Application of Combined Taps for Increasing the Shaping Accuracy of the Internal Threads in Aluminium Alloys

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Abstract

The main difficulties of shaping of internal threads with the required accuracy in aluminium alloys caused by a built-up edge were studied in this paper. A new design of deforming-cutting taps which allows the increase of the accuracy of internal threads was proposed. The difference of the new design from the existing ones is that each land of tap has both deforming and cutting teeth. An operation principle of the proposed tap is based on the preliminary plastic deformation with the following cutting of the workpiece material. In order to compare the proposed tap with existing designs of deforming and cutting taps, the comparative experimental study was carried out. The results of this experiment have shown that utilization of the proposed tap can essentially increase the quality of internal threads and prevent BUE formation.

Keywords: treading; thread quality; deforming-cutting tap; built-up edge; aluminium alloy

1. Introduction

The global trend of industry development, including engineering, aims to the production of parts and structural elements made of materials with high anti-corrosion properties, which can be easily rolled, forged, stamped, machined with edge tools, and with are characterized by a relatively high strength and low weight. Among these materials are aluminum alloys, which are three times lighter than iron and steel, have a high electrical conductivity, can be easily cast and machined with edge tools.

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However, despite a number of above-mentioned positive characteristics of aluminum alloys, there are significant difficulties in machining of number of structural elements made of these materials such as threaded holes. It caused by materials high viscosity and tendency to adhesive bonding, which makes difficulties for their machining because of built-up edge (BUE) formation on the tool cutting edge.

Threaded joints are very widespread, their share is 60-80% of the total number of junctions in instrument and mechanical engineering. Working capacity of threaded joints is determined by internal thread quality which, in turn, depends on the tool quality, the conditions and parameters of processing, coolants, etc. The formation of internal threads of small diameters is one of the most complex processes in comparison with single cutting edge machining. Because of design constraints the taps have incomplete geometry of working part and their strength is usually insufficient, coolant access and chip evacuation from cutting zone are very difficult. Processing is carried out virtually dry, what reduces the tool life and forces to reduce the cutting speed.

The treading process has been studied in detail by a number of researchers [1-20].

2. The effect of BUE on the accuracy of internal threads shaping

In processing of internal threads with a small diameter (M3-M6) in materials that tend to adhesion the BUE is formed on the rake face of the cutting tool. The BUE effect has both positive and negative sides.

Positive features are reducing of cutting forces and partial protection of tool working surfaces from wear occurrence. A negative fact is that the BUE changes the size of the tooth geometry of the tap (Fig. 1) and leads to a change in the size of the forming thread. The periodicity of BUE formation and tearing contributes to the degradation of the thread surface roughness.

![Fig. 1. The BUE on the rake face of the tap tooth.](image)

The accuracy of thread is being formed can be expressed by means of accounting of processing errors:

$$\Delta_{D2} = \Delta_{H2} + \Delta_{F2} + \Delta_{P2} + f_{d}^{n} + f_{s}^{m} + f_{a}^{n} + \Delta a$$

where $\Delta a$ is the error of cut thickness increment because of the BUE; $\Delta_{H2}$ is the measurement error introduced by control gage; $\Delta_{T2}$ is the temperature error; $f_{d}^{n}$, $f_{s}^{m}$, $f_{a}^{n}$, are the inaccuracies of tap thread pitch diameter, pitch of thread and angle of thread respectively; $\Delta_{P2}$ is the error of breakage of thread pitch diameter.

One of the schemes for defining the geometric parameters of BUE is shown in Fig. 2, and [12]. For the calculations it can be simplified by replacing the rounding at the top of tooth with pointed wedge (Fig. 2 b).

Based on simplified scheme the value of increment $\Delta a$ is given by:
\[ \Delta a = H_o \frac{\sin\left(\frac{\pi}{2} + \gamma\right) \tan \gamma}{\sin\left(\frac{\pi}{2} - 2\gamma\right)} \]  

(1)

where \( H_o \) is the BUE height; \( \gamma \) is the back rake angle.

Fig. 2. The BUE geometry (a) and simplified scheme (b).

In order to determine the BUE height the experimental investigations of BUE formation in threading of aluminium alloy ENAB-42000 were carried out. Investigations were accomplished with taps \( \Phi 3 \), \( \Phi 5 \), \( \Phi 6 \).

Experiment has shown that at cutting speed \( V = 16.3 \) m/min the BUE height thread pitch diameter, for the considered taps sizes, was: 0.112 mm (M3), 0.173 mm (M5), 0.218 mm (M6); at cutting speed \( V = 23.2 \) m/min – 0.140 mm (M3), 0.192 mm (M5), 0.241 mm (M6); at cutting speed \( V = 33.7 \) m/min – 0.117 mm (M3), 0.173 mm (M5), 0.228 mm (M6).

After determining the value of the increment \( \Delta a \) by relation (1) results of calculations were summarized in the Table 1.

<table>
<thead>
<tr>
<th>Tap size</th>
<th>Cutting speed ( V ), m/min</th>
<th>Increment ( \Delta a ), mm</th>
<th>The tolerance of thread pitch diameter, mm</th>
<th>The ratio of increment ( \Delta a ) to thread accuracy, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>5H</td>
<td>6H</td>
</tr>
<tr>
<td>M3</td>
<td>16.3</td>
<td>0.026</td>
<td>0.023</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>23.2</td>
<td>0.032</td>
<td>0.023</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>33.7</td>
<td>0.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M5</td>
<td>16.3</td>
<td>0.040</td>
<td>0.023</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>23.2</td>
<td>0.044</td>
<td>0.029</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>33.7</td>
<td>0.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M6</td>
<td>16.3</td>
<td>0.050</td>
<td>0.029</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>23.2</td>
<td>0.056</td>
<td>0.034</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>33.7</td>
<td>0.053</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 shows that because of BUE the increment of \( \Delta a \) for thread M3 exceeds 1.4 times the tolerance, for M5 – 1.5 times, for M6 – 1.6 times.

The cut thickness \( a \) in threading is given by:
\[ a = \frac{P}{z} \sin \phi \]  

(2)

where \( P \) is the thread pitch; \( z \) is the number of lands; \( \phi \) is the chamfer angle.

The cut thicknesses for tap sizes M3, M5, M6 are shown in Table 2.

The calculations have shown that the increment value \( \Delta a \) is 45...180% of the cut thickness. This allows to conclude that the presence of the BUE on a tap teeth leads to instability of cutting by chamfer teeth, because the first tooth cut twice the thickness when the second one does not cut at all.

**Table 2. Cut thicknesses \( a \) depending on tool geometrics.**

<table>
<thead>
<tr>
<th>Size</th>
<th>Thread pitch ( P ), mm</th>
<th>Number of flutes ( z ), pcs</th>
<th>Chamfer angle ( \phi ), deg.</th>
<th>Cut thickness ( a ), mm ( \phi=6^\circ )</th>
<th>Cut thickness ( a ), mm ( \phi=19^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>M3</td>
<td>0,5</td>
<td>3</td>
<td>6</td>
<td>0,017</td>
<td>0,054</td>
</tr>
<tr>
<td>M5</td>
<td>0,8</td>
<td>3</td>
<td>6</td>
<td>0,028</td>
<td>0,087</td>
</tr>
<tr>
<td>M6</td>
<td>1,0</td>
<td>3</td>
<td>6</td>
<td>0,035</td>
<td>0,108</td>
</tr>
</tbody>
</table>

3. **Methods of the BUE control**

The numerous studies devoted to built-up formation show that it is necessary to increase the cutting speed in order to eliminate the negative effects of the BUE, which must be greater than 100 m /min, which is problematic for taps sizes M3... M6 [13].

Another way is producing of cutting tools made of tooling materials which are not subjected to built-up formation [14], for example, advanced ceramics or ultra-hard materials (diamond, CBN). However, these materials are not very appropriate for small-sized taps because of their high brittleness.

In order to prevent the harmful effect of the BUE some investigators [15] optimize the geometrical parameters of the cutting tool, which is not always effective, for example for tapping taps M3-M6 in aluminum alloys.

Probably the best way to prevent built-up formation is using of deforming taps. However, their high cost and strict requirements for the hole accuracy repel manufacturers from using them.

Some researchers propose to use combined machining which includes cutting and plastic deformation. The taps for this method consist of two parts: cutting and deforming. These parts can be arranged in various combinations cutting-deforming [2, 16] and deforming-cutting.

A further method is improving of the cutting conditions due to imposing of additional vibrations [17], for example by means of magnetostrictive actuators. This requires updating of machine tools and is not effective for the machining of small diameter holes in aluminum alloys, as it reduces the accuracy of the formed thread.

At present time in threading of holes in aluminum alloys the forced cooling is used to prevent BUE formation. This procedure is very complicated in forming of small diameter threads (M3-M6) because of the impossibility of coolant supplying through the cutting tool body.

4. **The new design of combined deforming-cutting taps**

The new combined deforming-cutting taps have been designed in order to reduce the effect of BUE formation in internal treading [18]. The design of deforming-cutting tap is shown in Fig. 3 [18].

Lands of chamfer contain cutting teeth 4 and plastically deforming teeth 5. At the length corresponding to the length of the chamfer, chip flutes are formed in such a way that each land of chamfer contains cutting tooth 4, relieved by all profile with a height of \( k_i=h_i \), where \( h_i \) is the first tooth height, and plastically deforming tooth 5 with a height \( H_i=h_i+\delta_i \), where \( \delta_i \) is the thickness of the deformable layer by the \( i \)-th plastically deforming the chamfer tooth. Values \( h \) and \( H \) have been gradually increasing since the first chamfer tooth.

The proposed tap operates in the following manner.
The rotational movement and coordinated with it axial movement are imparted to the tap. The cutting tooth 4 of the chamfer part carries out with rough shaping of the thread cutting material at depth $\Delta i$. Placed sequentially on the same land and on the same helical line deforming tooth 5 performs plastic deformation of profile on the value $\delta i$. Subsequent chamfer teeth machine the rest of the thread profile in the same way. The teeth of the full thread part 2 performs finishing of the thread by plastic deformation and also act as guiding elements.

The proposed design can improve the accuracy of internal threads, simplify the process and increase the tool life.

Fig. 3. The design of deforming-cutting tap: a – the chamfer land view; b – the cross section of chamfer.

5. Experimental investigation of different designs taps

Fig. 4a represents microsection of threaded hole M4, which was formed by cutting tap. On the side faces of profile it can be seen the typical for this method defects in the form of steps 1. Fig 4b shows microsection of thread obtained by deforming tap. Side faces have the curved surfaces that caused by thread defects of tap and have craters on the tops [19]. As can be seen from Fig. 4c in machining of thread holes (M2...M6) by proposed deforming-cutting taps the thread profile meets the requirements for thread profile in the best way. This profile do not contain visible defects which are typical for thread machining by cutting or deforming taps.

Fig. 4. Microsections of thread profile obtained by: cutting (a), deforming (b), deforming-cutting taps (c).

For quantitative assessment of internal threads accuracy obtained by different taps the experimental study has been conducted and their results have been analyzed. The experiments were carried out for thread M4 in aluminium alloy 5052. Cutting speed was $V = 0,11$ m/sec and the coolant was SP-3. Thread profile deviations were determined by consecutive measuring of pitch diameter $D_2$ with thread gages.

A comparison of calculated and experimental data shows that the largest deviation of experimental values of pitch diameter is 20% from required.

Fig. 5 represents the deviations distribution of actual pitch diameters of holes, which were obtained by cutting, deforming and deforming-cutting taps.

The obtained empirical distribution curve of the diameter deviation is similar to the normal distribution curve. The analysis of the normal distribution curve shows that the scattering of the thread pitch diameter $\Delta D_2$ for cutting tap is 150% of the thread tolerance M4 for tolerance grade 4H [20], for tolerance grade 5H - 140% and for tolerance grade 6H - 115%. The scattering centre is displaced to the right relative to the pitch diameter of the tap, which is due to errors in the technological system.
The measuring of pitch and half-angle of threads obtained by deforming and deforming-cutting taps have shown that these parameters fully met quality requirements and were in the tolerance limits. The accuracy of thread pitch diameter for the tolerance grades 4H, 5H and 6H were in the tolerance limits and maximum values in percentage are as follows: for deforming tap is 75%, for deforming-cutting taps - 45% of the pitch diameter tolerance (for tolerance grade 4H). This difference can be explained by the difference of the values of cutting forces and correspondingly different values of errors, determining the range of the distribution curve.

![Fig. 5. The distribution of pitch diameter deviations of thread M4 depending on tap design: 1 – cutting, 2 – deforming, 3- deforming cutting.](image)

### 6. Conclusion

The influence of built-up edge on the tap teeth on the threads quality in aluminium alloys has been studied. A new design of deforming-cutting tap, which has both deforming and cutting teeth on the each land was proposed. A principle of operation of proposed tap is based on preliminary plastic deformation with following cutting of workpiece material. The results of experimental study have shown that utilizing of proposed combined deforming-cutting taps in processing of internal threads with a small diameter (M3-M6) in aluminium alloys can essentially enhance the accuracy and surface quality of threads.

### Acknowledgements

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### References


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