11th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

INFUENCE OF STRESS-STRAIN STATE ON DIMENSIONAL ACCURENCY IN MULTI-STAGE EXTRUSION PROCESS OF CAN-FLANGED PART

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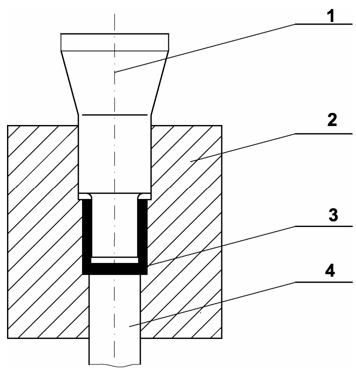
ABSTRACT
In last years there is a trend of permanent increase in the number of parts produced by cold extrusion. High shape and dimensional accuracy, good mechanical properties and material utilize, short production time, etc., among others, are the main reasons of this. Most of cold extruded parts can be classified like net shape or near net shape forming parts. But, the required tolerances and complexity of part is very often an obstacle in getting processes. Great number of factors that influent on dimensional accuracy of part and their interrelation makes very difficult to design the manufacturing process properly. Usually it implies a long way of continuous process improvement considering entire manufacturing process including machine and tool system, input material properties, stress-strain state, thermal condition etc.
The present papers deal with multistage cold extrusion process of can-flanged part, where the influence of stress-strain state to the dimensional accuracy has been investigated. The analyzed process consists from two stages: can-backward extrusion and radial extrusion. The investigation of the process was performed using FEM simulation and ABAUQUS explicit code
Key words: Cold extrusion, dimensional accuracy, FEM simulation

1. INTRODUCTION
Demands for increasing of dimensional accuracy of cold formed parts have been driving to the development of net-shape manufacturing in forging industry. To meet the goal of NSF – getting parts with very narrow shape and geometrical tolerances, detailed analyses of entire manufacturing process have to be performed and compensation of the various parameters influencing on dimensional accuracy done. The dimensional accuracy of cold formed parts depends on many parameters which can be classified in four major groups: starting material, tool system, machine and forming process [1]. Among these feature the forming process parameters (stress-strain state, forming load, temperature, lubrication etc) are significantly in particular due to affecting both - behavior of the tool and machine system during forming process and the dimensional deviation of workpiece. For example, elastic deformation of die and elastic recovery of components, which are one of the main sources of dimensional inaccuracy of cold formed part directly depend on value of forming load and thermal condition. With other side, stress-strain state and friction conditions, are responded for material flow and the process of die filling. Moreover, it is well known that material formability occurrence depends not only on stress magnitude, but also on stress scheme. The possibility of certain stress scheme in occurrence of material formability is in the opposite with the increase of spherical stress tensor [2]. By another words, negative (pressure) stress components are favorable for deformation process and getting defect free parts. With other side, tensile stresses very often induce appearance of micro-cracks in material structure which grow with increase of nominal stress value. It

could lead to visible damage of work-piece or irregular part function afterwards. The problem of dimensional accuracy is particularly presented in multi-stage processes. Being in this case metal forming process is not single operation but is composed of several forming steps, the number of influential factors is multiplied and additional ones such as: intermediate heat, surface treatment, positioning of work-piece etc., are involved.
In this paper, FE technique to find the influence of stress-state state on dimensional accuracy in multi-stage cold extrusion process of can-flanged part (shown in Fig.3) has been applied. The investigation was performed using ABAUQUS FE program package with explicit code.

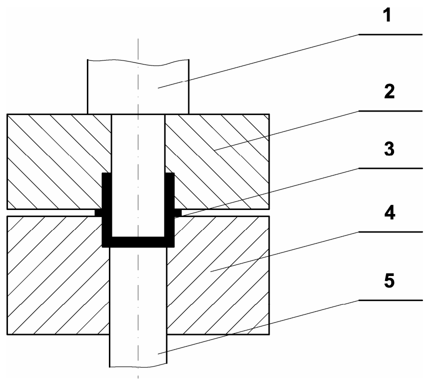
2. EXTRUSION PROCESS

Cold extrusion is a forming process which makes possible to produce different small and medium size parts with enhanced mechanical and geometrical properties. Extruded parts are mostly classified as NNSF or NSF parts. In this processes cylindrical billet positioned in die is pressed by moving punch and enforced to flow through necks in tool set.
Investigated multi stage extrusion process consists from two single operations: backward can-extrusion (Fig.1) and radial extrusion (Fig. 2). In first operation can-like part is obtained while in second one central flange is shaped. Dimensions of the final part are shown in Fig.3.



1- punch, 2- die, 3- workpiece, 4- ejector

Fig.1. Scheme of backward extrusion



1- centering mandrel, 2- upper die, 3- workpiece, 4- bottom die, 5- ejector

Fig. 2. Scheme of radial extrusion

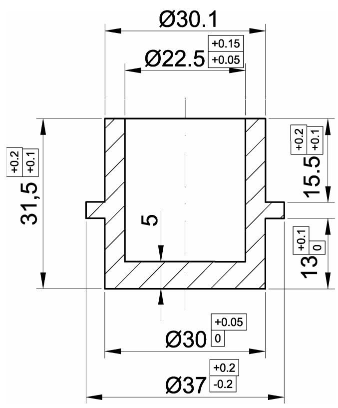


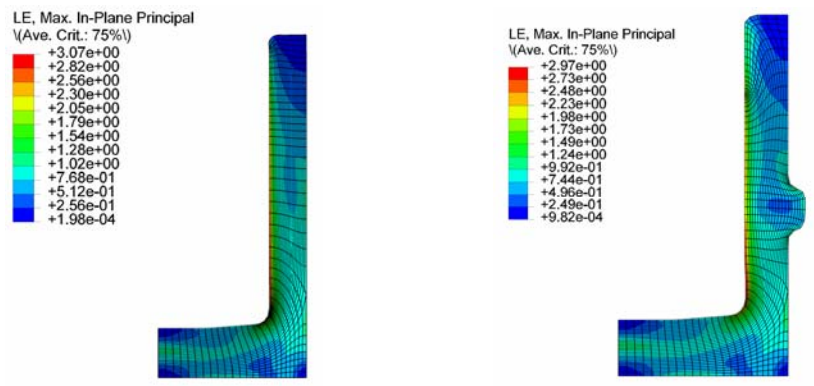
Fig 3. Dimensions of part

3. FEM ANALYSIS

Numerical FEM analysis of investigated model was conducted using ABAQUS software package. Virtual model for simulation of analyzed combined extrusion process was made on the base of the workpiece geometry and procedure shown in Fig.1-2. Tool and billet geometry including starting FE net, were set in the ABAQUS/CAE module. Within the presented investigations tooling was considered as rigid body and billet as elasto-plastic body. The billet was initially meshed with 1650 quadrilateral elements. In order to get more accurate results and to minimize the effect of tool penetration through elements due to large workpiece deformation, the billet was divided into five zones according to expected strain level and remeshing procedure was performed on every 100 increments. The zones were differing by the size and by the number of elements. Material was low carbon steel C1221 (corresponding UK steel is En2E) with the next flow curve: $\sigma = 660\,\varphi^{0.23}$ [MPa]. The coefficient of friction at workpiece/tool interfaces is assumed to be μ=0.1 (m=0.173).

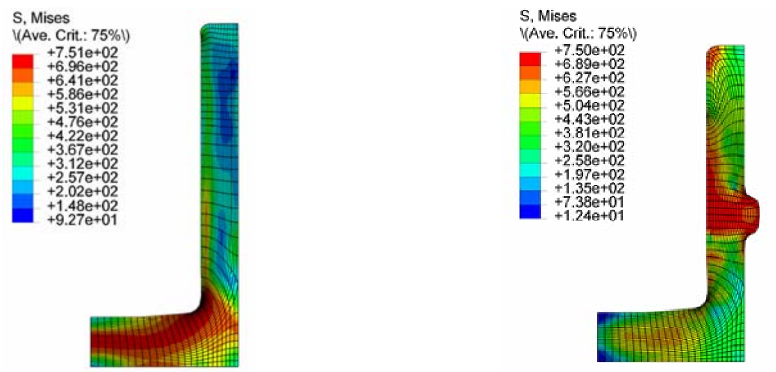
4. ANALYSIS OF RESULTS AND CONLUDING REMARKS

The FEM simulation has been carried out in two continuous steps. Fig 4 shows geometry of deformed parts with effective strain distribution after backward and radial extrusion, while the effective stress along the axial cross section of the workpiece is given in Fig.5. As it can be seen, strain distribution over workpiece is very heterogeneous. In the process of backward extrusion maximum values of effective strain appears on the inner surface with the pick at the zone around the wall-bottom edge, and obtained values indicate that there is possibility of cracks appearance. On the top of workpiece there is zone which is not almost included in deformation process-so called dead zone. It is very interesting that the top of workpiece stays very low deformed and after radial extrusion process, in spite of direct pressure by upper die (Fig.4.b). Simulation has also shown that in the process of backward extrusion it is very hard to obtain smooth top surface and the nominal high of workipiece (dimensions in axial direction). The same problem occurs with outer diameter of flange after radial extrusion, and in many cases calibration of these surfaces has to be done. Main reason of errors of part height lies in elasto-plastic characteristic of workpiece material and filling of die/workpiece gap.



a) backward extrusion *b) radial extrusion*

Figure 5. Distribution of effective strain



a) stress backward extrusion *b) radial extrusion*

Figure 5 - Distribution of effective stress

Forming load of the punch in backward extrusion causes very high radial stresses which considerably deform die in radial direction, influencing that way the dimensional inaccuracy of the workpiece. Dimensional errors of outer surface of the part are determined by the elastic deformation of the internal surface of the die, whilst the errors of inner surface are affected by the punch's deformation. High radial stresses of the die are usually greater than the yield stress of the workpiece material, so when the punch is removed, additional plastic deformation of workpiece is induced. This process is known as secondary yielding. Obtained values of the effective stress of workwiece (Fig. 5) and loading of the punch and the die (max. normal pressure is about 2700MPa) signify that secondary yielding could be expected and dimensional part errors present. High values of the die loading, also

lead to the very intensive displacement of the outer surface of the part after ejection. Reasons of this are elastic recovery of part and die relaxation. Dimensional changes in part diameter after ejection depend on realized stress values and elastic properties of workpiece and the die material.
FEM simulation has also shown that for the given part geometry during radial extrusion material folding may occur. The folded zone appears on the inner surface of workpice at flange level, as it shown in Fig.6. Analyzing this phenomenon, it has been concluded that folding process is very sensitive to friction conditions and die geometry, especially on the radii's of upper and bottom die.

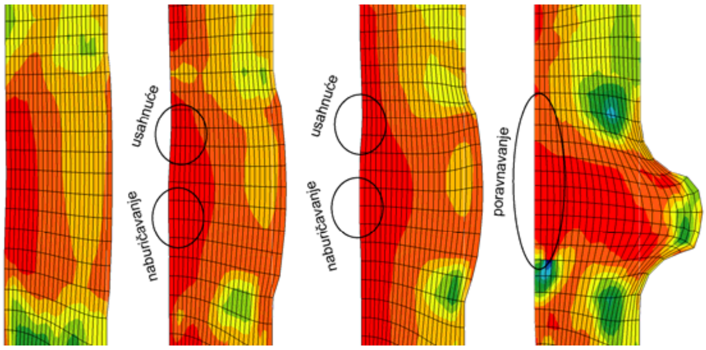


Figure 6. Material folding in the process of radial extrusion

5. ACKNOWLEDGEMENT

Investigation presented in this paper has been part of the research project „Investigation, development and application of near net shape forming technology for production of bearing and cardans elements – TR 6333B", financed by Ministry of science and environmental protection of Republic of Serbia. The authors are grateful for the financial support.

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