TECHNOLOGICAL IMPROVEMENT AND OPTIMIZATION IN MULTIPLE-CAVITY FORGING PROCESS WITH FINITE ELEMENT METHOD (FEM)

Ferenc TANCSICS, Tamás GERGYE, Dr. Ernő HALBRITTER

Scéchenyi István University, Györ, Hungary, tancsics@sze.hu

ABSTRACT

Forging is a technology frequently used in the production of vehicle parts. The shape and dimension of the blank and occasionally of the finished work piece are provided, and the mechanical properties of the base materials are improved by forging. In the production of vehicle parts competitiveness is becoming more and more important. Frequently, competitiveness can only be increased by making the product to strict deadlines, by improving the quality and by reducing the production costs.

These complex requirements can only be met by quicker, more exact and more reliable production planning. Our work is aimed at setting out an example for improvement, as well as at elaborating an optimization method for presenting the results gained in order to increase the potential to enter the markets. In improvement of mechanical properties the good grain flow free off folds is very important. A case of folds in grain and its elimination will be presented through an industrial task. In multiple-cavity forging process the blank has significant influence on how much force and work are required in forming. A blank which requires less work in forming is considered more favourable. In making comparisons it is required that various blanks have the same volume.

Various blanks were designed with Pro/Engineer software and the same volumes were provided by optimization restricted within the design software. By taking the blank areas into account, in restricted optimization we tried to find a solution how to realize gradual forming beside constant volume of various blanks. The optimization method we have elaborated will also be presented through an industrial task.

*Keywords**:** forging, gradual forming, blank.*

INTRODUCTION

Grain flow produced during the forging process follows the direction of material flow and, if everything goes well, the shape of the work piece. There is one important requirement: the direction of loading should be the same as the grain flow. Grain flow can be revealed by taking cross-sections with deep-etching. In our presentation, grain flow has also been revealed based on the results of FE simulation, where we had to develop the programs in *DEFORM* software.

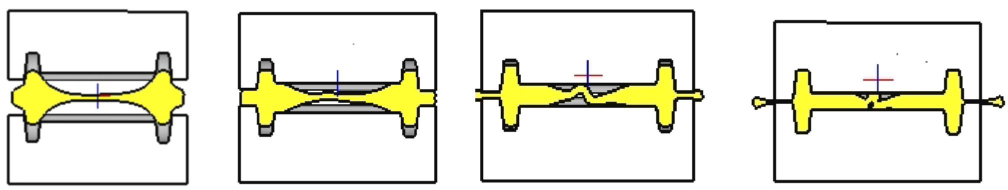


Fig.1 Fold and lap in die forging.

Actually, grain fold is an error in the flow of a material. The pictures in Fig. 1 show distortion, the folding in the work piece, how the so-called lap is produced in a wrongly designed die forging.
The lap on the finished work piece can often be detected visually, but any grain fold can only be detected by revealing the grain flow. Finite element software can successfully be applied to establish the reason for grain fold and moreover to eliminate the grain fold. In the field of volume forming, the most widely used purpose-oriented finite element systems are *DEFORM*, *SuperForm*, *Simufact* and *QForm*. The software clearly detects the location of the lap if it also occurs during simulation / Fig. 2 /.

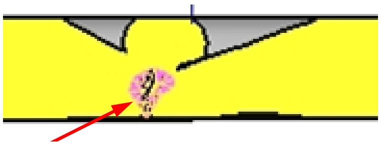


Fig.2 Indication of a lap with DEFORM software.

With finite element software, an error in the material flow can be concluded based on the direction and magnitude of the material flow velocity, too. Finite element software can serve as an effective means in detecting and eliminating the errors in the material flow, but only if the user of the software knows and recognizes the factors that have influence on material flow.

Factors influencing the material flow are as follows:

- Die geometry
- Properties, volume, geometry and heat distribution of the material to be formed
- Friction occurring at contact of the work piece to the die [4]
- Type and movement relation of the forming die

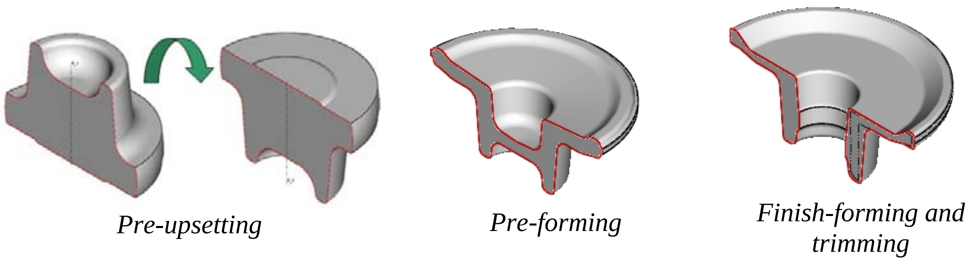


Fig.3 Intermediate parts of ring gear support.

In the forging plant of RÁBA Axle Ltd. the forging of the ring gear support is made in a multiple-cavity forging operation. The pictures in Fig. 3 show the shape of the work piece during forging, while a sectional view of the finishing tool is shown in Figure 4. On one side of the finished forging there is slight grain fold / Fig. 5 /.
By using the finite element simulation we were looking for the reason for the grain fold and for a means of eliminating it. It could be established that the material has everywhere filled up the cavity in front of the lower dead-point of the die, but after the cavity had been filled up significant excess of metal passed into the gutter with unfavourable material flow.

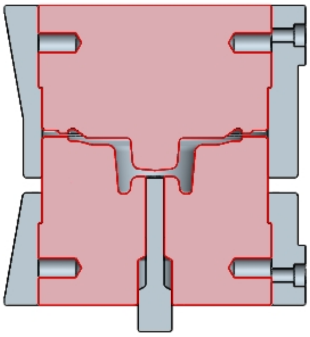


Fig. 4 Finish-forming tool.

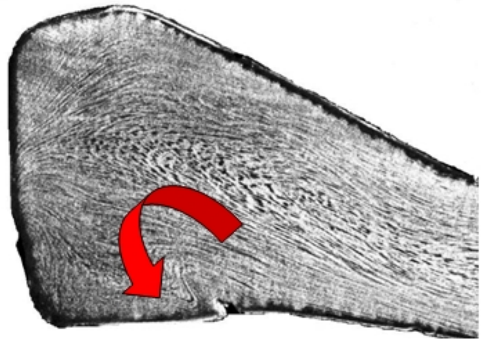


Fig. 5 Detection of grain fold with etching the cross-section on one side of the ring gear support.

Intensive material movement was detected in the direction of the parting line above the critical part, and in the surroundings of the section marked with the red arrow / Fig. 5 and 6 / there was a dead area or eddy current.

In our opinion, the dead area could be caused by the unfavourable location of the parting line and presumably by some significant friction caused by insufficient lubrication at the location in question. The eddy current of the material was also confirmed by the photograph of the velocity vectors taken at the junctions / Fig. 6 /.

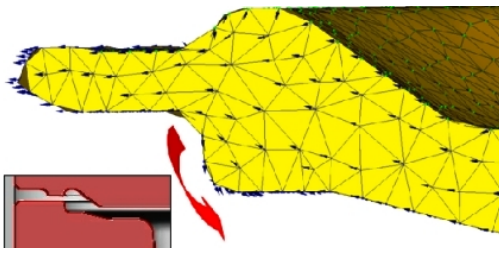


Fig.6 Velocity vectors of material flow.

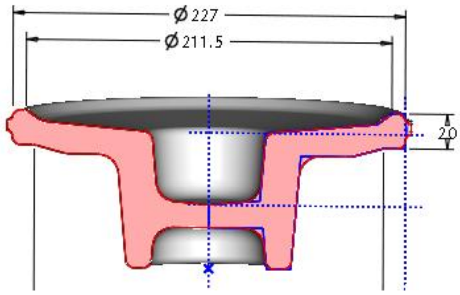


Fig.7 Selected blank dimensions / V= 999378 mm^3 A=123180 mm^2 /

As we know, the material flow at the forming surface of the stationary tool can only be tangential. If the tangential arrows change direction along the surface, the material will flow back at that location.

Flow back can be detected at the location marked with the red arrow in Fig. 6. Error in material flow has been eliminated partly by reducing the blank volume, and partly by improving the friction conditions at the critical locations. A solution had to be found to modify the blank dimensions, so that we get to a blank with the desired volume and shape. It could only be solved by changing several dimensions. Reference to dimensional changes in correct volume will be made under the next item. The change we implemented was successful, saving material and energy as well as tool-sparing at the same time [1].

PROVIDING A BLANK WITH THE CORRECT VOLUME

During the multiple-cavity die forging process the blank to be put into the finish-forming cavity has an influence on the grain flow of the forging and, also on the force and work required in forming. Within certain limitations, the blank geometry can freely be selected, but the consistency of the initial volume should be controlled in various situations. In the case of various blanks, constant volume can be provided with limited, extreme value calculation. The applicability of the limited extreme value calculation was methodically inspected with *Pro/Engineer* software [2]. Our understanding and experiences are summarized as follows.

In the case of parametric software, the geometrical model can be modified and the modified dimensions clearly define the new geometry and its volume. There is a functional relationship between the variable dimensions and the model volume. In *Pro/Engineer* software this functional relationship can only be handled if the function value is measured and a note taken on the measurement result.

Generally, blank geometry is characterized by several dimensions. From these dimensions – based on professional experience – we shall select those dimensions which are required to obtain various blank versions. In limited extreme value calculation *Pro/Engineer* searches for the extreme value maximum of the function created with volume measurement, by methodically changing the selected values, but only up to the point where the volume value which has been set as a limiting condition is reached. The value given as a limiting condition can be reached by the software in case of several dimensional combinations. From a professional point of view the most favourable one of the possible solutions has to be selected. Usually, it still remains a complicated task. A fitting solution can be facilitated with some tricks, but they can only be used under certain circumstances.

It frequently occurs that one blank is more regular than another one. A more regular blank is understood here, one whose area is less at a given volume. In such a case, the value of the modified area will also be specified as a limiting condition, in addition to the desired volume. The application is presented in the multiple-cavity die forging process of the ring gear support / pictures in Fig. 3 /.

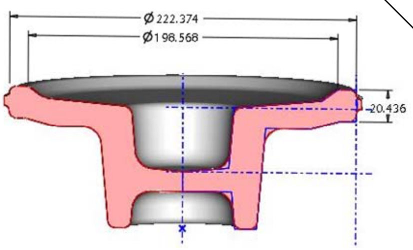
During finish-forming, the height of the work piece decreases while the diameters increase. In this particular task the blank diameters were very close to the diameters of the finished work piece.

The following figure shows the dimensions to be changed, the values of the blank volume and area. When a change was made, the area was taken as 120,000 mm^2. The volume of the modified blank was practically the same as the original volume.

The magnitude of the geometrical change can be influenced by the minimum or maximum of the values that are permitted to be changed. This limited optimization method was also used in minimizing the total forming work required in multiple-cavity die forging.

Limited extreme value calculation

- *Looking for the extreme value maximum or minimum of the function created by measurements*
- *As a limiting condition, the desired volume and area are specified.*
- *Variable dimensions are defined and their permitted intervals are specified.*



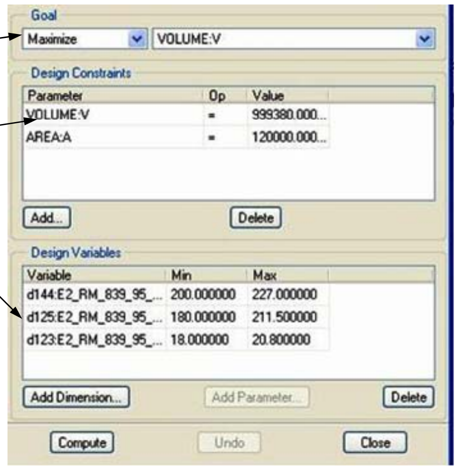


Fig.8 Modified blank dimensions / V= 999380 mm^3 A=119 999 mm^2 /.

MINIMIZING THE WORK REQUIRED IN FORMING

Recently, there has been a significant increase in the price of forged work pieces / Fig. 9 / [3].

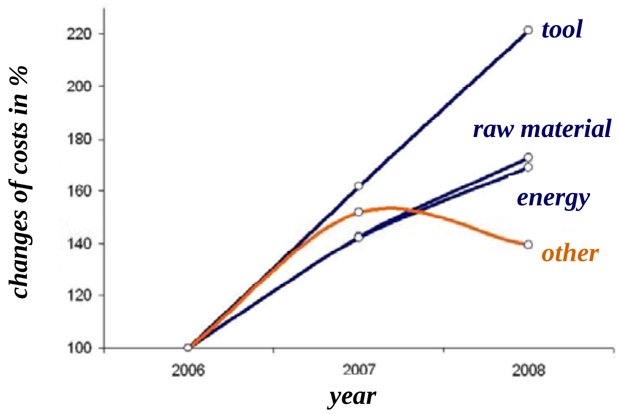
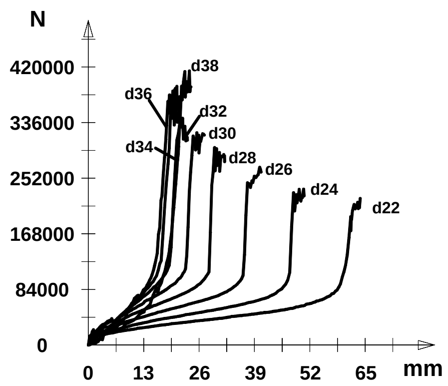


Fig.9 Changes of production cost by components for 1kg forging in the recent years.

This could be explained mainly by higher technical requirements and by the increase in energy costs and material prices / Fig. 9 /. Being familiar with the trends, cost reduction is a very important task for maintaining competitiveness.

In the multiple-cavity die forging process, beside the grain flow of the finished forging, the blank to be put into the finish-forming cavity has an influence on the force and work required in finish-

forming and on the lifetime of the die, too. A simple example will show how the work required in forming could be minimized by optimization of the blank.
In this simple example the blank was cut from a cylindrical bar stock, and then the cut bar was forged into a ball (sphere) of R=20 mm radius in a die.
Diameters (d = 22, 24, 26, 28, 30, 32, 34, 36, 38) of the initial bars were selected according to the commercial avaliablity. The length of the cut bar was determined by volume consistency. Simulation of forging the balls was completed with a geometrical model of the blanks, using the finite element method.
In simulation inspections we plotted the diagram of force vs. stroke / trim thickness is 2mm with an open gutter, initial cylinder volume is 105% of the ball volume, initial temperature of forming is T=1000°C, the Coulomb friction coefficient is μ=0.3, temperature of dies is 200°C, die speed is 250 mm/s, material is Cr4 as per DIN-41 – Fig. 10 /.



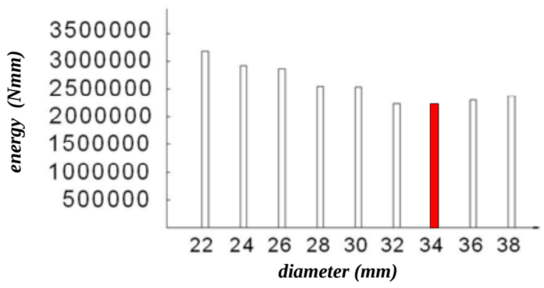
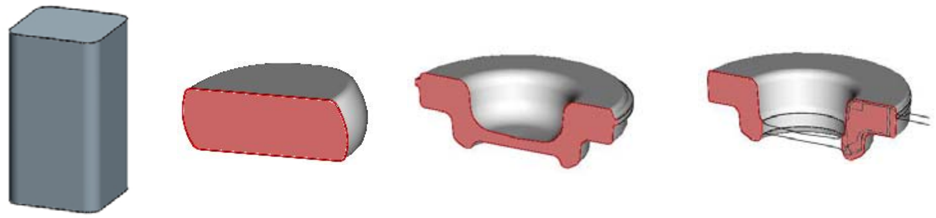


Fig.10 Diagram of force vs. stroke with blanks of various diameters and constant volume.

Fig.11 Work required in forming blanks of various diameters and constant volume.

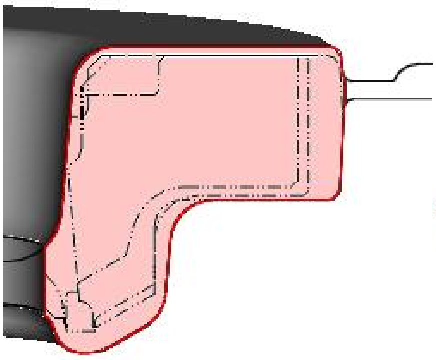
The work required in forming was determined by the area below the curve, based on the diagram of force vs. stroke.
In Fig. 11 you can observe that the work required in forming has an extreme value minimum in this particular task. Of course, it is not always so simple to minimize the work required in forming, but the concept can be utilized in many cases. A criterion of applicability is that the geometrical model of the blanks should be made with constant volume in case of sophisticated parts too.
The previous item represented how this can be achieved. Further steps in the inspection are possible using the capabilities of finite element software (e.g.: Deform, SuperForm, Simufact). The applicability of this method in practice has been inspected in multiple-cavity forging of the flange stub, taking the whole forming process into account [3].



Starting material *Pre-upsetting* *Pre-forming* *Forging*

Fig.12 Multiple-cavity forging of flange stub.

In this task we had to solve unification of forgings that have similar geometries.



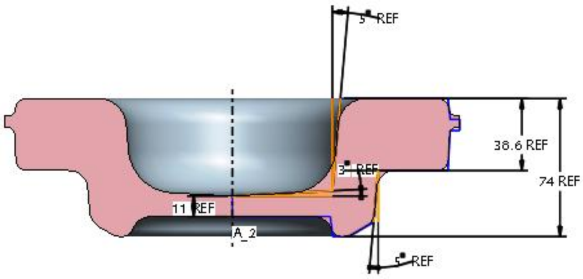


Fig.13 Sections of flange stubs with different geometries.

Fig.14 Changed angles and / or heights of the basic body.

Three dimensions (H= 60, 65, 70 mm) were selected as the upset height of the initial parts. At the end of upsetting, the pre-upset parts were put into the pre-forming cavity. The properties of the parts put into the pre-forming cavity were inherited. Inherited properties are temperature, mesh density, material grade, specifications given as boundary conditions and, of course, geometry.

Several versions of pre-formed geometry have been inspected. Blanks of constant volume and various geometries were provided with limited extreme value calculations, by using *Pro/Engineer* software. In limited extreme value calculations we started from a volume-insufficient basic body. The basic body was modified – volume of the basic body was increased as desired – by changing draft angles and/or some of the heights / Fig. 14 /.

When the desired volume was provided by changing the indicated draft angles only, the original angles in Fig. 14 were changed to 5.79º, 8.94º and 6.87º from left to right. When the desired volume was provided by changing the indicated heights only, the original heights in Fig. 14 were changed to 75.69, 39.68 and 11.03 mm.

When changing both the angles and the heights, the resultant values are 75.54 mm, 39.58 mm, 11.03 mm, 3.11°, 5.44°, 5.21°.

The finite element simulation was primarily aimed at reducing and optimizing the work required in the whole forming process. In the cases we have inspected, the smallest value of required work was gained with the blank upset to 65 mm, and changed both in draft angle and in height / marked with “both” in Fig. 15 / [3].

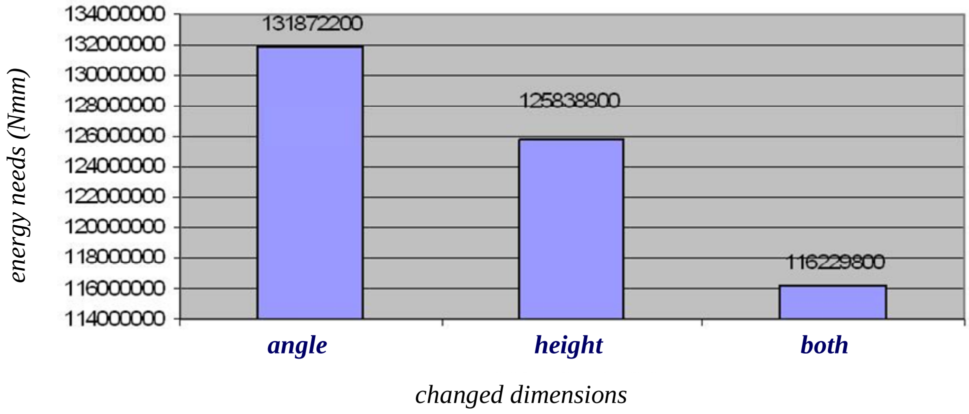


Fig.15 Work required in forming various blanks pre-upset to 65mm.

The force required in forming has separately been inspected as it was limited by the available machine fleet. Out of the blanks upset to 65 mm, the blank whose base body was changed geometrically both in angles and in height required the least force in forming .

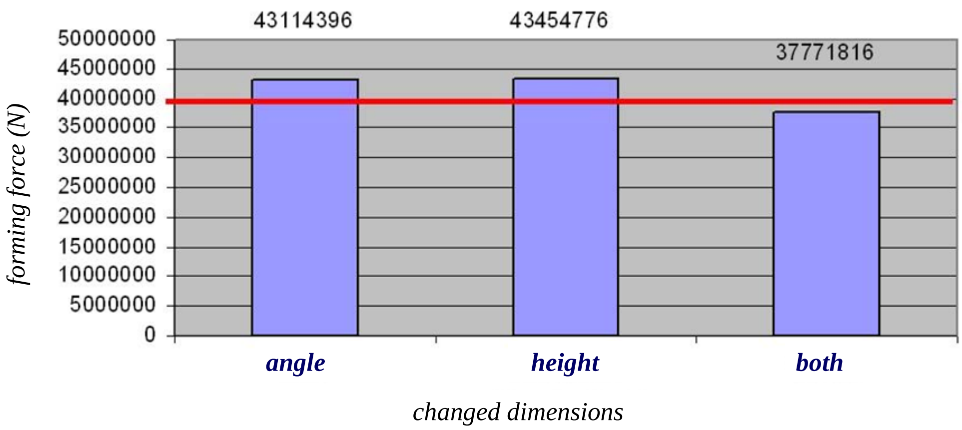


Fig.16 Force required in forming various blanks pre-upset to 65 mm.

Fig. 16 shows that not every blank met the force limit (40MN) indicated in red. In forging the flange stub we have inspected the distribution of the strain and grain flow, too. In these inspections, the whole forming process was taken as a basis.

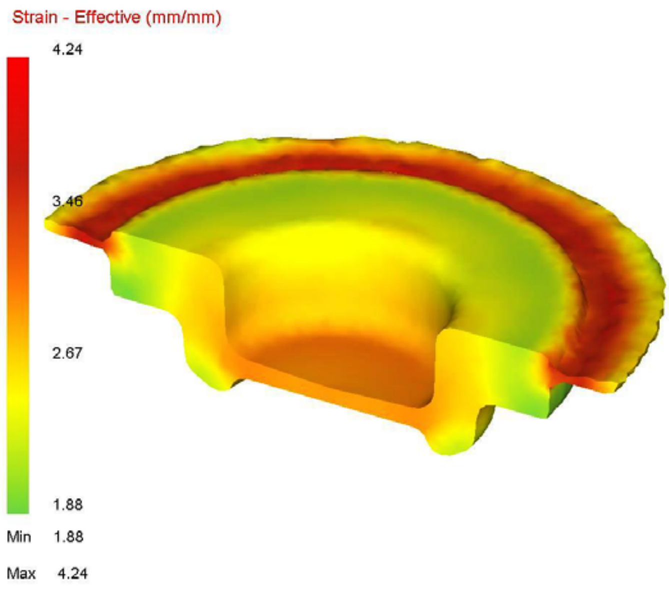


Fig.17 Strain distribution in finish-forming the flange stub.

Trial production of unified forging has been completed / Fig. 18 /.

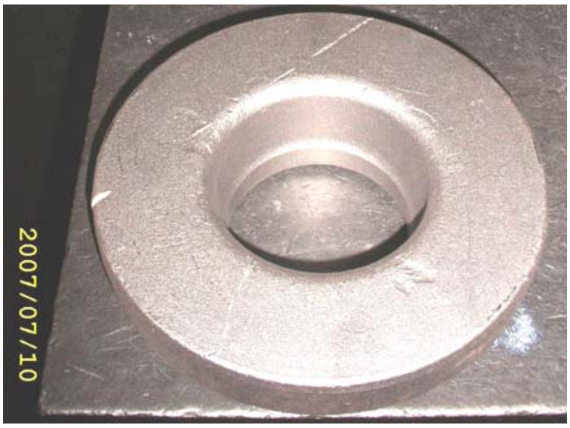


Fig.18 Flange stub from trial production.

CONCLUSIONS

Recently, 3D geometrical modelling of the parts, and the application of geometrical models in finite element inspections are more and more frequently used. Further progress can be provided by elaborating some methods that better utilize or sum up the capabilities of the applied software.
During our inspections we have inspected work required in the whole forming process with *DEFORM* finite element software on various blanks, and the constant volume of the blanks was

provided with multivariable limited extreme-value calculation, applying *Pro/Engineer* software. For gradual forming, the magnitude of the area of the intermediate shapes was also taken into account in limited extreme-value calculations.

While applying the elaborated method in multiple-cavity forging of the flange stub, favourable force and work demands required in forming, as well as proper grain flow, have been achieved.

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