NUMERICAL ANALYSIS OF THE EXTRUSION PROCESS OF TWIST DRILLS

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Abstract
The paper presents numerical analysis results of hot forward extrusion of twist drills. The calculations were made using DEFORM-3D v10.0, the simulation programme based on the finite element method (FEM). The numerical analysis of the process was performed in a three-dimensional state of strain which took thermal phenomena into account. A geometric model employed in the conducted numerical simulation is presented. As a result of the conducted research, force parameters of the process, distributions of effective strain, reduced stress, and temperature could be determined. In effect, it has been proven that twist drills can be formed by extrusion. The obtained results constitute an introduction to a complex analysis of metal forming processes for drills.

Keywords: twist drill, extrusion, FEM, DEFORM

1 Introduction
Similarly to such tools as lathe tools and milling cutters, twist drills are produced on a mass scale in a very wide range of type dimensions. Drill production methods include such techniques as milling, special rolling (including skew rolling by four segments as well as rolling of a drill profile with simultaneous twisting in a four-roll configuration). Other well-known production methods of drills include forging a drill profile and then twisting it using a special device, cross-wedge rolling, and extrusion [1-3, 18]. Drills produced by means of metal forming methods have better strength properties than the ones which are produced by milling; also, they have high geometric and dimensional accuracy. Metal forming of drills is significantly efficient as it helps to save expensive tool steel, which consequently results in a considerable price reduction of the final product.
The development of producing drills by metal forming methods began in the 19th century when Stephen A. Morse (1861) invented a drill with spiral grooves [4, 5]. The current state of knowledge about metal forming of such tools is limited and it predominantly describes special rolling processes. For this reason, it seems justified to raise the problem of twist drill extrusion. The paper presents results of an initial numerical analysis of this drill forming method. The numerical analysis mainly focuses on extruding only a working part of the twist drill, the scheme of which is illustrated in **Fig. 1**. When designing a drill forging, the guidelines for constructing cutting tools presented in the specialist literature [6-9] were employed. It was also assumed that the drill forging had a grinding allowance of 0.3 mm on its diameter. To construct a die, the

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authors took advantage of their own considerations as well as of the data made available by drill producing company MAY - DÖRRENBERG KG [10].

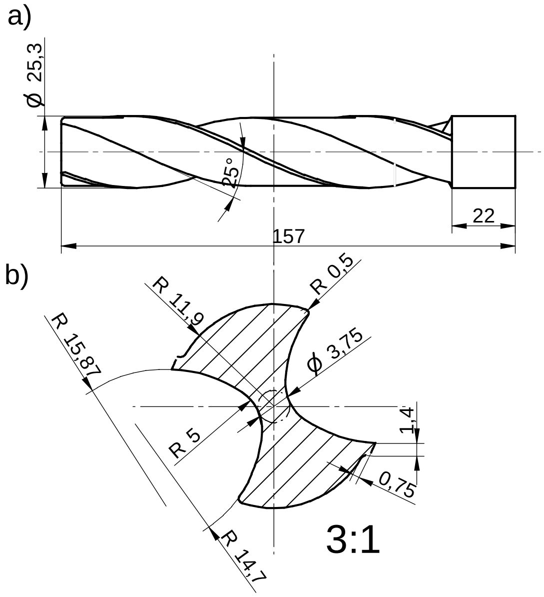

Fig. 1 Scheme of analyzed drill: a) general view, b) cross-sectional view

2 Description of twist drill extrusion process

As schematically illustrated in **Fig. 2**, in drill extrusion the punch (2) forces a bar section heated to the hot forging temperature through a special hole in the die (3) whose shape reflects the shape of the drill working part (1). During extrusion the cross section of the drill is formed and, simultaneously, the drill is twisted in accordance with an inclination of the profile of the die hole.

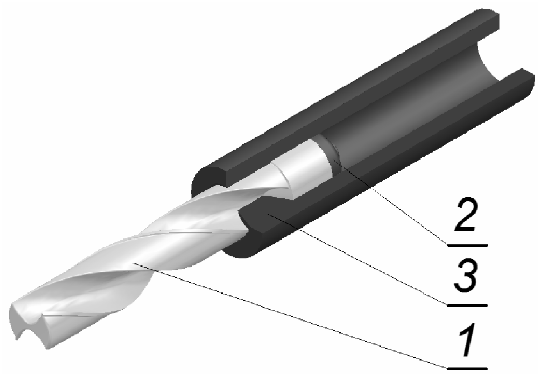

Fig. 2 Scheme of twist drill extrusion process (described in the paper)

With this method, drills whose diameter is bigger than 10 mm are extruded. In the case of workpieces with smaller diameters, there is a risk that the lower limit of the hot working

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temperature will be exceeded. In order to secure the appropriate temperature, extrusion is predominantly performed using high-speed presses. Before the extrusion process begins, the workpiece is heated to the temperature appropriate for hot forging in salt furnaces, thanks to which it is possible to additionally obtain a thin lubricating layer on the workpiece surface, which improves the process [1, 11]. The drills are removed from the die after the extrusion during the return motion of the press slide. To do so, special press tools with a rotating die are used. A scheme of such device is illustrated in **Fig. 3**. The formed drill (1) is removed using the cross-bar (4) which is placed between the die (2) and the container (5). Removing the drill (1) out of the die (2) works analogically to the operation principle of crossed helical gears. The cross-bar (4) moves rectilinearly while the punch (3) is being retracted; with the drill (1) which is fastened to it, the cross-bar transforms its rectilinear motion into a rotating motion of the die (2), which consequently leads to removing the ready drill (1) out of the die. With extrusion it is possible to obtain both uniform drills and their working part only which is most often welded to an appropriate kind of shank, depending on the need. The extrusion method can also be used to produce tri-spade drills, drills for concrete, enlarging drills, and the like.

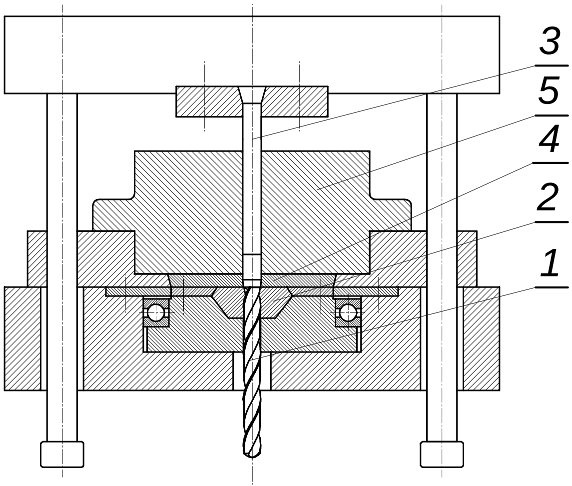

Fig. 3 Device for twist drill extrusion (described in paper) [12]

Owing to the kinematics of metal flow, twist drill extrusion is very much similar to severe plastic deformation (SPD), particularly to the method of twist extrusion (TE). Twist extrusion consists in pushing a metal strip through a die with a helical impression in order to produce a fine-grained structure without changing overall dimensions of the specimen [19, 20]. It is however possible to point out some differences between twist drill extrusion and the TE method. In contrast to the TE method, in twist drill extrusion the workpiece shape and dimensions are changed intentionally, which results in a different distribution of plastic strains. Also, there is only one shear plane in the die input zone.

3 Numerical model

The analysis of the twist drill forward extrusion process was performed using the DEFORM – 3D simulation programme. A geometric model of the analyzed problem corresponds to the

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scheme presented in **Fig. 2**. In the analyzed case, a workpiece in the form of bar with the temperature T_w of 1150°C was modelled using four-node tetragonal elements. Initially, the workpiece diameter was 23 mm, while the internal diameter of the container was equal to the outer diameter of the drill being formed. It was also assumed that the drill being formed was made of C60 steel, whose material model was taken from the material model database of the simulation software used. Furthermore, it was assumed that the punch velocity *v* was constant and equal to 130 mm/s, the heat exchange coefficient between the workpiece and the tools (whose temperature T_t was of 300°C) was equal to 5 kW/m^{2}K, while the heat exchange coefficient between the workpiece and the environment was equal to 0.2 kW/m^{2}K [13-16]. Friction on the material-tool contact surface was modelled using constant friction and the friction factor m was equal to 0.4 [17]. Other geometric parameters of the die used in the simulation are shown in **Fig. 4**.

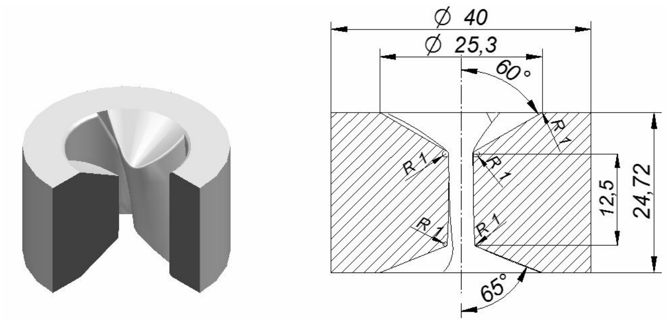

Fig. 4 Scheme of die used in twist drill extrusion simulation

4 Results and discusion

As a result of the conducted FEM analysis, a twist drill forging (shown in **Fig. 5**) was obtained. The obtained forging of the working part of the drill corresponds to a mill drill. However, in order to obtain a ready tool, it is necessary to perform grinding on the forging diameter, to cut the forging to obtain a suitable length, to sharpen it, and – given the analyzed case – to join the working part with the shank. Joining both parts of the drill can be performed by friction welding. Yet, one of the shortcomings of extruded drills is that they do not have a core diameter which would increase toward the shank, therefore it is necessary to leave allowance to obtain core convergence and to perform another grinding. Also, it can be easily observed that the drill illustrated in **Fig. 5** does not have gentile exits of the chip grooves; however this constitutes no obstacle when chips are removed during drilling. **Fig. 6** presents strain distribution on the surface of the drill forging and in the drill forging cross section. Analysing the data presented in **Fig. 6**, it can be observed that the strain distribution in the drill forging is not uniform as its highest values occur in the drill core, where the most considerable cross sectional reduction occurs. The strains in the cross section of the formed drill are distributed in layers. As the spade width increases radially, the strains starting from the drill center gradually decrease and reach minimum values on the surface of the drill spade. The obtained strain distribution is significantly different from the strains obtained by the twist extrusion method, where the strains have the minimum values in the specimen core and then, as the distance from the specimen center increases, the strain values increase radially, too.

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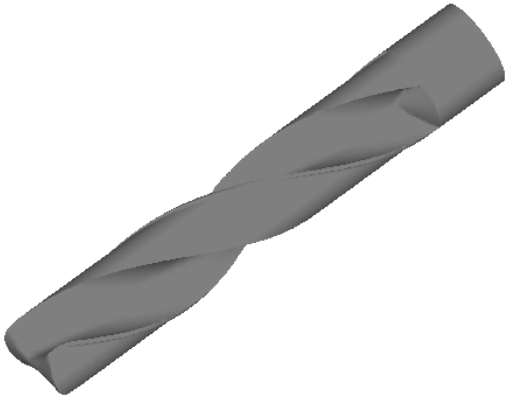

Fig. 5 Drill forging obtained in FEM calculations

Considerably lower strain values which occur in the drill blade result both from a slight diameter reduction of the workpiece in this area and from considerable material cooling caused by the colder tools. Such strain non-uniformity results in lack of uniformity of product properties on the product diameter. This is not favourable as far as drills are concerned because of the cutting torque load during drilling which is transmitted mainly by the drill blades to the machine tool.

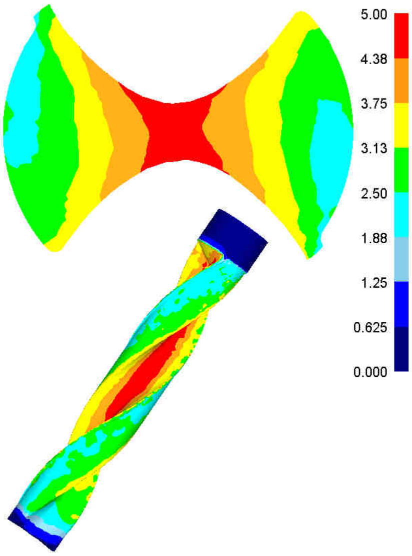

Fig. 6 Effective strain distribution

One of the results obtained in the course of the conducted numerical analysis concerns the course of extrusion force, which is illustrated in **Fig. 7**. The maximum value of the force does not exceed 450 kN. Nevertheless, its course should be taken into consideration as it significantly differs from typical courses of forces which occur in forward extrusion. Despite a decrease in the workpiece length, which means decreasing the contact surface between the material and the container, no significant decrease in the extrusion force value occurs. The force characteristics in

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the analysed case are similar to the ones obtained in backward extrusion in which the force does not change in the steady stage if the material undergoes slight cooling. This stems from a decrease in the temperature of the formed material as well as from considerably high strain velocity values that are caused by a high velocity of forming.

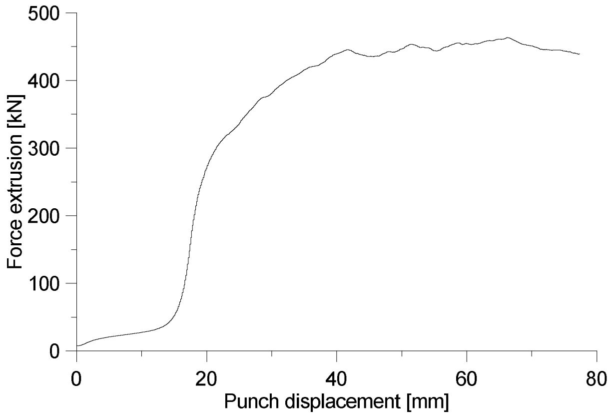

Fig. 7 Force in twist drill extrusion process

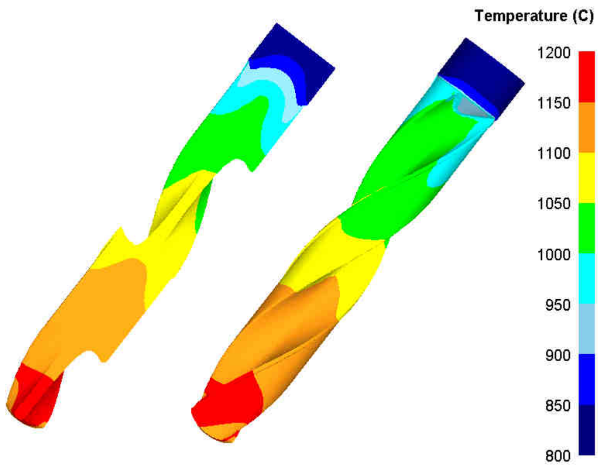

Fig. 8 Drill temperature distribution in final process stage

Fig. 8 presents a temperature distribution in the final stage of the process. In spite of a relatively high velocity of the punch which was to level temperature drops of the material, the temperature of the workpiece confined in the container decreases to a value of approximately 800°C at the end of the process, while the temperature in the dead zones decreases to approximately 950°C. These considerable decreases in the temperature do not however lead to a significant increase in the value of the forming force in the steady stage. Undoubtedly, no clear increase in the force value with a simultaneous decrease in the temperature result from a decreasing height of the workpiece, which, in turn, leads to an approximately constant value of the extrusion force. The formed drill has the highest temperatures in its frontal parts which were the first to leave the die. The temperature in the frontal part of the drill increases to approx. 1200°C, which results from

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the heat generated by plastic deformation and friction action on the die surface. The temperature in the formed drill decreases along the axis opposite to the direction of material flow. Such temperature distribution results from the fact that the first layers of the material entering the deformation zone have a higher temperature than the farther layers which undergo cooling due to a longer contact with cooler tools. Therefore, it can be assumed that the temperature of farther layers of the material entering the deformation zone will gradually decrease with time. This means that the temperature is higher in the frontal part of the drill as illustrated in **Fig. 8**. The difference between the material temperature in the container and in the die results from the heat generated by plastic deformations and friction action on the die surface. The conducted analysis has shown that when extruding steel at high velocities, the temperature distribution during the process is determined by the workpiece -tool heat exchange coefficient and punch velocity.

Fig. 9 shows a distribution of reduced stresses in the formed drill. The registered stress distribution occurred when their highest values were predicted, that is in the time interval when the force maintained an approximately constant value, which also corresponded to the maximum values of the force. A characteristic of the presented stress distributions is that they are concentrated in the area where the chip groove exits are located and where the drill shank diameter gets reduced to the diameter value of the blade.

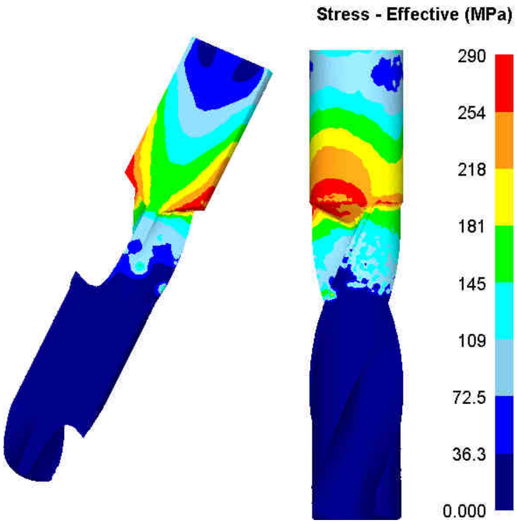

Fig. 9 Numerically determined distribution of stresses

The highest values observed in these areas reach up to 290 MPa. Such high values of stress are connected with an intensive cooling of these areas (**Fig. 8**), which increases deformation resistance. Also, an increase in the stress values in these areas results both from sizing drill grooves by spiral prongs and from reducing the diameter value of the shank to that of the blade. The stress distribution provides useful knowledge as for predicting failures of drill extrusion dies. Increased stress values in the exit zones of the chip grooves may cause premature wear of spiral prongs in the die. It may undoubtedly be expected that a higher susceptibility to failures will occur on the die fault where the drill shank is formed into the working part of the drill. The distribution of shear stresses τ_{zr} and $\tau_{\theta z}$ determined in the plane normal to the direction of material flow is shown in **Fig. 10**. The Z axis of the coordinate system shown in this figure

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corresponds to the axis of the drill being formed. In both cases, the presented distributions of shear stresses take characteristic patterns. The shear stresses in the radial direction have positive values in most part of the analyzed area; reaching the maximum directly over the flutes. The closer it is to the drill spade centers, the stresses gradually decrease and their values become negative in the central parts. As for the shear stresses in the tangential direction, there is less disproportion between their values and affected areas. The shear stresses in the tangential direction have the highest values over the die edges that form margins and over the passive edge of the drill spade. These values are negative over the edges that form margins, while over the passive edges they are positive.

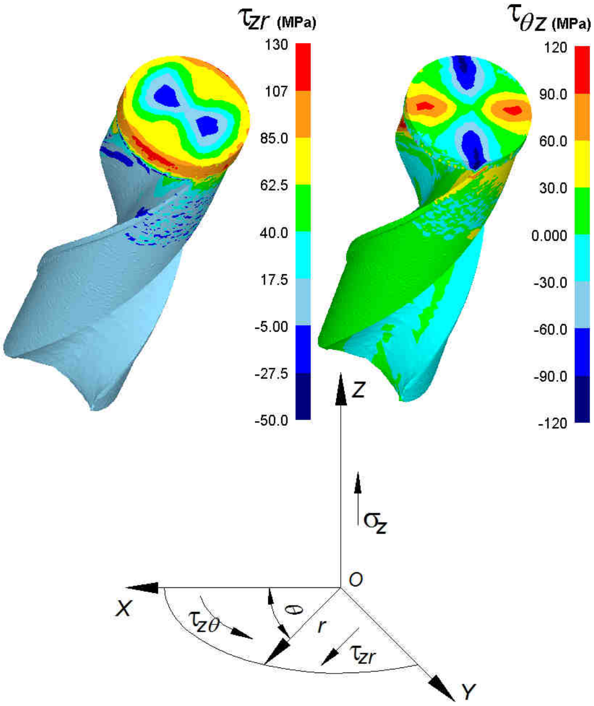

Fig. 10 Numerically determined shear stresses

5 Conclusion

Based on the conducted numerical simulations of the twist drill extrusion process, the following observations were made:

- twist drill extrusion is more favourable in the case of bigger diameters owing to their higher thermal capacity,
- the required punch velocity of 130 mm/s did not prevent the material from over-cooling,
- despite intensive cooling of the workpiece, the forming force did not increase in any considerable way,
- the obtained distribution of strain rate is totally different from the one obtained with the TE method,
- the highest strain values occur in the drill core and they decrease as the drill radius increases,

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- the ratio between maximum strains and minimum strains is εimax/εimin = 2,
- the highest values of reduced stresses (290 MPa) occur over the spiral projections which are responsible for forming flutes.

The obtained results have also provided valuable information concerning tool design and areas in which the heaviest load may occur. Despite its application in industrial production of drills, extrusion is not widely popular, and further experimental and theoretical analyses are required to achieve process optimization.

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