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APPLICATION OF PHYSICAL AND MATHEMATICAL MODELLING TO ANALYSIS OF DIFFERENT FORGING PROCESSES OF CONSTANT VELOCITY JOINT BODY

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Abstract

The aim of this research was to compare the two forging processes of CV joint body. They differ both the shape of the die and initial preform dimensions. The comparison was performed on the basis of physical and numerical simulation. The material characteristics of steel UC1 were determined by plastometric tests, physical modelling of the processes were made using filia wax and numerical simulations were run by means of the FEM based SuperForm 2005 software. The simulations provide relevant information to design analysed process. Forging processes of CV joint body using arched dies is better than conical dies as regards more uniform flow of material, lower pressures in tools and forging forces.

Key words: CV joint body, numerical simulation, physical modelling, die shape, strain distribution

1. INTRODUCTION

Numerical and physical modelling methods contribute to the development of new technologies for manufacturing products with complicated shapes, especially for the automotive industry, e.g. cold forging of gear wheels or constant velocity joint body forging (Meidert et al., 1992).

Constant velocity joints (CV or homokinetic joints) are irreplaceable car components. They transmit torque from the gearbox to the front wheels (figure 1). Their production has been steadily increasing in recent years. A CV joint consists of a spider, a race and a casing. A casing is most difficult to manufacture because of its irregular shape. Currently cold and hot multi-operation forging in closed dies with a complex deformation scheme (direct and indirect extrusion) is used in mass production (Vazquez & Altan, 2000; Vazquez et al., 1996).

The shape of the die mainly determines the forging process. Currently three types of die profiles: streamlined, arched and conical are generally used. During direct extrusion the streamlined die profile ensures the maximum reduction of: redundant strains, extrusion forces and cross-sectional nonuniformity. The problem, however, is in determining and making the proper profile therefore often an simplified arched or conical profile is used. Both the solutions have their strong and weak points. Nevertheless, they can ensure good extrusion parameters and good product quality and they are easy to produce.

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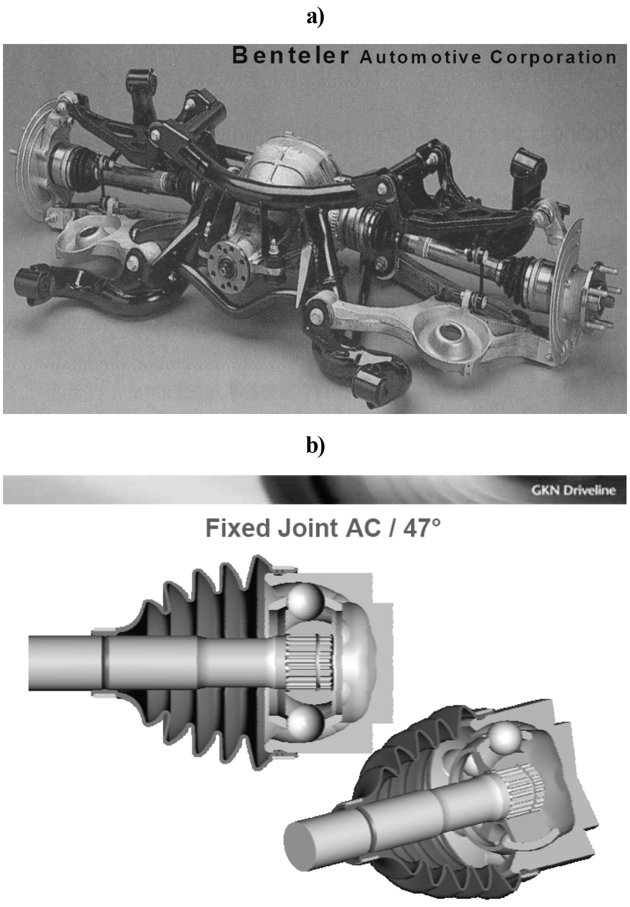

Fig. 1. a) Car axle, b) CV joint (www.gkn.automotive.com).

Thus for each CV joint body one should determine the optimum die shape whereby the forces can be significantly lowered, the material flow can be improved or/and the tool wear can be reduced.

The aim of this research was to compare the two forging processes of CV joint body. They differ both the shape of the die and initial preform dimensions.

2. INVESTIGATIVE METHODOLOGY

The forging of the CV joint body consists of several operations. The first two hot forging operations were analysed in the paper.

In the first process the arched die and preform with diameter of 55 mm and height of 76.45 mm were used and in the second process the conical die and preform with diameter of 50 mm and height of 91.75 mm were applied. A schematic of the tools and preforms is shown in figure 2.

In order to reach the objective of research the following tasks had to be carried out:

- **plastometric tests** in which stress – strain relationships needed for mathematical modelling and for selecting a model material for physical modeling were determined,

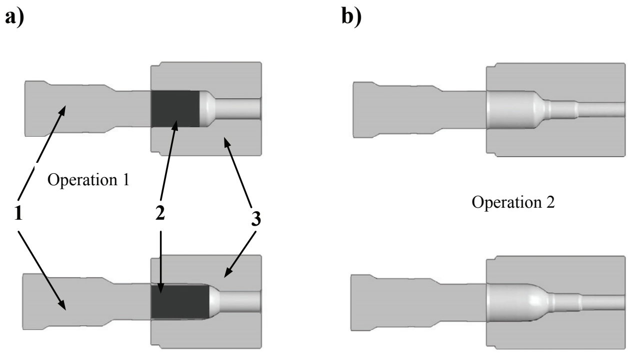

Fig. 2. Schematic of tools used in investigation of operations 1 and 2: a) conical die, b) arched die, 1 – punches, 2 – preforms, 3 – dies.

- **physical modelling** – physical modeling was made using filia wax.
- **numerical modelling** – thermomechanical models of the forging processes were carried out and forging forces, strain and temperature distributions and tool pressures were determined.

2.1. Plastometric tests

Strain hardening curves of steel UC1 at three temperatures: 650, 900 and 1000°C and two strain rates: 0.1 and 10 s^{-1} (the conditions were based on a real forging process) were determined by plastometric torsion tests. The curves are shown in figure 3.

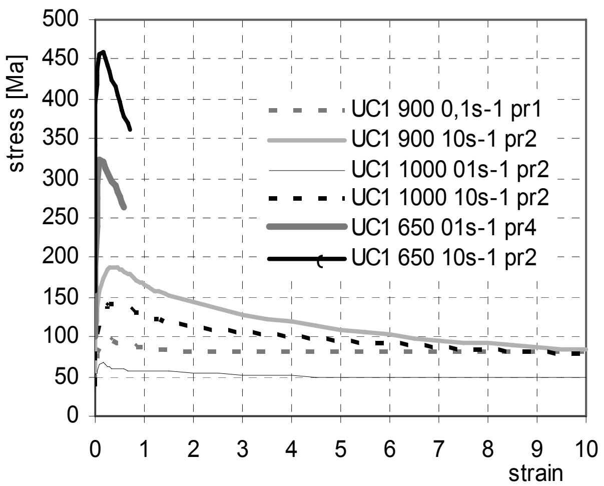

Fig. 3. Stress – strain relationships obtained from torsion tests.

3. PHYSICAL MODELLING

In order to properly plan and carry out physical modelling experiments one must select a proper modelling material simulating the behaviour of the real material. According to the basic physical modelling assumptions, the modelling material should be characterized by a much lower (100-1000 times) flow stress level and satisfy several conditions of similarity to the real material, such as: similarity in the plastic ranges, geometric and frictional similarity. The most important is similarity in the plastic range. This means that a modelling material should have the stress – strain curve shape as near as possible to that of the real material.

The steel tools shown in figure 4 were used in the physical modelling. The individual die halves were joined using two tightening bands so that they could be opened to examine the flow of the material.

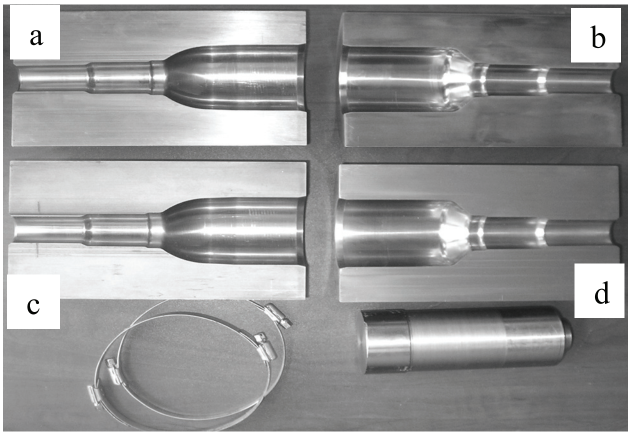

Fig. 4. *Tools for 2 operations: a) arched dies , b) conical dies, c) tightening bands, d) punch.*

In order to make it possible to observe the material flow, specimens in the form of two cylinder halves with marked straight perpendicular to their axes lines spaced every 5 mm on the symmetry surface (figure 5) were used in the physical model. All the tests were conducted at a temperature of 22 °C.

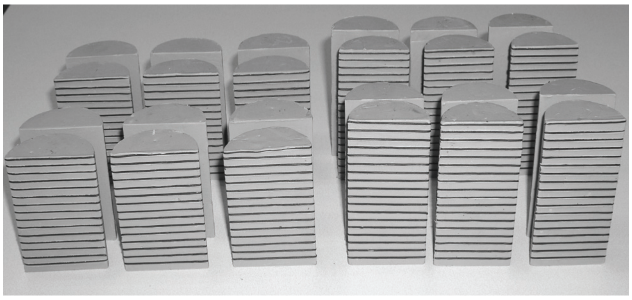

Fig. 5. *Sets of model material specimens with initial dimensions: diameter d_1=50mm and height h_1=76.45 (15 flow lines) and d_2=55mm and h_2=91.75 (18 flow lines) for conical and arched dies respectively.*

3.1. Similarity condition

In order to match model materials to the real material (steel UC1) different wax mixtures were tested and a *database of model materials* was used (Hawryluk, 2006). A preliminary qualitative analysis was made to select model materials best matching the real material flow curves. Because in the forging process the most operations were performed at 1000 °C and with strain rate of 10^{-1} therefore the stress – strain curve of model material should be matched to the curve of real material just at this conditions. The final choice was made using a new plastic similarity condition (Hawryluk, 2006). In accordance with the condition, similarity coefficients *t* and scale coefficient *C* for the selected model materials were calculated. Coefficient *t* is a dimensionless quantity which allows one to simply and quickly determine the degree of fit of the model material stress – strain curve to the real material curve. The coefficient is equal to zero at the ideal fit of the two curves. The chemical composition, scale coefficient *C* and similarity coefficient *t* for the particular mixtures are shown in table 1. The stress – strain curves for the filia wax and steel UC1 are shown in figure 6.

Table. 1. *Coefficients t, C and chemical composition of materials used for modelling forging of steel UC1*

Chemical composition	*t*	*C*
filia + 5% paraffin + 5 % lanolin	0.06	269.3
filia + 10 % paraffin + 10 % lanolin	0.09	307
filia + 5% paraffin	0.024	285
filia + 5% Vaseline + 5 % lanolin	0.035	344.6
filia	0.023	366.7

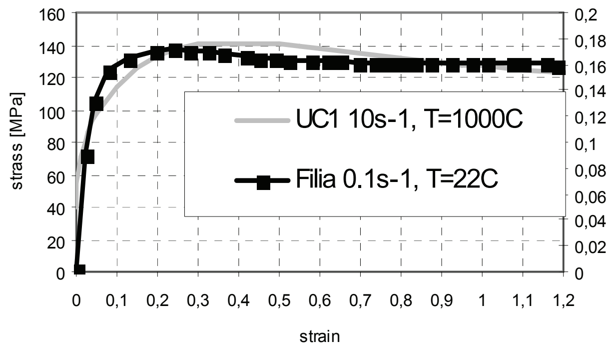

Fig. 6. *Flow stress versus strain for filia and steel UC1.*

According to the similarity coefficient values given in table 1, the stress – strain curve of filia wax is best fitted to the UC1 flow curve.

The geometric similarity condition has a scale of 1:1. Because in analyzed processes the high plastic strains occur the elastic strains could be neglected. Fulfillment of frictional similarity between the real and model process was one of the largest problem. It was impossible to measure friction coefficient in real process, therefore the simple experiments – ring test of real and model material were performed and on the basis of this experiments the technical vaseline as lubricant in physical modeling was applied.

3.2. Model material test results

Figure 7 shows the deformed forgings in physical modelling with flow lines for a) arched dies and b) conical dies. Macroscopic examination revealed differences in the material flow for both tools. When the arched dies and a smaller diameter preforms are used, the material flow in the specimen's cross section is more uniform than in the case of the conical tools. It is confirmed by lower bending of the flow line for arched die than for conical die (l_a<l_b).

smaller value of friction coefficient between the knockouts and the deformable material was accepted due to the short contact time of these elements.

Table 2. *Initial temperatures of tools and preforms.*

	Conical tools	Arched tools
	Initial temperature [°C]	
Temperature of preform	920	920
Die operations 1, 2	140	140
Pusher operations 1, 2	140	140
Punch operation 1	200	200
Punch operation 2	220	220

Figure 8 shows a scheme of process for the first operation. In the next operations the boundary conditions between deformed material and the punches

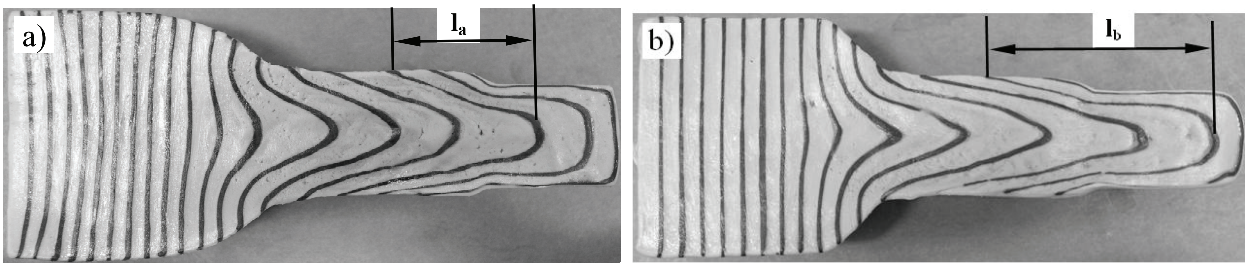

Fig. 7. *Comparison of model material flow in: a) arched tools, b) conical tools.*

4. NUMERICAL MODELLING

Simulations of multioperation forging by means of deformable tools (punches and dies) for the thermomechanical model in an axisymmetrical strain state were run using the MSC SuperForm2005 software.

Boundary conditions close to the ones prevailing in the real process were adopted. Young's modulus (versus temperature) for the preform was taken from the SuperForm2005 software library for material C60 (it can not be possible to determine such relationship for steel UC1 but the chemical composition and mechanical properties of UC1 and C60 are very similar) and the flow-stress versus strain rate and temperature curves for steel UC1 obtained from the plastometric tests were used (in numerical form). Automatic finite element mesh rearrangement during computations was applied to the preform. The deformable tools were made from X40Cr13 steel, the thermal and mechanical properties of this material were also taken from the SuperForm2005 software library. The SHEAR friction model and the coefficients of friction: 0.2 between the punches and the deformable material and 0.1 between the knockouts and the deformable material were adopted. The

and the dies were defined in the same way. Table 2 shows the initial temperatures of the used tools and preforms at successive operation. These temperatures were determined on the basis of temperature distribution in real experiment.

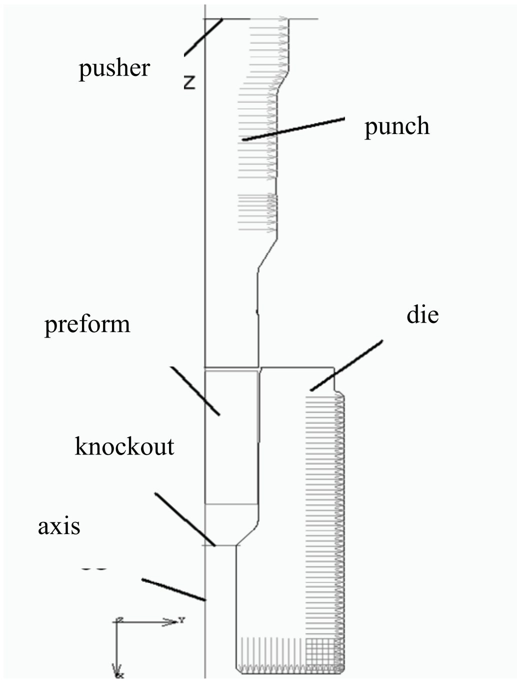

Fig. 8. *Scheme of process for first operation (arrows indicate directions in which displacements were blocked by punch and die).*

In MSC SuperForm2005 software the kind of an applied press must be determined in order to simulate better the real process. According to real press a crank press with a inside crank of 400 mm and a 2520 mm long connecting-rod was adopted. A crank press speed of 24 rpm (one revolution took 2.5 s) was assumed. In this case the position and velocity of punch depend on the angular position of the press crankshaft.

4.1. Forging force

Figure 9 illustrates the differences in the magnitude of value and course of the forces for all the operations, calculated by FEM, as a function of the distance of the punch from the press's lower dead centre. The punch travel distance needed to upset the input material in case of the arched die is clearly longer due to the fact that the input material for the first operation performed using the set of arched tools is more slender, but the maximum force level is lower than for the conical dies. The first operation in both cases has to ensure good alignment of preform for the second operation (this affects product quality).

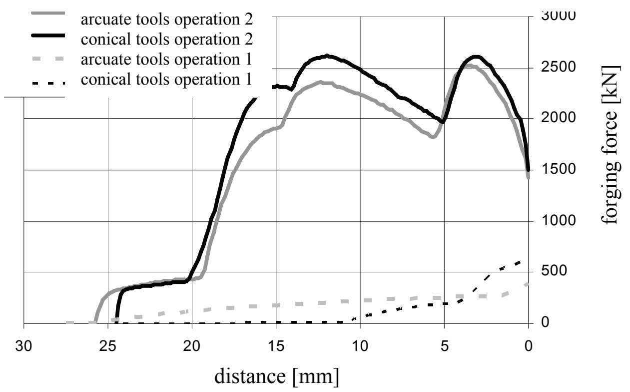

Fig. 9. *Forces on punches in successive operations versus punch distance from press lower dead centre.*

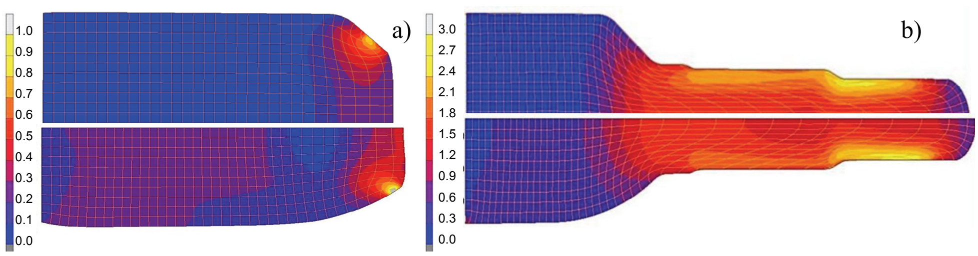

Fig. 10. *Plastic strain distribution after a) first and b) second operation.*

In the second operation the preform underwent large deformations due to a large reduction in the diameter. The maximum force level in the second operation for the arched tools is about 80 kN lower than for the conical dies.

4.2. Strain distributions

Plastic strain distributions at the end of each operation with plotted material flow lines are shown in figure. 10. The same scale of strain values was used in each operation for better comparison.

The plastic strain distributions differ considerably due to shape of the die and dimensions of initial material. In spite of lager deformation in first operation for arched die smaller total strains were obtained after second operation than for conical die.

4.3. Temperature distributions

The temperature distribution was determined by numerical modelling with initial temperature of tools and preform presented in table 1. In both cases the initial temperature of the preforms was 920°C. Then the specimens were cooled for 2 s at a temperature of 50°C prior to forging. It caused decrease in temperature about 30°C in the outer layers, which might have significantly affected the forging force and strain deformation uniformity.

In the first operation the change of temperature was slight. The heat is mainly transferred to the tools. In case of the forging made in the conical tools a contact of deformed material with tools lasted through almost the entire deformation and decrease in the temperature was nearly uniform in external regions of preform. In case of the arched tools (where preform has smaller diameter), the material was not in contact with the tools over the whole cylindrical surface and so a smaller decrease in temperature than for the conical dies was recorded (figure 11a).

In the second operation the material underwent large plastic deformations whereby temperature considerably increased (by about 60°C) in the middle part of the forging. The lowest temperature occurred at places of contact with the punches, where the material is not subject to large plastic deformations and heat is rapidly transferred to the tools (the punch temperature 220°C). At places of contact with the dies high friction generates much heat which compensates the transfer of heat to the tools (figure 11b).

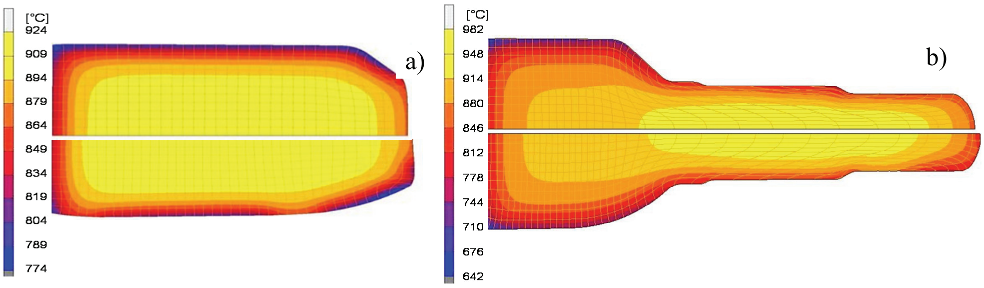

Fig. 11. Temperature distribution for preforms forged in conical and arched dies after: a) operation 1, b) operation 2.

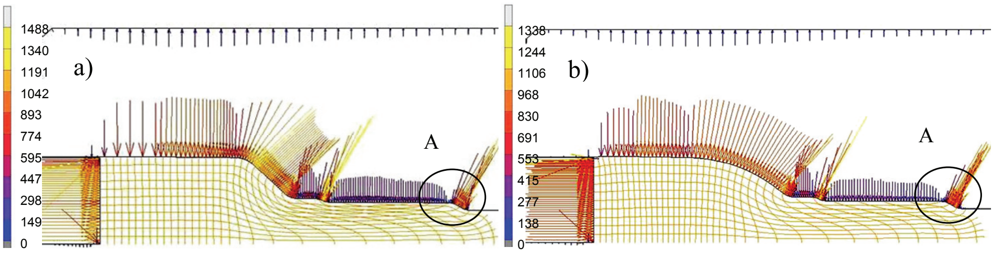

Fig. 12. Vector distribution of unit pressures on a) conical and b)arched tools at press angle of 173°.

4.4. Unit pressures

Figure 12 shows the distribution of unit pressures on dies for angular position of the press crankshaft of 173°. (For applied crank press the position of punch depends on the angular position of the press crankshaft). During both the first and second operation higher pressures were recorded in the case of the conical dies.

During the second operation on third reduction step (region A in figure 12) unit pressures were found to be the highest - (2180 MPa) for the conical and (2050 MPa) – for the arched die. This high pressure confirms observation of large wear of tools in this region in real process.

5. CONCLUSIONS

1) The multioperation forging of the CV joint body was carried out at the preform initial temperature of 920°C. In the course of the process the temperature inside the forging increases while in the outer layers decreases due to heat transfer to tools.
2) The flow of the material was more uniform in the arched dies than in the conical ones.
3) Lower forces on the punch were obtained for the arched dies.
4) The concentration of unit pressures on the radius of the first and second step of the arched and conical dies can cause increased wear in these regions.
5) Forging processes of CV joint body using arched dies is better than conical dies as regards more uniform flow of material, lower forging forces and pressures in tools.

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Web page: www.gkn.automotive.com

ZASTOSOWANIE MODELOWANIA FIZYCZNEGO I MATEMATYCZNEGO DO ANALIZY PROCESÓW KUCIA PRZEGUBÓW HOMOKINETYCZNYCH

Streszczenie

Celem pracy było porównanie dwóch procesów kucia przegubów homokinetycznych. Procesy te różniły się zarówno kształtem matrycy jak i wymiarami przedkuwek. Charakterystyki materiałowe zostały wyznaczone w próbie skręcania, na ich podstawie jako materiał modelowy wybrano syntetyczny wosk filia. Modelowanie matematyczne wykonano za pomocą programu SuperForm2005. Przeprowadzone badania wykazały, że zastosowanie matryc łukowych pozwala uzyskać mniejsze naciski na narzędziach oraz równomierniejsze płyniecie materiału niż dla matryc stożkowych.

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