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# MODELLING OF THE FORGING PROCESS OF A CONICAL TOOTHED WHEEL ON A CRANK PRESS

*В статье представлены результаты численного анализа процесса ковки конического зубчатого колеса, которое формируется за три перехода: начальная осадка, предварительное формирование и заключительное создание зубьев. Численный анализ процесса проводился с помощью коммерческого программного обеспечения DEFORM-3D, основанного на методе конечных элементов (МКЭ). Моделирование было сделано в трехмерном пространстве напряжений. В результате были определены следующие данные: напряжения, деформации, температура и распределение давлений на контактной поверхности, а также возможность изготовления зубчатых колес методом объемной штамповки. В представленной статье также рассмотрено влияние изменения объема формирующего инструмента на усилие деформирования. Анализ результатов численного исследования процесса ковки конического зубчатого колеса подтверждает возможность производства венцов конических зубчатых колес методом объемной штамповки.*

*У статті представлені результати чисельного аналізу процесу кування конічного зубчатого колеса, яке формується за три переходи: первинне осаджування, попереднє формування і кінцеве створення зубців. Чисельний аналіз процесу проводився за допомогою комерційного програмного забезпечення DEFORM-3D, яке базується на методі скінченних елементів (МСЕ). Моделювання було виконано у тривимірному просторі напружень. В результаті були визначені наступні дані: напруження, деформації, температура та розподіл тиску на контактній поверхні, а також можливість виготовлення конічних зубчатих колес методом об'ємного штампування. У представленій статті також розглянуто вплив зміни об'єму формуючого інструменту на зусилля деформування. Аналіз результатів чисельного дослідження процесу кування конічного зубчатого колеса підтверджує можливість виробництва вінця конічного зубчатого колеса методом об'ємного штампування.*

**Introduction.**

Toothed wheels have a wide application in various driving mechanisms. Due to their function in machines, they have to fulfill strict requirements. Increasing of their resistance and durability is realized in various ways. It is most often reached by application of better materials and appropriate thermo - chemical treatment. The easiest and the cheapest is, however, appropriate forming of the product internal structure due to metal forming. At present, in majority of cases toothed wheels semi-finished products are made by means of forging, yet toothing is made by means of machining [1]. The implementation of metal forming processes for manufacturing of toothed wheels semi-finished products with formed toothing lowers considerably numbers of operations needed for their manufacturing and lowers manufacturing costs.

In the case of agricultural machines drive, conveyors drive and other devices drive, toothed wheels can be manufactured with finally formed toothing, without allowances necessary for machining. However, in the case of precise high-speed mechanisms, additional machining with allowance usage is needed. In both cases, metal forming of teeth enlarges their static and fatigue resistance and increases wear resistance.

**Forming processes of toothed wheels applied in industry.**

Toothed wheels belong to elements of complicated shapes, which results in technological difficulties during their manufacturing. The application of toothing forging is of great importance in the case of conical wheels manufacturing. Machining of such a type of toothing requires the usage of complicated and expensive machines.

At present, in majority of countries, metal forming processes of toothed wheels are applied. In Poland, in Metal Forming Institute in Poznań, the technology of conical toothed wheels forging of final geometry [2, 3] was worked out. This process is realized at the forging crank press MAXI. Initially machined semi-finished products of shape close to the forging outline (Fig. 1) are used for forging.

The forging with toothing is finally formed in one operation, during one stroke of the press, without additional sizing operations. Next, the flash, side surface, head surfaces ant the hole undergo machining. The application of machined billet allows for quite precise and repeated retaining of its volume, due to which forming forces can be reduced.

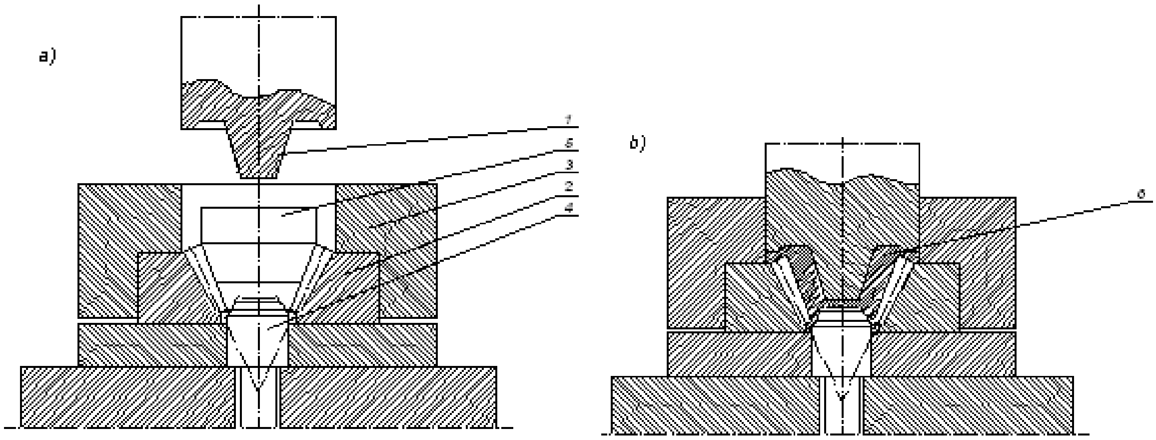
Research works were done at the Department of Computer Modelling and Metal Forming at Lublin University of Technology, which aimed at working out the technology of forging in hot conditions of conical toothed wheels from the formed preform.

The important issue during metal forming in hot conditions is the appropriate choice of scope of material heating temperatures. In the case of toothed wheels forgings it is advisable to use high forging temperature 1100 – 1250°C [4]. In such a case, it is necessary to reduce the time of contact of metal and tools. Moreover, during designing, dimensional changes resulting from thermal expansion of tools and products should be considered. This is especially important at forging of wheels without allowance for machining. It is also indispensable to apply heating without scale.

**Numerical analysis of the forging process of conical toothed wheel on the crank press.**

This paper presents results of theoretical analysis made on the basis of finite element method (FEM) of the forging process of conical toothed wheel with straight teeth of module m=5mm and number of teeth z=17 according to Fig. 2.

Numerical analysis of the forming process of the conical wheel together with toothing was conducted for forging in hot conditions in three impressions (during three strokes of the press slide).




*a* *b*

**Fig. 1. Schema of the forging process of conical toothed wheel according to the method worked out in INOP: a) the beginning of the process, b) the end of the process; 1-a punch, 2- die insert 3-mounting, 4-pusher's mandrel 5-billet formed mechanically 6-finished forging of the wheel [2]**

At the first stage of forging, the initial billet upsetting between tools flat planes took place; at the second stage, preform in initial impression was formed; at the third stage, forging of toothed wheel rim in finishing impression was made.

Bars with diameters $\phi$ 55 mm and length l = 90 + 0,5 mm of type 16CrMo4 were used as billet. It was assumed in calculations that the process was realized at the forging crank press of pressure 16MN and stroke 280mm. The forging of toothed wheel had initially formed holes with a web in the middle part. The toothing was to have allowances for finishing machining, due to which it was possible to obtain products of high precision. It was assumed that the billet would have parallel head surfaces and its volume would be precisely stated.

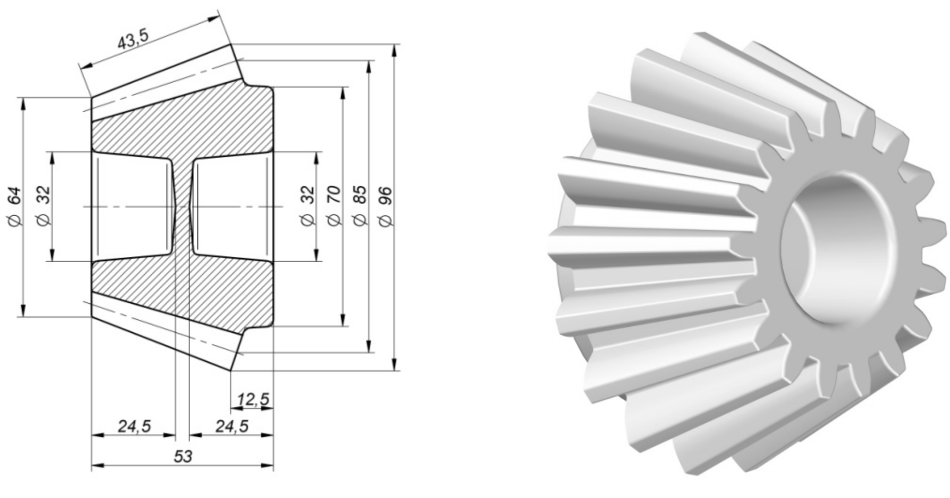
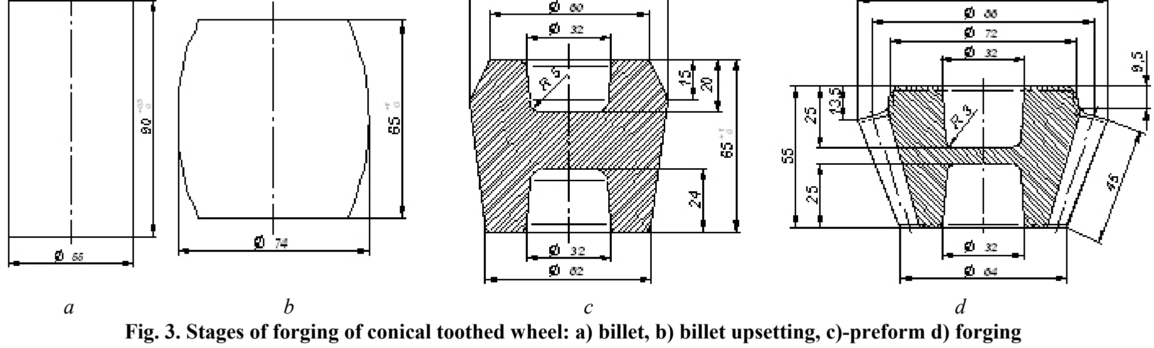



**Fig. 2. Drawing and forging model of conical toothed wheel**

Such a prepared billet of the initial length l=90mm and height h=65mm underwent upsetting between tools flat planes. The further stage consisted of forging in the initial impression, and next in the finishing impression, according to the schema presented in Fig. 3.



*a* *b* *c* *d*

**Fig. 3. Stages of forging of conical toothed wheel: a) billet, b) billet upsetting, c)-preform d) forging**

Semi-finished product after upsetting was placed in the impression, where punching and external outline of the preform forming took place. At the last stage, final forming of the toothed wheel forging together with toothing was present. The obtained forging had in the central part a web of the thickness about 6mm.

It was assumed that the time of one full stroke was 0.67s. In numerical calculations, material model of steel 16CrMo4 from the software DEFORM-3D data was used. It was assumed that the billet was heated to the temperature 1150°C ,yet, the temperature of tools during the process was constant and equal 250°C. Friction factor at billet-tool surface of contact was m=0.4, coefficient of heat exchange between the tool and material was 10kW/$m^2$K, and between the material ant the environment-0,2 kW/$m^2$K.

During upsetting the billet temperature was within the upper scope (1150 $^{o}$C),only at surfaces of contact with tools its lowering was observed to about 900$^{o}$C. During moving the semi-finished product to the next impression the temperature was leveled within the scope 1130 – 1150 $^{o}$C.

The force necessary for billet upsetting was relatively small and equal about 350kN. The preform upset at the first stage together with the distributions of strains and temperatures was imported to the next stage of simulation. Other conditions of the process were assumed as in the upsetting operation. Fig. 5 presents distributions of strains in the formed preform, depending on the process advancement.

It should be noticed that the material total plasticity took place only at the last stage of the forging, when the material fulfilled almost all the impression. The impression was designed in such a way that metal during forging did not touch the tools walls in the neutral plane Fig. 4 and Fig. 5. Because of that, the preform without flash could be directly moved to the last impression Fig. 6. Stresses in the cross section of the preform did not exceed 100 MPa, they were larger only in the punching mandrels area, reaching up to 150MPa, which was the result of intensive material cooling in this area leading to the increase of forming resistance.

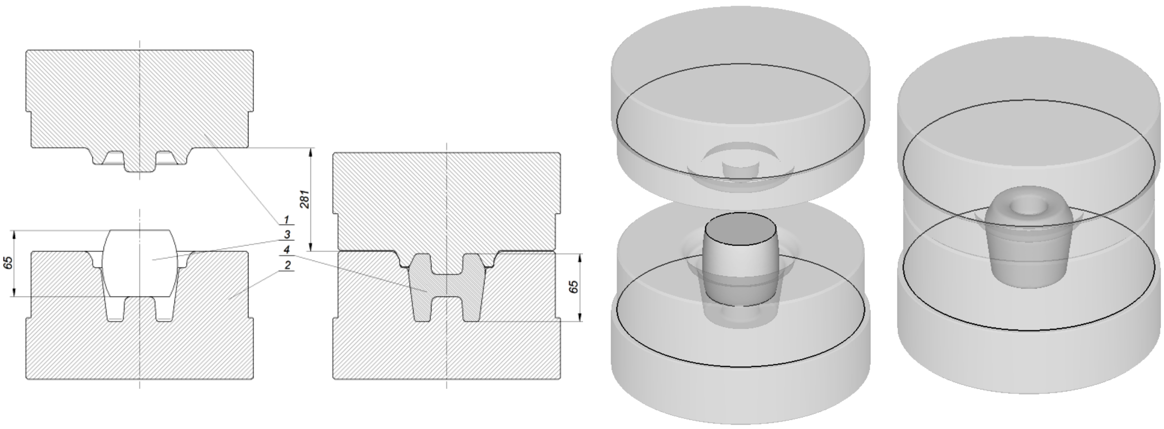



**Fig. 4. Geometrical model of initial forging of toothed wheel preform (description in the paper)**

The largest decrease of the temperature up to about 850 $^{o}$C was noticed in the web area, where tools contacted the formed metal longer. However, on the other surfaces of contact between preform and dies, a relatively small cooling appeared up to 1020 - 1050$^{o}$C.

During placing the preform into the finishing impression, the temperature stabilized at the level 1100$^{o}$C, which guaranteed retaining good plastic properties of the formed metal in the last impression. At the final stage of this stage of the process, the force reached 850kN.

Such a small value of force results from the fact that in the forging of preform, there was no stage of striking and squeezing of the material which is present at the initial stages of typical die forging processes.

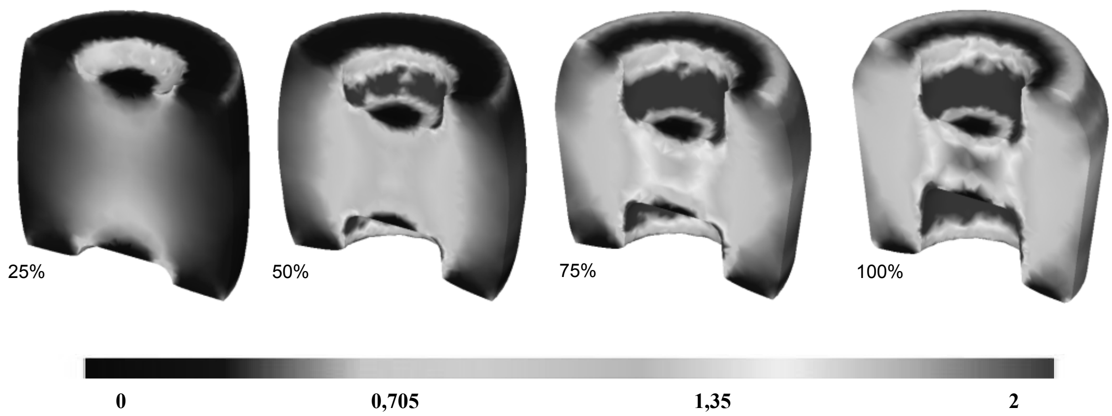



**Fig. 5. Distribution of strains in the impression of the formed preform depending on the process advancement determined by FEM**

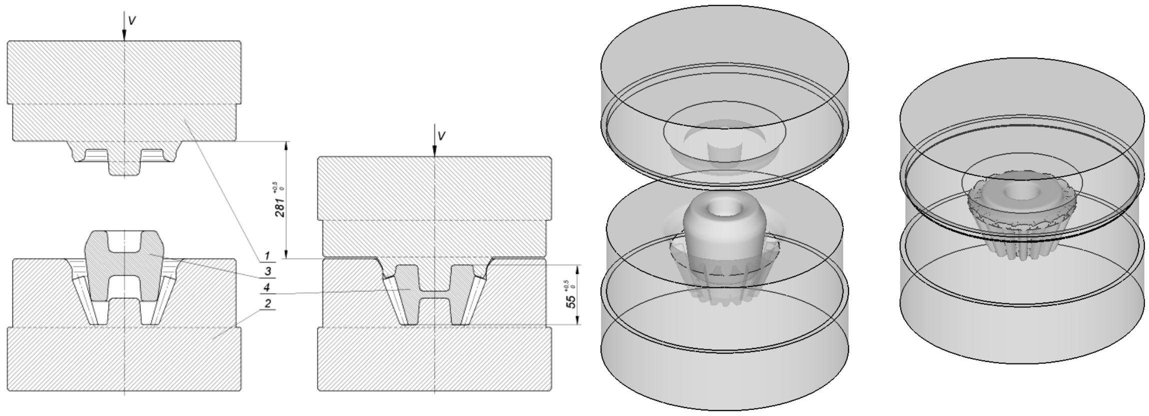



**Fig. 6. Geometrical model of forging of toothed wheel in finishing impression (description in the paper)**

During forging of the wheel in the finishing impression, a small axial flash (Fig. 7) appeared, which should be removed mechanically before the further machining. However, in order to enlarge tolerances of semi-finished product volume changes, it was proposed to make a compensator in tools in the form of ringed recess of the volume about 3000 mm$^3$. The choice of its placement results from the way metal fulfills the tools impression.

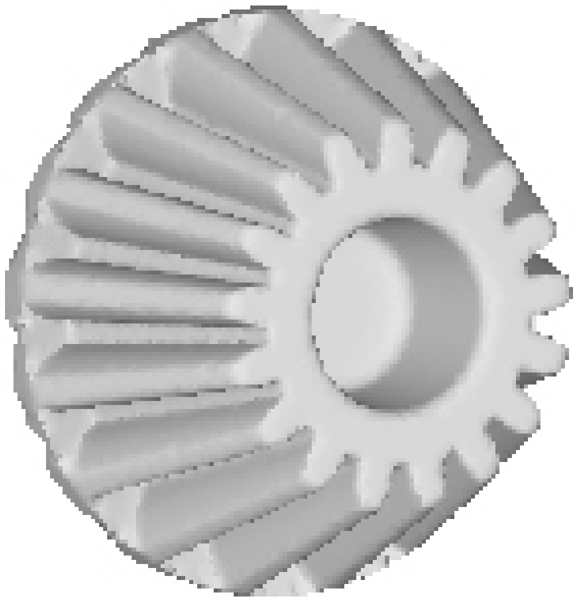


**Fig. 7. Conical toothed wheel forging shape calculated by FEM**

In Fig. 8 the way of fulfilling of the finishing impression by metal in the process of forging of conical toothed wheel is shown. The area at the head surface of the toothed wheel rim was fulfilled at the last stage of the forging process. Because of that, the compensator did not act on the proper fulfilling of the impression and the forging had the assumed to obtain shape (Fig. 8 and Fig. 9).

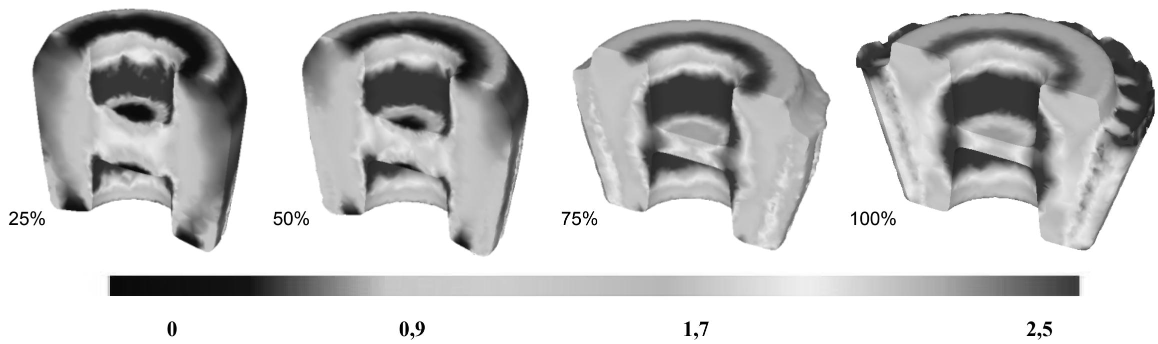



**Fig. 8. Distributions of strains in the section of the formed forging of toothed wheel in the finishing impression depending on the process advancement determined by FEM**

The next Fig. 9 presents distributions of stresses and temperatures in cross section of the forging at the final stage of forging. The largest stresses were observed in the area of the formed web (Fig. 9, *a*). They reached the value of about 200MPa. Larger stresses were also present in the area of axial flash (up to 150MPa). Stresses in the area of toothed wheel rim were relatively small (about 120-140MPa).

The final temperature of the forging was relatively high (Fig. 9, *b*). The largest decrease of the temperature was in the area of web and head surfaces. The forging central area had constant temperature (about 1100$^{o}$C).

At precisely determined billet material volume equal 210000mm3,and at the application of the appropriate preform, the value of forming force did not exceed 7500kN. Even small increase of billet material volume resulted in rapid increase of the forming force.

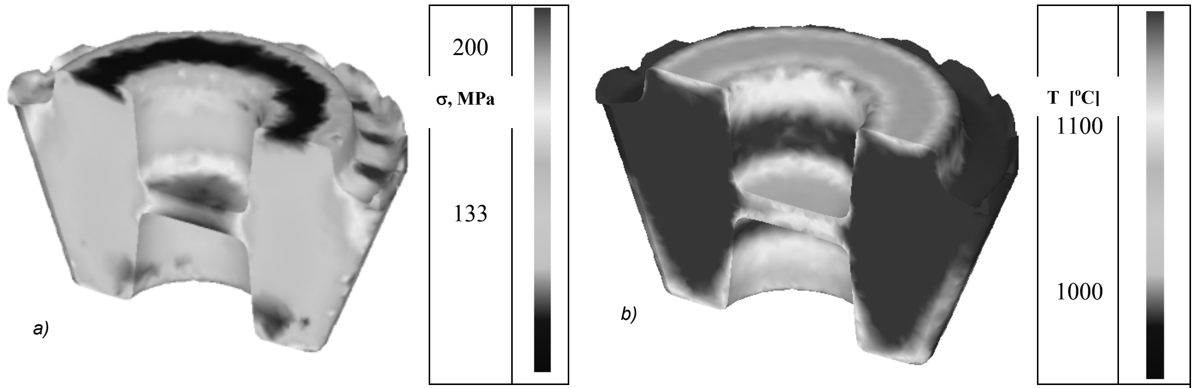



**Fig. 9. Distributions of stresses intensity - a, temperature - b observed at the final stage of toothed wheel forging in the finishing impression**

At increasing the billet volume of 3000 mm$^3$(the length was enlarged to 90.8mm) and, apart from the implementation of compensator, a considerable increase of the forming force up to 12500kN was observed (60% more in comparison with the nominal volume). The further increase of material volume could lead to the press slide seizure near the lower dead center.

**Summary.**

The conducted numerical analysis of the forging process of conical toothed wheel, made basing on FEM, confirms the possibility of forming of toothed wheel rims by means of metal forming processes. The obtained in simulations distributions of stresses on surfaces and sections of the formed toothing do not exceed 140MPa, which is precious information connected with tools durability in the impression toothed areas. Such stresses should not lead to faster impressions wear. However, the fast wear of dies will be caused by the process large temperature. Hence, tools should be manufactured as changeable dies inserts placed in the dies mountings. Interesting information can be read from distributions of forming forces in supportive and finishing impressions. Even a small increase of the billet material volume leads to the rapid growth of the forging forge at the final stage, and further increase of volume may lead to the machine seizure. The application of the forging in many dies, in which in initial impressions preform is formed without toothing, and in the final impression only the toothed wheel rim is forged, allows for a considerable decrease of forming forces.

Although the techniques of metal forming of elements develop rapidly, metal forming processes of toothed wheels toothing have not been fully worked out yet. Hence, it was assumed as purposeful to conduct research works aiming at improving of these forming techniques of toothing, applied at present in industry, and at working out of alternative methods of toothed wheel manufacturing in these processes. The obtained results may be used for industry needs. The presented in this paper results of research works should be treated as an introduction to the complex theoretical and experimental analysis of toothed wheels forming, which is planned to be made at the Lublin University of Technology.

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