sposobów eliminacji sprężynowania powrotnego jest kształtowanie z wstępnym podgrzewaniem materiału wyjściowego. Takie rozwiązanie wiąże się jednak z dodatkowymi kosztami wynikającymi z operacji nagrzewania materiału i konieczności jego zabezpieczenia przed utlenianiem.

W artykule analizowano kształtowanie elementu ze stali AMS 5604, stanowiącego fragment owiewki silnika lotniczego. Celem pracy było określenie wpływu skutków sprężynowania powrotnego powstającego podczas "dwukrotnego" tłoczenia na odchylenie wymiarów wytłoczki od wartości nominalnych. Na podstawie analiz numerycznych określono również optymalną granicę plastyczności materiału zapewniającą utrzymanie maksymalnego odchylenia od wymiaru nominalnego mniejszego niż 0,1 mm. Zmianę wartości granicy plastyczności uzyskano poprzez podgrzanie blachy przed tłoczeniem do odpowiedniej temperatury.

1. Introduction

Sheet metal forming processes are an essential part of modern industry because they allow for production of high quality products with complex geometry at low manufacturing costs. They make it possible to produce a wide range of the drawn-parts, starting from the small metal fancy goods over the car-body elements to the big structural elements of air- or spacecrafts. Most of them can be manufactured as the finished products without necessity for further machining. Technological progress in sheet-metal working results from the need for an increase in productivity and accuracy of the drawn-parts. The execution of these is possible due to improvements

of the forming tools, automation and computerization of technological processes.

Although deep-drawing steels are typical materials used in sheet-metal working other materials like: higher-strength steels, stainless steels or light metal (Al, Mg, Ti) alloys are used more and more often. However application of these materials involves a necessity of solving new technological problems which did not find a proper reflection in technical literature. Most of the problems result from poor drawability of the sheets and improper tribological properties [1,2]. A spring-back phenomenon, which essentially affects shape and dimensional accuracy of the elements, poses another problem, which is very difficult to solve [36]. Large nonlinear

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plastic deformations accompanying sheet-metal forming cause accumulation of high amount of elastic energy, which releases as a spring-back after material unloading. Value of spring-back as a consequence of the amount of stored energy depends on the deformed material properties and its thickness, tool geometry, forming method etc. All these parameters have to be taken into consideration during sheet-metal forming design.

Sheet-metal forming using rigid tools i.e. punch, die and blankholder is the most frequently applied method. Unfortunately, poor drawability of some materials makes it impossible to use classical forming methods. In these cases, forming in higher temperatures [79], superplastic forming - SPF [10-11], high-energy-rate forming [12-14] or hydroforming [15-18] and also „viscous pressure forming” (VPF) [19] are recommended. However, all these methods need additional capital expenditure because of expensive and complicated tooling, necessity of purchase of new machine and what is more all these methods are less productive than classical sheet-metal forming.

This study concerns forming possibilities of the element, which is a part of aircraft engine deflector. Analysis has been carried out using numerical simulation. The element is made of AMS 5604 steel, which is used in aircraft industry due to high mechanical properties and good corrosion resistance. Because of the high spring-back phenomenon during cold forming, the element is manufactured by hot forming. Although such a technology allows for obtaining the exact shape of the element, the costs grow with the necessity of preheating and material protection against oxidation.

2. Methodology for determining of the drawn-part deformation after spring-back

Until recently prediction of the spring-back phenomenon was possible only for bending processes of the elements with simply geometry (usually having a constant bending radius), which were made of well known materials. Such analyses have been carried out basing on the empirical recommendations available in handbooks or simple analytical calculations. Although finite element method is used for spring-back prediction more and more often a description of material behaviour under loading and unloading still poses a serious problem. In order to simulate multiple stamping processes allowing for spring-back assessment it is necessary to define exact contact and the proper size of the finite elements for the deformed material and tool. In the analyses an explicit algorithm was used for spring-back definition. The simulation was carried out in four steps:

1. first stamping
2. determination of the spring-back after first stamping operation,
3. second stamping
4. determination of the spring-back value after second stamping operation and after trimming of the drawn part to the required dimensions.

The springback was determined by measurement of the distance between the corresponding nodes with taking into consideration a real sheet thickness, as it is shown in Figure 1.

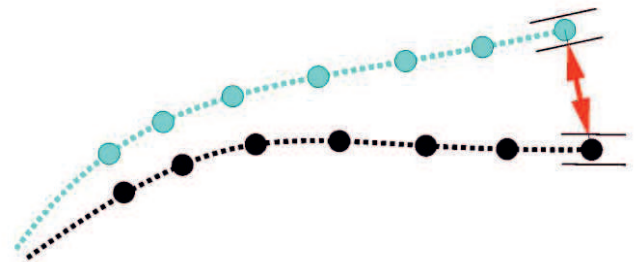


Fig. 1. Scheme of measurement of the distance between drawn part before and after spring-back

3. Numerical simulation

Commercial PAM-STAMP2G System [20] was used in the numerical simulations. Perfectly stiff material model for forming tools and elastic-plastic material model with linear strain hardening for the sheet material were assumed in the calculations. Strain hardening modulus has a constant value. The Hill 48 criterion coupled to an isotropic hardening law was used. Besides that, the software supports the use of the HILL 48 criterion coupled to an isotropic and kinematic hardening law [20]. Contact corresponding to the conditions of calculation is selected automatically when the solver is launched.

The shape and basic dimensions of the drawn part are shown in Figure 2a. Sheet thickness is 0.5 mm. Figure 2b presents a scheme of two-time stamping process. After first stamping operation the drawn part is put upside down and stamped using the second punch. This technique enables producing higher plastic strains for the stamped drawn part and minimizes springback effect.

In order to obtain the required element shape two-time stamping was proposed. Two sets of stamping tools were used. Each one consists of the die, punch and blank-holder. The punch geometry for the first and second stamping operations is respectively, shown in Figures 3 and 4.

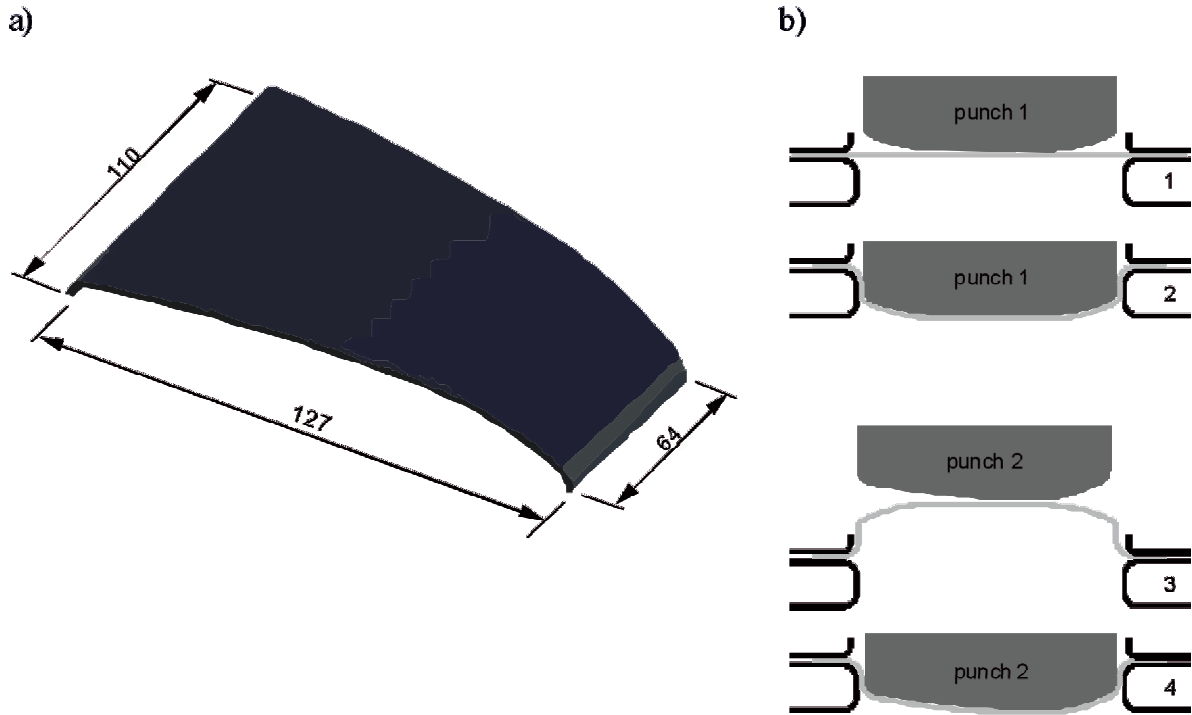


Fig. 2. Drawn-part stamping process: a) the shape and basic dimensions of the analysed drawn-part, mm; b) stamping process operations

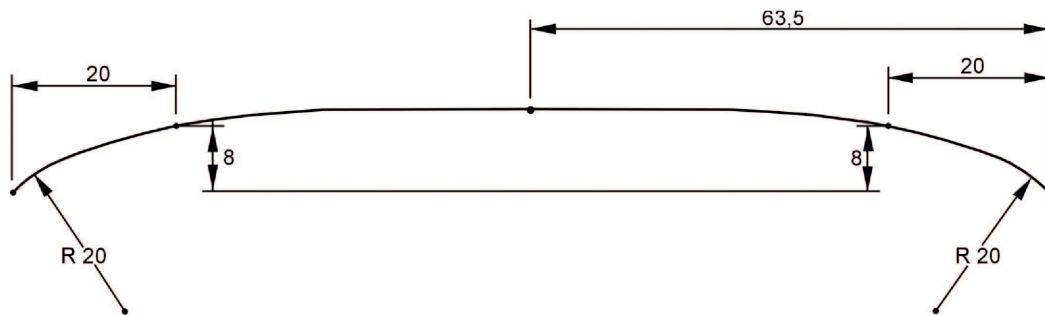


Fig. 3. Geometry of the punch used in first stamping operation

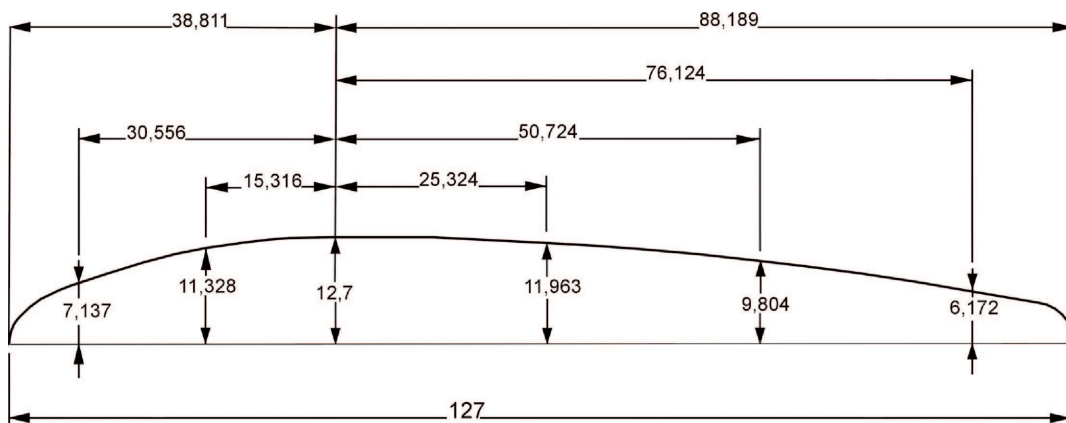


Fig. 4. Geometry of the punch used in second stamping operation

The die models were prepared basing on the geometry of the proper punches. Fillet radius of the dies was 5 mm. Surface models of the dies and punches were prepared in CATIA V5 System and saved in an IGS format file. Based on the prepared models finite element mesh was automatically constructed with DeltaMESH tool, which allowed for generation of shell elements, especially designed to simulate sheet-metal forming processes. The mesh was automatically optimised after each forming stage.

By default, the appropriate boundary conditions are assigned to the nodes for the elements of the specific group. In case of the die both translation and rotation in all directions were locked. While rotation in all directions and translation only in X and Y were locked for the punch. Hence the punch could move in Z direction with a defined velocity. Similarly, rotation in all directions and translation in X and Y directions were locked for the blank-holders. The specified load was applied to the blank-holders so they could operate in Z direction. There were no defined any boundary conditions for the nodes of the blank. In order to the proper measurement of the springback it was necessary to remove all movements of the body to make sure that only the springback phenomenon was analyzed.

Belytschko-Tsay element formulation was used in the stamping simulation. Belytschko-Tsay elements are the simple and efficient elasto-plastic shell of 3-node and 4-node finite elements [20]. They are based on the concept of uniform reduced integration. Moreover, the elements are characterized by:

- Midlin-Reissner's Theory: the transverse shear strain, constant in the thickness, is taken into account
- each node has three degrees of freedom in translation and three degrees of freedom in rotation
- no transverse shear locking
- thickness integration rule: defines the distribution of the integration points across the thickness, and the weight of each point. Gauss rule was used were the weight is different and the distribution is done to improve the quality of the results
- number of integration points through the thickness: five points was used for a good quality of results
- excellent CPU time.

The numerical model for the tool used in the second stamping operation is shown in Figure 5.

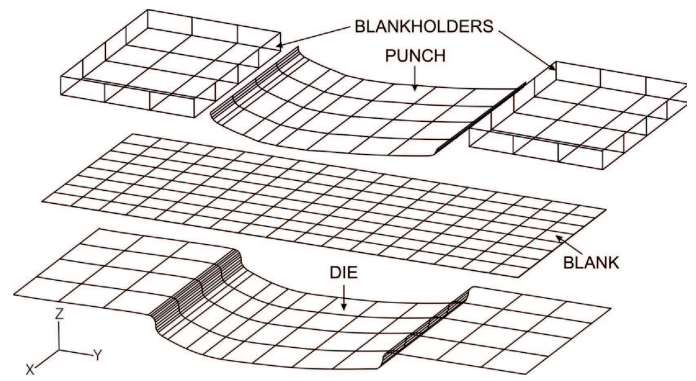


Fig. 5. Finite element mesh for the tool used in the second stamping operation

An influence of the drawbeads on spring-back was one of the analysed factors. In the analysis an effective draw-bead model was used. A real draw-bead geometry shown in Figure 6 is used for determination of frictional resistance during stamping process and for ascribing them to bar elements, which are presented in Figure 7. Drawbeads are defined with bar elements, but only for the geometric aspect of these elements (position of the node), not for the mechanical properties. A detailed calculation algorithm of frictional resistance on the drawbeads is described in [20]. The drawbead dimensions are as following: $R1=1.0$ mm, $R2=2.0$ mm, $L2=4.0$ mm, $D=0.5$ mm.

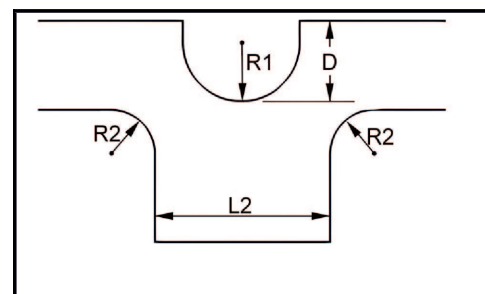


Fig. 6. Scheme of the draw-bead

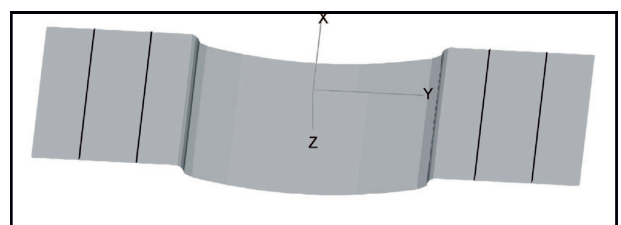


Fig. 7. Location of the draw-beads on the die

Trimming along the line, which was marked in Figure 8, was the last forming stage.

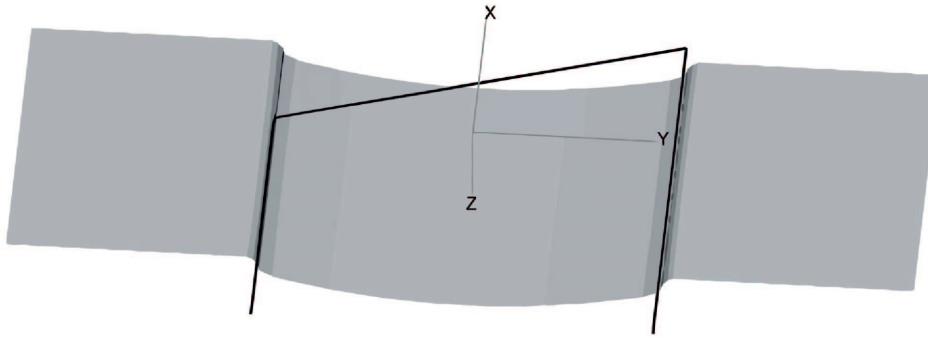


Fig. 8. Trimming line

4. Material

Mechanical properties of AMS 5604 steel vary depending on the delivery conditions. Some properties are presented in Table 1.

Stamping process was analysed for 6 values of yield point σ_{pl} which are presented in Figure 9, and a constant value of strain hardening modulus of 2 GPa. Although Young's modulus varies with temperature, especially at high temperatures, and the numerical model is able to take it into account, a constant Young's modulus $E=200\text{GPa}$ was assumed in the calculations. A detailed analysis, which takes into consideration changes in value of Young's modulus vs. temperature will be carried out after determining the optimum value of yield point. In

the analyses it was also assumed that the required value of Yield point will be achieved regardless of delivery condition. It will be realised by preheating of the material to the proper temperature. Determination of the yield point vs. temperature for the individual delivery conditions will be continued in further research.

5. Parameters of the stamping process assumed in the numerical simulation

In search of an optimum solution the numerical simulation with and without drawbeads was carried out. Process parameters are given in Table 2.

Mechanical properties of AMS 5604 steel in ambient temperature (based on manufacturer data)

TABLE 1

Property	Delivery conditions						
	A	H900	H925	H1025	H1075	H1150	H1150-M
Tensile strength, MPa	1103	1448	1379	1269	1207	1103	1034
Yield point, MPa	1000	1379	1345	1172	1148	1034	896
Elongation $A_{50}\%$	5.0	7.0	8.0	8.0	8.0	11.0	12.0
Rockwell hardness, HRC	C35	C45	C43	C38	C37	C35	C33

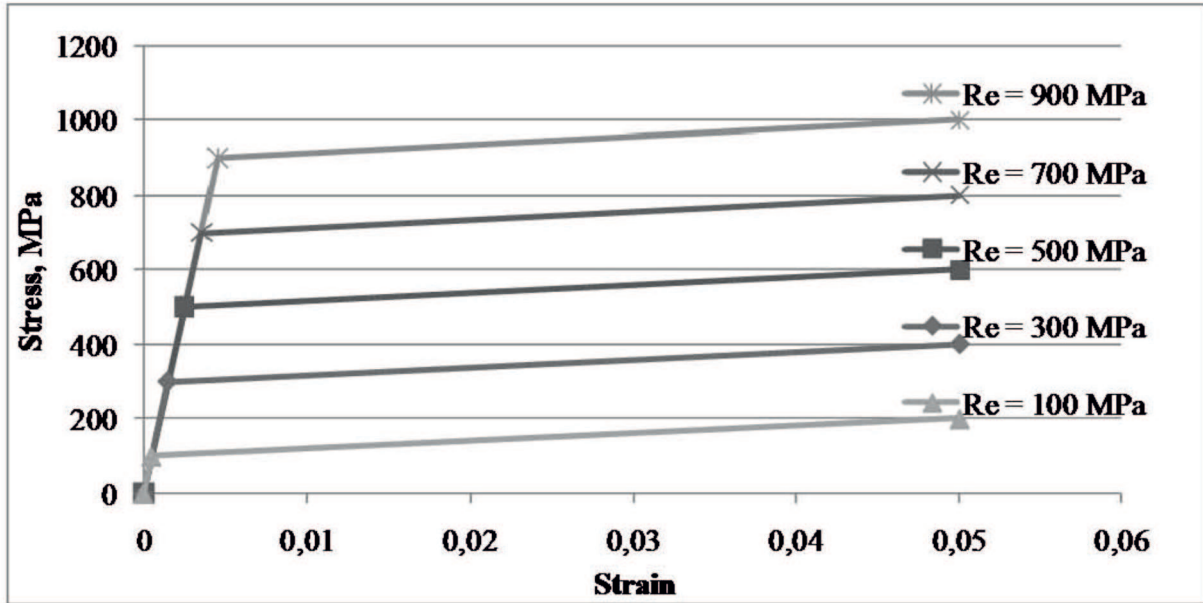


Fig. 9. Strain-stress curves

TABLE 2

Parameters of the forming process

Forming with no drawbeads			Forming with drawbeads		
Blank-holder force, kN	Friction coefficient	Rolling direction	Blank-holder force, kN	Friction coefficient	Rolling direction
200	0.12	x	50	0.12	x

Value of friction coefficient was experimentally determined for hot forming using so called “ring test” in presence of technological lubricant

6. Numerical calculation results

The highest value of yield point for which a difference between the stamped drawn-part and the basic one does not exceed 0.1 mm was determined as a result of the numerical calculations. In Table 3 the dimensional deviations for the analysed values of yield point are presented.

TABLE 3
Dimensional deviations for the analysed values of yield point $\sigma_{pl}(T)$

$\sigma_{pl}(T)$, MPa	900	700	500	300	100
Δl_{max} , mm	1.2	0.8	0.2	0.09	0.05

Further calculation results are presented for the material with yield point of 300 MPa. Figure 10 presents dimensional deviation between the basic element and the element after trimming operation and spring-back for a stamping variant with draw-beads.

From Figure 10, which presents the outer and inner side of the drawn element, it is seen that the deformation after spring-back is non uniform. Maximum dimensional deviation equals 0.0901 mm. The calculated value of spring back does not exceed the assumed tolerance of 0.1 mm.

In Figure 11 the dimensional deviation between basic drawnpart and the stamped one in the chosen section is shown. Maximum value of deviation after second stamping operation was 0.0873 mm. Trimming does not affect the dimensional deviation significantly.

Thickness of the drawn part is an essential parameter in analyses of sheet-metal forming. According to Fig. 12, which shows thickness distribution, it is seen that there is no significant thinning of the drawn-part wall. Thinning is about 10% of the initial sheet thickness $t=0.5$ mm.

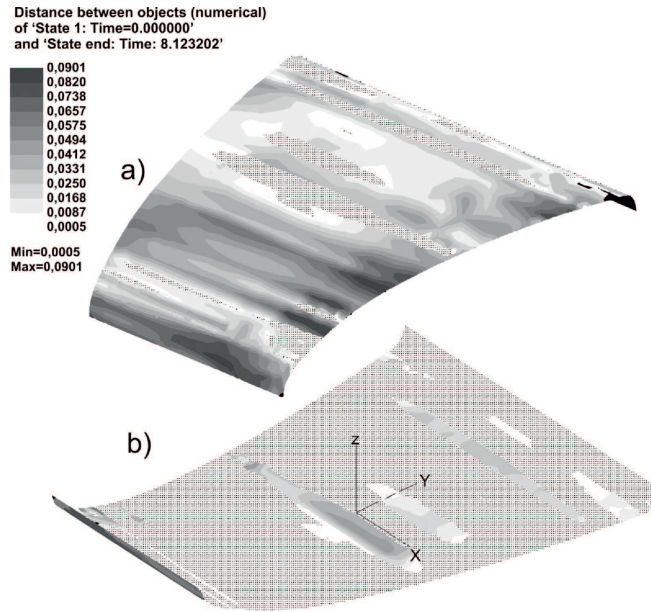


Fig. 10. Dimensional deviation, mm, between the nominal element and the element after trimming and spring-back variant with drawbeads: a) outer side, b) inner side

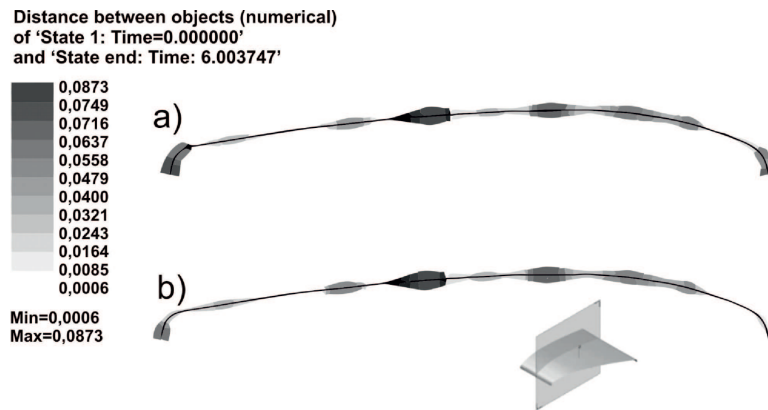


Fig. 11. Value of deformation, stamping variant with no draw-beads: a) dimensional deviation after second stamping operation, b) dimensional deviation after trimming

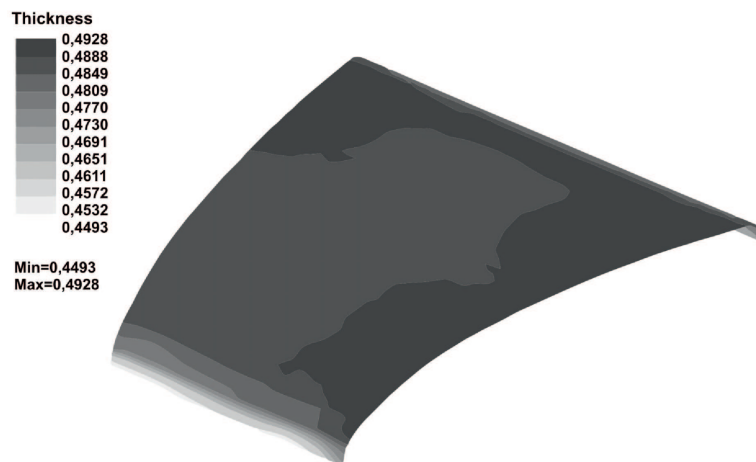


Fig. 12. Thickness distribution after stamping operation with draw-beads

7. Conclusions

In this work numerical analysis of springback effect occurring during stamping process of aircraft engine part made of AMS 5604 steel was performed. Based on the results of the analysis the following conclusions can be drawn:

- Stamping temperature of the drawn-part made of AMS 5604 steel should be chosen so that, in each analysed variant, during final phase of stamping yield stress was not greater than 300 MPa,
- The analyzed two stamping variants: with drawbeads and without drawbeads produce similar values of distance between nominal deflector and post stamping deflector.
- Maximal distance between drawnpart before and after spring-back according to scheme presented in the work in both cases doesn't exceed 0.09 mm.
- The impact of cutting operation on the final shape of the drawn-part is insignificant.
- In the analyzed case thickness of drawn-part in the thinnest area drops 10% compared to the initial sheet thickness.

Acknowledgements

Financial support of Structural Funds in the Operational Programme – Innovative Economy (IE OP) financed from the European Regional Development Fund – Project "Modern material technologies in aerospace industry", Nr POIG.01.01.02-00-015/08-00 is gratefully acknowledged.

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