Tool Life Investigation of the Thread Making Tools

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The article deals with an experimental investigation tool life of the thread making tools. During long-time tests, the uncoated taps for M12 threads making were used. They were produced from high speed steel with cone type C. Three helix angles ω = 0°, 15° and 35° of taps have been investigated at the cutting speeds of 10 mmin^{-1} (within the first experimental phase) and 20, 30, 40 mmin^{-1} (during the second phase). The holes for threads making were pre-drilled into workpieces that were bars (with a cross-section of 30 x 60 mm). They were produced from C45 steel that is a standard material used at long-term tests of tool durability. Microhardness of the workpiece bars was checked within preliminary tests as well as a rank angle of tools to be ensured the same conditions of experiments. The changes in a size of the M12 thread outside the tolerance field 6H, the visible changes in tool wear and the brittle fractures of the tools have been selected as the criteria for tool life evaluation. Achieved results were statistically processed and the dependencies of thread length (m) and tool life (min) respectively on the cutting speed were plotted. The types of tool wear have been also analysed at individual cutting speeds.

Keywords: tool life, thread, tap, experiments, helix angle, tool wear

1 Introduction

Nowadays, a tremendous technological development in the manufacturing industry and manufacturing industries is making large amount of effort for their mass production with the best quality products having higher reliability and economical in cost. One of the very common machine operations used in manufacturing industry is a tapping of a screw thread. Hole-making is a class of machining operations that are specifically used to cut a hole into a workpiece. Machining, a material removal process, creates features on a part by cutting away the unwanted material and requires a machine, workpiece, fixture, and cutting tool. Hole-making can be performed on a variety of machines, including general machining equipment such as CNC milling machines or CNC turning machines. Specialized equipment also exists for hole-making, such as drill presses or tapping machines. The cutting tool is a cylindrical tool with sharp teeth that is secured inside a piece called a collet, which is then attached to the spindle, which rotates the tool at high speeds. By feeding the rotating tool into the workpiece, material is cut away in the form of small chips to create the desired feature.

Process of holes making has been widely used within all industry sectors. Usually, tapping is the last stage of the manufacturing process, therefore good tolerance (both geometrical and dimensional) and surface finishing must be achieved in order to result in a perfect assembly, with no clearance [1].

Internal threading is a highly complex operation not only due to the necessity to synchronize the ma-chine rotation and feed motion but also to features such as chip ejection difficulty (mainly in blind holes and in materials with short chip) and the difficulty in cooling and lubrication, when they are required. These issues are aggravated when machining large threaded lengths. This leads to great con-cern for it cannot fail, since it is an operation in many cases performed in work-pieces that already present high added value, and its failure would generate great expenses [2]. It is usually the last operation held in the workpiece manufacturing.

Tap (Fig. 1) is multi-wedge cutting tool with an active part in required profile in which a groove is ground. This groove forms the tool face and divides the base screw surface of the tool for a specified number of teeth. At the same time, it is used to remove the chips from the cutting site. The cutting part of tap (L1) has the shape of a cone, the bevel of the cone corresponds to the angle of adjustment of the major cutting edge.

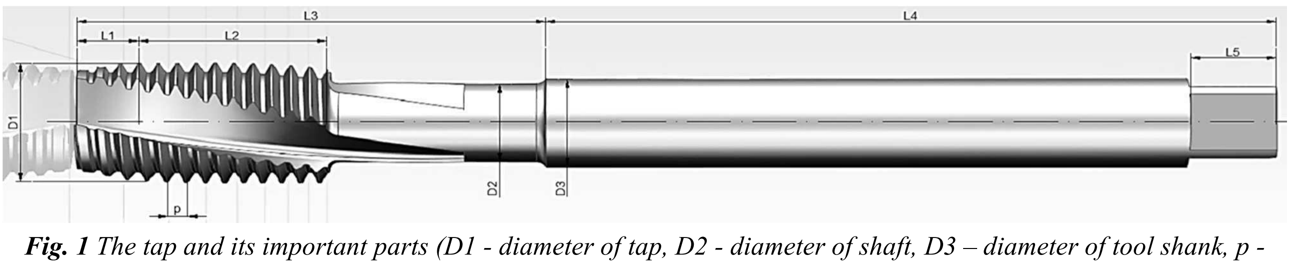


Fig. 1 The tap and its important parts (D1 - diameter of tap, D2 - diameter of shaft, D3 – diameter of tool shank, p - lead of thread, L1- length of cutting part, L2 - length of finishing part, L3 - length of shaft, L4 - length of tool shank, L5 - length of square shank)

Figure 2 [3] shows in detail the cutting part of tap, where

- P (Pitch) is the distance (mm) from a point on the screw thread to a corresponding point on the next thread measured parallel to the axis;
- β (the thread profile angle) is the angle between the flanks of the thread measured in an axial plane;
- ω (Lead angle / helix angle) of the thread is the angle of the thread at a pitch diameter with a plane perpendicular to the axis. The lead angle ω (helix angle) is dependent on and related to the diame-ter and the pitch of the thread.

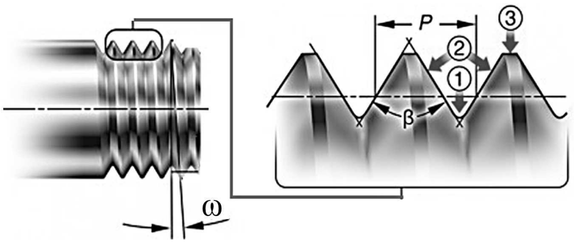


***Fig. 2** Cutting part of a tap in detail [3]*

There are many problems related to the tapping process such as thread dimensional accuracy, thread form error, and surface roughness of thread forms.

The lack of synchronism and stiffness of the machine tool or fastening systems results in a non-uniformity of the threads. Moreover, some tool materials as, for example, cemented carbide, require great pattern of synchronism and hardness in order to obtain success with the tool [4]. Thus, the synchronism between rotation and feed motion is highly important for manufacturing threads with good accuracy and surface quality [5]. Cutting fluids are often used in tapping processes and are believed to be beneficial to the reduction of tapping forces and improvement of thread quality [6].

Researcher Stephan et al. with his colleagues [7] studied the thread forming process and showed the influence of tap geometrical parameters and process parameters on the forming torque. Fromentin et al. [8] pointed out that the resistance of the work material and the lubricant are the two main parame-ters affecting the process. They specified that the flows of material in very severe frictional conditions at the interface of the thread lead to a strongly deformed tap on the surface. Cutting force in internal threading with tap, when the diameter and the pitch are equal, is influenced by tool geometry [9]. Zetek et al. [10] examined the tribochemical mechanisms lubrication during the form tapping process and therefore optimized the formulation of the lubricant.

All studies (not only mentioned above) resulted in the statement that tapping is difficult operation which is influenced by many factors, not only due to the large number of cutting edges involved into the tool [11], but also due to the complicated synchronization necessary between the rotational and the feed movements of the tap [12], a task particularly difficult at high speeds.

The present study aims to investigate the dependencies of thread length and tool life on cutting speed for three helix angles of taps to be possible predict the behaviour of tools at the machining.

2 Conditions of experiments

As a machined material was selected steel STN 41 2050 (C45) that is the standard material used at the long-term durability tests. It is non-alloyed steel, which is a reference material for tool life tests according to the relevant standards. The workpieces were the flat bars with length of 500 mm and the cross section of 30 x 60 mm with tolerance h11, presented in Fig. 3. Chemical composition of C45 steel is in Table 1 [13].

***Fig. 3** Experimental workpieces*

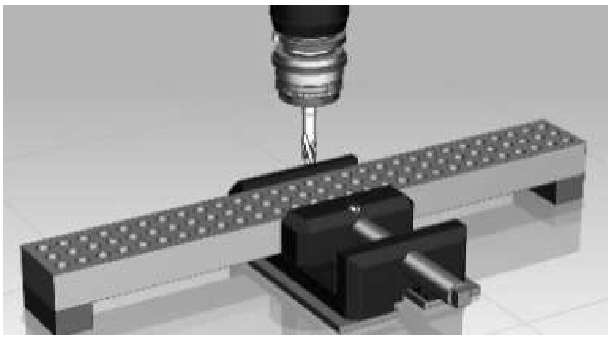


***Fig. 4** Workpiece fastened to the flat jaws during the tests*

***Tab. 1** Chemical composition of C45 steel [13]*

Component	C	Si	Mn	P	S	Cr	Ni	Mo
[%]	0.44	0.3	0.66	0.014	0.029	0.15	0.14	0.03

The workpieces were fastened to the flat jaws during the tests and their ends were supported as it is shown in Fig. 4. The holes ϕ 10.2 mm were pre-drilled and consequently processed by countersinking according to tools´ producer recommendations. The 5 % process fluid type of JCK PS was used during machining at CNC machine Pinnacle VMC 650.

The commercial taps with the metric profile and tool diameter of 12 mm for the threads production of 6H tolerance (Fig. 5) were selected as tools for experiments. The taps with cutting cone type C and helix angles ω = 0°, 15° and 35° were uncoated. The tools were produced from the HSS-E steel what is high performance steel with a homogeneous microstructure for cutting tools. The functional length of threads at tool with helix angle 15° and 35° was 20 mm, what means that the tool worked to the depth of 25.25 mm of pre-drilled hole. For helix angle ω = 0°, the depth of the thread was reduced in 5 mm as it is recommended by supplier what resulted in a cut depth of 15 mm. It was done due to the possibility to remove chips from the bottom of holes, what in the opposite case could cause a damage of cutting tool.

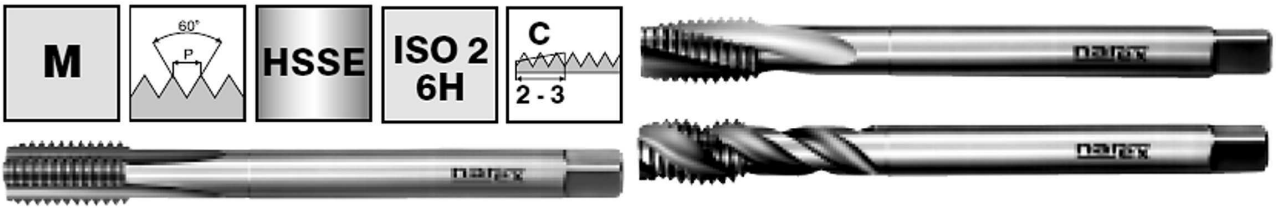


Fig. 5 *Taps used at the experiments*

3 Experimental study

3.1 Preliminary tests

Within the preliminary tests, the hardness of workpieces has been tested. Measurements were carried out by means of digital microscope containing calculus Vickers CV-400 DAT, with a resolution of 0.01 mm and a test load of 1000 g. Hardness measurement was performed at 20 locations of the workpiece cross-section. Based on measuring values, it could be said that hardness of the samples did not exceed the maximum value of 301.665 HV, while the hardness deviations from the average hardness of the material did not exceed +/- 5 %. The positions of points, in which the hardness has been measured, and the workpiece positioned in the measuring equipment respectively, are shown in Fig. 6.

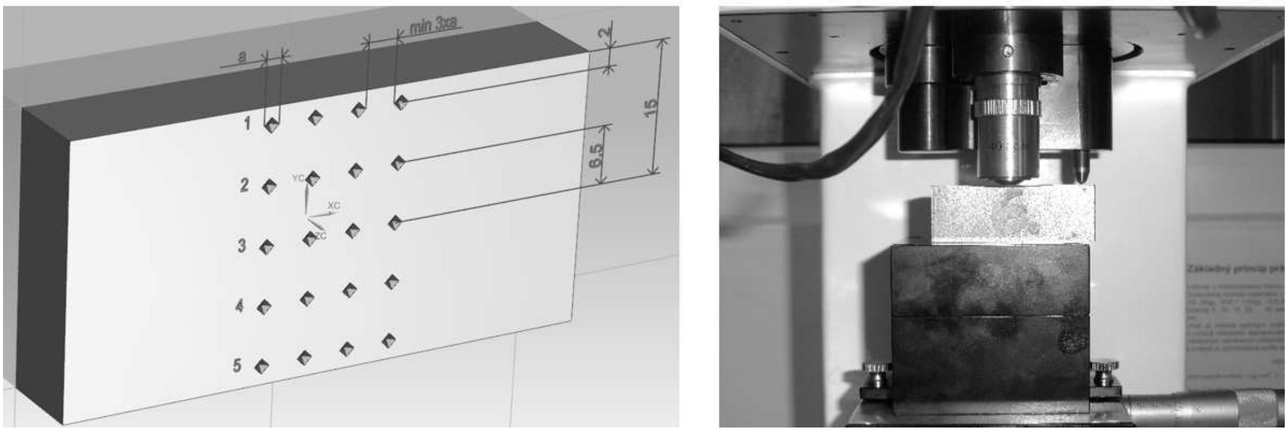


Fig. 6 *Locations of points of hardness testing on samples*

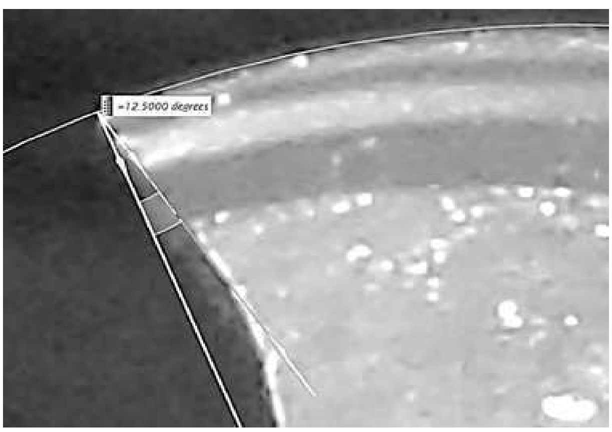


Fig. 7 *Measuring of face angle in a back plane of experimental tool*

The next factor, that was investigated within the preliminary tests, was a rake angle, because of its checking to be ensured the same conditions during experiments. The measured rank angle in a back plane at one of the experimental taps is presented in Fig. 7.

3.2 The first experimental phase

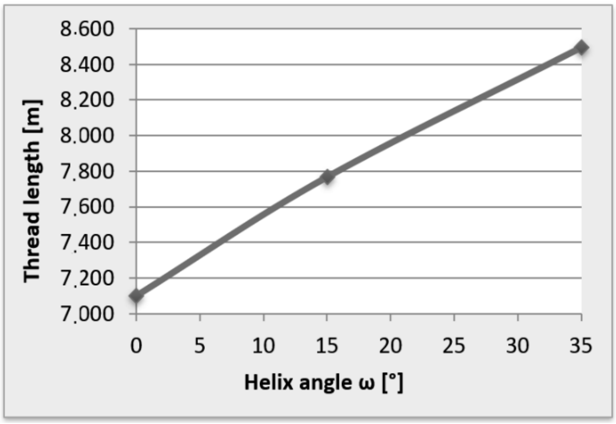
Cutting speed v_c = 10 mmin^{-1} was used in the first phase of the research based on the tools´ producer recommendation. The feed per revolution of the tap is given by the pitch of M12 thread, so the feed rate per minute is connected to the number of revolutions.

Due to a possibility to compare achieved results, the brittle fracture has been selected as a criterium for tool life evaluation in this phase. The experiments have shown that important effect on durability has the pitch of the thread. When cutting the face of the tap at an angle other than ω = 0°, it occurs to the transformation of the shape of cutting edge (at the zero angle, the face of tool has a precisely negative shape of a workpiece, while the cutting edge, as a line that is created by intersection of the face and the back surfaces of the tool, describes the future thread profile in the axial cross-section). However, the turn direction of the thread helix also influences the direction of a chip leaving, which is another factor affecting the wear of the cutting tools, especially in processes where the conditions of chip removal from a cutting zone are difficult, as is the case with threading of through holes. As mentioned above, the inclination of the helix angle of tool of the size ω = 35° produces a minimum torque at thread cutting and also ensures that the chips are formed into a smooth and regular screw face. [14,15]

The average values of measured thread length [m] and tool life [min] for three helix angles of taps are presented in Table 2, while the graphical representations of the obtained data on helix angles are shown in Fig. 8.

Tab. 2 *Measured values of thread length and tool life of taps*

Helix angle [°]	Thread length [m]	Tool life [min]
0	7.100	15.310
15	7.767	16.748
35	8.493	18.314



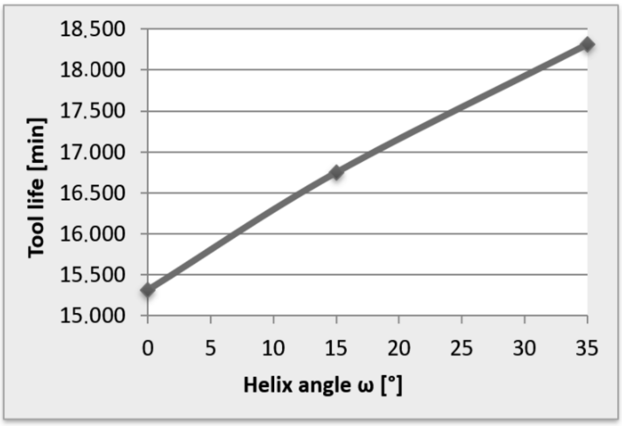
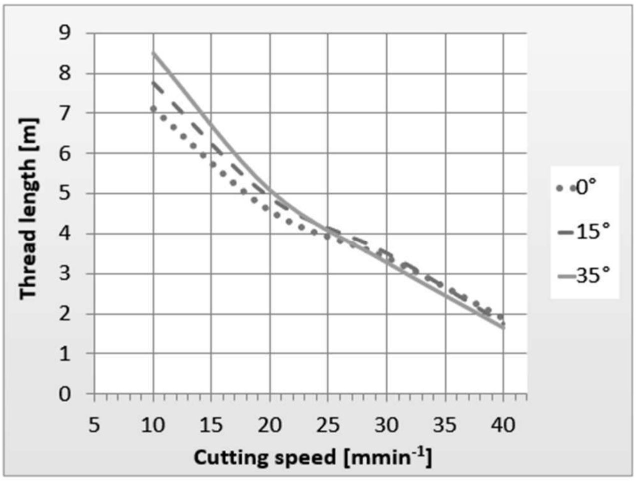


Fig. 8 *The dependencies of thread length and tool life on helix angle*

However, the tests carried out within the first phase (at the cutting speed 10 $mmin^{-1}$) have shown that durability of all tested tools was higher than it is given by producer. It was a reason, why the authors decided to continue in experiments and to use higher cutting speeds at the machining within the threads making.

3.3 The second experimental phase

Based on results obtained at preliminary test authors decided to use higher cutting speeds 20, 30 and 40 $mmin^{-1}$ within the main experiments (2nd phase) and to study the dependencies of thread length on cutting speed as well as the tool life on cutting speed for helix angles ω = 0°, 15° and 35° of studied taps. The measured values were submitted to the remoteness testing according to Grubbs´ test at the significance level of 0.05 that indicates a 5 % risk of concluding that a difference exists, when there is no actual difference. [16] The results of statistical processing confirmed the strong functional dependences of the measured values in all studied cases. Obtained results are shown in Figure 9.



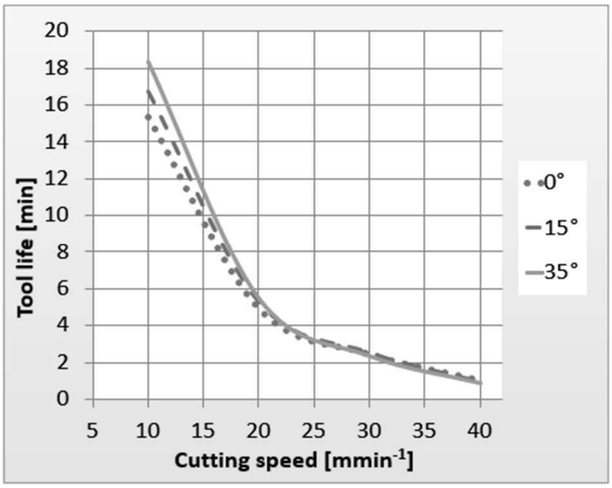


Fig. 9 *Dependencies of machined thread length and tool life on cutting speed for three investigated helix angles*

A change in a size of the M12 thread outside the tolerance field 6H, a visible change in tool wear and a brittle fracture of tool have been selected as a criterium for tool life evaluation. [17] The assessment of tool wear level has been done by means of thread gauge and digital microscope camera DigiMicko 2.0 scale.

It was found out that the tool wear caused by plastic deformations mostly appear at the flank or at the tool corner. At the cutting speed of 20 $mmin^{-1}$, apart from the abrasive attrition on the tool flank and the plastic deformation, the built-up-edge began to appear at cutting edge (Fig. 10). The highest lifetime has been shown at a tool with a helix angle of 35°. Similarly, as it was at $v_c = 10$ $mmin^{-1}$, neither in this case, the inconvenient dimensional tolerances determined by the standards were not measured in the holes before the tool fracture.

Fig. 10 *Example of tool wear (built-up-edge) at cutting speed* $v_c = 20$ $mmin^{-1}$

Cutting speed of 30 $mmin^{-1}$ caused cutting edge fracture, built-up-edges, a relatively intensive adhesion of material on the tool flanks, intensive erosion and deformation of the tool corner. Threads with worse surface quality and incorrect profile started to appear. It should be noted that brittle fracture of tool occurred shortly after what this thread began to appear. The greatest durability at $v_c = 30$ $mmin^{-1}$ was achieved by tools with helix angle of 15°. It seems to be a compromise between the strength of the cutting tool wedge and the ability of the tool to remove a chip out of the threaded hole. An example of tool wear at cutting speed $v_c = 30$ $mmin^{-1}$ is shown in Fig. 11.

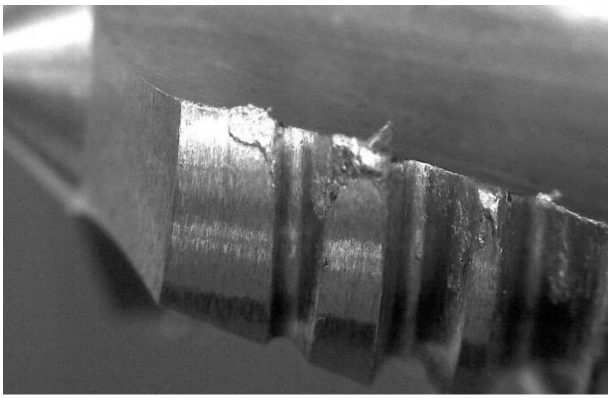


Fig. 11 *Example of tool wear at cutting speed* $v_c = 30$ $mmin^{-1}$

The wear at a cutting speed of 40 $mmin^{-1}$ was similar to 30 $mmin^{-1}$, with the difference that the wear intensity was higher. Highest durability was achieved by tool with 0° helix angle. The reason probably lies in the highest strength of the cutting wedge.

4 Conclusions

By increasing cutting speeds, a higher productivity can be achieved, either increasing profitability or lowering the cost of the manufactured component. This increase, however, has to also be advantageous in terms of tool wear as, as was demonstrated by preliminary tests, the tool breaks out suddenly without any noticeable deterioration in thread quality. Since the threading belongs to the last operations, the tool fracture would cause a failure with almost all machined surfaces.

After cutting speed increasing the intensity of tool wear also increased. The brittle fracture of tested tools usually appears a while after visible plastic deformation at tool flank or corner, after built-up-edge formation or after material chipping. At cutting speed 20 $mmin^{-1}$ the highest durability was observed at the tool with pith angle of 35°, but at the speed 30 $mmin^{-1}$ it was at angle of 15°. It is probably a compromise between the stiffness of the tool wedge and the ability of the tool to remove a chip out of the hole that is machined. The highest durability of tool at cutting speed 40 $mmin^{-1}$ was achieved by tool with 0° helix angle. The reason is probably the highest strength of the cutting wedge.

In the next future authors claims to study the taps behaviour during machining and a possibility to evaluate tool wear by means of recorded vibrations.

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