UTILIZATION OF FORMING TOOL WITH VARIABLE BLANKHOLDER FORCE FOR DRAWING OF AL ALLOYS

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Abstract

Drawing of stampings technology is nowadays the most using technology for sheets processing. Because of stamping’s weight reduction is these days actual sheet processing from aluminium alloys which by their properties differ a lot from commonly using deep-drawing sheets. To achieve maximal plastic deformation with material fracture is necessary to use sheet with required mechanical properties and properly chosen forming technological properties. Common tools for deep-drawing don’t enable to lively reply of necessity to change blankholder force during sheet drawing. On the experimental tool for deep-drawing with variable blankholder force are in the paper evaluated two variants of drawing methods for irregular shape of stamping. In the first case was stamping from AA6016 alloy designed with constant blankholder force. In the second case was blankholder force optimized and during drawing was changed in dependence on drawing depth. Calculation of blankholder force in dependence on drawing depth was carried out by means of numerical simulation in software PAM-STAMP 2G. Result of optimalization was strain distribution change in critical places of stamping. Strain distribution on stamping is measured by means of optical system ARGUS.

Key words: Drawing of Sheets, Aluminium Alloys, Analysis of Deformation, Numerical Simulation, Optical Systems

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’s 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. is 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. Time when great part of technological preparation of production tasks was made by principle attempt-error is almost gone. Advantages of sheet drawing technological processes modelling arise mainly from feedback when calculated result of numerical calculation enables us opportunity to optimize functional surfaces tool shapes, 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.

In the frame of grant project solving on Department of Engineering Technology - Technical University of Liberec was developed drawing tool which enables changing of blank holding force values in dependence on drawing depth. Change of blank holding force value during drawing is made by optimal using of forming material plastic properties. Due to reducing stamping’s weigh is in these days very topical processing of sheets from aluminium alloys which differ a lot by their properties from commonly using deep-drawing steels. In paper are evaluated two options for non-regular shape stamping drawing methods from alloy AA 6016. In the first case was stamping from alloy AA 6016 produced with constant holding force. In the second case was holding force optimized and was changing during drawing in dependence on drawing depth. Optimization of holding force in dependence on drawing depth was carried out by means of numerical simulation in software PAM-STAMP 2G. As a result of optimization is change in strain distribution in critical areas of real stamping. Strain distribution analyzes on real stamping is made by means of system ARGUS.

2. MECHANICAL PROPERTIES OF TESTED MATERIAL

As was already written in previous chapter, for tests was chosen aluminium alloy marked like AA 6016. Such alloy is commonly using alloy in automotive industry for stampings production. From the using numerical simulation in software PAM-STAMP 2G point of view is necessary knowledge of forming material mechanical properties. On this account was necessary to define mechanical values and value of normal anisotropy r in directions 0°, 45° and 90° toward rolling direction of tested alloy AA 6016 [1], [2]. Stress-strain curve was in software PAM-STAMP 2G defined by means of relation denoted as Krupkovsky law [3]:

\[ \sigma = K(e_0 + e_p)^n \]

where \( \sigma \) is true stress, \( K \) is strength coefficient, \( e_0 \) is offset of strain, \( e_p \) is plastic strain and \( n \) is strain hardening exponent. Required mechanical values which determinate forming sheet character was set down by means of static tensile test. Graphical dependence of static tensile test routine for tested material AA 6016 is shown in fig. 1. Mechanical values from static tensile test are given in table 1.

![Fig. 1. Static tensile test routine for material AA 6016, thickness 1,1 mm](image-url)
Table 1: Mechanical properties of material AA 6016, thickness 1.1 mm

<table>
<thead>
<tr>
<th>Direction</th>
<th>$R_m$ [MPa]</th>
<th>$R_{p0.2}$ [MPa]</th>
<th>$A_{80mm}$ [%]</th>
<th>$K$ [MPa]</th>
<th>$n$ [-]</th>
<th>$\varepsilon_0$ [-]</th>
<th>$r$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>260</td>
<td>146</td>
<td>28.1</td>
<td>480</td>
<td>0.2511</td>
<td>0.011</td>
<td>0.695</td>
</tr>
<tr>
<td>45°</td>
<td>252</td>
<td>139</td>
<td>31.6</td>
<td>469</td>
<td>0.2612</td>
<td>0.012</td>
<td>0.465</td>
</tr>
<tr>
<td>90°</td>
<td>248</td>
<td>138</td>
<td>29.1</td>
<td>464</td>
<td>0.2622</td>
<td>0.011</td>
<td>0.569</td>
</tr>
</tbody>
</table>

3. DRAWING PROCESS NUMERICAL SIMULATION

First step for drawing process numerical simulation in software PAM-STAMP 2G is creation of functional surfaces of tool. Source data for creation tool surfaces are CAD models of centre-line punch surfaces, die and blank holder in format *.IGES. These surfaces were imported into software PAM-STAMP 2G and automatically was generated mesh for calculation by means of FEM (Final Element Method). At mesh creation is necessary to properly choice size of mesh elements because this option greatly influences quality and time of calculation. By choosing small elements there is extend in calculation time of whole project. On the other hand is necessary to take into account that too big elements (in relation to radiuses of curvatures on geometry) insufficiently plot geometry curves and lower calculation accuracy in these areas [4]. Tool functional surfaces geometry for drawing stamping can be seen in fig. 2.

![Tool functional surfaces geometry for numerical simulation](image-url)
The aim of numerical simulation was to find optimal blank holder force value to produce stamping. It is quite complicated stamping where blank holder force value is crucial about stamping’s quality. First simulations were carried out under constant blank holding pressure. When blank holding pressure was set as low (constant force 100 kN during whole drawing process), there was enormous wrinkling on stamping. Under higher blank holding force (constant force 150 kN during whole drawing process), there was on stamping inclination to wrinkling in critical stamping’s areas. Example of numerical simulation result for variant with constant blank holding pressure 100 kN is shown in fig. 3.

Fig. 3. Example of numerical simulation result for variant with constant blank holding pressure 100 kN

In areas with critical zones is possible from numerical simulation results suppose wrinkling creation. To lower deformation in areas with critical zones was propose variant with variable holding pressure when is holding pressure changes in dependence on drawing depth. Initial holding pressure was set as 150 kN. Such holding pressure is applied until moment when punch achieves distance 60 mm (half stamping’s height). During subsequent 60 mm of drawing depth is this holding pressure linearly lowered up to value 80 kN in tool lower dead centre. From numerical simulation results with variable holding pressure was evident lowering of maximal deformation in critical zones. Experimental measurement (real stamping production) was carried out for such obtained curve of holding pressure evolution.

4. EXPERIMENTAL MEASUREMENT

In the frame of solving grant project on Department of Engineering Technology in TU of Liberec was developed drawing tool which enables using variable holding force in dependence on drawing depth. Compare to steel sheets are sheets based on Al more sensitive to proper settings and keeping defined technological condition during drawing. Maximal using of aluminium alloy’s plastic properties is thus greatly influenced by choosing suitable technological conditions during sheet drawing. Blank holder of drawing tool is controlled by four hydraulic cylinders with possibility to regulate pressure during drawing. Frequency of closing and opening hydraulic valve is 1 kHz and thus it is possible with high accuracy and quickly react on requirements for choosing hydraulic pressure in system by means of hydraulic circuit PID regulation. At choosing constant holding force was not possible to produce good-quality stamping on one drawing operation. At choosing low holding force when stamping did not occur fracture, there was massive wrinkling of sheet in the flange area. Effort to remove such undesirable effect by means of increasing holding force led to fracture of stamping. During solving of grant project was developed software for controlling hydraulic aggregate which controls blank holder and nowadays is possible to arbitrarily change holding force value
during drawing. By such holding force controlling system was achieved optimal using of forming materials
plastic properties and stampings were possible to produce on one drawing operation. Holding pressure
evolution for testing material was obtained by means of numerical simulation in PAM-STAMP 2G. Strain
distribution on real stamping and detection of critical zones was carried out by means of contact-less system
ARGUS. Advantage of this system is that enables to gain very quickly deformation map on whole surface of
watched specimen (stamping) and also enables to flexible react on necessities for changing adjustment of
technological parameters. To measure deformation by system ARGUS is necessary on semi-product apply
regular point mesh (grid)) whose displacements after deformation are evaluated by system. For accuracy of
calculation (deformation analyzes) is crucial points distance of deformation mesh [4]. Was chosen etched
electrolytic deformation mesh with initial points distance 2 mm. This way prepared point mesh has good
resistance against abrasion during forming and simultaneously is without great influence on surface quality.
A disadvantage is that for a bigger dimension of semi-product is not possible to create mesh continuously
(size is limited by size of etching screen) and consists from different parts. Between them is created gap
where is not possible to evaluate deformation. Own measurement then is carry out so that on stamping are
placed calibration measuring stones and characteristic points which serves for joining individual images or
define length dimensions. Analyzed object is then scanned from different angles an position so that in one
image are at least 5 for system readable coded points. That enables to put together whole 3D image of
stamping and evaluate points of mesh displacements and create map of deformation on stamping. In fig. 4 is
shown real stamping with detail of deformation mesh and strain distribution by contact-less system ARGUS

![Fig. 4. Stamping designed for deformation analyzes and strain distribution on stamping](image)

From carried out experimental measurements of strain distribution on stamping is evident that critical zones
measured by numerical simulation and experimentally are matching. In fig. 4 are by points A, B, C and D
marked critical zones with maximal deformation on stamping and these zones will be further compared with
deformation obtained by numerical simulation in PAM-STAMP 2G. Example of strain distribution evaluation
on real stamping by means of section put through zone C and D is shown in fig. 5.

![Fig. 5. Strain distribution along section – points C and D (analyzes by system ARGUS)](image)
In table 2 is done comparison of thickness reduction in critical areas of stamping measured by means of numerical simulation (PAM-STAMP 2G) and by optical system ARGUS.

**Table 2** Comparison of measured values and numerical simulation

<table>
<thead>
<tr>
<th>Thickness reduction [%]</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAM STAMP 2G</td>
<td>27.5</td>
<td>26.0</td>
<td>26.0</td>
<td>25.5</td>
</tr>
<tr>
<td>ARGUS</td>
<td>26.5</td>
<td>25.5</td>
<td>24.5</td>
<td>29.0</td>
</tr>
</tbody>
</table>

5. **CONCLUSION**

From comparison of results measured by numerical simulation in PAM-STAMP 2G and real measurement (ARGUS system) was proved great matching and thus is possible to consider numerical simulation as a very suitable tool for stamping’s critical areas. Quite easy is possible and very rapidly optimize sheet drawing process adjustment. From both carried out deformation analyzes of tested material is evident that stamping’s deformation in critical areas approaches FLC (Forming Limit Curve). At using constant holding pressure wasn’t successful to produce stamping without any flaws. At using tool with variable holding force where was evolution of holding force optimized by means of numerical simulation was possible to produce good-quality stamping. However stamping is pressable with high risk of fractures creation and is possible to presume also higher scrap in series production.

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**LITERATURE**


