

CAPABILITIES OF USING FEM IN SHEET-METAL FORMING

The aim of this study was to determine and select boundary conditions of modeling and FEM simulation for plastic processing on the example of sheet-metal forming. For sheet-metal deformation analysis, Deform 3D has been used. The study presents research methods for real and virtual conditions. There are also described common features and these differentiating obtained results. Research of conducted process of sheet-metal forming allows to determine the effectiveness of computer research methods. The finite-element method can be used as an effective tool for the study of plastic processing phenomena considering various operating conditions of individual elements provided the appropriate tools for FEM analysis.

Keywords: FEM calculations, modeling of plastic processing, simulations, sheet-metal forming, metallographic study

1. Introduction

One of the current problems of modern research and works connected with tribological processes during plastic processing is to evaluate friction resistances in a typical friction node. This results in the necessity to select appropriate tools and research methods, for instance, systems of numerical analysis which use Finite-Element Method. In the literature there are many works of tribology concerning studies supported by simulations and Finite-Element Methods. These papers present results of the studies on friction for specific research of plastic deformation. Less commonly, however, there occur studies on tribological simulation for more complex processes of plastic processing. In tribological research using FEM described in literature, there are significant differences in the results of simulation. This fact can be explained by different boundary conditions selected for each analysis. Thus, it is important to analyze phenomena experimentally or with mathematical methods and matrix calculations techniques connected with them.

Defining contact phenomena and selection of friction parameters in software used for process phenomena analysis, for instance, change of contact pressure, change of real surface contact point, change of speed of tools and materials, change of plastic deformation, etc.

In many computer analyzes, values of abovementioned parameters are averaged to one representative factor defined as friction factor. Determination of analysis conditions in this way is based on experience and intuition of people doing numerical analyzes. This fact can have significant impact of the final re-

sult. Thus, research with the use of FEM is connected with the necessity to choose software which will reliable reflect simulation of the analyzed phenomena of plastic deformation. Despite these difficulties, the attempt to define boundary conditions in plastic processing with using computer calculations methods for analyzed models and friction hypotheses has been concerned important. Due to unusual character of sliding friction – because in plastic deformation it can be included into unconventional tribology processes – to perform numerical analysis Deform 3D ver. 10 and Autodesk Inventor 2014 has been used. This paper discusses the impact of boundary conditions selection on obtained results with the effects of metallographic changes of surface layers of deformed materials and tools.

Then, obtained results are summarized and discussed in relations with the occurrence of surface layers' changes in characteristic systems. The comparison was connected with selection of appropriate models and boundary conditions for analyzed process [1-3].

2. Research methodology

Depending on the type of the process and technological conditions, friction forces in plastic deformation can influence the process positively as well as negatively. In sheet-metal forming processes, which are included in cold plastic processing, occur various friction conditions and speeds of analyzed points on both sides of deformed element – Fig. 1.

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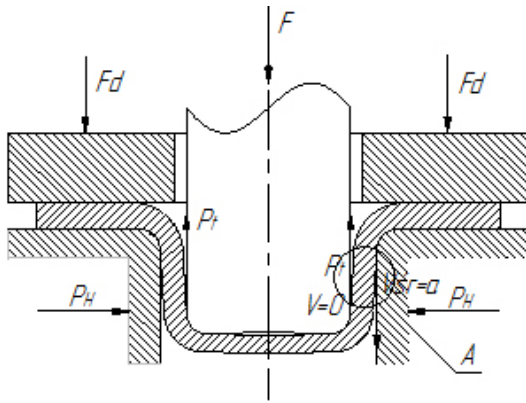


Fig. 1. Scheme of friction forces affect during extrusion with clamp

Friction occurring in clamp affects the increase of axial tensions. Friction resistances in clamp have negative effect and can lead to the break of extrusion. Deformed sheet-metal friction on drawing ring increases pressure of the stamp and the risk danger of extrusion breaking away, and thus it affects the process negatively.

Moreover, in both cases friction increases drawing forces. Only deformed sheet-metal friction on stamp surface affects positively, because it increases stamping force. Friction also affects boundary deformability as well as change of wall tightness. Extrusion tightness on the stamp edge increases to the value equal or smaller than the tightness of extrusion flange.

Clear changes in extrusion tightness occur also in the point of contact with stamp head. Metal being in contact with stamp flat surface becomes homogenously thinner while metal placed within contact area with radial part of stamp becomes thinner non-homogenously. In further research occurs the growth of extrusion wall thickness. Change of extrusion wall thickness is affected not only by friction resistances between stamp and sheet-metal but also various technological factors such as: stamp radius point, sheet-metal thickness, extrusion forces and others. In order to obtain assumed objectives, own research method allowing to define friction forces for selected friction model has been developed. The research object is a rigid-plastic system. Analyzed tribology problem is related to the move of the C-shaped sample subjected to the compression and given plastic deformations. Kinematic model of developed friction node is shown in Fig. 2.

Deformed sample is moved with defined speed over surfaces of a rigid tool with given roughness. The side wall of extrusion slide over a tool with speed similar to stamp speed. Metal flow direction in this case is opposite to stamp movement direction. In the area of matrix rounding, slide speed decreases reaching a minimum value in undeformed part of the flange. In extrusion bottom slide speeds are low and contact between the tool and deformed sheet-metal is defined at the moment of stamp contact.

During this process, friction resistances occurring in the clamp, on the edge of extrusion, in the drawing tool, on the stamp have to be overcome [4,5].

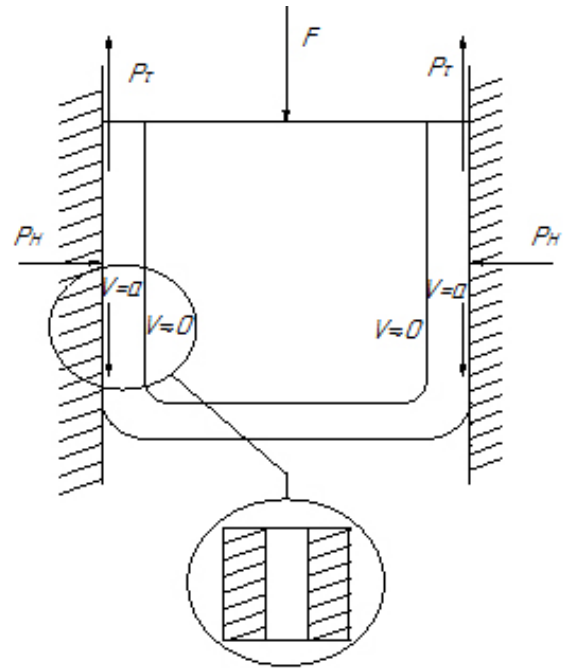


Fig. 2. Kinematic model of friction node with analyzed sample section

2.1. Metallographic research

Metallographic research of the surface layer of deformed material was done in accordance with Fig. 1. Obtained states of the surface of steel samples have been analyzed for various materials thickness and deformations. Structure of analyzed sample, both in the surface and centre areas, consists of homogenous ferrite grains with the size from 20 to 30 μm and the clusters of grain cementite – Fig. 3 and 4. In the structure of sheet-metal central area at ferrite grains – Fig. 5 the effects of plastic deformation occur as numerous bands – Fig. 6. Form and shape of α -phase grains shows that technology of sheet-metal used to the analysis consisted of recrystallization annealing without final deformation operation.

The tools used in the process are made of heat-treatable chrome steel 40H according to PN-89/H-84030/04 (European Standard EN-41Cr4). Prior the research anvil material has been subjected to a heat treatment including quenching at 850°C in oil providing bainitic-martensitic structure with hardness 590 HV – Fig. 7 and 8.

2.2. Research and simulations using Finite Elements Method

Implementation of numerical simulation in research of plastic deformation requires the selection of appropriate boundary conditions, and hence some initial assumptions that have a significant impact on the final results. Each FEM calculation relates to physical model in question located in space – local or main coordinate system. Issues connected with plastic processing, especially sheet-metal forming are very complex processes

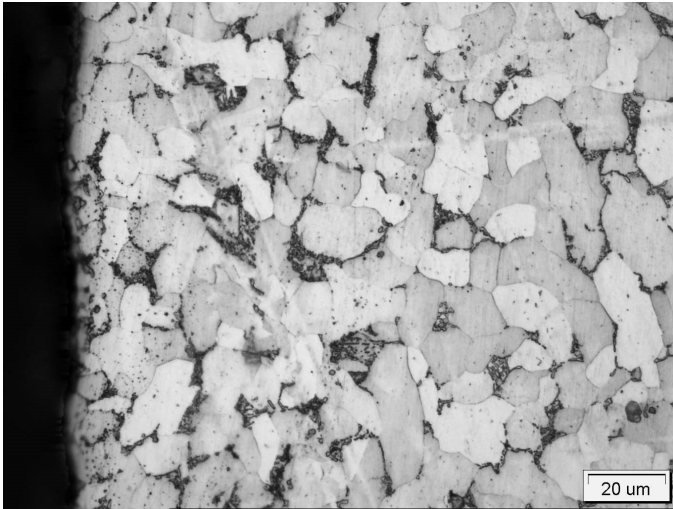


Fig. 3. Ferrite grains with granular cementite in the plate of element 4. Surface area – Nital etching

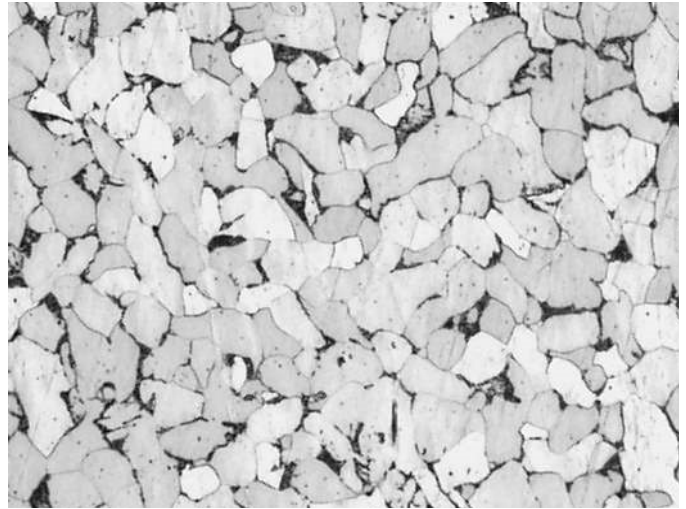


Fig. 4. Homogenous ferrite grains with cementite in the plate of element 4 (central area of sheet-metal)

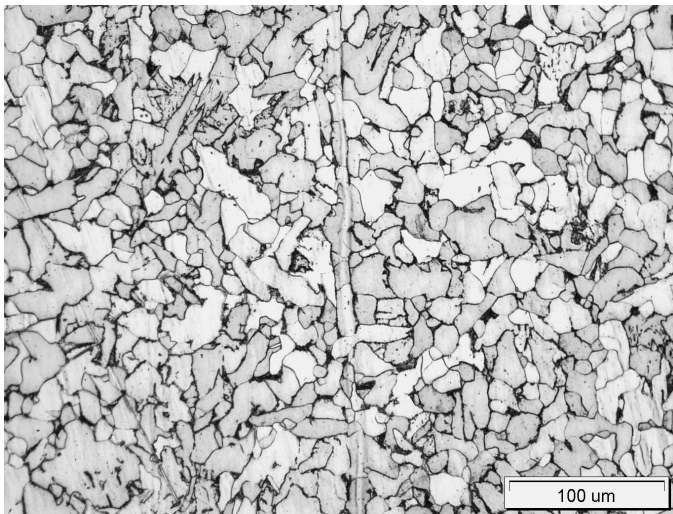


Fig. 5. Deformation bands at the structure of analyzed element's 4 sheet-metal – Nital etching

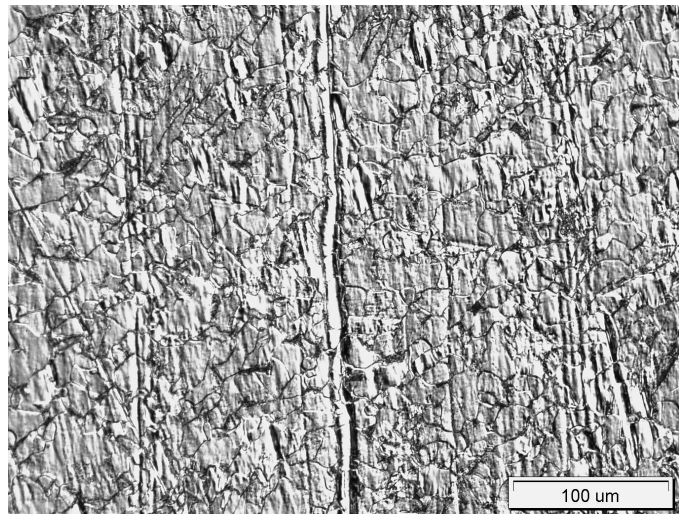


Fig. 6. Deformation bands at the structure of analyzed element's 4 sheet-metal – Nital etching

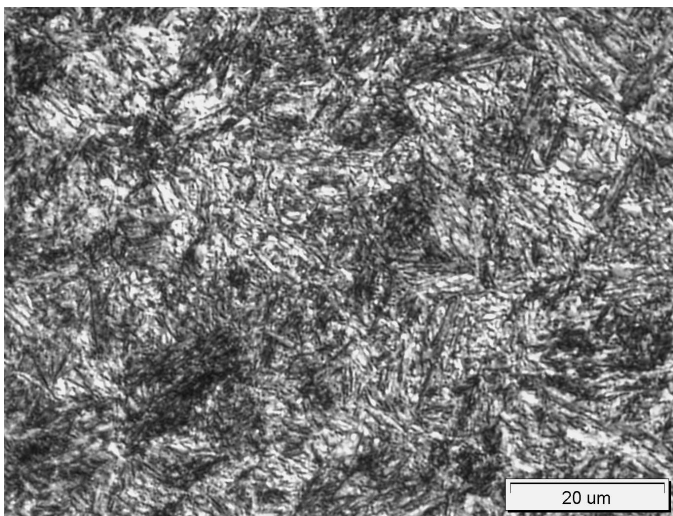


Fig. 7. A microsection's martensitic-bainitic structure of anvil made of steel 40H after quenching in oil

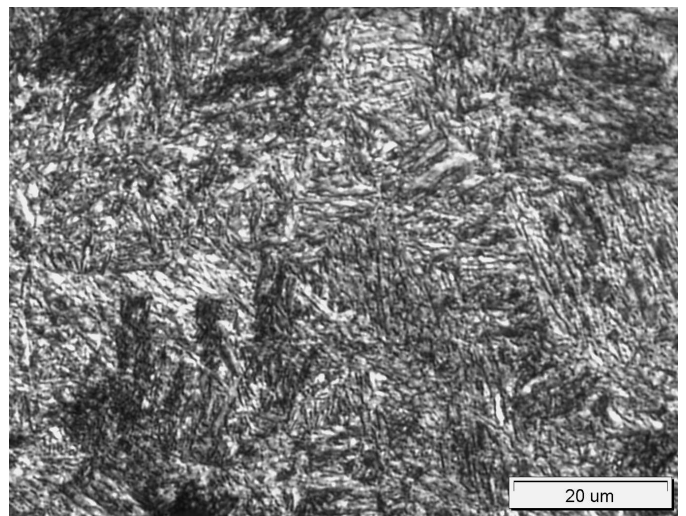


Fig. 8. A microsection's martensitic-bainitic structure of anvil made of steel 40H after quenching in oil

which are affected by a number of technological factors. In order to perform computer analysis, theoretical friction model in the form of sample has been developed – see Fig. 2.

In the studies on complex technological processes connected with plastic processing, Deform 3D software has been used to evaluate boundary conditions. These conditions rela-

ted to the determination of kinetics of the research stand elements, load dynamics, movement speeds and material properties [6].

Test results are shown in the figures: maximum deformation of material – Fig. 9, maximum stress effective – Fig. 10, actual tension in sample – Fig. 11, rate material deformation – Fig. 12.

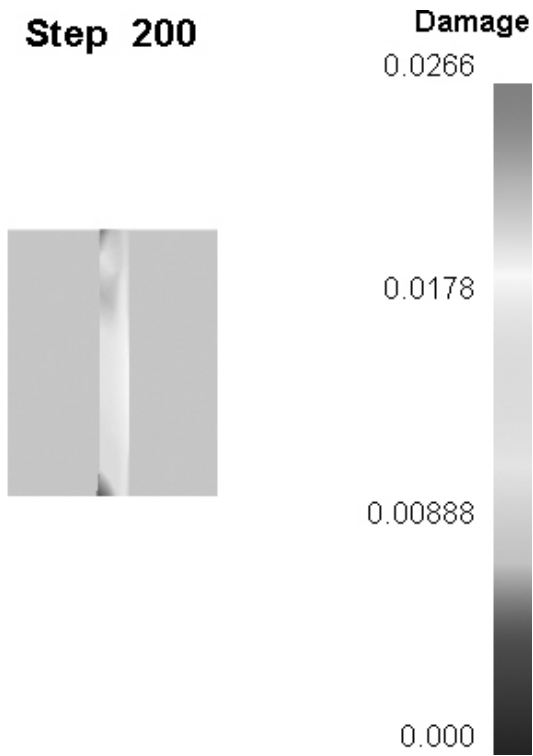


Fig. 9. Maximum deformation of material between stamp and matrix

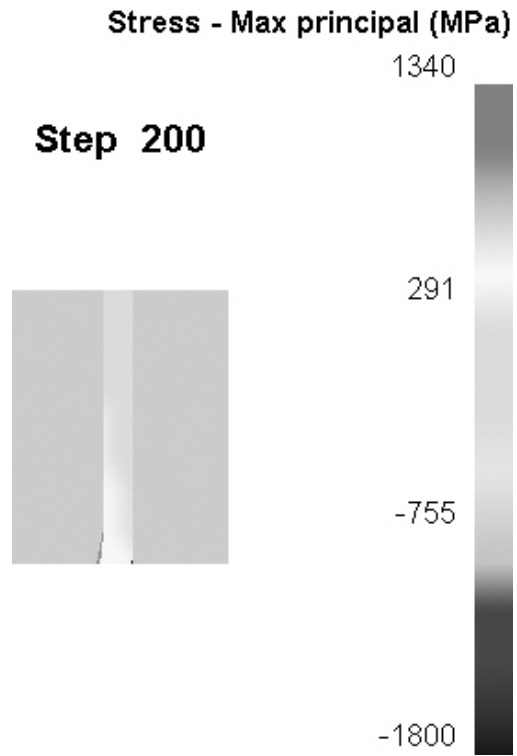


Fig. 10. Maximum tension occurring in the material sample

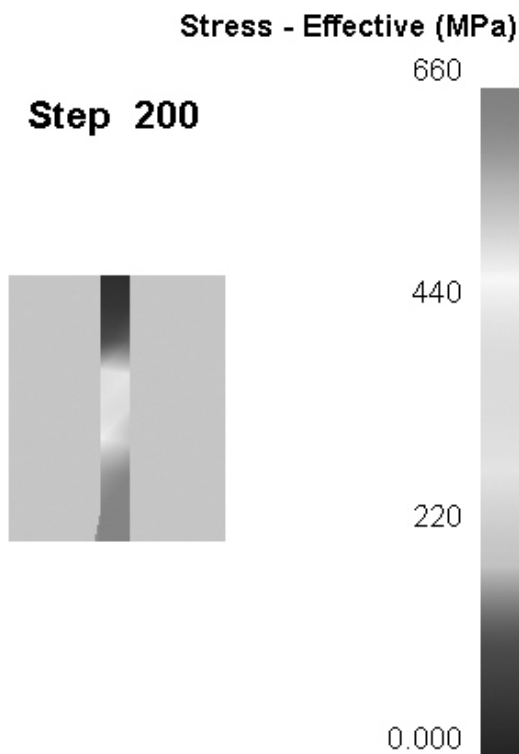


Fig. 11. Actual tension in analyzed sample

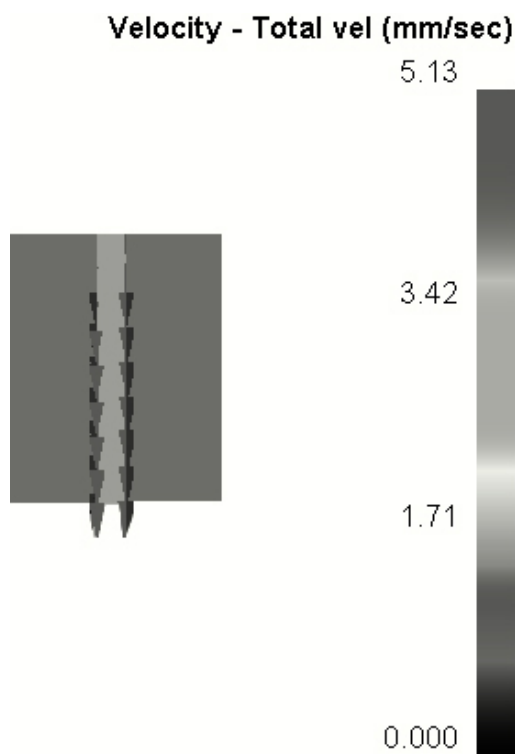


Fig. 12. Shift of deformable material

External surfaces of virtual models are written mathematically as perfectly flat surfaces. With such a simplification the following issues are not taken into account: adsorbed environment particles, metal oxides and irregularities occurring on the surface layer. Computer developed models of friction node have isotropic nature while most metals have structural and deformable anisotropy, which is a significant mistake in modeling [8]. Simplification of area mapping may cause improperly generated FEM net. Too large discrepancy between the real results and FEM results enforces the use of automatic or manual adaptive process involving cyclic net modification and shape functions connected with it. Above consideration indicates that results obtained with Deform 3D should not be the end of problem analysis procedure. After obtaining numerical solution, the analyzed tribological systems should be subjected to the process of error estimation and models validation, for instance, by inverse tests [9,10]. Then, the results of analyzed CAE processes can be considered correct, and errors corresponding with them as negligible.

3. Conclusions

Increasing the efficiency of plastic processing of metals is associated with the use of analyses and numerical simulations. Using of Finite Elements Method benefits as a result of the savings obtained through calculations and appropriate design of tribology processes. While analyzing existing works describing issues of computer simulations of tribological processes, it can be concluded that there are a large variety of defining the contact phenomena, friction models and research methods. In numerical analysis there is a relationship between the friction conditions and kinematic, dynamic ones in given technological process. These conditions during the implementation of simulation are defined as simplified and representative for the process – their selection is often based on intuition of researcher. In the realization processes of plastic deformation between materials and tools sliding friction dominates, while the actual material-tool contact surfaces are considered as nominal. During the material deformation friction resistances on the surfaces inhibit free flow of deformable material. As a result of this process, various areas with different degrees of deformation can be divided in the volume of deformable element. Reliability of obtained results depends on boundary conditions, geometry of analyzed area, method of its discretization, the number and shape of finite elements and physical properties of the analyzed object. Change of the friction resistances' value directly affects the distribution of stresses and deformations in the material and has a significant impact on the proper realization of the process. In FEM computer

analysis of plastic deformation, roughness and waviness of the surface is defined with friction coefficient, which is not always coincided with theoretical approach. Development of further theoretical research is one of the important factors determining realization of experimental research in plastic deformation of metals. So, researchers are looking for methods and means allowing for more precise modeling of phenomena in contact area. The most important for FEM development will be expansion and implementation of algorithms of contact issues. Numerical simulations using FEM provide accurate achievement of the results, which obtaining in analytical way will be extremely difficult or even impossible. However, on the basis of analyzed works it can be noticed that friction resistances occurring in plastic processing have a significant impact on the kinematics of deformable material flowing, which mainly affects the final results of the process.

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