UTILIZATION OF ADVANCED COMPUTATIONAL MODELS FOR DRAWING PROCESS NUMERICAL SIMULATION OF TITANIUM ALLOY

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Abstract

These days there can be observed still increases requirement about products quality at keeping low price level. Such contending claims of market environment force producers in every branch of engineering industry to innovate their technological procedures and to process new progressive materials with specific utility properties. Regarding great development of numerical simulations there is not only use of computation methods but also qualitatively higher level of modeling technological processes where PCs behave as computational models on which it is possible to simulate also such processes which would be very difficult to carry out on the real part under operating conditions. Numerical simulations results are greatly influenced by knowledge and quality of input data. There are mainly boundary conditions which characterize simulated process, knowledge of the stress and deformation behavior of forming material and last but not least also selection of the proper computational model. For the most used computational models is material deformation behavior described only by static tensile test in combination with normal anisotropy coefficients. However for specific materials, thus also titanium alloys, is such characterization insufficient and is obvious that results from numerical simulations observed from this measurement do not agree with the real forming processes (mainly stamping). In this paper is described possibility to use advanced computational models for drawing process numerical simulation by software PAM STAMP 2G and method how to obtain input parameters for the material definition of the formed material. Results from the numerical simulation are compared with experiment ones.

Keywords: Drawing of Sheets, Numerical Simulation, Computational Model, Titanium, Testing of Materials

1. INTRODUCTION

Sheet drawing technology is one of the most spread technologies for metal parts production in all industrial branches. Such technology enables production of parts with different shapes (plane or bulk ones) as well as parts of many sizes. Mainly advantages of parts produced by this technology are as following: good-quality surface, high accuracy of defined dimensions and quite high stiffness with minimal part weight. In the case of cold forming there is also increase in yield strength, ultimate strength and fatigue strength in dependence on degree of deformation. Required shape and size change of initial material is made by applied outer forces which cause plastic deformation of forming part (e.g. sheet). Produced part final quality is influenced by many parameters which are really necessary to take into account during part design. It is mainly proper choice of technological parameters like e.g. blank-holding force value, lubrication method for forming part, choice of the workpiece shape and so on. Important role during production process, lay-out and choice of optimal pressing technological conditions play numerical simulations. Using information technologies in the preparation of the technological production mean not only lower time consumption of whole pre-production phase but also huge cost savings. Advantages of sheet drawing technological processes simulations arise mainly from feedback when computed results of numerical calculation enables us opportunity to optimize tool shapes functional surfaces, proper choice of technological parameters and so on. From detailed stamping process analyze it is possible to ensure dimensional stability of stampings, compliance of specified thickness

tolerances, appearance of areas with minimal deformation or detection vice-versa critical zones with danger of wrinkling or cracks creation. Massive spreading of numerical methods for computation forming technologies makes possible to process new types of materials with different mechanical properties. Among them can be also found titanium alloys. However, processing of these specific material reveals some production problems which are possible to eliminate by proper pre-production phase where take a crucial place numerical simulations of the production processes by means of FEA. To measure truly reliable results with the best accuracy is beside geometrical requirements for stamping shape also necessary knowledge about material deformation behavior and proper selection of computational model. Proper definition of boundary conditions and selection of computational model significantly takes effect in the areas of forming limit deformations. With regard to reality that there is a strong effort of sheet processors to fully use deformation abilities of the formed material and also to minimize number of the technological operations, such selection of computational model is truly very important. Thus there are for materials with specific properties developing computational models with higher and higher accuracy which characterize material deformation behavior also in the areas of limit deformation.
In this paper is evaluated the computational model influence on the numerical simulation accuracy in the environment of PAM-STAMP 2G at forming the titanium alloy Ti6Al4V ASM 4911. Mutual comparison of results obtained experimentally and by numerical simulation was carried out for simple stamping with rotary shape (cup) which is possible to make in the labs of Department of Engineering Technology (TU of Liberec). For deformation analyses by means of Final Element Analysis (FEA) there were used two anisotropic computational models marked as Hill 48 and Vegter Lite.

2. METHODOLOGICAL BASE AND EXPERIMENTAL PART

Beside geometrical knowledge of stamping shape are for material model definition necessary mechanical properties of the forming material. Basic values for definition of anisotropic model marked as Hill 48 are as following: Young´s modulus, Poisson´s ratio, density, stress-strain curves and also normal anisotropy coefficients for directions 0°, 45° and 90° regarding rolling direction. These are commonly available tabbed values and can be measured by the static tensile test [1]. To fulfill definition of material model marked as Vegter is truly necessary to expand experimental tests by several types of tests. These are shear and compressive tests and tests under multi-axial stress states. As a minimal condition to be able to define model marked as so-called Vegter Lite can be taken static tensile test for directions 0°, 45° and 90° regarding rolling direction. From such measured values are evaluated stress-strain curves and normal anisotropy coefficients. Other tests which are necessary for definition of Vegter Lite model are the hydraulic bulge test and so-called plane strain test. From the hydraulic bulge test is determined effective stress-strain curve and deformation ratio in directions 0° and 90° which characterizes anisotropic material behavior under multi-axial stress state. From the plane strain test is computed again stress-strain curve. All these three tests were carried out in the experimental part.

2.1. Static tensile test

The static tensile test is the basic test to determinate mechanical properties of the tested material and makes possible to obtain information about deformation abilities of the tested material [2]. In Table 1 are shown measured mechanical properties of titanium alloy Ti6Al4V ASM 4911 with thickness 0.6 mm and directions 0°, 45°and 90° regarding rolling directions. Graphical illustration of measured results from the static tensile test is shown in Fig. 2.

Table 1 Mechanical properties of the tested material (Titanium alloy Ti6Al4V ASM 4911)

Rolling direction	**Yield strength** $R_{p0,2}$ [MPa]	**Ultimate strength** R_m [MPa]	**Uniform ductility** A_g [%]	**Total ductility** A_{80mm} [%]	**Strength coefficient** C [MPa]	**Strain-hardening exponent** n [-]	**Plastic strain equivalent** φ_0 [-]
0°	476.7	601.2	8.8	21.7	865.9	0.1161	0.9588
45°	472.1	586.3	6.7	21.5	762.4	0.0729	2.1361
90°	507.2	627.4	10.1	21.4	864.4	0.0965	2.6353

2.2. Hydraulic bulge test

The hydraulic bulge test represented the second major part of the experiment. For this test is very important fact that there is bi-axial stress state cause it is very important “point” for the future utilization in different yield criterions. Due to the different stress state in comparison to the static tensile test, for its stress-strain curve it is necessary to compute so-called effective stress σ_{EF} [MPa] and effective strain φ_{EF} [-]. Computation of all important values is summarized by means of equation (1), (2) and (3). [3]

$$\sigma_{EF} = \frac{pR}{2t} \tag{1}$$

$$\varphi_{EF} = \frac{2\sqrt{3}}{3}\sqrt{\varphi_1^2 + \varphi_1\varphi_2 + \varphi_2^2} \tag{2}$$

$$t = t_0 \cdot e^{\varphi_3} \tag{3}$$

where:

σ_{EF}	- effective stress	[MPa];	p	- pressure	[MPa];
φ_{EF}	- effective strain	[-];	R	- radius of curvature	[mm];
$\varphi_{1,2,3}$	- true strains;	[-];	t, t_0	- actual and initial thickness	[mm].

For the own measurement of the hydraulic bulge test there was used the contact-less optical system ARAMIS. The principle of such measurement is shown in Fig. 1. Measured material is placed between upper and lower blank-holders and two scanning cameras are added right before the tested material (titanium alloy in this case). Of course very important is location of transparent glass before cameras cause just after fracture of material there is a lot of hydraulic oil “flying” towards cameras. Because it is optical system there is very important to properly adjust cameras (their calibration, shutter time, focusing, distances, angles and so on) and provide proper lighting for the whole scanning area.

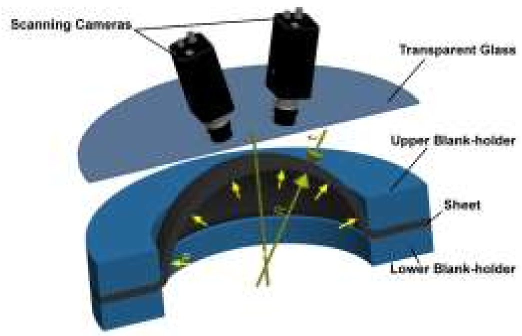

Fig. 2 Principle of the hydraulic bulge test with contact-less optical system ARAMIS

As the whole evolution of the hydraulic bulge test was scanned by the contact-less optical system ARAMIS, subsequently it was possible to compute distribution of both major strain φ_1 and minor strain φ_2 within the required area (top of the sphere). Due to that was also possible to compute strain in the thickness direction φ_3 which is important to know for computation actual thickness - see equation (3). Finally by fitting best-fit sphere over computed part it was possible to find out required radius of curvature R [mm]. After that it was possible with equations (1). (2) and (3) to compute effective stress σ_{EF} [MPa] and effective strain φ_{EF} and to plot stress-strain curve for the bi-axial stretching state of stress (the hydraulic bulge test). From these values was subsequently created the scatter plot - see Fig. 3. It is not possible to use continuous increasing of pressure due to time delay in sensor and hoses. After that was also used (as in the case of the static tensile test) the power-law equation acc. to Swift and via fitting (nonlinear curve fit) was computed stress-strain curve and all important constants (C, n, φ_0). Values of these constants for the hydraulic bulge test were as following: C = 1532 MPa, n = 0.2869 and φ_0 = 0.03453. Such values are truly very important to compute very significant bi-axial point in the advanced computational models in numerical simulations (e.g. for Vegter yield criterion). Beside values of uni-axial tensile (eventually compression) point and normal anisotropy coefficients are these values the crucial for proper computation of required yield criterion.

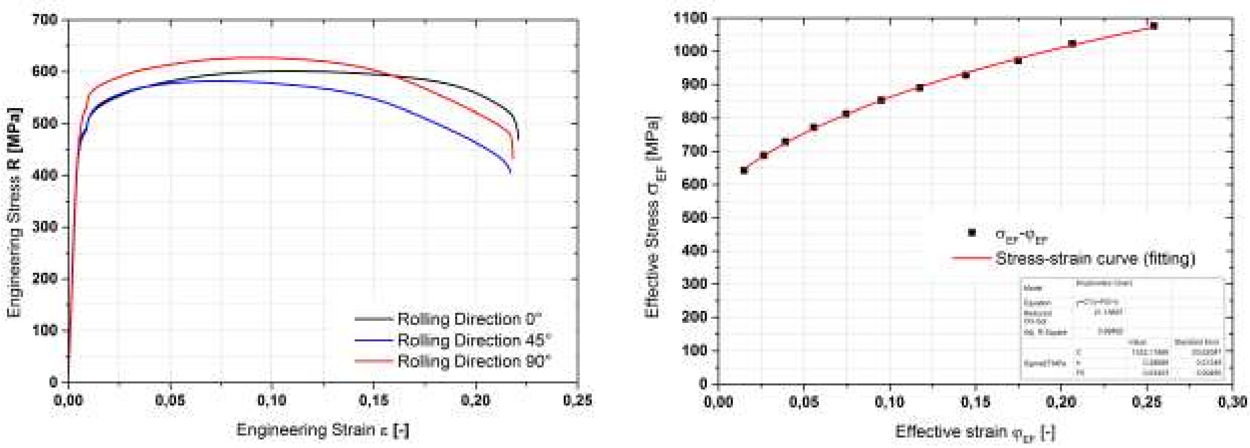

Fig. 2 Results from the static tensile test (left) and the hydraulic bulge test (right) – titanium alloy

2.3. Plane strain test

The plane strain test is typical that there is prevent deformation in the width direction and that is why there is necessary to use sheet modified sample with notch. Deformation in the direction of sample loading is than compensated just by the change in sheet thickness and in the area between notches can be whole strain taken as plane strain. In the notch area there is rapid depletion of material plastic properties and crack is created. Thus achieved strain in the direction of sample loading is very low and that´s why there was used very high accurate strain gauge Epsilon 3542 for strain measurement. Shape of tested sample and whole measurement method is shown in Fig. 3.

Fig. 3 Sample for the plain strain test (left) and method of its measurement (right)

Analogous to the static tensile test, also the plain strain test was carried out for three directions regarding the rolling direction (0°, 45° and 90°). Results of measurement the plain strain test are shown in Fig. 4 (left). For numerical simulation there were used two computational models. First model (Hill 48) is simpler and is used for material definition data measured only from the static tensile test and for rolling direction 0, 45°and 90°. Such model is commonly used for steel sheets forming simulations and from experiences is fully adequate for common deep-drawing materials. As a second computational model was chosen model Vegter Lite which in detail describes material planar anisotropy and used tests also at multi-axial loading. Such model is much more time consuming than model Hill 48 cause there is difficult data processing and to carry out all tests. Comparison of both mathematical models which characterize yield criterion is shown in Fig. 4 (right).

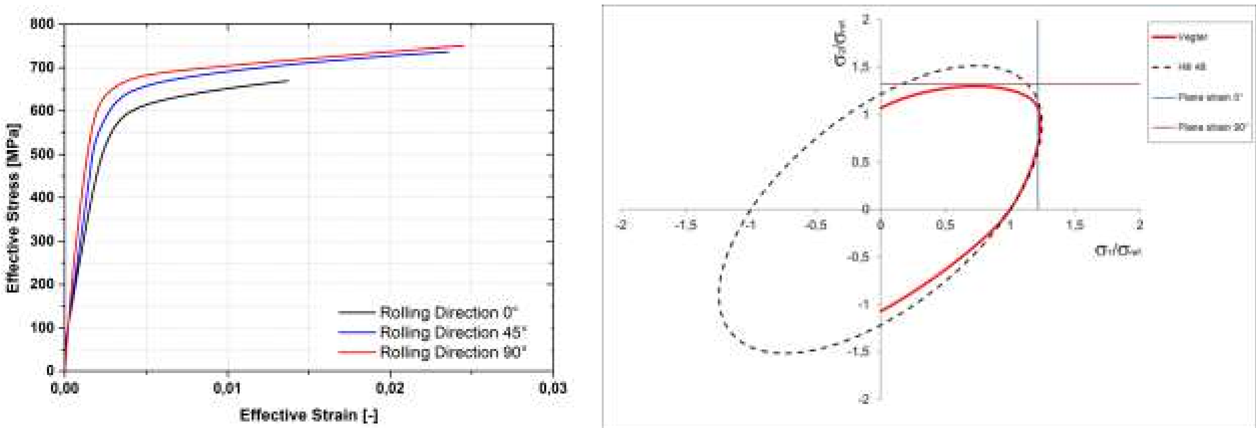

Fig. 4 Result of the plain strain test (left) and comparison of used yield criterions (right)

3. NUMERICAL SIMULATION

For numerical simulation was chosen simple drawing of rotary shape (cup) with diameter 80 mm. Initial diameter of the workpiece was 140 mm. Such size (diameter) was chosen just on the formability limit with purpose to achieve strain limit stages which could show markedly the influence of computational model. Blank holding force was 50 kN. For every contact between tool and formed sheet was chosen friction coefficient of 0.12. Result of numerical simulations for both computational models revealed totally different results. By using the computational model Hill 48 there was during calculation massive elements collapsing in product (cup) wall (as it is shown in Fig. 5). The stability of computation was lost already at drawing depth 30 mm. Thus on the basis of results from numerical simulation by model Hill 48 could be stated that such drawing process for titanium alloys is totally impossible (material appeared to be without any formability).

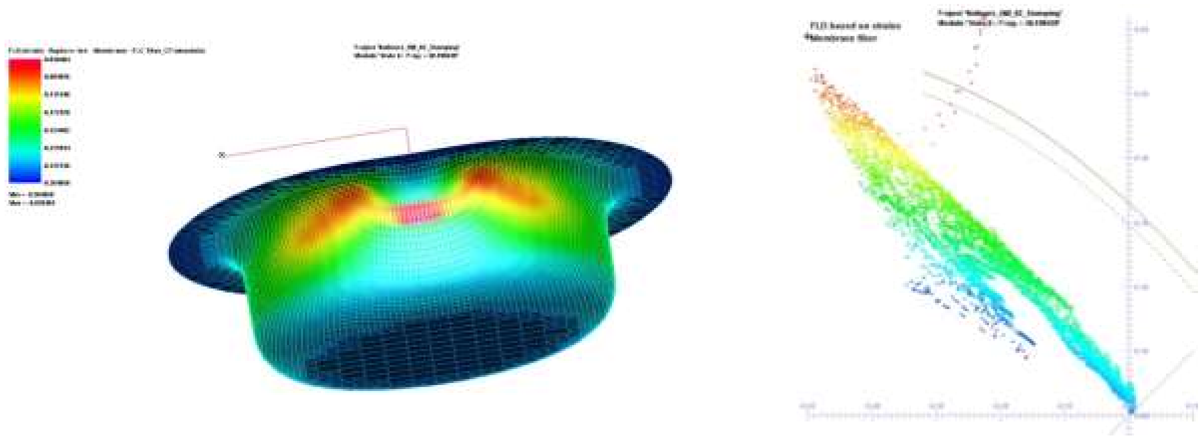

Fig. 5 Results of the numerical simulation for model Hill 48

Numerical simulation using the computational model according Vegter Lite was computing without elements collapsing in the product (cup) wall. So that final product was according this numerical simulation formable. By experimental forming of this product (cup) in labs it was possible to draw it and there weren´t any cracks occurrence. Results of numerical simulations for model Vegter are shown in Fig. 6.

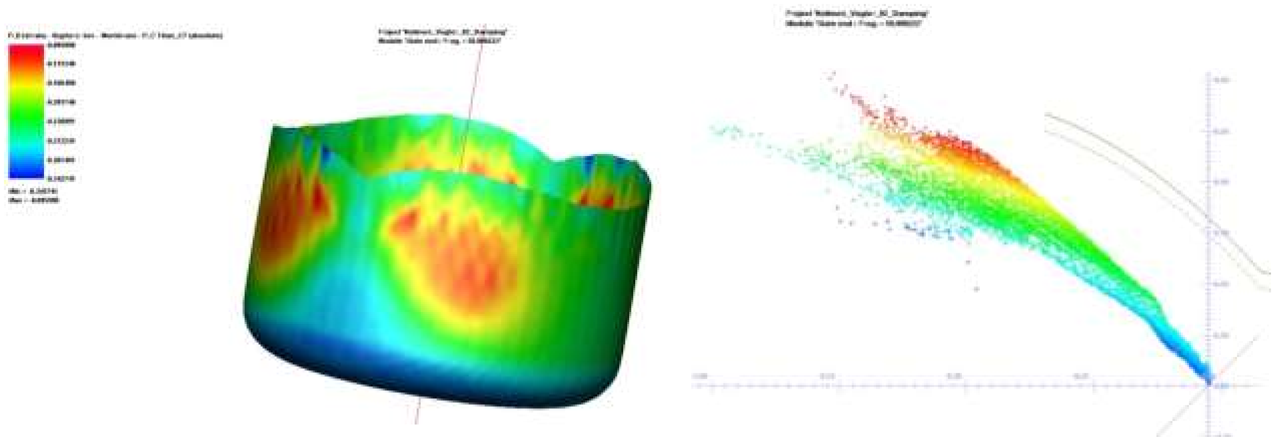

Fig. 5 Results of the numerical simulation for model Vegter Lite

CONCLUSION

Influence of computational model on numerical simulation results was measured on simple rotary product (cup) by using computational models Hill 48 and Vegter. Concurrently with numerical simulation was carried out experiment under the same technological conditions, which served for comparison equality of results from numerical simulation and experiment (simple drawing of cup). At choice of computational model Hill 48 is evident that numerical simulation results don´t correspond to reality achieved by experiment. This simulation finally revealed crack creation in the bottom of cup. At choice of computational model according Vegter was stamping formable on the basis of numerical simulation results. On the basis of carried out measurements and experiments it´s possible to state that computational model Vegter is for special alloys and zones with high deformation much more suitable than model Hill 48. The computational model Vegter embodies higher matching of numerical simulation results with the real ones (experiment). The computational model Hill 48 is in the area of limit deformations sensitive to collapsing of final elements mesh. Disadvantage of using model Vegter rests in fact that such test is very time consuming cause there is necessary to carry out many experiments, preparation of tests and data evaluation. All of these disadvantages can be taken as a “tax” for its higher accuracy and possible applicability for many materials which are used these days (aluminium alloys, titanium alloys, some high-strength steels and so on). Last but not least should be here mentioned utilization of so-called plain strain test to characterize deformation behavior of titanium alloy because such test is not used very often.

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