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GUIDELINES FOR IMPROVEMENT OF FORGING PROCESS AND PART ACCURACY

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ABSTRACT
Like products, manufacturing processes have to continuously be improved to meet all challenges and requirements they are faced at global market. In forging technology which roots dates as far back as civilization, for a long time process and die design were mainly based on trial and error procedure, which is costly and time consuming and it may not give the optimum solution. In addition, forged parts generally require subsequent machining in order to achieve proper geometry and dimensional accuracy of final product. To overcome these demerits, theoretical background of forging process has to be improved and new procedure like precise forging applied.
In this paper variables related to accuracy of forged parts and possibilities of accuracy improvement will be discussed. In that purpose some results and conclusions obtained from simulation of forging process of axial-symmetrical component for automotive industry are given. Analyze of forging process is carried out by using FEM and ABAQUS program package.
Key words: forging, accuracy, FEM

1. INTRODUCTION
In past, forged part had reputation of irreplaceable elements owing to high performance and high reliability in applications where tension, dynamic load, demanding environments, human safety etc. are critical considerations. It provides forging prominent position among the various manufacturing methods and there was no hard pressure to this industry for new and advanced products and processes. But, by time, the vacancy between performances of forged parts and parts produced by other ways slowly vanished. Permanent rise in the cost of energy and raw materials, demands for increasing accuracy of forged parts, pressure from global market, higher ecological demands etc. additionally, influenced the position of forging industry. These things forced many forgers to make a review of their manufacturing technique so they can be cost competitive and gain higher quality than the rivals.
One of the most important subjects of research and development in forging both cold and hot (warm), is precision forging where high accuracy, complex and net shape components can be produced. By another words, precise forged components are 'ready-to–assembly' i.e. additional machining are minimized or zero. In contrary to conventional forging process which is mainly based on trial and error procedure and realized through open dies why the enhanced machining allowances of workpiece are needed, precision forging is related with closed dies and requires better understanding and tight control of process parameters as well as tool technology.
Dimensional accuracy of final product which can be achieved by precision forging according to ISO IT standards are IT7-IT9 in case of hot forging and IT5-IT6 for cold forging [1]. For example machining allowances of hot die-closed forged gears are range only 0.10mm per flank and clutch gearing have ready built in teeth surfaces [2].
Development of precision forging is highly related to use of computers and results of theoretical investigations of forming process. With the support of computer aided design tools 3-D simulation of complex forming operations becomes feasible within reasonable time. In addition, modeling in details

together with the FEM analyze and process simulation, gives the opportunity to change the parameters such as dimensions, number of stages, perform shape, taper angles, fillet radii, shrinking factor, etc. easily and on optimal way. Such approach made it possible to push out the trial and error procedure and led to significant reduction of time and effort on process design and manufacturing stages.

2. PARAMETERS AFFECTING THE ACCURACY OF FORGINGS

The accuracy of forging parts is affected by many parameters which can be classified in four major groups [3]:

- *Input material variables* (billet volume, dimensions, shearing quality, physical/mechanical properties, surfaces quality, heat treatment etc
- *Tool system variables* (tool design, tool making accuracy, tool setting accuracy, surface quality, tool material characteristics, loads resistance, elastic behavior, wear rates, etc.)
- *Forming machine variables* (machine design, kinematics, stiffness, guidance system, elastic deflection, energy deliver system, part handling capacity, etc.)
- *Forming process variables* (metal flow, billet and die temperature, friction condition, lubrication, forming speed and load, forming sequence for multi-stage processes, heat generation and transfer, scale, shrinking etc)

To meet demands towards the higher accuracy of the forged parts, it is crucial to determine influence (single and interrelated) of above mentioned parameters. Further, it is very important to define optimal values and permissible fluctuation of variables both before and during forging process.

2.1. Input material

Initial material and billet geometry are very important for accuracy and quality of forged parts. Knowledge of material properties is basic provision for efficient designing of forging process and in that purpose the flow stress of material of workpiece is main feature should be considered. Fluctuations in the chemical composure, microstructure, grain size of workpiece material cause variations in flow stress. Result of this is change of process parameters, including elastic behavior of workpiece, material flow, hardening, etc. For example investigation of influence of workpiece material condition (three different flow curve of the same material were considered [Ck15-DIN]) in case of cold forging (extrusion) of bearing axle (Fig 1) shown that forming load can vary more than 30% (Fig 2). Also, for billet with highest starting flow stress initial crack were appeared on the inner surface of bottom-wall crossing zone.

Figure 1 – Cold extruded part

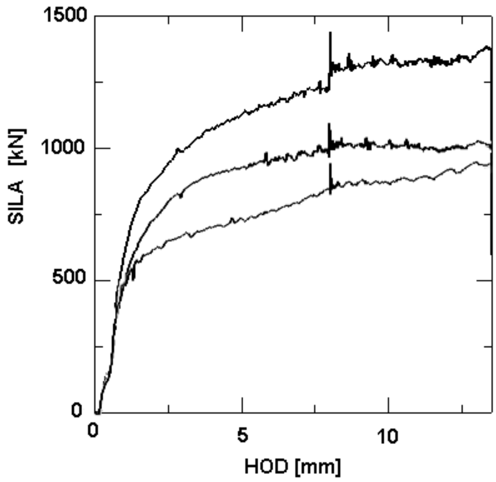

Figure 2 –Variation of forming load

Proper billet size and shape are essential for precise forging process. Variation of the volume (mass) of the billet directly affects elastic deformation of tool and machine and there is a danger of toll overloading if billet volume is lager from regular. Typically allowed volume variations are between ±0.5 and ±1% [2]. This can be achieved by precise shearing or sawing of the billets.

2.2. Tool system

With increasing demands on shape complexity and demands on the accuracy of the forged parts, the tool becomes more and more important factor for costs and quality of the workpiece. The influence of tool system to accuracy of forged part is very complex. First of all there is tool design. It is well know that there exits number of possibilities for tool setup, even in case of very simple part geometry. That why it is hard to give precise guidelines for tool design, but some general rules linked to tool functionality, right billet positioning, exact guidance of tool elements, punctual tool assembling etc., have to be properly solved. Also, there is a problem of tool manufacturing. The accuracy of the tool making and deviation from the desired values are related to systematic errors of workpiece so great attention has to be paid to this item. For instance, when designing tool components if one provides turning rather than milling operations, it will substantially improve the accuracy of tool and consequently workpice accuracy.

High load-pressure and thermal changes during forging process cause elastic deformation of tool components. Being forged parts are the replicas of the tool geometry, it lead to shape and dimensional deviation of workpiece. Elastic deformations in tool system together with tool wear process are recognized as a main source of inaccuracy of precise forge parts. In order to improve the accuracy of forged parts i.e. negate these effects detailed analysis has to be carried out.

FEM analysis is powerful tool by which elastic behavior of tool during forging process can be efficiently simulated and then compensation of tool dimension errors easily performed. In that purpose ABAQUS program package were used to evaluate elastic deformation of the punch and the die in first operation (backward extrusion) of manufacturing process for part shown in Fig.1. The figures of elastically deformed punch and die when maximum deforming load (F_{max}=660 kN) is applied are shown in Fig 3. Largest axial displacement of the die bottom was U_2=0.13 mm, while the radial displacement U_1=0.026 mm. Largest elastic contraction of the punch takes place at the end of the forming process with amounts of 0.6 mm. By superpositioning elastic deformations of the punch and the die, an error in the bottom thickness of workpiece is estimated to 0.73 mm.

Inaccuracy in radial direction of forged part can be minimized by making die dimension large relative to the size of workpiece, or better way by using reinforcement elements like are compressive prestersing rings or strip-wound containers [4].

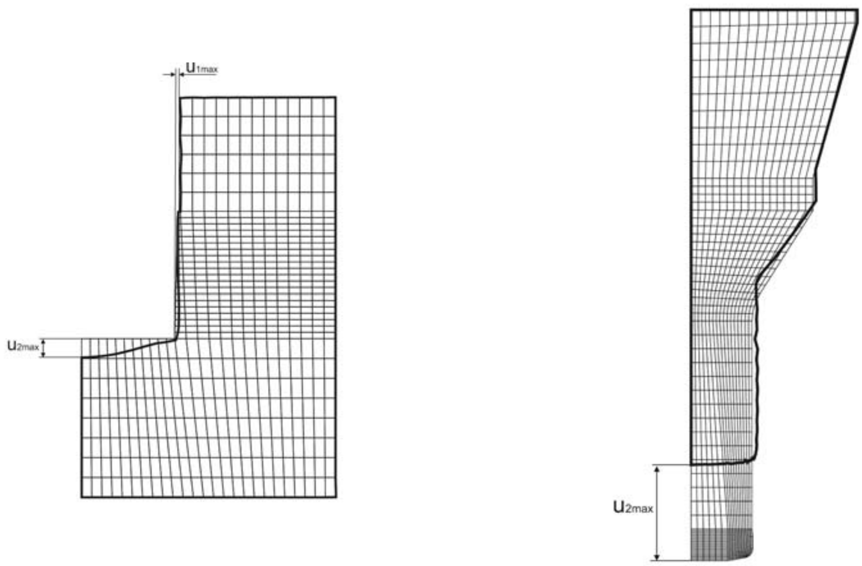

Figure 3 – Elastic deformation of die and punch in backward extrusion of bearing axle

2.3. Forming machine

Investigations of dimensional accuracy problem in precise forging pointed out that there is direct correlation between press-related incurrence and part dimensional deviations. According to [5] press-related inaccuracies may be defined as the geometry errors of the press system caused by the guideway clearance, the thermal distortion of press members and press elastic deflections under forming forces. Geometrical and dimensional errors of formed parts due to press elastic deflection are

derived from the dies deviations being the dies are rigidly mounted onto the press ram and table. Investigations [5] shown that press ram and frame contribute more than 90% of total press deflection, and that horizontal displacement and table tilt can be up to 5 mm [6]. Furthermore, press nonlinear deflections, originated from guideway clearance and contact gap between press members (in case of mechanical press), superimpose dies deviations and additionally reduce accuracy.
The increase of press stiffness coefficient has positive effect on press punctuality and part accuracy. High value of press stiffness is particularly recommended for machines with fluctuation of forming force, what can be often detected at mechanical presses. At mechanical presses, as the force varies, thickness of part bottom varies too. In case of cold forging the priority is given to the press with stiffness coefficient greater than 1000[kN/mm] [3].

2.4. Process parameters

It can be said that almost all process variables affect, more or less, the accuracy of forged parts. However, thermal occurrences and forging sequences of multi-stage process are most complex and important. For achieving optimal manufacturing condition, reliable tool function and good dimensional accuracy constant tool and forging temperatures are of great importance. In warn and hot forging, workpiece temperature is most relevant factor and therefore must be carefully controlled at the exit of heating device. To avoid thermal changes in cold forging, special attention has to be paid to lubrication. It should be applied uniformly and persistently throughout entire forging process.
When designing manufacturing process often there are several ways that forging can be made. For precision forging the best sequence would be one in which minimum wears occurs in the finish die.

3. CONCLUSION

Forging is a money, time and material effective way of production parts with enhanced properties. But it is significantly complex process with many variables too. In order to minimize geometrical and dimensional errors of final part systematic investigations of input material, tool system, machine and process parameters are essential. In this paper some theoretical and practical guidelines to increase accuracy of forged part have been presented.

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