THE COMPUTATIONAL MODEL INFLUENCE ON THE NUMERICAL SIMULATION ACCURACY FOR FORMING ALLOY EN AW 5754

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Abstract
These days there is the main effort of car producers in the highest extent to decrease environmental load at car operation. One of the possibility represents reduction of the car weight. That is why there is still increasing portion of using strength materials and alloys based on the aluminium during last years. Processing of these specific materials reveal production problems which can be mostly eliminated by the proper pre-production phase. At this design part of the production technological processes take place predominant role numerical simulations of production process by FEA. For proper computation there is beside geometrical requirements on the stamping shape also necessary knowledge of the material deformation behavior and choice of the suitable computational model. For specific materials mentioned above are still developing new computational models with higher accuracy. In this paper is evaluated the computational model influence on the numerical simulation accuracy in the PAM-STAMP 2G environment at forming aluminium alloy EN AW 5754. For deformation analysis by FEM were used two anisotropy computational models marked like Hill 48 and Vegter. Numerical simulation results are evaluated based upon comparison of the deformation distribution on real stamping and measuring drawing force value. Deformation distribution on the real stamping is carried out by means of contact-less optical system ARGUS.

Key words: Computational Model, Aluminium Alloy EN AW 5754, Anisotropy, Photogrammetry, FEA

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 spatial ones as well as parts of many sizes. Advantages by this technology produced parts are mainly: good-quality surface, high accuracy of defined sizes and quite high stiffness at minimal part weight. In the case of cold forming there is also improve 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 effect of outer forces which cause plastic deformation of some of the bulk of forming part volume (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 semi-product shape and so on. Important role during lay-out of production process and choice of optimal technological conditions at stamping plays numerical simulations. Using information technologies in the branches of technological preparation of production brings not only speed up of whole pre-production phase but also huge savings. Advantages of sheet drawing technological processes modelling arise mainly from feedback when calculated result of numerical calculation enables us opportunity to optimize tool shapes functional surfaces, proper choice of technological parameters and so on. By detailed stamping process analyze is possible to ensure dimensional stability of stampings, compliance of specified thickness tolerances, appearance of areas with minimal deformation or vice-versa critical zones detection with danger of wrinkling or fractures creation. Massive spreading of numerical methods for calculation forming technologies enables to process new types of materials with different properties. Among them can be also found aluminium 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 production processes by means of FEA. To measure truly proper 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 stamping limit deformations. With regard to reality that there is a strong effort of sheet processors to fully use deformation abilities of formed material and also to minimize number of the technological operations, such selection of computational model is extra important. Thus there are for materials with specific properties still developing more and more accurately computational models which characterize material deformation behavior also in the areas of limit deformations.

In this paper is evaluated the computational model influence on the numerical simulation accuracy in the environment of PAM-STAMP 2G at forming aluminium alloy EN AW 5754. Mutual comparison of results obtained experimentally and by numerical simulation was carried out for simple stamping with rotary shape (cup) which is possible to product in the laboratories of Department of Engineering Technology – Technical University of Liberec. For deformation analyses by means of FEA were used two anisotropic computational models marked as Hill 48 and Vegter.

2. MATERIAL MODEL DEFINITION

Beside geometrical knowledge of stamping shape are for material model definition necessary mechanical properties of forming material. Basic values for definition of anisotropic model marked as Hill 48 are follows: Young’s modulus, Poisson’s ratio, density, stress-strain curves and also normal anisotropy coefficients for directions 0°, 45° and 90° on rolling direction. These are commonly available tabbed values and values measured by 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 Vegter can be taken static tensile test for seven specimens directions within interval from 0° up to 90° (static tension test á 15°). From such measured values are evaluated stress-strain curves and normal anisotropy coefficients. Another test which is necessary for definition of Vegter model is so-called Bulge test. From this test (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.

2.1. Static tensile test for material EN AW 5754

With regard to material properties knowledge necessity for computational model Vegter were static tensile test carried out for seven cut-out directions on rolling direction within the interval from 0° up to 90°. From these measured values were subsequently determinate true stress-strain curves and coefficient of normal anisotropy. Measured true stress-strain curve was also approximated by Hollomon equation. Example of true stress-strain curve for the direction 0° is shown in Fig. 1. Calculated constants characterizing mechanical properties of the aluminium alloy EN AW 5754 are further shown in the table 1. These values are subsequently used for material definition in the common computational model Hill 48 and quite new model Vegter.

![Fig. 1 True stress-strain curve for material EN AW 5754 (direction 0°)](image-url)
2.2. Bulge test

The hydraulic Bulge test is a method of testing a sheet in balanced bi-axial stress state (tension). A thin disc is clamped around the edges and subjected to increasing fluid pressure on one side. As the sheet bulges, the region near the dome becomes nearly spherical [2]. Whole test is scanned by couple of cameras (via ARAMIS system). So tensile stresses \( (\sigma_1, \sigma_2) \) can be calculated according equation:

\[
\sigma_1 = \sigma_2 = \frac{p \cdot R}{2 \cdot t} \quad \text{[MPa]}
\]

where:
- \( p \) – pressure \([\text{MPa}]\)
- \( R \) – radius of curvature \([\text{mm}]\)
- \( t \) – actual thickness \([\text{mm}]\).

Values of true strains (major strain \( \varphi_1 \), minor strain \( \varphi_2 \) and strain in thickness direction \( \varphi_3 \)) are computed directly from contact-less optical system ARAMIS. Results of this measurement are not mentioned in this paper because of the space. Actual thickness \( t \) can be derived from equation:

\[
t = t_0 \cdot e^{\varphi_3} \quad \text{[mm]}
\]

where:
- \( t_0 \) – initial thickness \([\text{mm}]\)
- \( \varphi_3 \) – strain in thickness direction \([\text{mm}]\).

However, due to balanced bi-axial stress state there have to be used values of effective stress \( \sigma_i \) [MPa] and effective strain \( \varphi_i [-] \). These can be calculated for balanced bi-axial stress state from equation:

\[
\sigma_i = \sigma_1 = \sigma_2 \quad \text{[MPa]}
\]

\[
\varphi_i = \frac{\sqrt{12}}{3} \cdot \sqrt{\varphi_1^2 + \varphi_2^2 + \varphi_1 \cdot \varphi_2} \quad [-].
\]

Table 1 Mechanical properties of material EN AW 5754

<table>
<thead>
<tr>
<th>Rolling direction [°]</th>
<th>Strength coefficient ( C ) [MPa]</th>
<th>Strain hardening exponent ( n [-] )</th>
<th>Offset strain ( \varphi_0 [-] )</th>
<th>Coefficient of normal anisotropy ( r_a [-] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>431,1</td>
<td>0,261</td>
<td>0,0291</td>
<td>0,650</td>
</tr>
<tr>
<td>15</td>
<td>424,6</td>
<td>0,259</td>
<td>0,0301</td>
<td>0,661</td>
</tr>
<tr>
<td>30</td>
<td>413,5</td>
<td>0,258</td>
<td>0,0304</td>
<td>0,733</td>
</tr>
<tr>
<td>45</td>
<td>401,2</td>
<td>0,250</td>
<td>0,0311</td>
<td>0,759</td>
</tr>
<tr>
<td>60</td>
<td>401,6</td>
<td>0,252</td>
<td>0,0306</td>
<td>0,777</td>
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<tr>
<td>75</td>
<td>403,7</td>
<td>0,253</td>
<td>0,0303</td>
<td>0,701</td>
</tr>
<tr>
<td>90</td>
<td>408,4</td>
<td>0,255</td>
<td>0,0304</td>
<td>0,661</td>
</tr>
</tbody>
</table>
In Fig. 2 is shown effective stress-strain curve (black one) for material EN AW 5754 with approximation according Hollomon equation (red one).

![Effective stress-strain curve for material EN AW 5754 and approximation by Hollomon equation](image)

**Fig. 2** Effective stress-strain curve for material EN AW 5754 and approximation by Hollomon equation

### 3. NUMERICAL SIMULATION

For numerical simulation was chosen simple stamping (cup) of rotary shape with diameter 80 mm. Size of semi-product was 165 mm. Such size (diameter) was chosen just on the formability limit on purpose to achieve strain limit stages and computational model influence was revealed more markedly. Blank-holder force was 24 kN. For every contact between tool and formed sheet was chosen friction coefficient of 0,06. For numerical simulation were used two computational models. First model (Hill 48) is simpler and is using for material definition data measured only from static tensile test for rolling direction 0°, 45° and 90°. Such model is commonly used for steel sheets forming simulation and from experiences is for these materials fully sufficient. As a second computational model was chosen model Vegter, which (as was already mentioned before) in detail describes material planar anisotropy and using tests also at multi-axial loading. Such model is much more time consuming than model Hill 48 from the data preparation and experiments point of view.

Result of numerical simulations for both computational models revealed totally different results. By choice of computational model Hill 48 there was during calculation collapsing of elements in stamping (cup) wall. Thus on the basis of results from numerical simulation by model Hill 48 stamping was un-formable. Numerical simulation by choice of computational model according Vegter was calculated correctly and there wasn’t collapsing of elements in stamping wall. So stamping (cup) was by this numerical simulation formable. By experimental forming of this product (cup) it was possible to stamp it and there weren’t fractures. From such point of view was result of numerical simulation by Vegter evaluated as suitable and further comparison of equality between results of numerical simulation and experiments was carried out only for results from computational model by Vegter. Computational model influence on numerical simulation result for both models Hill 48 and Vegter is digestedly shown in Fig. 3 where is truly evident collapsing of elements in stamping wall (bottom fracture) in the case of computational model Hill 48.
Fig. 3 Numerical simulation results at using computational models Hill 48 (a) and Vegter (b)

4. COMPARISON OF EXPERIMENTAL VALUES AND NUMERICAL SIMULATION RESULTS

For comparison numerical simulation results and experimentally measured results was necessary to find out strain values on real stamping. To determination strain distribution on stamping (cup) was used method of deformation meshes (pattern for optical systems) on the formed stamping surface. This deformation mesh was made by electro-chemical etching and for deformation evaluation was used contact-less optical system for deformation analysis marked as ARGUS. To analyze deformation by system ARGUS is commonly used electro-chemically etched mesh with dot pattern. With regard to shape and complexity of stamping are used deformation meshes with different dot patterns. There is high accuracy with finer spacing. Disadvantage is rapid increase of data quantity and mesh higher sensitivity to possible faults at acquiring stamping images. For experimental measurement was chosen deformation mesh with point spacing 2 mm. By selection of this spacing is ensured sufficient accuracy of computation and there isn’t also such high data quantity. System ARGUS enables (on the basis of known dots coordinates and their spacing before and after deformation) to compute shape and deformation on stamping. Comparison of results from experimental measurement and numerical simulation was carried out by means of strain distribution along section. In Fig. 4 are shown results from numerical simulation with section denotation for deformation analysis and strain distribution at experimentally produced stamping. In Fig. 5 is shown graph showing strain distribution along analyzed section for stamping computed by numerical simulation in the environment PAM-STAMP 2G (Fig. 4a) and experimentally produced stamping (Fig. 4b).

Fig. 4 Strain distribution – PAM-STAMP 2G numerical simulation (a), experiment – scanned by ARGUS (b)
Influence of computational model on numerical simulation results was measured on simple rotary stamping (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. At choice of computational model Hill 48 is evident that numerical simulation results don’t correspond to reality achieved by experiment. This simulation revealed bottom fracture of stamping. At choice of computational model according Vegter was stamping formable on the basis of numerical simulation results. There was for this result further evaluated equality of strain distribution with already produced stamping. Strain of experimentally produced stamping was measured by optical system ARGUS. By comparison of strain distribution from numerical simulation (by using Vegter model) and real strain measured by system ARGUS was find out quite good results matching. 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 more proper 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 its time costingness due to many necessary experiments, preparation of tests and data evaluation. These represent price for its higher accuracy.

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