NUMERICAL SIMULATION OF SHEET PROFILING PROCESS FROM ALUMINUM ALLOY

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Abstract

Structured sheet metals are becoming more and more popular for using in lightweight constructions. In the present research three different schemes to produce structured sheet from aluminum AW6061-T6, namely stretch forming (two type of die) and stamping using elastomer, were investigated. Evaluation criteria for application of these schemes were proposed. Numerical models for each technological scheme with some assumptions were developed in the software package DEFORM™. The dimensions of sheet were limited only by the thickness (1 mm) and for numerical simulation a little part of the sheet was used. Influence of FE-mesh (type and number of elements) on calculation accuracy was estimated. Also such characteristics as power parameters of process, fields of internal stress and geometry of resulting profile were estimated.

Keywords: Structured sheet metal, finite element model, numerical simulation, aluminum.

1. INTRODUCTION

The structured sheet metals are sheet metals with hexagonal bumps (**Fig. 1**). They have much potential for using in lightweight constructions. Structured sheets metals have more rigidity than the flat-rolled sheet metals. For example, structured sheet metals can be used in automobile industry, where the most important characteristics of constructions are safety, weight and environmental compatibility [1]. Materials determine weight of an automobile and its petrol consumption. Reduction of automobile's weight by 100 kg leads to the reduction of environmental compatibility on 0.7 l per 100 km [1]. Application of aluminum structured sheets allows realize a required level of reliability of car body and, at the same time, to reduce a volume of used materials by production.

The investigated structured sheet has the following features [1, 2]:

- more rigidity in comparison with flat-rolled sheet
- improved heat exchange with environment
- effective absorption of sound vibrations

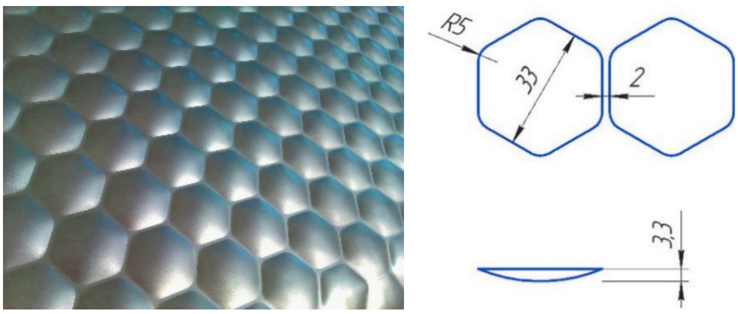


Fig. 1 Structured sheet and its geometric characteristics (in mm)

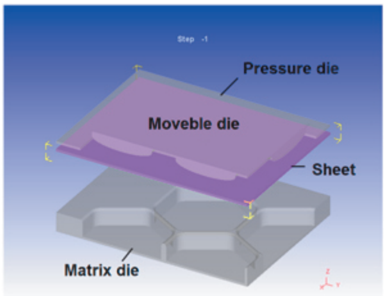
Butt et al. in [3] experimentally showed that such shape of structured sheet allows to reduce significantly drag coefficient C_d for Reynolds numbers ranging from $3.14 \cdot 10^4$ to $2.77 \cdot 10^5$. That is structured sheets can be used in constructions that are effected by air flows in order to reduce air resistance of such constructions.

The objective of this study was theoretic investigation of different deformation patterns for production of aluminum structured sheet with dimensions 500 mm x 500 mm. Several possible technological schemes of structured sheet production with thickness 1 mm from aluminum alloy AW 6061-T6 were investigated. Using software package DEFORM^{TM} for all technological schemes were developed the numerical models of production process of structured sheet with unlimited horizontal dimensions. One of the evaluation criteria of technological scheme application was a power parameters calculated on the basis of developed models.

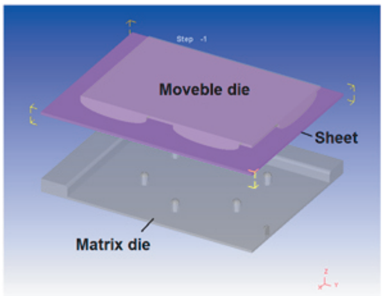
2. SELECTION OF DEFORMATION PATTERN

Choice of deformation pattern should meet following criteria:

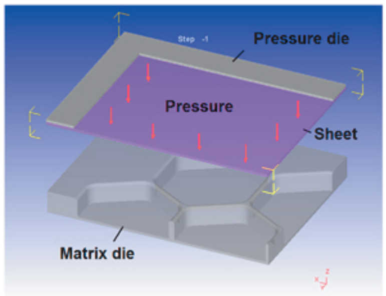
- possibility of application by present conditions;
- universal use (for sheets with different thickness);
- minimization of energy-power costs;
- minimal thickness variation;
- repeatability of structured sheet shape;
- adaptation of scheme to the periodicity of sheet structuring process.



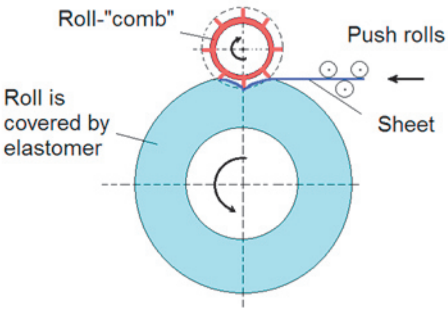
a) stretch forming (embossing). Matrix die type A



b) stretch forming (embossing). Matrix die type B



c) stamping using elastomer (hydraulic forging)



d) rolling

Fig. 2 Deformation pattern of thin aluminum sheets (in section)

Three following schemes were chosen as main deformation patterns (**Fig. 2**): 1. stretch forming (embossing); 2. stamping using elastomer (hydraulic forging); 3. rolling.

By stretch forming shape of movable die should have the shape of structured sheet. At the same time the shape of matrix die can be different. For example, in study [2] for production of structured steel sheets was used a matrix die with hexagonal recesses (**Fig. 2a, 2c**).

In study [4], rolling was mentioned as a method of the structured sheets production (**Fig. 2d**). One of two rolls was like a comb, another one had a bigger diameter than the first one and was covered with elastomer. The second roll with the bigger diameter rolls a sheet and presses it in a space between «needles» of the first one. The «needles» of the comb touch the sheet at the border of three hexagonal elements and completely determine the shape of the sheet. A numerical model of stretch forming process, where matrix die type B was used (**Fig. 2b**) was developed on the basis of this method. This matrix die has "needles" as a comb and allows receive the required structured sheet by stretch forming process.

3. DEVELOPING NUMERICAL MODEL OF STRUCTURED SHEET PRODUCTION IN DEFORM™.

For calculating mode of deformation by different deformation schemes using DEFORM™ it was performed numerical simulation of described processes. Finite Element method is the most popular numerical method by performing such tasks. The Finite Element mathematic model performed in DEFORM™ is based on Lee-Kobayashi approach. The principle of this method is minimal capacity of plastic deformation. This principle is as follows [5]:

$$\delta\pi = \int_V \bar{\sigma}\delta\dot{\bar{\varepsilon}}dV - \int_{S_f} F_i \delta v_i dS + K\int_V \dot{\varepsilon}_V \delta\dot{\varepsilon}_V dV = 0, \tag{1}$$

where the first summand is a capacity of plastic deformation; second summand - capacity of external forces; third summand - change of volume; $\bar{\sigma} = \left[3/2\left(\sigma'_{ij}\ \sigma'_{ij}\right)\right]^{1/2}$ - stress intensity; σ'_{ij} - stress deviator; $\bar{\varepsilon} = \left[3/2\left(\varepsilon'_{ij}\ \varepsilon'_{ij}\right)\right]^{1/2}$ strain rate intensity; ε'_{ij} - strain rate deviator; δv_i - virtual velocity field that complies with boundary conditions; V - volume of deforming material; F_i - external forces S_f, K - constant.

A solution of equation (1) is a vectorial velocity field v_i that complies with boundary conditions. Field of strain rate is determined by vectorial velocity field as follows:

$$\dot{\varepsilon}_{ij} = \frac{1}{2}\left(\frac{\partial v_i}{\partial x_i} + \frac{\partial v_j}{\partial x_i}\right) \tag{2}$$

Relation between stress and strain rate is shown in Levy-Mises equation:

$$\sigma'_{ij} = \frac{1}{\lambda}\dot{\varepsilon}_{ij} \tag{3}$$

$$\lambda = \frac{3}{2}\frac{\dot{\bar{\varepsilon}}}{\bar{\sigma}} \tag{4}$$

$$\dot{\varepsilon}_{ij} = \frac{3}{2}\frac{\dot{\bar{\varepsilon}}}{\bar{\sigma}}\sigma'_{ij} \tag{5}$$

The basic equation for plastic zone is equation (1), for rigid zones - equation (6):

$$\int_V \bar{\sigma}\delta\dot{\bar{\varepsilon}}dV = \int_V \left(\frac{\bar{\sigma}_0}{\dot{\bar{\varepsilon}}}\right)\dot{\bar{\varepsilon}}\delta\dot{\bar{\varepsilon}}dV, \qquad \dot{\bar{\varepsilon}} \le \dot{\bar{\varepsilon}}_0 \tag{6}$$

where $\bar{\sigma}_0 = \bar{\sigma}\left(\bar{\varepsilon}, \dot{\bar{\varepsilon}}_0\right)$; $\dot{\bar{\varepsilon}}_0$ takes on a defined critical value [5].

This approach and the method based on it allow to create a numerical model of sheet deformation process and to calculate mode of deformation in metal.

3.1. Initial data for calculation in DEFORM™

There was an assumption made that rigid zones of the sheet (under pressure die, **Fig. 2a, 2c**) have a little impact on mode of deformation in the middle area of sheet (under the top and bottom dies, **Fig. 2**). For this reason was developed the numerical model with the condition that the sheet has only defined thickness (1 mm), but it's another dimensions are endless. Hexagonal structured element of profile was divided into six equal parts. For simulation it was used only one (equiangular triangle with side 20.2 mm, **Fig. 3**). Temperature of sheet and dies was 20 °C. Dies were rigid. Elastomer was replaced by evenly distributed load on the surface of sheet. Displacement rate of movable die was 0.5 mm/s.

The material of sheet was AW6061-T6. All rheological properties of aluminum were chosen from material's library of the software package DEFORM™ with temperature range 20 - 250 °C, strain rate range 1 - 100 s^{-1}. Yield strength, TS was 275 MPa, tensile strength σ_m - 393 MPa.

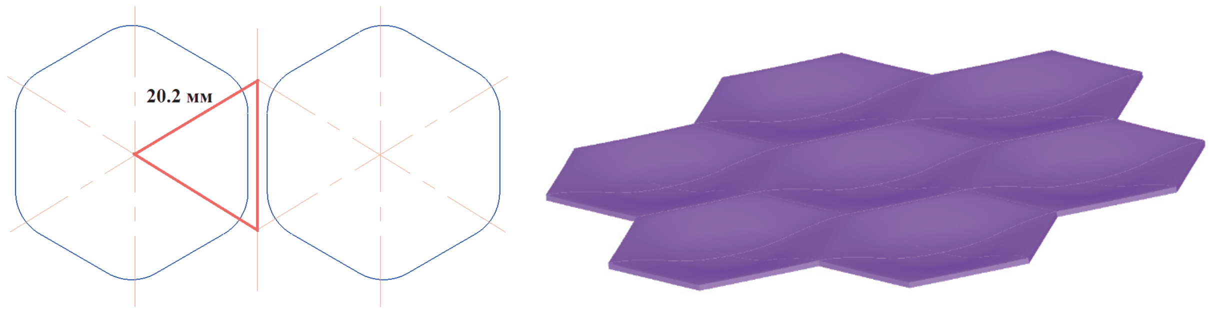


Fig. 3 Geometric shape of the single element of structured sheet. The red paint shows the element of structured sheet which reflection allows repeat the shape of the whole structured sheet entirely

In study the contact between sheet and die was determined by friction factor m with value 0.2. $f_k = m \cdot k$, where f_k - friction stress (MPa), k - flow stress (MPa).

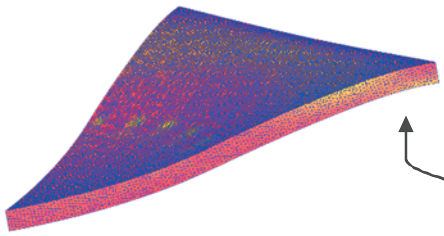
Software package DEFORM™ allows work with two types of elements: brick that has 8 nodes and tetrahedron with 4 nodes. Calculations were made with different mesh, as variable parameters by these calculations it were chosen the type of elements and their count. As a main mesh for models' creation it was chosen a mesh with tetrahedral elements of equal size. The mesh consisted of 187160 elements.
Boundary conditions were determined as follows:

- Symmetry conditions were determined on three side edges of a sheet (symmetry axis on **Fig. 3**);
- The contact between a sheet and a die was determined with the heat exchange coefficient 11 N / (mm·s·K) [6];
- The contact between a sheet and environment was determined with convectional heat exchange coefficient was 20 N / (mm·s·K) [6].

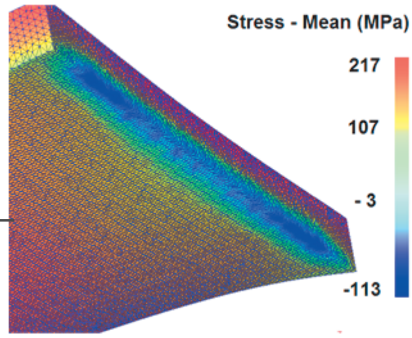
3.2. Evaluating results in DEFORM™

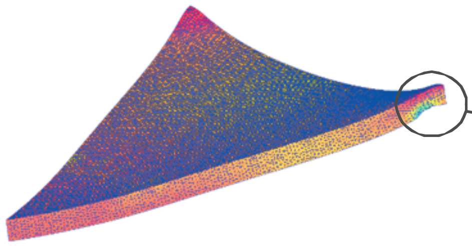
It was investigated: the power parameters of the process and mode of deformation in each studied scheme. Besides, it were calculated the fields of stress rate intensity and strain rate intensity by sheet's volume, fields of internal stress after removal of load and the change of geometric parameters of a sheet.

Calculating stress fields of a sheet (**Fig. 4**) showed reaction of metal by structuring and weak points. **Fig. 4** illustrates that the use of matrix die type B by stretch forming leads to unequal thinning of a sheet (up to 0.26 mm) at the joining point of a sheet and a die that is left after removal of the load. Application of the another schemes where matrix die type A is used leads to unessential thinning at the joining points of a sheet and a die (up to 0.2 mm by stamping using elastomer and up to 0.12 by stretch forming). It should be also pointed out that application of matrix die type B doesn't allow reach the required geometric parameters of structured sheet what leads to formation of unacceptable deflections (up to 1.46 mm) at the joining points of two nearby elements of structured sheet.

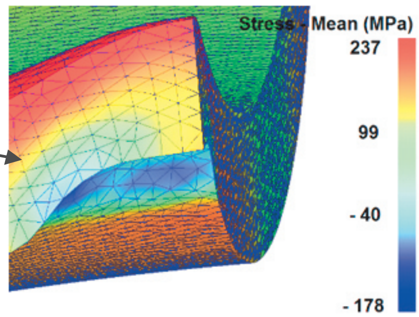


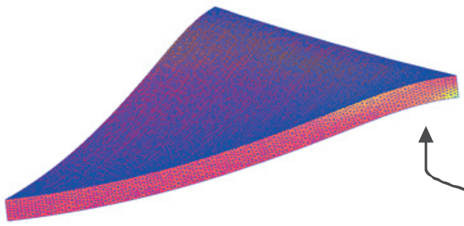
a) stretch forming using matrix die type A





b) stretch forming using matrix die type B





c) stamping using elastomer

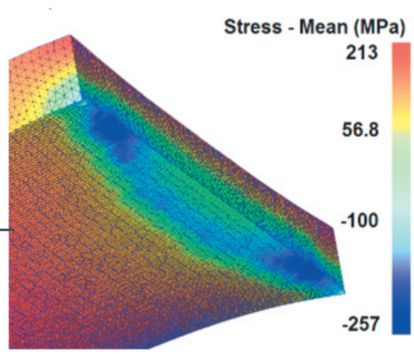
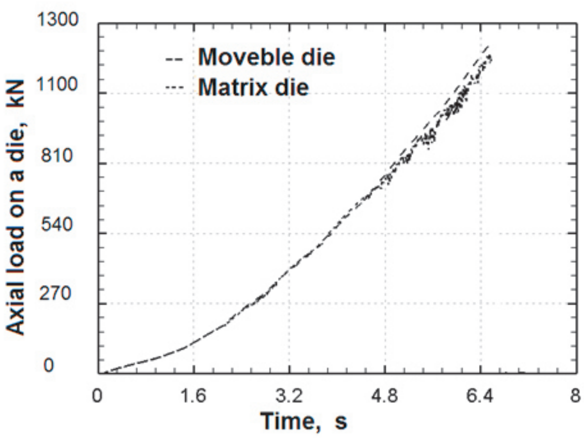
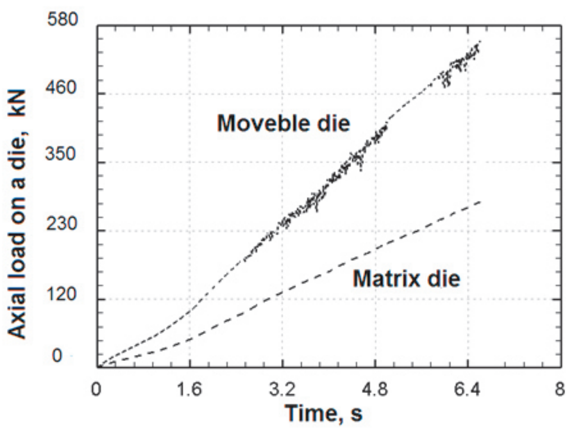


Fig. 4 Distribution of maximal internal stresses in the body of a sheet

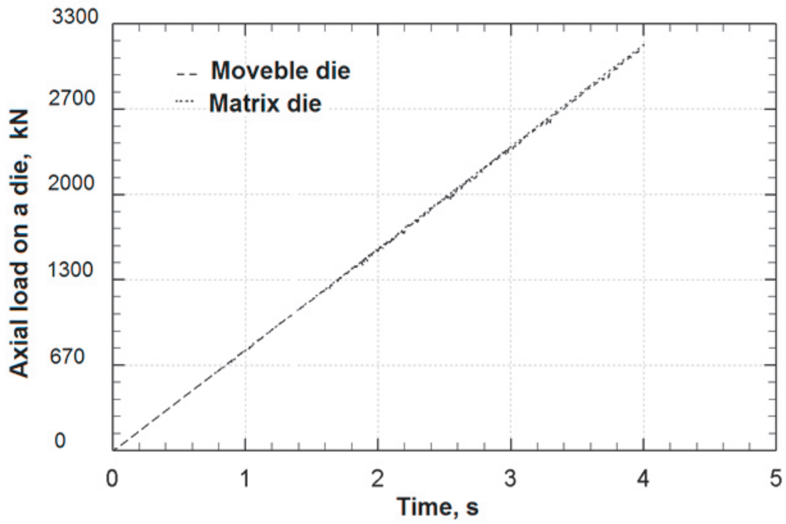
As it was expected the main 'weak points' by all structuring schemes were the places of contact between a sheet and a matrix die where operate compressive stress (**Fig. 4**) and where stress intensity mainly reaches maximal values. These values didn't exceed the limit of breaking stress of the material.



a) stretch forming using matrix die type A



b) stretch forming using matrix die type B



c) stamping using elastomer

Fig. 5 Axial load on a die by production of structured sheet dimensions 500 x 500 mm

Fig. 5 presents calculated dependence between axial load on a die (towards the move of a press) that is needed to produce structured sheet with dimensions 500 x 500 mm (without rigid zones) and time of the process. The application of elastomer demands from press more axial load comparing with stretch forming in matrix die type B (**Fig. 5b**) where the contact area of sheet and die is significantly smaller.

4. CONCLUSION

- Numerical simulation of sheet structuring process by the proposed schemes showed that the most proper deformation pattern for producing of a preset structured sheet are: stretch forming used matrix die type A and stamping used elastomer.
- The developed finite element mesh can be used by developing the new numerical model that takes into account influence of the pressure die and rigid ends of a sheet (the case when sheet has finite dimensions).

ACKNOWLEDGEMENTS

The research has been performed at Peter the Great St. Petersburg Polytechnic University under the contact № 14.Z50.31.0018 with the Ministry of Education and Science of the Russian Federation.

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