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Tomasz BULZAK[*], ZbigniewPATER[**], Janusz TOMCZAK[***]

NEW EXTRUSION PROCESS FOR PRODUCING TWIST DRILLS USING SPLIT DIES

Abstract

The paper presents a new extrusion process for producing twist drills using split dies. The design of the dies is described, where the profile of the flute-forming element is the same as the profile of the flute on the plane inclined to the drill axis at an angle equal to the helix angle. The proposed method for the extrusion of twist drills by the new type of dies is verified by numerical modeling. Three cases of the extrusion process are modelled, each with a different position of the flute-forming element relative to the axis of the drill. The paper investigates the effect of the position of the flute-forming element on the angle of inclination of the flutes and the cross-section shape of the drill. Numerical modeling is performed using DEFORM-3D.

1. INTRODUCTION

Extrusion processes are widely used in the manufacture of a broad range of products for various industries. The most common methods of extrusion are forward and backward extrusion. There are also special types of extrusion, including KoBo extrusion, hydrostatic extrusion, and Conform extrusion. Extrusion is mainly applied in the production of long products of varying cross-section (Fang, Zhou & Duszczyk, 2009; Jiang, 2015; Cristobal, Ramírez, Ruiz, Ortiz & Jacobo, 2017). Extrusion processes are also used to produce more

[*] Lublin University of Technology, Nadbystrzycka Street 36, 20-618 Lublin, Poland, +48 815384244, t.bulzak@pollub.pl
[**] Lublin University of Technology, Nadbystrzycka Street 36, 20-618 Lublin, Poland, +48 815384242, z.pater@pollub.pl
[***] Lublin University of Technology, Nadbystrzycka Street 36, 20-618 Lublin, Poland, +48 815384244, j.tomczak@pollub.pl

compact products such as combustion engine pistons (Dong & Chen, 2008). Currently a growing interest in screw extrusion can be observed. Screw extrusion is a process by which the material is pushed through a helical hole in the die. The material leaving the die moves with a helical motion which is a combination of progressive and rotational motion. Screw extrusion is used in the manufacture of such components as twist drill, rotors of pumps, helical gears, etc. (Kim, Kubota & Yamanaka, 2008; Hwang & Chang, 2014; Bulzak & Pater, 2013).

Twist drills can be extruded through single and split dies. Extrusion through unitary dies consists in pushing the material through a die with a helical channel whose contour corresponds to the shape of the twist drill (Liekmeier, 1992). In the case of split dies, the material is pushed through two dies with oblique protrusions that form helical flutes and give the drill its helical shape (Bulzak & Tomczak, Pater, 2014, 2016). Split dies can be designed in two ways, as schematically shown in Figure 1. In the first method, the geometry of the flute-forming elements (protrusions) corresponds to the contour of the flute in plane n_1 perpendicular to the drill axis (Figure 1a). In the second method, the geometry of the flute-forming element is consistent with the contour of the flute in plane n_2 normal to the flute (Figure 1b). This article presents the results of numerical simulations of the process of extrusion of twist drill in which tools with flute-forming elements normal to flutes were used.

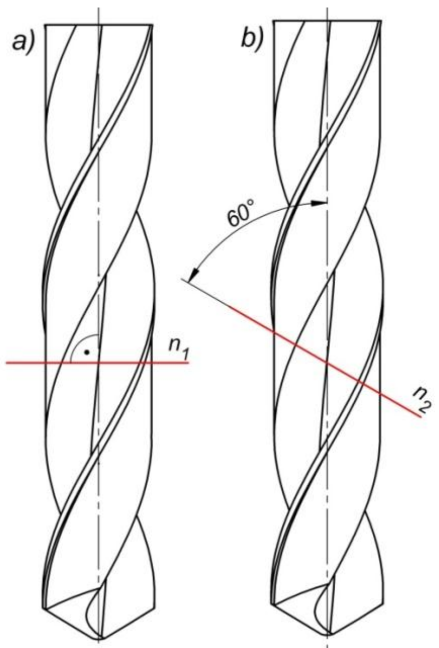

Fig. 1. Schematic of the position of the contour of the flute-forming element relative to the twist drill axis – description is provided in the text

2. METHOD AND GOAL

Similarly as in the case of milling of twist drill, the position of the flute-forming element relative to the extruded twist drills can be defined based on the position of point *S*, which marks the point of intersection between the axes of the flute-forming protrusion and the twist drill. The position of point *S* is defined by two values: *x* and *y*. The schematic of the position of the flute-forming element is shown in Figure 2. The present article reports the results of numerical simulations of the process of extruding twist drills for the following positions of point *S* : 1) $x = 0.5y$; 2) $x = y$; 3) $x = 1.5y$.

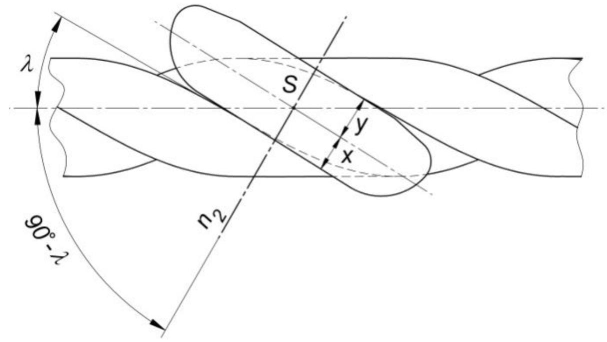

Fig. 2. Schematic of the position of the flute-forming element relative to the extruded twist drill

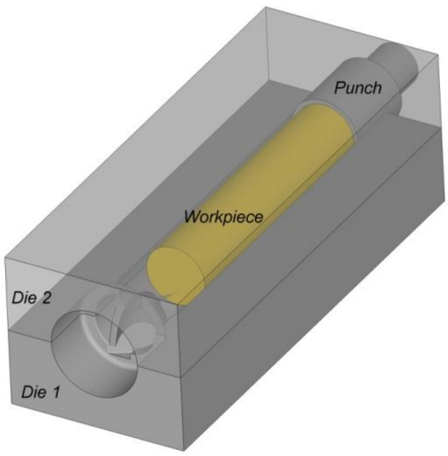

Fig. 3. Geometric model of extrusion of twist drills using split dies

Numerical simulations based on the finite element method were performed using Deform-3D software. In order to carry out the numerical simulations, three geometric models of the process of extrusion of twist drills were constructed, one of which is shown in Figure 3. A ∅27 × 120 mm billet, whose initial temperature was 1150°C, was modelled using tetragonal finite elements. It was assumed that the tools were ideally rigid and their temperature was constant at 300°C. The material model of the workpiece material (DIN – 102Cr6) was gleaned from the library of the software used. The heat exchange factor between the material being formed and the tool was assumed to be 10 kW/m^2K, and that between the environment and the material was 0.2 kW/m^2K. The friction on the contact surface between the workpiece and the tools was described by the constant friction model, with the assumed friction coefficient m = 0.5.

3. RESULTS OF NUMERICAL SIMULATIONS

Based on the simulations, the effect of the position of the flute-forming element on the course of the extrusion process and the dimensional accuracy of the obtained twist drill was determined. Fig. 4 compares the transverse profiles of the twist drill extruded at variable point *S* positions. By far the greatest compliance with the theoretical profile was achieved for the twist drill profile extruded with point *S* exactly at the center of the flute ($x = y$). A good match with the theoretical profile was also obtained with point *S* positioned near the margin ($x = 0.5y$). When point *S* was positioned at $x = 1.5y$, there was a large discrepancy between the CAD profile and the FEM profile in the area of the rear surface of the flute. The remaining part of the flute differed only slightly from the theoretical contour in the area of the drill margin.

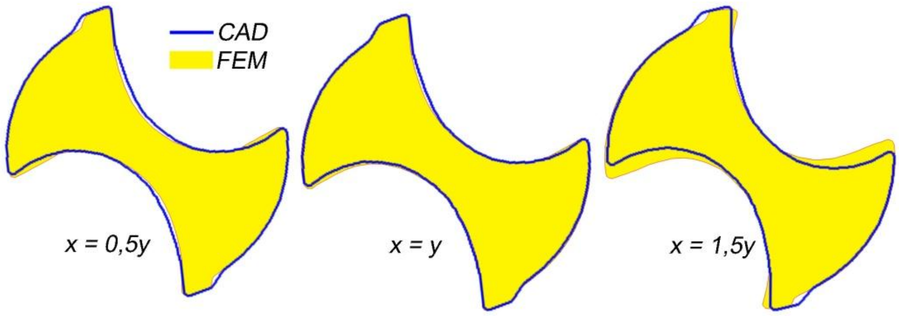

Fig. 4. A comparison of the profiles of twist drills extruded at different positions of point *S* with the theoretical profile

The position of the flute-forming element also has a significant impact on the helix angle λ. A comparison of the geometries of twist drills extruded at different positions of point *S* is shown in Figure 5. The largest helix angle λ was obtained when the position of point *S* was defined as $x = 0.5y$. As the distance *x* increased, the helix angle λ of the extruded twist drills became smaller.

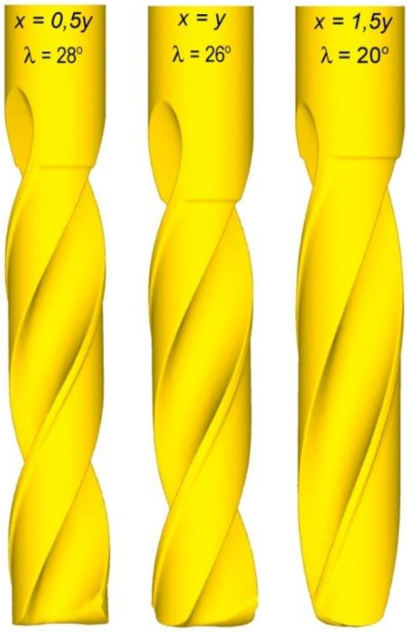

Fig. 5. Geometry of twist drills extruded at different positions of point S

The helix angle λ depends on the axial velocity $V_z$and the circumferential velocity V_θ of material flow. Figure 6 shows the distribution of the axial velocity $V_z$of material flow. In the first two cases (*x = 0.5y* ; *x = y*), the velocities of the material exiting the die were similar. A marked difference was found for the third position (*x = 1.5y*), where the velocity of the material exiting the die was lower than in the other two cases.

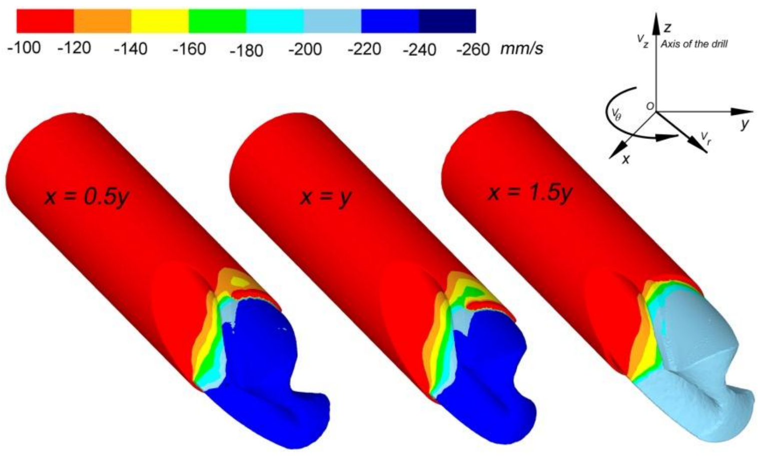

Fig. 6. Distribution of velocity of material flowing in the axial direction V_z

The position of the flute-forming element also affects circumferential velocity V_θ which is responsible for the twisting of the extruded drill. Maps showing the distribution of circumferential velocities of material flow are shown in Figure 7. An increase in distance *x* led to a reduction in circumferential velocity of material flow. This reduction was very small for $x = 0.5y$ and $x = y$. A significant drop in flow velocity of the material was observed for $x = 1.5y$, which was reflected in the fact that the drills extruded at this position of point *S* had the smallest helix angle.

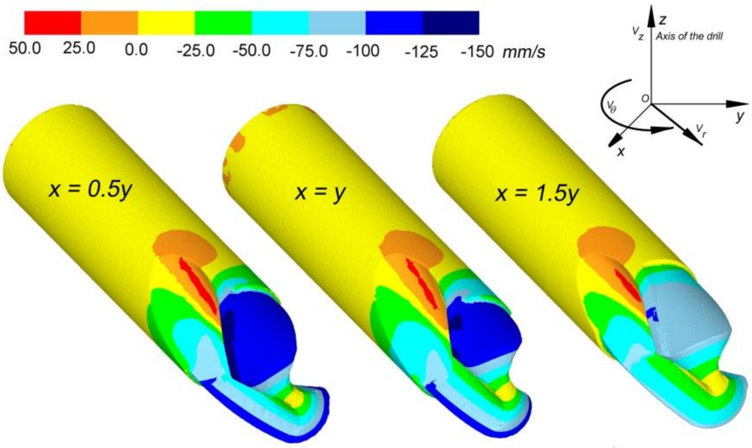

Fig. 7. Distribution of velocity of material flowing in the circumferential direction V_θ

Fig. 8 shows numerically determined distribution of the plastic strain for the investigated cases of twist drill extrusion. In the cross-sections of the obtained twist drills, the largest plastic strains were concentrated at the web of the twist drill. The value of strain decreased in the peripheral part of the cross section of the twist drill. Strain on the surface of the flute for $x = 0.5\ y$ and $x = y$ was the greatest in the margin area. For $x = 1.5y$, the largest values of plastic strain were found at the edge of the land.

The curves of forming and expansion forces determined using the finite element method are shown in Figures 9 and 10, respectively. For all cases, an increase in the extrusion force was observed, which resulted from the cooling of the workpiece. The expansion force, after reaching the maximum value, decreased along with the decreasing height of the billet placed in the die container. The force parameters for the extrusion force and the expansion force for the die parameters x = 0.5 y and x = y were similar. When x = 1.5 y, both the extrusion force and the expansion force reached smaller values. In the process of split-die extrusion of twist drills, this is a typical situation, i.e. the extrusion force decreases along with a decrease in the helix angle of the extruded twist drill.

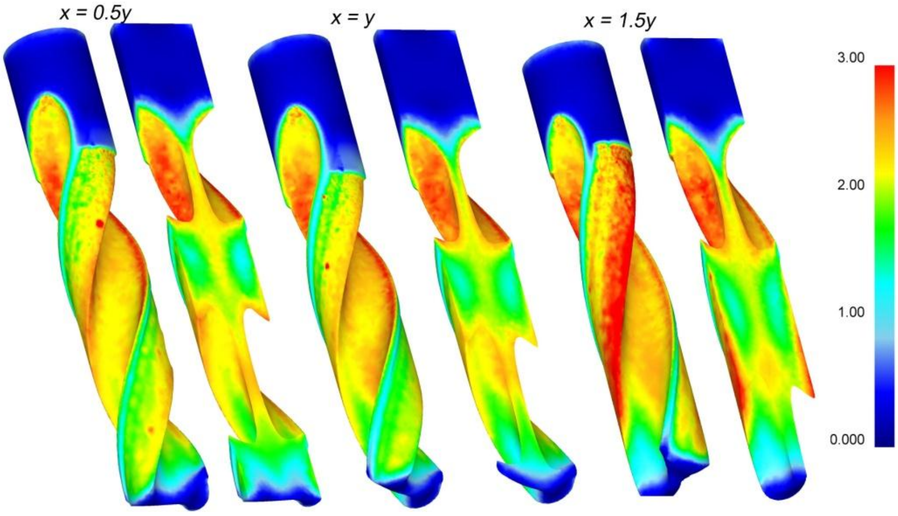

Fig. 8. Distribution of effective strain

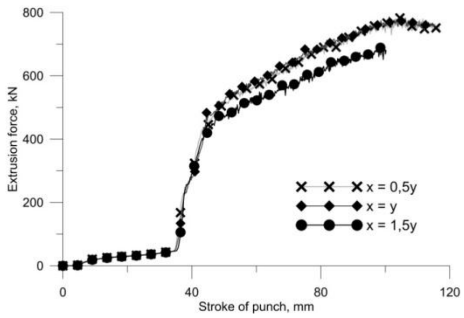

Fig. 9. A curve of punch extrusion forces

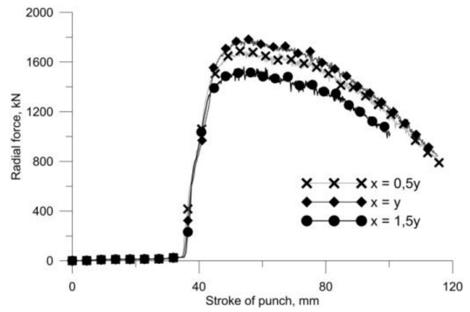

Fig. 10. A curve of expansion forces acting on the die

4. RESULTS OF EXPERIMENTAL TESTS

The positive simulation results led the research team to verify them under laboratory conditions.Fig. 11 shows the dies and the apparatus used in the experiments. Experimental tests were carried out using Pb1 lead as model material. In the experiments, extruded rods with a diameter of 27 mm and length of 120 mm. The experiments were conducted using a PYE 160 universal hydraulic press. The numerical and experimental results confirm that twist drill can be formed by extrusion process using new design split dies.

Fig. 11. Apparatus for split-die extrusion of twist drills

Twist drill blanks with a diameter of ∅ 30 mm formed during the experimental study are shown in Fig. 12. The obtained twist drills were characterized by reproducibility of dimensions, including screw thread pitch. No problems were encountered during the removal of the blanks from the die cavity. Also, no defects were found on the surface of the drill during removal of the forgings from the die cavity. The fact that the twist drills could be properly removed from the die cavity without the need to unscrew them from the die confirms the correctness of the assumptions of the newly proposed method of extrusion of these tools. The helix angle of the twist drills obtained in the process is consistent with the angle calculated numerically using FEM simulations.

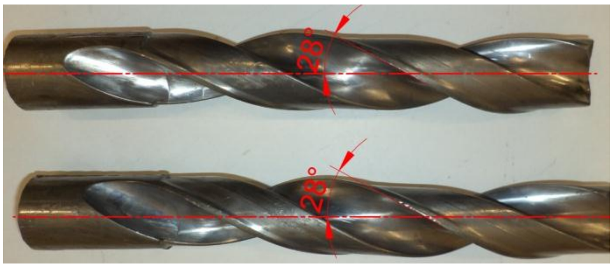

Fig. 12. Twist drills obtained in the experiments

5. CONCLUSIONS

The numerical and experimental investigations performed in this study lead to the following conclusions:

- twist drills can be extruded using dies with a flute-forming element positioned normally to the flute;
- dies with a flute-forming element positioned normally to the flute allow easier removal of the twist drill from the die cavity, especially in the margin area;
- an increase in distance *x*, which describes the position of the flute-forming element, results in an increase in the helix angle λ of the extruded twist drills;
- the contour of the flute is best reproduced when $x = y$; for $x = 1.5y$, the contour of the flute deviates the most from the theoretical contour;
- the smaller the helix angle λ, the smaller the extrusion forces;
- the experimental studies conducted using the model material confirmed the results of the theoretical FEM studies.

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