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COMPARATIVE ANALYSIS OF THE IMPACT OF DIE DESIGN ON ITS LOAD AND DISTRIBUTION OF STRESS DURING EXTRUSION

Abstract

In the paper a numerical comparative analysis of stresses in a steel die compressed by a ring during the extrusion process was presented. In the research, three design solutions of the die were used. The solutions vary depending on the quotient of the wall thickness of the die insert and the wall thickness of the compression ring while maintaining a constant tool diameter. The stresses occurring in the areas of the ring and the die were calculated depending on the design version of the tool and the pressure value. The analysis was carried out for the quotients of the die wall thickness to the ring wall thickness of 0.57, 1 and 1.75 and three press-in values of 0.004, 0.008 and 0.016 mm. The conducted research allowed determining the impact of the die design and assembly interference on the load bearing capacity. It was discovered that the use of a die insert with a smaller thickness compared to the thickness of the compression ring was the most advantageous from the point of view of the circumferential stresses.

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1. INTRODUCTION

An application of an extrusion process requires the use of precise calculation methods to obtain specific technological objectives. Extrusion is characterized by high deformation values, large unit pressures on the tool surface, often complex geometry of the product. In this technology, in addition to giving the right shape of the product, it is necessary to take into account the economically justified life of the tool. The tool with such large unit pressures is exposed to wear on the work surface, elastic deformation and cracking. The life of the dies depends on their proper design and execution, taking into account the appropriate thermal and chemical treatment and the mechanical response to the material selected, the sequence of individual heat treatment operations, and the conditions under which the extrusion itself runs (tool temperature, insert geometry, process speed, type and amount of lubricant providing optimal tribological conditions). Another important parameter is the type of tool material used.

Because of the high unit pressures, the effort of the die material is often so high that it leads to premature wear and even destruction. Information on a tool life is particularly important when dealing with issues related to increasing the efficiency of the extrusion process. An important parameter for optimizing tool life is the introduction of a pre-compression stress in the die insert through the use of the compression ring (Groenbaek & Lund, 2008; Frater, 1989; Joun, Lee & Park, 2002; Yeo, Choi & Hur, 2001; Zimpel, 1996; Nowotyńska & Kut, 2014). Dies pre-compressed (reinforced) by a single ring are used mainly for extruding wire rods. Dies inserts can be made of steel or sintered carbide depending on the required abrasion resistance and pressure.

The aim of the article is to present the results of the comparative analysis of the impact of die design through the use of different thickness of rings and the size of the compression on the load carrying capacity of the tool in the extrusion process.

2. NUMERICAL MODELING OF THE EXTRUSION PROCESS

Numerical calculations were made using commercial MARC / Mentat from MSC Software. The extrusion process was modeled for a die compressed with one steel ring using three different quotients of the die wall thickness to the ring wall thickness (g_m/g_p = 0.57; 1 and 1.75) and three different press-in pressures (δ = 0.004 mm, 0.008 mm) and 0.016 mm). This allowed determining the most loaded places and values of stresses in individual areas depending on the design of the die and the size of the used interference. To determine the assembly insert δ, the following formula was applied:

$$\delta = \frac{D_{zw} - D_{wp}}{2} \tag{1}$$

where: D_{zw} – outer diameter of the die insert [mm],
D_{wp} – inner ring diameter [mm].

The die pattern with dimensions is shown in Figure 1. The angle of the work cone is assumed as $\alpha = 30^{o}$, while the length of the bearing $l_k = 5$mm.

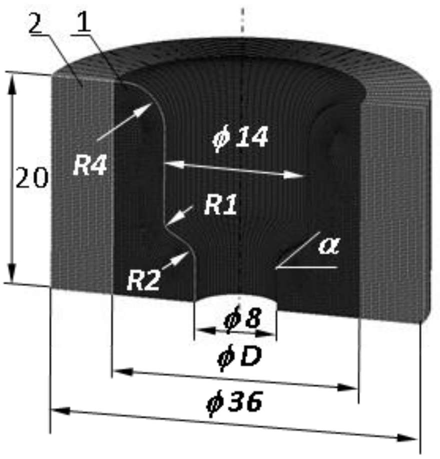


Fig. 1. Scheme of the die with dimensions (1 – die insert, 2 – compression ring)

A two-dimensional geometrical model of the process was constructed, which was analyzed with the assumption of axial symmetry (axial symmetrical model). An exemplary 3D expandable model with contact conditions for deformable bodies is shown in Figure 2.

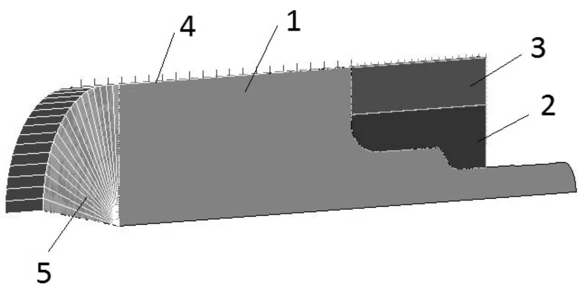


Fig. 2. Exemplary geometrical model of the analyzed extrusion process: 1 – formed material, 2 – die insert, 3 – prestressing ring, 4 – container surface, 5 – punch surface

The mechanical properties of the die (made of NC10 steel) are described by taking E = 210000 MPa and ν = 0.3. However, the properties of the extruded material are described by adopting an elastic-plastic body model with non-linear reinforcement. The values of the determined material constants for the extruded material were taken from the literature (Pater, 2003) and are given in Table 1. The friction model is described by Coulomb's law. The coefficients of friction between the extruded material and the rigid surfaces of the punch and the container and the deformable die were assumed to be equal of 0.3. On the other hand, the coefficient of friction between the die insert and the compression ring was 0.1 (Kut & Nowotyńska, 2011).

Tab. 1. Mechanical properties of the tested material

Material	Strain intensity ε	Yield stress σ [MPa]	Young's modulus E [MPa]	Poisson's coefficient ν
Lead (99.98%)	0	5	18 000	0.42
	0.05	10.42		
	0.10	13.27		
	0.15	15.59		
	0.20	17.30		
	0.30	18.78		
	0.40	18.72		
	0.50	18.64		
	1	19.05		

For the construction of finned elements of deformed material, the elements of the class 10 type – axisymmetric ring quadrilateral were used. Numerical simulation was performed using the global remeshing option. The size of the inserts and the compression ring was about 0.25 mm while the extruded material was about 0.4 mm.

In the paper an analysis of the circumferential stresses depending on the g_m/g_p quotient for three different assembly pressures was done. The circumferential stresses prevailing in the die insert and the ring during extrusion were determined.

3. CALCULATION RESULTS AND THEIR ANALYSIS

Often, in industrial practice, conical dies are used in the extrusion process. Despite many advantages of using such a die geometry, there is a danger of wear and tear even in the input area and at the calibration cone. This is due, inter alia, to the occurrence of such circumferential stresses in such dies. One way to reduce the damaging effects of these stresses on tools during extrusion is to use pre-compressed dies.

The purpose of the numerical tests was to determine the impact of the compressed die construction, expressed in a different ratio of the die insert thickness (g_m) to the ring thickness (g_p) and the size of the interference per peripheral stress value in the extrusion process. The compressed die tests were carried out for three cases of interference (1) which, as already mentioned, were: 0.004 mm; 0.008mm; 0.016 mm and three different ratios of die thickness to the thickness of the spring ring, i.e. g_m/g_p to 0.57; 1; 1.75. Stress readings were made at 7 points for all dies and inserts in the die insert and ring (Fig. 3).

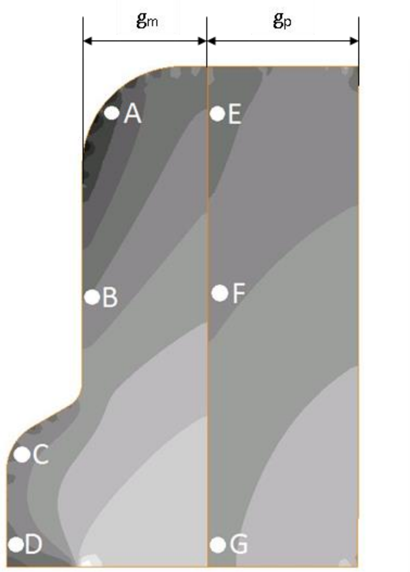


Fig. 3. Locations of measurement points of circumferential stresses

Figures 4 and 5 present the relationship of the circumferential stress prevailing in the die insert and the compression ring depending on the applied die design variant (g_m/g_p) for the three tested assembly pressures. By applying the appropriate die design realized by changing the thickness of the die insert and the spring ring, it is possible to influence on the values of maximum of peripheral stresses occurring in the tool during extrusion. From this point of view, the most beneficial is an application of the variant where $g_m/g_p = 0.57$ as the smallest values of circumferential stress in all the analyzed areas of the tool occurred, including negative stresses.

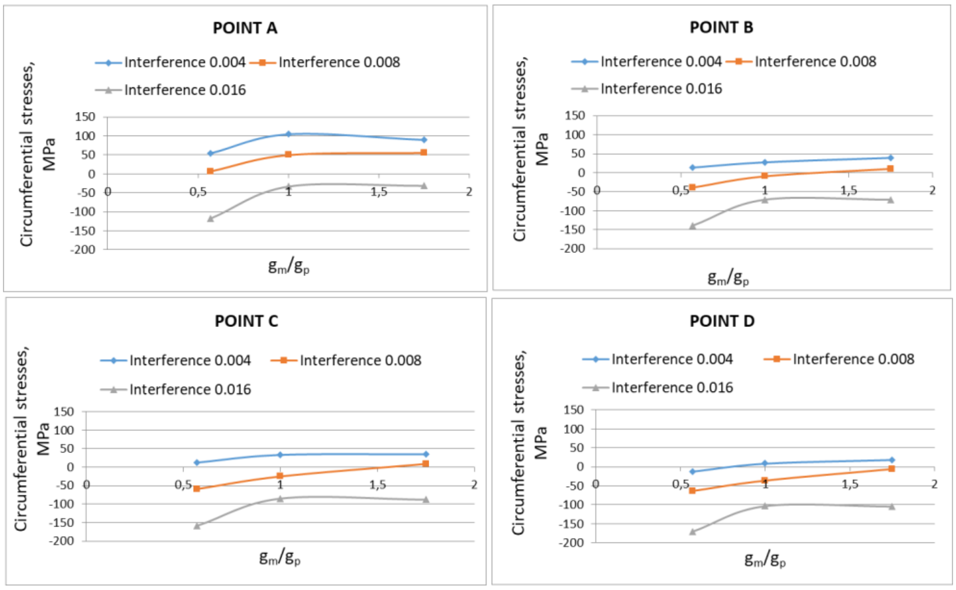


Fig. 4. The impact of the g_m/g_p quotient on the value of maximum circumferential stresses in individual areas of the die insert depending on the used assembly interference

With the use of pressure of 0.008 mm, the smallest positive values of circumferential stresses of 7 MPa and the highest negative values of these stresses equal to –170 MPa for the measuring point D with the pressure value equal to 0.016 mm were recorded in the area A. From the point of view of die durability C and D areas are significant as they are places most vulnerable to damage. In the case of the measuring area C, the study of the influence of different geometrical variants on circumferential stresses showed that at the pressure of 0.004mm and the geometrical ratio $g_m/g_p = 0.57$, the circumferential stresses reached the value of 13MPa. The use of the variant where $g_m/g_p = 1.75$ caused an increase of over two and a half times in the value of peripheral stresses and amounted to 35 MPa.

Figure 5 shows the calculated stress values in the area of the compression ring. In all considered geometrical cases and the areas of research, i.e. E, F, the values of peripheral stresses are positive. In particular measuring areas and the corresponding pressures, the stress values are similar, e.g. for the 0.004 mm pressure, they oscillate between 87-96 MPa for the area E. The differences occur only when different pressure values are used. The smallest values of circumferential stresses were noted for the 0.004 mm pressure when using a geometric variant where the die insert and the ring were of the same thickness. Hence, in the case of a compression ring, no significant change in the geometric variant was affected.

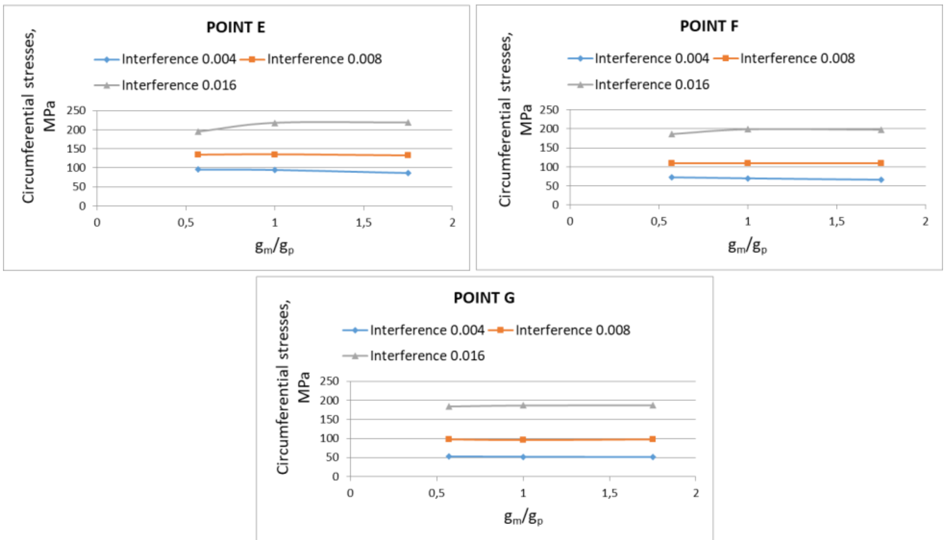


Fig. 5. The impact of the g_m/g_p quotient on the value of maximum circumferential stresses in individual areas of the compression ring depending on the used assembly interference

When comparing the values of circumferential stresses in the ring area with their adopted geometry, one can conclude that they are larger in the measuring areas of rings and range from 51 MPa and pressures 0.004 mm to 219 MPa for 0.016 mm for the variant $g_m/g_p = 1.75$.

When considering tool lifetime, apart from the values of peripheral stresses, the distributions and gradients are also important in the points selected for the analysis. Figure 6 presents examples of stress distribution results in a die compressed by a steel ring and the ring itself for three geometrical variants and exemplary pressures of 0.008mm and 0.016mm. The use of a pre-compressed die with one steel ring, depending on the different geometric variant, i.e. a different ratio between the thickness of the die insert and the compression ring (Fig. 6), changes the distribution of stresses mainly in the die material. For the variant where the thickness of the die is slightly smaller than the rings, one can notice the concentrated stresses at the die entrance as well as passing through the calibration strip. In contrast, there is no visible large stress gradient on the cross-section of the tool, i.e. a large variation in the magnitude of radial stresses. The die material in the whole area is more evenly loaded, which consequently at the same load causes a reduction in the level of stress values, which is very beneficial from the point of their overage and operational durability.

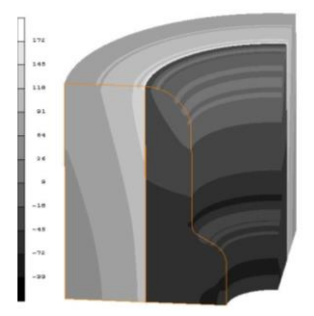
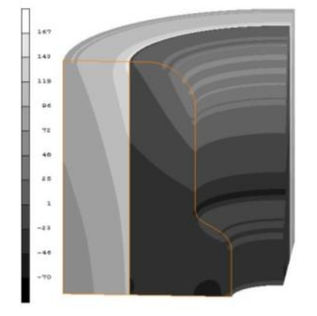
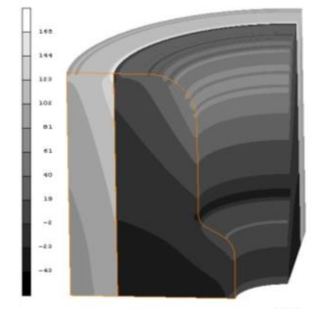
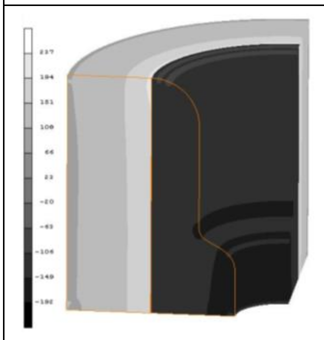
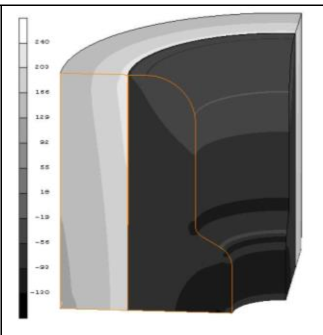
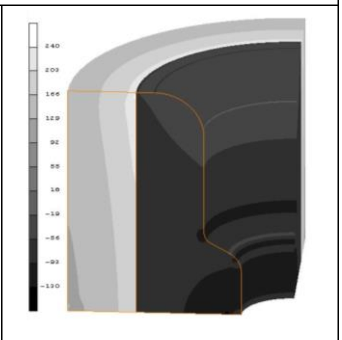
g_m/g_p = 0.57	g_m/g_p = 1	g_m/g_p = 1.75
Interference 0.008 mm		
		
Interference 0.016 mm		
		

Fig. 6. An example of distributions and values of peripheral stresses in the tool during extrusion with pressing 0.008 mm and 0.016 mm the use of g_m/g_p amounting to 0.57, 1 and 1.75

The use of die pre-compressed with a ratio of g_m/g_p = 1.75 causes the occurrence of stress differentiation on the cross section of the die material. Along with the change in the dimensional parameters of the die and the ring, the stress distribution also changes depending on the pressure value. This is particularly evident in the geometric variant g_m/g_p = 0.57. In this case, an increase of the pressure from 0.008 to 0.016 mm leads to a more even distribution of stresses in the entrance and exit areas of the die. In engineering practice, when selecting the interference in the case of the insert and compression ring made of steel, special attention should be paid to the fact that the stress strains between the insert and the ring occur as little as possible during the load. In addition, the values of circumferential tensile stresses in the ring should not exceed the permissible values. Therefore, it is important to look for such solutions, including geometric ones, in order to minimize unfavorable stress gradients.

4. CONCLUSIONS

Thanks to numerical modeling of real processes, in engineering practice one can choose the best variant of the technological process ensuring the longest possible tool life and high accuracy and repeatability of the dimensional and shape of products while limiting costly experiments. The numerical method applied allows the determination of stress values in a tool of any profile, taking into account differential stresses from extruded material and friction conditions. The obtained results showed the existence of a relationship between the geometrical parameters of the tools (expressed in the change in the thickness of the die insert and the compression ring) and the values of the assembly pressures and the values of peripheral stresses in pre-compressed dies.

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