Improvement of product accuracy and tool life at precise cold forming by suitable die prestressing

Izboljšanje natančnosti izdelka in vzdržljivosti orodja pri preciznem preoblikovanju v hladem z ustreznim prednapetjem matrice

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Abstract: In the case of cold forming of an inner race of a homokinetic joint an analysis of die prestress influence on the product accuracy and tool life was made. Definition of optimum working interference of shrink fit for the die in combination with suitable stiffness of a shrink ring is important for production reliability of cold-formed elements. Smaller interference dimension with the rigid shrink ring enables lower elastic deformation of the die, which means higher accuracy of the products on one side, smaller specific plastic deformation on the critical tool part on the other side and consequently a reduced progress of damages. Stiffness of the shrink ring can be increased with higher elastic module material and/or combination of a ring composed of a cemented carbide core and a winded spring strip.

Povzetek: Na primeru hladnega iztiskavanja kroglaste glave homokinetičnega zgloba je podana analiza vpliva prednapetja matrice na natančnost izdelka in vzdržljivost orodja. Določitev optimalne nadmere krčnega naseda za matrico v kombinaciji z ustrezno togostjo krčnega obroča je pomembna za zanesljivost proizvodnje hladno preoblikovanih elementov. Manjša krčna mera naseda v kombinaciji s togim krčnim obročem zagotavlja manjšo elastično deformacijo matrice, kar pomeni večjo natančnost izdelkov in na drugi strani manjšo specifično plastično deformacijo na kritičnem delu orodja in tako počasnejšo rast poškodb. Togost krčnega obroča lahko poveča-

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mo z večjim modulom elastičnosti materiala oziroma s kombinacijo obroča, sestavljenega iz jedra iz karbidne trdine in navitega vzmetnega traku.

Key words: cold forming, part accuracy, tool life, die prestressing
Ključne besede: hladno preoblikovanje, natančnost izdelka, vzdržljivost orodja, prednapetje matrice

INTRODUCTION

Cold massive forming of steels is an important technology in manufacturing of elements with demanding geometric forms and accurate dimensions. Fast development of automotive industry increases the requirements for manufacturing of elements with complex geometric forms and accurate dimensions. A product is understood as quality-made, when there are no inside or/and outside damages and when its dimension tolerances are as close to the centre of the tolerance area as possible. Attainment of accurate dimensions of a product and long tool life are two main requirements in the cold massive extrusion industry.

For a reliable manufacture of elements with the cold forming technology, a production process that ensures both quality manufacture of products and optimum tool life should be planned.[1] Figure 1 shows a forming system with input parameters of random and systematic deviation. The system response represents the desired function and/or in this case the product's quality and tool life within the desired and allowable scatter.

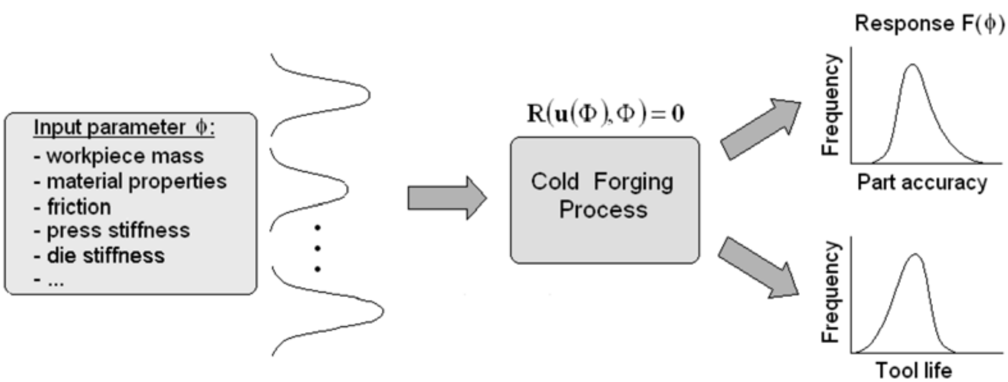

Figure 1. Scatter impact of input parameters of the forming system on the accuracy of products and tool life

A suitable die pre-stress and/or definition of the optimum shrink dimension is essential for long life of tools.[2] Dies for cold extrusion, which are heavily loaded, are prestressed with the help of the shrink rings. On the one side, it is necessary to ensure large enough prestress for as big as possible compensation of extreme loads of the forming process. as possible, However, one must be careful not to overload the tool too far in the plastic area by prestressing. Defining the appropriate tooling allowance requires good knowledge of the limit conditions that material can withstand without damages. The published text books propose more measures for evaluation of prestress together with cyclic tool loads. One of most often used criteria was defined by Hänsel;[3] it is based on the deformation energy

$$\Delta W^{t} = \Delta W^{e+} + \eta\, \Delta W^{p} \qquad (1)$$

where ΔW^{e+} represents specific deformation energy of the tensile stress and ΔW^{p} stands for specific energy of plastic deformations. In the equation above, η is a weight factor to the part of plastic deformations that cause damages in material. Graphic interpretation of this equation is shown in Figure 2, where tool life can be prolonged by reducing the influence of the specific deformation part of the tensile stress ΔW^{e+} and the specific part of plastic deformations ΔW^{p}. By the die pre-stress we can reduce loading of the tool $\Delta\sigma$ and decelerate damage development. Higher prestress makes the hysteresis loop move to the compression area. In this way the harmful effect ΔW^{e+} is reduced or even eliminated. The risk of damages can be reduced by an appropriate selection of materials for the shrink fit core. If we choose cemented carbide (prestressing E^{+})[4, 5] instead of steel, the system rigidity increases due to the higher elasticity module and deformation amplitudes $\Delta\varepsilon$ and consequently ΔW^{p} reduces accordingly. Lower deformation amplitudes of die are crucial for higher accuracy of products, as smaller deformation denotes smaller elastic deformation and in this way smaller elastic elongation of the die in the radial direction.

During the production process and under the conditions of mass production, the tools are loaded cyclically. The tool re-

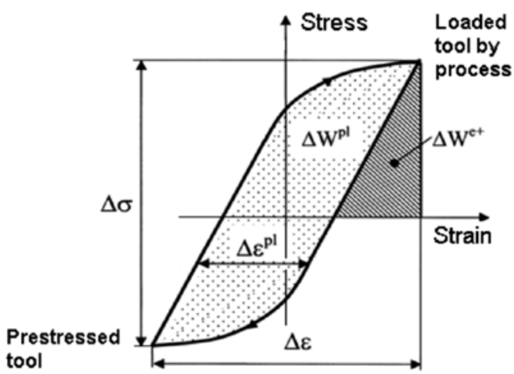

Figure 2. Effect of the specific deformation energy on the damage development

sponse on the critical spot is elasto-plastic and is defined by kinematic and isotropic hardening and damage development D

$$\dot{D} = \frac{\sigma_e^2 \left(\frac{2}{3}(1+\nu) + 3(1-2\nu)\left(\frac{\sigma_{kk}}{3\sigma_e} \right)^2 \right)}{2 \cdot S \cdot E(1-D)^2} \dot{p} \cdot \alpha(p) \qquad (2)$$

where E stands for the elastic module, ν is a Poisson ratio, σ_e is an effective stress, σ_{kk} is a spherical stress tensor and $\alpha(p)$ a function, which defines beginning of the damage growth with reference to the size of comparative plastic deformation p. Detailed information regarding the constitutive model for damage D, suggested by Pedersen, is given in reference.[6]

The main objective of this research is to analyze the impact of the die prestressing on the accuracy of the product and tool life in cold extrusion of a inner race of the homokinetic joint (Figure 3). With suitable die prestressing the improvement of the product accuracy and tool service life is achieved, as well as the reliability of cold forming system.

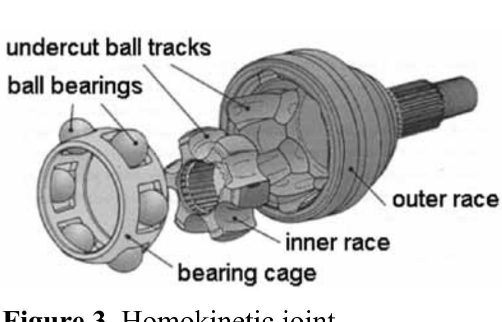

Figure 3. Homokinetic joint

ANALAYSIS OF THE RIGIDITY IMPACT ON THE ACCURACY OF THE INNER RACE

The forming process for manufacture of the inner race consists of three passages through the press (cf. Figure 4). At the first passage a preform (a) is made in the three-stage tooling. Heat treatment (process annealing) and surface treatment of the preform follows. As the lubricant carrier the preform contains phosphate and MoS_2. From the point of the tool life, the second passage is the most critical, as in operation (b) the required geometrical form of the preform is made and in operation (c) the product bottom is pierced. In the third passage, during the operation (d) calibration of the product is made to the specified dimensions of spheres diameter D_1 and D_2 and the product height. Hereinafter, the analysis will be given regarding the die rigidity impact on the accuracy of the inner race, namely for the last operation, where calibration of a pre-form is performed in order to achieve the final dimensions of the product (d) and impact of the die rigidity on the tool life for operation (b).

For the calibration of the inner race we used die with a conventional ring and die with a Strecon ring in order to analyze the die prestress on the product accuracy. Figure 4 shows the characteristic dimensions of spheres D_1 and D_2, of the inner race and the product height. Table 1 gives the values for dimensions

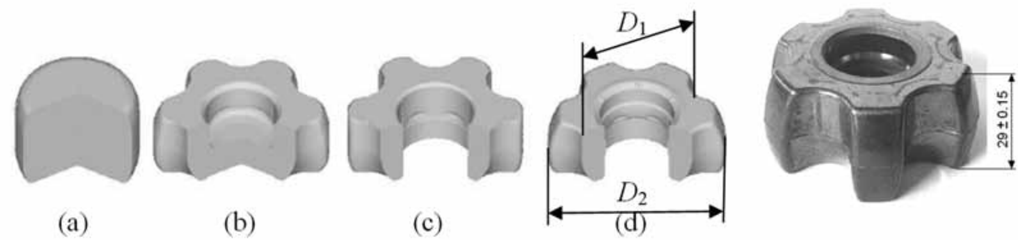

Figure 4. Sequence of forming operations in manufacture of the inner race and a product development

Table 1: Data for dimensions D_1 and D_2 for the die with the conventional and the Strecon shrink ring

Product (mm) (by drawing)	Die (mm) (by drawing)	Manufactured die (mm)	Cold forged product (mm)
D_1 70.9 + 0.15/–0.1 D_2 50.9 ± 0.2	Clasic shrink ring		
	D_1 70.8–0.02	D_1 70.81–70.87	D_1 70.83–71.09
	D_2 50.8–0.02	D_2 50.79–50.87	D_2 50.83–51.14
	Strecon shrink ring		
	D_1 70.78–0.02	D_1 70.74–70.79	D_1 70.95–70.98
	D_2 50.78–0.02	D_2 50.74–50.79	D_2 50.98–50.99

D_1 and D_2 for the product by the drawing, constructional drawing of the die, the manufactured die and for the final product for the conventional and the Strecon shrink ring.

The Table 1 shows that the conventional shrink ring does not ensure manufacture of the inner race within the desired tolerances. With reference to the too high elastic elongation of both key dimensions of the die with the conventional ring, the objective is to manufacture a more rigid die. Instead of the conventional die composed of external steel ring with tooling interference 0.6 % , we used a shrink ring Strecon E^+ of cemented carbide and winded spring strip with tooling interference 0.4 % (cf. Figure 5). The die interference 0.4 % means that the outside die diameter is 0.4 % bigger than the inside core diameter of cemented carbide. The advantages of the Strecon ring are both that it enables higher extrusion pressures within the die working area and that its high rigidity substantially reduces the cyclic plastic deformations that are characteristic of a crack development on the working surfaces of tools in cold extrusion. The manufacturer of the new ring ensures

25 % smaller elongation of the inner race outside diameters. Due to the deviation of key diameter tolerances with the conventional die, we decided to reduce dimensions D_1 and D_2 on the die with the Strecon shrink ring by 0.02 mm, namely D_1 to 70.78 – 0.02 and D_2 to 78.0 – 0.02.

The main diameters of inner race in the upper and lower die with Strecon ring were made with lower tolerances. Tolerance comparison of dimensions D_1 and D_2 for the product by the drawing, the die and the calibrated product for the conventional and the Strecon ring is shown in Figure 6. Elastic ra-

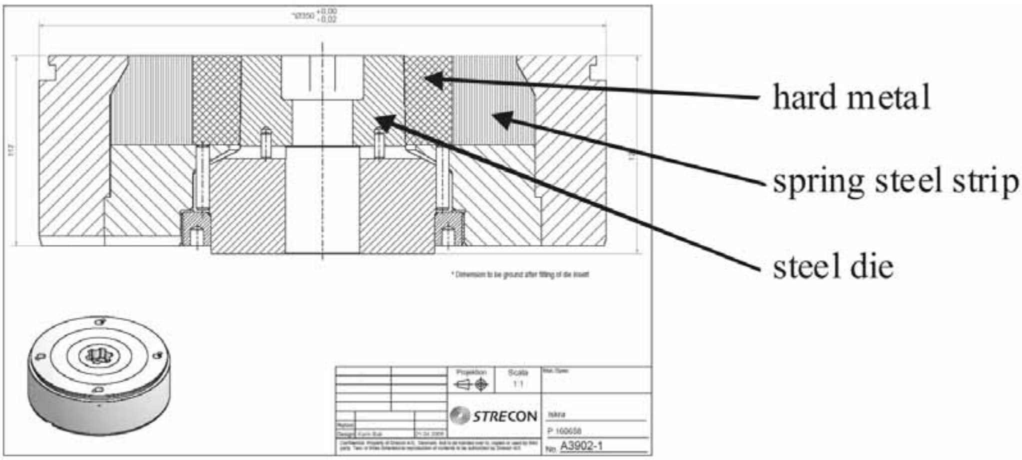

Figure 5. Lower die for inner race calibration

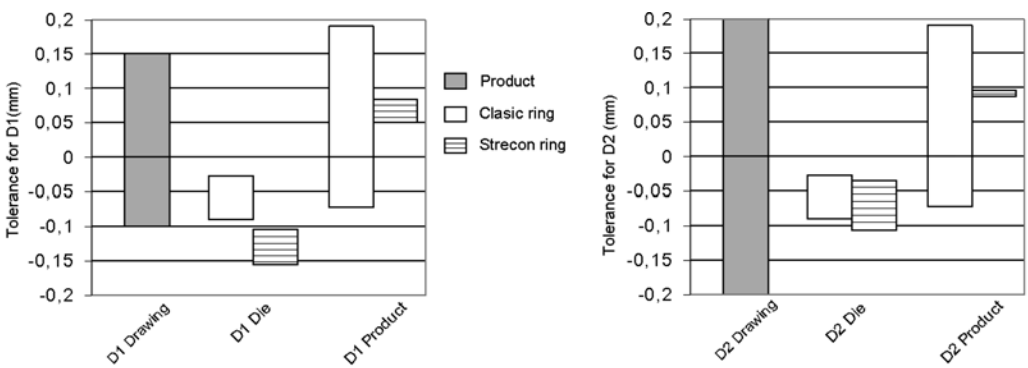

Figure 6. a) Tolerance scatter for dimension D_1 and (b) Tolerance Scatter for dimension D_2 of the spherical head for the conventional and Strecon shrink ring

dial elongation of the die with the Strecon shrink ring compared to the die with the conventional ring is lower for 20 %. Lower elastic elongation of the die is essential for higher accuracy of the product.

Furthermore, we were interested in the impact of a mass scatter of the product on the dimension D_1 of the inner race for the die with the conventional and the Strecon ring (cf. Figure 7). Strecon ring ensures smaller deviation for the dimension D_1 and in this way allows greater mass scatter of the formed piece. Suitable rigidity of the shrink ring is therefore essential to achieve desired dimensional accuracy of the products with the complex geometry.

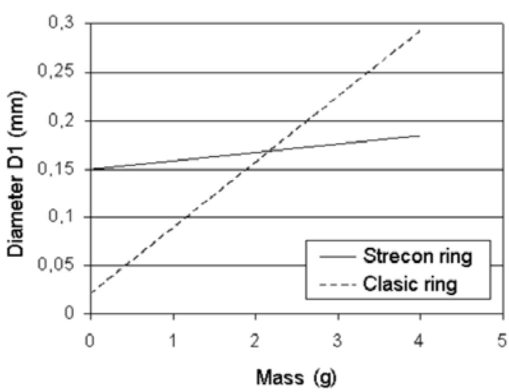

Figure 7. Impact of mass scatter on the accuracy of the diameter D_1 of the inner race with different die rigidities.

Analaysis of impact of die rigidity on tool life

In manucturing of the complex forms and accurate dimensions, tool life and/or good tool endurance is very important for reliability of the production. When producing such products, the main vital parts like dies, counter-punches and punches are loaded to the extreme limits of endurance, where even small deviations from the set values of the impact parameters can cause critical damage growth and too early destruction of tools. Great scatters regarding the tool life are characteristic of such production. Therefore, it is important that for a successful and reliable production we analyze, define and control those parameters that have an important influence on the tool life. It is known from practice and theory that key parameters with an impact on tool life are:

- optimum design, accurate definition of load and correct sizing of vital tool parts,
- selection of suitable materials and their optimum heat treatment and
- use of modern treatment procedures and protection of active tool parts against wear.

In the case of the preform extrusion (Figure 4, operation (b)) the impact of different die prestress on damage development was analysed. We analysed a die with a steel ring and 0.8 % tooling allowance and Strecon *E*+ prestress ring with 0.6 %

tooling allowance. The die was in both cases made from steel ASP 23 with hardness (60 + 1) HRc.

Figure 8 shows typical damage of the die working surface. For analysis of the tool life it is necessary to define the loads that are caused by the forming process on the tool surface. Active tool parts are loaded by stresses, which have been calculated by means of numerical analysis of the forming process. The tool was loaded cyclically as under conditions of mass production. The tool response on the critical spot is elasto-plastic and is defined by kinematic and isotropic hardening and damage development.[7] Increments of plastic deformations are in individual loading cycles relatively small. However, during the process of massive loads, these increases accumulate and cause macroscopic faults on the tool.

First we set the loads with a MKE analysis of the forming process. Based on the loads, tools were analysed by the help of

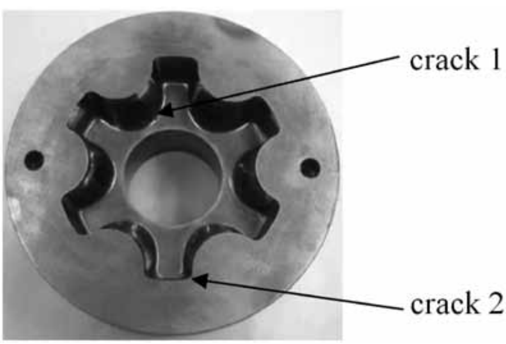

Figure 8. Occurrence of cracks on the lower die for cold forming of the inner race preform

MKE (Figure 9 (a)). For the numerical analysis the program Deform 3D V9.1 was used.[8] The results of the analysis show the most probable point of damage in the inside of the die (Figure 9 (b)). With the module for tool damage analysis, development of damages was analysed.[9]

Loads were copied to the die surface and we repeatedly performed cyclic loads. The response in the critical points of the die is elastoplastic and is described by the hysteresis loops, which results from kinematic and isotropic hardening of material at a concurrent damage development. Figure 10 shows impact of different tooling allowances on the position of the hysteresis loops in the stress deformation conditions at the cyclic load. Hysteresis loop E+ (0.6 %) is visibly narrower, therefore the specific part of plastic deformation is smaller and growth of damages slower. Slower damage growth in E+ ring compared to the steel ring is shown in Figure 11. A detailed insight into damage development within one cycle reveals that in the initial part of the cycle, when the tool is still in the elastic condition, damages do not grow. Towards the end of the forming operation, after the load of the tool increases so high that the stress in the critical points exceeds the yield stress, the damages in the tool increase intensively. When the stroke ends, ejection of the formed-piece follows and the tool is relieved of load. The first part of the load relieving is elastic; the second one is plastic due to the load in the opposite direction, caused by the prestressing of the shrink ring.

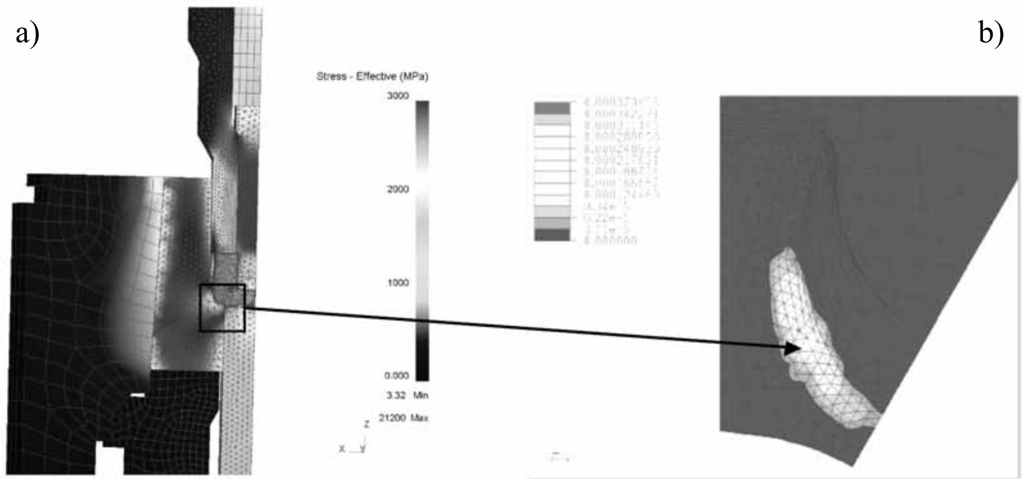

Figure 9. MKE-analysis of tools for operation – (a) and (b) damage on the tool

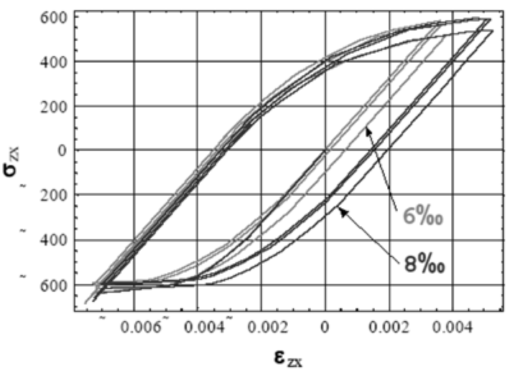

Figure 10. Hysteresis loop in cyclic loads of the die with steel ring and allowance 0.8 % and Strecon E+ ring and allowance 0.6 %

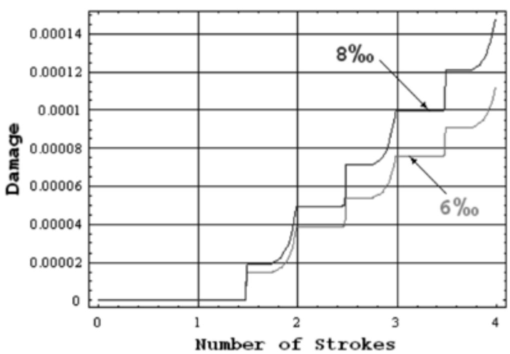

Figure 11. Damages depending on the number of loads for die with allowances 0.6 % and 0.8 %

For a reliable product manufacturing, adjustment of the preform mass to the maximum scatter of ± 0.5 % from the nominal value and the flow stress of ±8 % from the average value is required in addition to the suitable die rigidity. In this way with the Strecon ring we ensure the product height in tolerance of ±0,1 mm with the process centering index C_{pk} > 1.67 and endurance of the die on average for 38,000 pcs (operation b, Figure 4). Tool life in the last calibration operation is not as problematic. With optimum input parameters we can achieve over 70,000 pcs of manufactured inner races with one set of dies.

CONCLUSION

This article analyses impact of the die rigidity on dimensional accuracy of the inner race and on the tool life. Definition of the optimum die shrink fit is one of the key factors for reliable manufacture of products both from the point of view of product accuracy and the optimum tool life. Greater rigidity of the die shrink ring reduces cyclic plastic deformations on tool surface, which are typical for damage development. On the other side, greater rigidity of the shrink ring reduces radial elastic deformations of the die and in this way ensures stable dimensional accuracy of products. Greater die rigidity enables also compensation of greater mass scatters of input blanks. In short, die rigidity has a great impact on reliability and consequently on cost effectiveness of the production using precise cold forming.

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