

THE INFLUENCE OF MACHINING CONDITIONS ON BURR SHAPES WHEN DRILLING REACH-THROUGH HOLES IN DIFFICULT-TO-CUT MATERIALS

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Summary

In the work presents the problem of burr shaping when drilling reach-through holes into plates from austenitic steel X5CrNi18-10 and titanium alloy Ti6Al4V ELI. Drills made of high speed steel were used without coating and with nanolayer TiAlN coating. The emulsion as cooling-lubricant medium was used. When drill exits hole, burrs of different shapes are formed. When machining stainless steel plates by uncoated drills the majority of burrs have shapes difficult to deburring (uniform burr of large height, crown burr or uniform burr of large height with drill cup). Cutting speed and feed ratio values no effect. Coating presence turns burrs into easy to deburring shapes (uniformed burr of very small height with drill cup or without a cup). When drilling titanium alloy plates burrs have shapes of crown, uniformed burr of small height with torn drill cup or uniformed burr of small height with petals. Cutting speeds and feed ratio values influence on burr shapes unimportant, but generally machining with greater speeds and small feeds may be recommended. The presence of coating do not influence burrs shape. Cause of coating inactivity in this case is the result of its chemical affinity to titan alloy.

Keywords: burr, drilling, stainless steel, titanium alloy, coating

Wpływ warunków obróbki na powstawanie zadziorów przy wierceniu otworów przelotowych w materiałach trudno obrabialnych

Streszczenie

W pracy poddano analizie proces powstawania zadziorów podczas wiercenia otworów w płytach ze stali austenitycznej X5CrNi18-10 oraz stopu tytanu Ti6Al4V ELI. Stosowano wiertła ze stali szybkoobrotowej, niepowlekanie oraz z powłoką TiAlN Balinit Futura Nano. Emulsją była ciecz chłodząco-smarująca. Przy wyjściu wiertła z otworu powstają zadziory różnych kształtów. Zdecydowana większość zadziorów dla wszystkich wartości prędkości wiercenia i posuwu przy obróbce stali nierdzewnej wiertłami bez powłok ma kształt utrudniający proces ich usuwania. Obecność powłoki zmienia kształty zadziorów na łatwo usuwalne. Wartości parametrów wiercenia przy obróbce stopu tytanu na kształty zadziorów oddziałują mniej znacząco. Zaleca się jednak stosować większe wartości prędkości wiercenia i mniejsze posuwu. Na kształt zadziorów nie wpływa natomiast obecność powłoki na wiertle. Oddziaływanie powłoki jest spowodowane jej powinowactwem chemicznym z tytanem. Potwierdzają to wartości współczynnika tarcia między wiórem i powierzchnią natarcia.

Słowa kluczowe: zadziór, wiercenie, stal nierdzewna, stop tytanu, powłoka

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1. Introduction

The modern industry makes increasingly demands to used technologies of machine parts production, particularly to ensure correct shapes of their edges. The realistic geometry of the edge is largely determined by burrs formed when machining, and their removal is necessary for safety reasons as well as to avoid the influence of burr effect on the friction and wear process of working surfaces of machine parts. The presence of burrs on the edges requires the use of additional process steps to minimize or delete them. According Aurich [1], a study carried out in the German automotive and machine tool industries showed that the deburring causes an increase of about 15% in man power and cycle times. In addition, a 2% share in the reject rate and a 4% share in machine breakdown times due to burrs. Averaging the presented distribution without any weight factors the share accounts of up to 9% of total manufacturing cost. An economic evaluation of the impact of burrs related production cost has been provided by Aurich too [1]: the costs are estimated as up to 500 million Euro expense per year only in Germany.

Therefore, investigations of burr forming when proceeding modern construction materials are very important.

2. Knowledge state

The ISO 13715:2000 [2] defines the edge of a workpiece as burred if it has an overhang greater than zero. A comprehensive definition was proposed by Beier [3]. According to it, a burr is a body created on a workpiece surface during the manufacturing of a workpiece, which extends over the intended and actual workpiece surface and has a slight volume in comparison to the workpiece, undesired, but to some extended, unavoidable [4].

Various studies of the burr formation process when drilling are known. According to Gillespie [5], in drilling the burr formed at the entrance of the hole can be a result of tearing, a bending action followed by clean shearing, or lateral extrusion when chip forming and impacting of cutting edges. Kim and others [6] describe drilling burrs as uniform burr with or without a drill cap, crown burr or petal burr according to their shapes and formation mechanism. When drilling stainless steel, Stein [7] revealed small or large uniform burrs as well as crown burrs, and when low alloyed steel drilling small or large uniform burrs, transient burrs and crown burrs were found. It was found that the constant ratio between burr height and undeformed chip thickness may be a fundamental property of work material for particular tool geometry [7].

When drilling of intersecting holes, the workpiece exit angle is an important factor in determining burr size and shape. The shape of burrs around on axis holes is more uniform than the shape for off-axis holes, and this difference is

probably determined by the variation in exit angles between the two configurations [8]. Heisel [9] investigates burr formation in short hole drilling. A reduction of burr height when increasing feed is achieved. An increase of speed does not increase burrs. On the other hand, Stein and Dornfeld [7] described that increase speed and wear of the drill edges increase the height of burrs. The geometry of the drill greatly affects the burr formation. Lager helix angle and increasing point angle reduce burr height and thickness, as revealed Dornfeld in [10].

3. Research conditions

The process of drilling holes in plates from X5CrNi18-10 austenitic chromium-nickel steel (PN-EN 10088-1:2005) and Ti6Al4V ELI biphasic ($\alpha + \beta$) titanium alloy was investigated. The X5CrNi18-10 steel due to good corrosion resistance, susceptibility to cold working, and good weldability, is widely used in the production of household appliances, dishwashers-conditions dishes, cutlery and consumer goods. In addition, this type of steel is used in construction of devices for processing meat and poultry, tanks and containers for storing food and so on. The Ti6Al4V ELI titanium alloy is widely used in the production of implants and in-medical devices. Some properties of the materials investigated are given in the Table 1, and microstructure in Fig. 1.

Table 1. Properties of materials researched

Material	Hardness HB	Yield, MPa	Tensile strength, MPa	Thermal conductivity, W/mK
X5CrNi18-10	≤ 215	≥ 190	500-700	15
Ti6Al4V ELI	≤ 334	830	900-1160	6.7

When processing the stainless steel, drills from high-speed steel were used with a diameter of 6 mm, the point angle $2\kappa_r = 110^\circ$ and the angle of groove inclination $\lambda_s = 30^\circ$. Drilled plate thickness was equal 10 mm. As cooling-lubricant medium the emulsion Castrol Syntilo RHS EX was used with concentration of 10%. Studies were realized in range of cutting speed 9-20 m/min and feed value 0,05-0,13 mm/rev.

When processing the titanium alloy, drills from high-speed steel were used with a diameter of 5 mm, the point angle $2\kappa_r = 118^\circ$ and the angle of groove inclination $\lambda_s = 23^\circ$. Drilled plate thickness was equal 13 mm. As cooling-lubricant medium the emulsion EMULGOL ES-12 was used with concentration of 5%. Studies were realized in range of cutting speed 3-10 m/min and feed value 0.04-0.08 mm/rev.

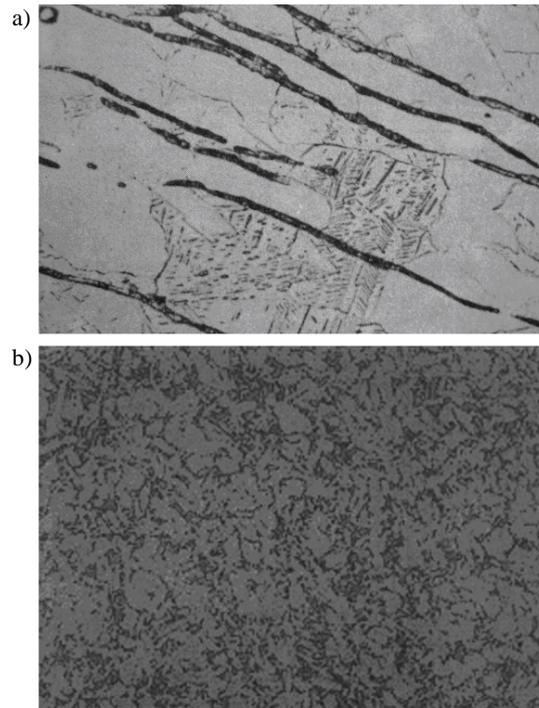


Fig. 1. Microstructures: a) X5CrNi18-10 steel,
b) Ti6Al4V ELI titanium alloy

Not coated drills were used as well as drills coated with BALINIT Futura Nano coating [4]. It is the nanolayer coating of TiAlN with microhardness $HV_{0.05} = 3300$ MPa.

4. Investigation results

The analysis of the burr shapes at the entrance of the hole when machining stainless steel allows for the following division (Fig. 2):

- Very small uniform burr;
- Large uniform burr;
- Crown burr;
- Very small uniform burr with drill cap;
- Large uniform burr with drill cap;
- Large uniform burr with petal.

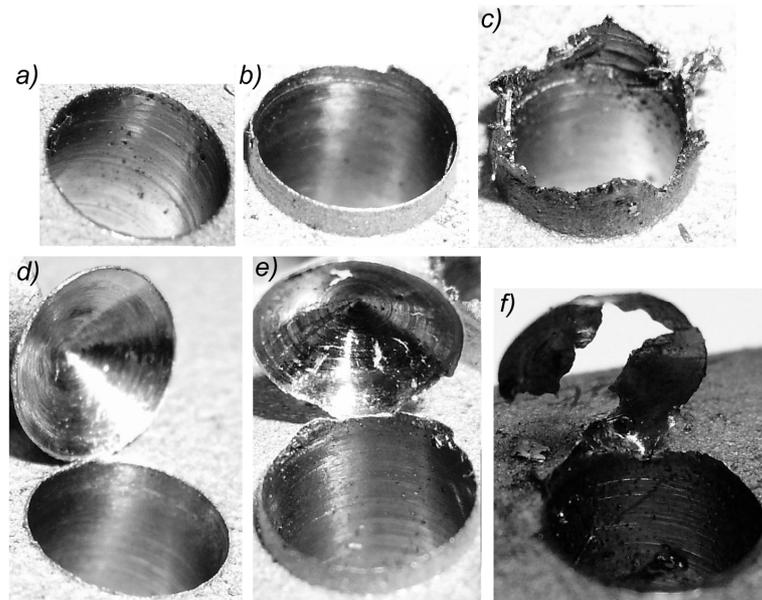


Fig. 2. Burr types when drilling reach-through holes in stainless steel plate: a)+f)

The feed ratio and drilling speed as well as the presence of coating on the drill influence on the shape of the burr (Tab. 2).

Table 2. The influence of stainless steel drilling conditions on burr shapes

Drilling parameters	Not coated drill	Coated drill
$v\downarrow, f\uparrow$	Burrs of type <i>d</i> and <i>f</i> (Fig. 2) for 100% of holes	Burrs of type <i>a</i> and <i>d</i> (Fig. 2) in equal amounts
$v\uparrow, f\uparrow$	Burrs of type <i>c</i> and <i>e</i> (Fig. 2) in equal amounts	Burrs of type <i>d</i> (Fig. 2) for 100% of holes
$v\downarrow, f\downarrow$	Burrs of type <i>b</i> , <i>c</i> and <i>e</i> (Fig. 2) in the ratio 2/3 : 1/6 : 1/6	Burrs of type <i>b</i> and <i>e</i> (Fig. 2) in equal amounts
$v\uparrow, f\downarrow$	Burrs of type <i>e</i> (Fig. 2) for 100% of holes	Burrs of type <i>d</i> (Fig. 2) for 100% of holes
Comments: \downarrow – minimum value, \uparrow – maximum value.		

It can be seen that when using the not coated drill the vast majority of burrs regardless of drilling speed and feed ratio has a large height and thickness, which hinders the process of their removal. The presence of the coating significantly improves the shape of the burr, leading them to shapes easily removable or even eliminating. This is due to reduction of friction between

contacting drill, chip and the walls of the hole and also due to the lower temperature in the contact zone. The exception is the work with low cutting speeds and feeds, because these conditions are created for large-sized burrs.

The analysis of the burr shapes at the entrance of the hole when machining titan alloy allows for their following division (Fig. 3):

- a) Small uniform burr;
- b) Crown burr;
- c) Small uniform burr with torn drill cap;
- d) Small uniform burr with one or two petals.

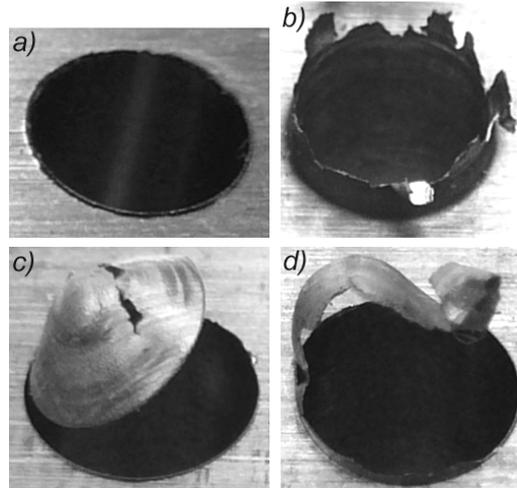


Fig. 3. Burr types when drilling reach-through holes in titan alloy plate: a)-d)

Table 3. The influence of titan alloy drilling conditions on burr shapes

Drilling parameters	Not coated drill	Coated drill
$v \downarrow, f \uparrow$	Burrs of type <i>a</i> and <i>d</i> (Fig. 3) in the ratio 1/3 : 2/3	Burrs of type <i>a</i> and <i>d</i> (Fig. 3) in the ratio 1/3 : 2/3
$v \uparrow, f \uparrow$	Burrs of type <i>a</i> and <i>d</i> (Fig. 3) in the ratio 1/3 : 2/3	Burrs of type <i>a</i> and <i>d</i> (Fig. 3) in the ratio 1/3 : 2/3
$v \downarrow, f \downarrow$	Burrs of type <i>b</i> and <i>d</i> (Fig. 3) in the ratio 1/3 : 2/3	Burrs of type <i>d</i> (Fig. 3) for 100% of holes
$v \uparrow, f \downarrow$	Burrs of type <i>a</i> and <i>c</i> (Fig. 3) in the ratio 1/3 : 2/3	Burrs of type <i>c</i> (Fig. 3) for 100% of holes
Contents: \downarrow – minimum value, \uparrow – maximum value.		

Unlike stainless steel, when titan alloy drilling parameters of cutting influence on the burr shape to a lesser extent, although it can be recommended to

work with larger drilling speeds and low feed ratios. It does not influence the presence of coating on the drill (Table 3). In authors's view, "inactivity" of burrs to change the cutting parameters is caused by high plastic properties of the Ti6Al4V ELI alloy (see Table. 1). However, little effect of coating could be due to the result of its chemical affinity to titanium alloy. The presence of titanium and aluminum atoms in the coating and in the material being processed results in their mutual exchange and interaction of materials when contact.

In order to confirm this hypothesis, there were analyzed changes in the mean coefficient of friction between the chip and the rake surface of drill when drilling titanium alloy. The friction coefficient was calculated on the basis of the analysis of changes in chip thickness as follows:

- The calculation of the chip thickness ratio k_h according to the formula:

$$K_h = \frac{\bar{h}_{ch}}{h_D} \quad (1)$$

where \bar{h}_{ch} – chip thickness (average of 10 measurements), $h_D = f / 2 \sin \kappa_r$ – average undeformed chip thickness, f – feed ratio, κ_r – major cutting edge angle;

- The calculation of the shear angle Φ according to the formula [11]:

$$\operatorname{tg} \Phi = \frac{\cos \gamma}{K_h - \sin \gamma} \quad (2)$$

where γ – the rake angle to the periphery of the drill equal $\operatorname{tg} \gamma \approx \frac{\operatorname{tg} \lambda}{\sin \kappa_r}$;

- The calculation of the mean coefficient of friction μ on the rake face according to the formula [12]:

$$\operatorname{tg} \mu = \operatorname{tg} \left(\frac{\pi}{4} - \Phi + \gamma \right) \quad (3)$$

The results of calculation are shown in Fig. 4. The values of the mean coefficient of friction when drilling titanium alloy with not coated drill are smaller, often by 50%.

5. Conclusions

In conclusion, it must be stated as follows:

- When drilling holes in stainless steel, the presence of Futura Nano coating significantly improves the shape of the burr, leading them to shapes easily removable or even eliminating. The exception is the work with the low-speed cutting speeds and feeds, as these conditions are created for large-sized burrs.

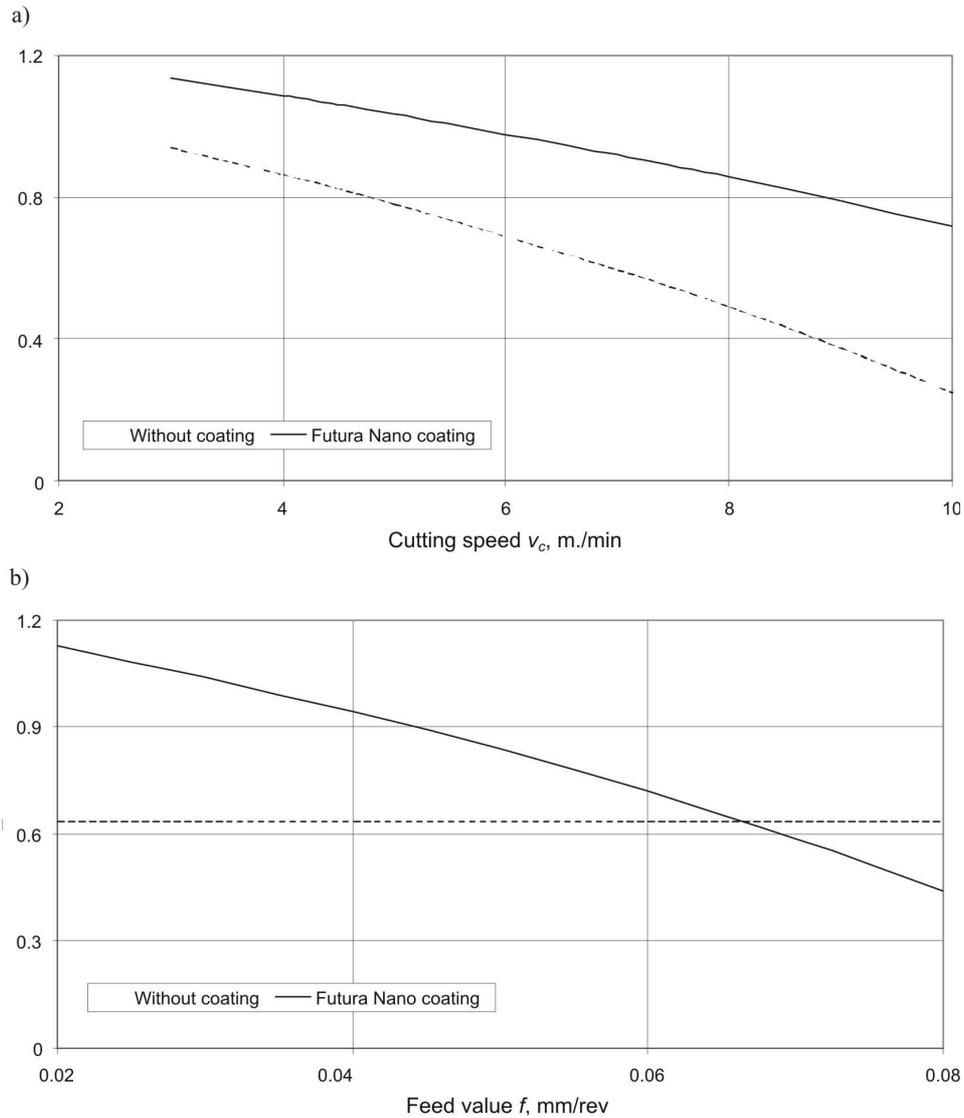


Fig. 4. Changes of middle friction coefficient on a rake face when drilling titan alloy

• When drilling holes in titanium alloy drilling parameters influence on the shape of the burr to a lesser extent, but it can be recommend to work with greater drilling speeds and low feeds. The presence of coating does not influence on the burring. Passivity of burrs to changes in working conditions is due to the high plastic properties of titanium alloy and due to the chemical affinity of the coating material of titanium alloy.

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