

Thread Forming Tools with Optimised Coatings

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Abstract: Different tool geometries have been developed by leading companies in the tool industry to different aims of application. The fastest progress can be observed in the development of coatings, in spite of this it can be noticed that there are only few coating types, but they can be used in a wide range. For users it offers the great advantage to select appropriate tool easier. Coating types, developed specially to individual aim of application, offer much better solution, compared to the generally used coating types. Platit AG, dealing with the development of optimised coating types, has requested our specialised group to carry out tests on specialised coating types. Our present study is going to summarise the results of the tests, carried out with thread forming tools.

Keywords: thread forming; minimal quantity of lubrication; coating types; CrTiN; AlCrN; AlTiN

1 Characteristics of Thread Forming Operations

Thread forming operation is a technological alternative to the thread drilling. Due to the developed coating types and tool materials, high-performance tools have appeared on the market, being able to achieve greater productivity under certain conditions: although higher forming speed values can be applied, the tool life has a multiple of the value, gained by thread drills [1, 2].

Compared to the thread drilling, the thread forming operation has the below listed advantages:

- there is no chip development, causing several problems in case of thread drilling during the chip flow from the hole [3],
- the same geometry can be used to blind and through holes,
- due to the cold formation there is an increase in the strength of the thread (this fact has an increased importance especially in case of threads, having small diameter, see **Figure 1**)[4],

- compared to the thread drilling operation, it is possible to carry out the thread forming operation with double forming speed values and at the same time with increased tool life,
- the same clamping device can be used like in case of thread drilling (there are no special demands).

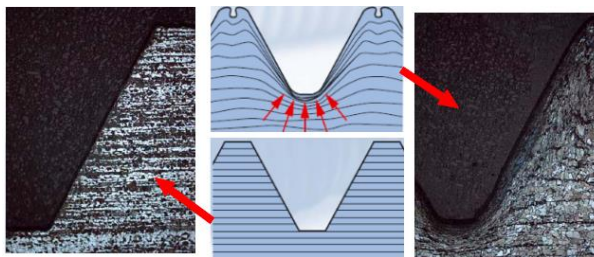


Figure 1

The difference between threads, machined with cutting and forming operation (on the left side of the picture: thread, machined with cutting operation)

As disadvantage we must mention that tool producing companies do not suggest to carry out forming operations of plastic materials or materials, having high fracture strength ($>1400 \text{ N/mm}^2$) and low breaking extension ($<5\%$). In case of steels, titanium and nickel alloys, having a fracture strength value higher than 1200 N/mm^2 , it is recommended to apply emulsion lubrication of 10% instead of MQL (minimal quantity of lubrication). In case of thread forming it is necessary to make a core hole; however, the size of the necessary hole is different: for example, in case of a thread with size M6x1, the diameter of the core hole is 5 mm in case of thread drilling, while in case of thread forming it is $\text{Ø}5.55 \text{ mm}$. Thread forming operation is more sensible to the diameter of the core hole and to the shape adherence (e.g. roundness error). If the core hole is smaller than the permissible size than there will be an increase in the torque demand and a decrease in the tool life. Knowing this fact we have to emphasise: a greater attention should be paid to the preparatory works in case of thread forming operation.

2 Aims and Conditions of the Examination Process

The examinations have been carried out on thread formers, having a size of M6x1 6HX (HSSE) – the tools have been deposited with 5 different coating types. The types and the most important data of the coating types, deposited on the tools, are the following:

- #1 original (deposited by the producing company) TiN-coating, with a thickness of $2\text{-}4 \text{ }\mu\text{m}$ and hardness of 2300 HVM,
- #2 CrTiN (monolayer) coating with thickness of $2.5 \text{ }\mu\text{m}$ (hardness: 38 GPa),

- #3 **Al_{0,6}Ti_{0,4}N-coating** with thickness of 2.5 µm (hardness: 42 GPa),
- #4 **Al_{0,5}Cr_{0,5}N-coating** with thickness of 2.5 µm (hardness: 42 GPa),
- #5 **TiN coating** with thickness of 2.5 µm (hardness: 38 GPa).

The coating types, marked with #2 ... #5, have been deposited by the subsidiary of Platit AG (Pivot s.r.o., Sumperk, Czech Republic) on bright, high-speed steel tools. Having studied the tool catalogue of the company, selling thread forming tools, this tool structure is recommended to constructional and carbon steels, alloyed and unalloyed aluminium and to unalloyed yellow brass. The allowable range of forming speed values is 12-25 m/min. The hole, to be formed, may be either through (> 1.5xd) or blind hole (> 2.5xd).

With the execution of the examinations we wished to find answer to the following questions:

- Where and what kind of wear types do develop on the forming tools? How is the deterioration of the tool affected by the coating type?
- How is the behaviour of the forming tools affected by different forming speed values?
- Which from the coating types will be the optimal solution under the test conditions, applied by us?
- What kind of behaviour can be observed in case of thread forming operation of materials, having high fracture strength and in case of MQL?
- In what way can the deterioration process of the forming tools be followed best?
- What kind of changes can be observed in the torque development and in the machined surface if flood type of lubrication is applied instead of minimal quantity of lubrication?

In order to evaluate the results in an objective way we have measured the torque demand of the tools by a rotating multicomponent dynamometer, produced by Kistler at every fifth thread and after every 5th-10th thread we have checked the wear process of the tools by a microscope. From the point of view of users, the behaviour of tools is not the only fact, being relevant, the quality of the machined threads has an important role as well; therefore the threads have been regularly checked by us with a gauge.

The workpieces, prepared to the examinations, have been made from a pre-tempered material grade 40CrMnMo7 (W. Nr. 1.2311), having a fracture strength of 945 N/mm² and breaking extension of 7.75%. In the industry this tool steel is a widely used base material in case of injection moulding and pressure casting die.

The thread forming operations have been carried out on through holes of 1.5xd. In case of a deeper hole it is recommended to use internal MQL, so the external lubrication, applied by us, will not be optimal anymore [5]. The MQL device

vaporizes vegetable based oil, type: TRIM TAP NC, with the help of compressed air, and it can be directly led to the forming tool through the nozzles. The desired oil quantity can be regulated with the valves of the device. According to the most literatures, the applied quantity is between 5...50 ml/h. (In case of application of the traditional, so-called flood type of lubrication the liquid flow may achieve or even exceed a value of 50 l/min.) On the applied machine (type: HCS250, produced by TKM (Germany)) the oil consumption can be measured with the help of an external electronic device, developed by us [3].

Every coating has been tested at three different forming speed values (14, 20 and 25 m/min) so that the circumstances of the MQL should remain as it is. During the trials, the internal (operating) pressure of the MQL device had a value of 3 bar, while the external pressure, causing the pulverizing, was 0.6 bar. The trials have been carried out with these values, the delivered oil quantity was 21 ± 0.5 ml/hour, according to our measurements.

Table 1
Test's parameters

Forming speeds, m/min	14	20	25
Hole depth (trough hole), mm	1.5xd		
Pilot hole diameter, mm	Ø5.55		
Workpiece	40CrMnMo7 (W. Nr. 1.2311)		
MQL unit parameters (TKM HCS250)	internal pressure, bar	3	
	external pressure, bar	0.6	
Measuring system	KISTLER 9257A measuring unit+Dynoware software (Kistler AG)		
Machine tool	Mazak Nexus 410A Vertical Center		

3 Tests' Results in Case of Application of Minimal Quantity of Lubrication

The suitability differences between the coating types have been reflected well by the results of the tests, carried out by us. Based on our experiences, the most evaluable results have been gained at forming speed value of 20 m/min. At the lowest forming speed value (14 m/min) the tools have worked with „too” long tool life, therefore (due to time and material saving) we have discontinued the execution of tests after having achieved a certain number of machined holes. The highest forming speed value (25 m/min) has been found too high in case of certain coatings: due to the very low number of machined holes these types could not be used under industrial circumstances.

Figure 2 shows the phases of thread forming operations, furthermore, the deterioration process of tool teeth and the development of vibrations. The left side of the picture shows the temporal development of forming operation parallel with the curve of torque development, registered by the torque measuring device where,

- the 1^{st} part is the so-called running-in phase when the roughing part of the thread forming tool enters the hole (it means a three-thread upgrade),
- the 2^{nd} part is the phase, belonging to the gradual development of thread. A small increase can be noticed in the torque demand as an increasing portion of the forming tool surface will ream the wall of the hole,
- 3^{rd} part is the phase of reversion. Reversion means a change in the rotation direction after that the forming tools unscrews from the hole, already machined. The change in the rotation direction results in negative values of torque, the amount of this value reflects how great friction is caused by the thread forming tool in the thread during the reversion.

The development of torque can be seen on the right side of **Figure 2**, when the forming tool has already suffered a deterioration to a great extent and it has resulted in the development of vibrations.

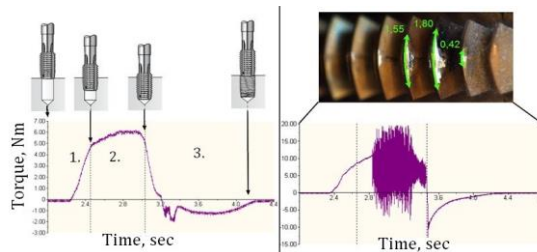


Figure 2

The phases of torque curve, the development of vibrations due to the deterioration of the tool

During the execution of the tests we have observed that every forming tool has started to work with a relatively great torque. The values, registered by us at the beginning, have decreased after having achieved 10-20 holes, after that – parallel with the increase of the tool deterioration – they have started to rise again. The drastic torque increase and the appearance of the vibrations have occurred when the critical wear has developed on each forming row of the tools (**Figure 3**).

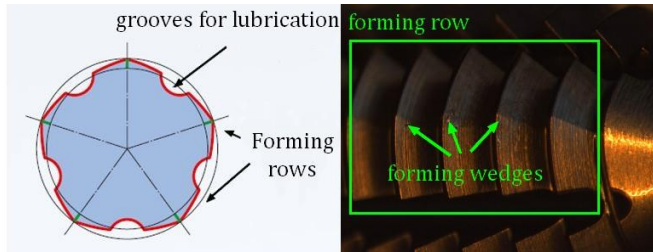


Figure 3

Basic construction of the forming tool. The left side of picture: interpretation of forming rows (section). The right side of picture: forming row and forming wedges (view from above)

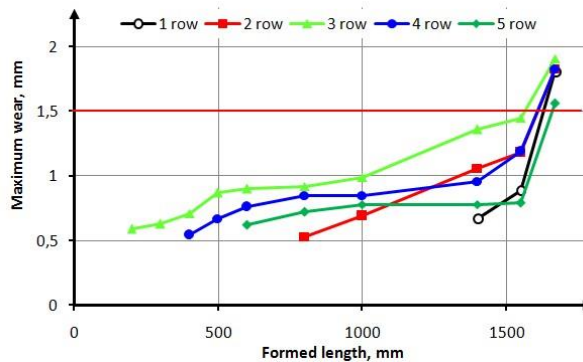


Figure 4

Maximum wear values, measured on the CrTiN-coated tool

On **Figure 4** the greatest wear values are shown, measured on the forming rows of CrTiN-coated tool, in function of the machined hole length at forming speed value of 20 m/min. In the majority of cases the wear has developed on every roughing forming wedge (i.e. on the first three pitches of the tool). Our experiences show that in case of M6 tool it is enough to pay attention to the greatest measurable wear value as it reflects the condition of the tool under test circumstances with the necessary accuracy. The thick line, marked on the diagram, shows the wear limit (1.5 mm): if this value is exceeded by the wear values, measured on every forming row, then the tool most likely will deteriorate during the formation of the next few holes.

On **Figure 5** the maximum torque values have been depicted in function of the summarised maximum wear values. The continuous graph has been drawn based on the measured values and it shows a correlation of 99 percent. Based on it we rightly suppose that there should be a tight and clear correlation between the torque demand and wear development, under such circumstances. This announcement can not be made universal for tools, having different construction and size: it would be necessary to carry out several check inspections to do this statement. As it can be seen well, there are no measured results between the two

last torque measurement values (in the zone, marked with a circle), it means we do not have information about the „behaviour” of this zone. In order to draw well-founded conclusions it would be necessary to carry out further examinations on this zone.

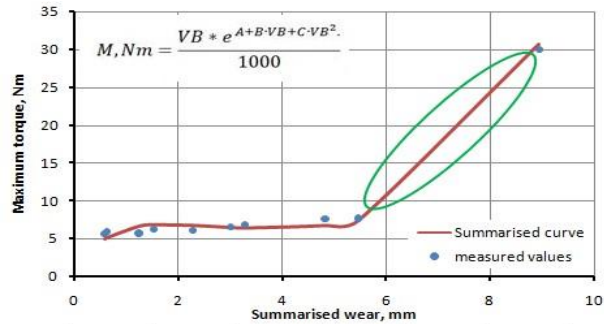


Figure 5

The development of the maximum torque values, in function of the summarised wear

The main aim of the examination process was to determine differences between the performance of different coating types. The number of machined holes is the most suitable character to do it. The maximum measured wear values have been shown on **Figure 6**, in function of the number of machined holes. The thick line, marked on the diagram, shows the maximum torque limit of 8.5 Nm: if this value is exceeded during the tests, then the tool most likely will deteriorate during the formation of the next few holes. Analysing the figure it seems to be clear that there can be even a fourfold difference between the number of machined holes (due to the coating layer type).

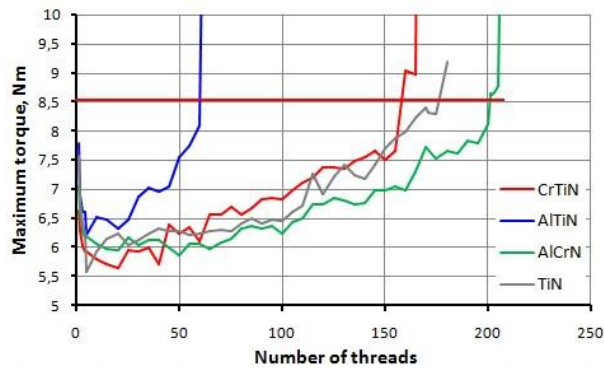


Figure 6

Maximum torque values at a forming speed value of 20 m/min

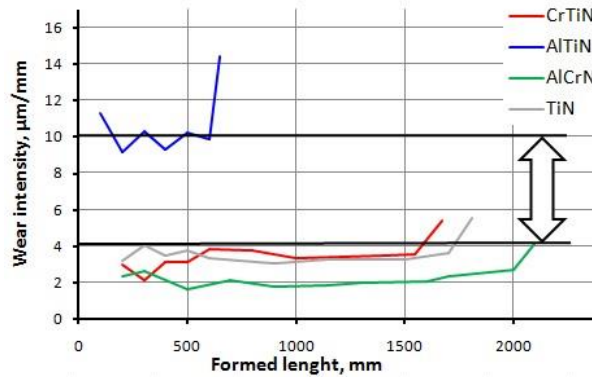


Figure 7

Wear intensities at a forming speed value of 20 m/min

The differences between the coating types can be defined numerically with the below formula:

$$\text{Wear intensity, } \frac{\mu\text{m}}{\text{mm}} = \frac{\text{Cumulated wear size of rows, } \mu\text{m}}{\text{summarised machined length, mm}} \quad (1)$$

The wear intensity has been indicated on **Figure 7**, in function of the formed length. The AlTiN-coated tool excels with its considerable and oscillating wear intensity. Other coating types have worked with (approx. 60 percent) lower and almost steady wear intensity. This is an important information from the point of view of predictable deterioration process and condition monitoring of tools.

4 Comparison of Cases with MQL and Flood Type of Lubrication

The flood type and the minimal quantity lubrication can be seen in **Figure 8**.

Tests were made at a forming speed value of 18 m/min. The core holes were made with different diameters ($\varnothing 7.3$; $\varnothing 7.4$; $\varnothing 7.5$; $\varnothing 7.6$ mm), because we wanted to get a clear picture about the effect of the change in the core hole.

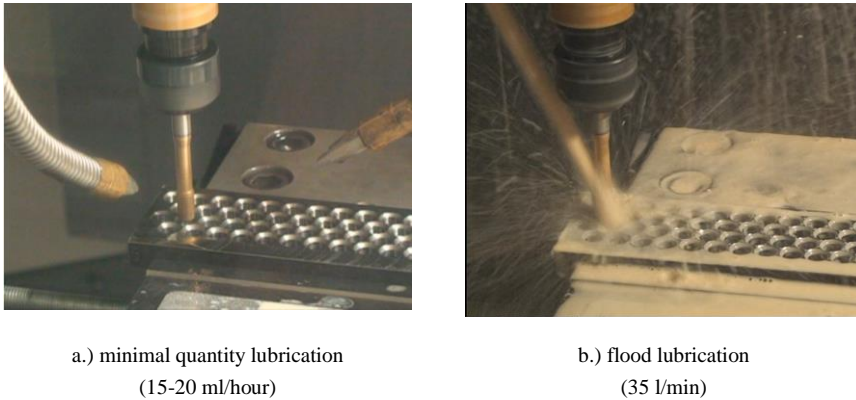


Figure 8

Two types of cooling and lubrication

10 holes have been made in case of both types of lubricating methods. Tool wear has not been measured during the trials, the same tool was used for the tests in case of both lubrication methods. The **Table 2** shows the values recommended by the manufacturers.

Table 2

The measured and the real size of the core holes

Size of pilot drill, mm	Ø7.3	Ø7.4	Ø7.5	Ø7.6
Measured size (average), mm	7.36±0.01	7.41±0.01	7.58±0.01	7.63±0.01
Recommended hole diameters, mm: 7.41-7.48 mm [6]				

The registered and measured torque values can be seen in **Figure 9**. Based on the measured results, it can be observed that minimal quantity lubrication required less torque in every case. If we increase the core hole diameter, the difference between the two lubrication methods will be smaller and smaller. This phenomenon can be explained by the fact that by the increase of the core hole diameter, the forming part of the tool touches the workpiece material on a smaller and smaller surface. On this surface the adhesion reducing effect of the lubricating oil film is lower.

It can be seen, that the difference between the two types of lubrication methods is 19 percent in case of the recommended core hole size.

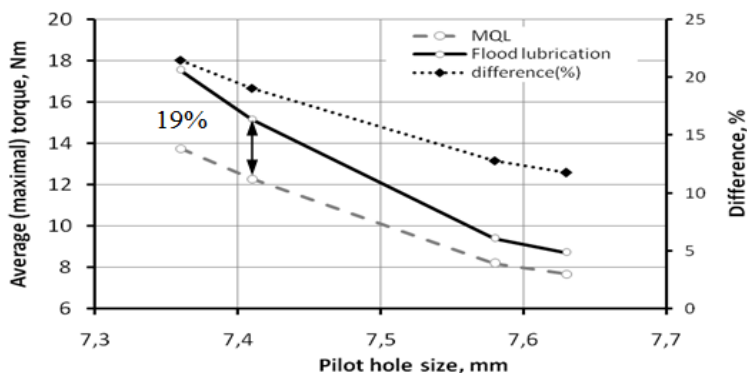


Figure 9

Average torque versus pilot hole size in case of different types of lubrication

From these results the conclusion can be drawn that the friction between the tool and the workpiece is significantly reduced by minimal quantity lubrication under the circumstances, applied by us – and parallel with it, less energy is needed for the forming operation. Our experiences and the negligible costs of the MQL unit should be considered when calculating operating costs. The difference between the two lubrication methods point to the fact that minimal quantity lubrication is less „sensitive” to the changing of core hole size. If there is a decrease in the core hole diameter (due to the deterioration of the drill) or, on the contrary, there is an increase therein, then minimal quantity lubrication can be used with greater certainty. Of course, several tests are necessary to verify this statement. We will have the opportunity to carry them out.

The machined surface can be seen in **Figure 10**. A more favourable surface finishing effect of minimal quantity lubrication can be observed on the images. (The photos were made by stereomicroscope, with different magnification.) In case of cooling and lubrication by an emulsion, the machined surface is more „ragged”, cavities and droplets can be noticed.

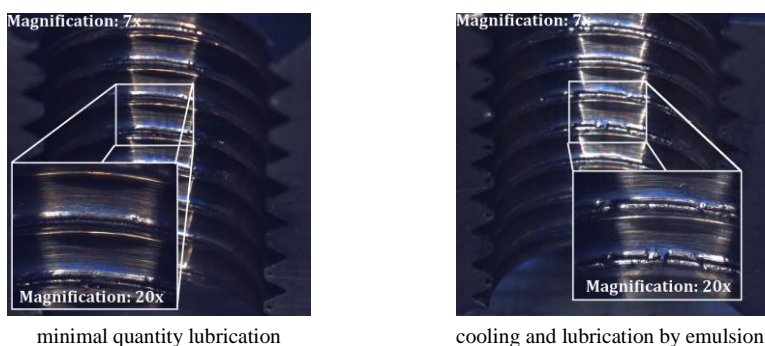


Figure 10

Pictures of the thread – pilot hole 7.41 (7x, 20x magnification)

Summary

Some questions have been put by us during the description of the aims of the present examination process. The answers, given below, have been found:

- From the analysis of the places, where wear has developed, it has become clear that primarily the roughing-forming wedges have suffered wear, it does not depend on the coating type, tested by us. Based on the measurements, carried out by us, it has been proved that in case of forming tools, having size of M6, the maximum wear can be determined with the length of wear arch, it is 1.5 mm: if this value is exceeded by the wear values, measured on every forming row, then the tool will achieve its performance limit soon.
- It has become clear that the performance of the original tool, coated by the producing company, has been overmatched by the tools, coated by Platit (it has become clearly visible at the lowest forming speed value).
- Under the present test circumstances, the increase of the forming speed values drastically decreases the number of machinable holes, therefore the forming speed value of 25 m/min is too high.
- The wear condition of the forming tools can be followed by the torque measurement very well. From the examination process, carried out by us, it has become clear that the upper torque limit is 8.5 Nm – if this value is exceeded, the tool deterioration is expected.
- Our tests have clearly confirmed the following fact: with the use of an appropriate selected coating (i.e. optimised to the task) results can be achieved, being unapproachable by any universal („industrial”) coating. This conclusion, drawn by us, can be confirmed by the following fact: at a forming speed value of 14 m/min the so-called „industrial” coating has „produced” only 15 holes, the AlTiN- and AlCrN-coating types more than 500 holes.
- The value of the forming torque may be by 19 percent lower in case of MQL (with mostly recommended pilot hole), compared to the flood type of lubrication. According to the photos, taken by the electron microscope, the surface intactness and smoothness of the thread profile is much favourable if MQL is applied, compared to the flood type of lubrication. In this way the machined thread may be better not only from point of view of strength, but – probably - from the aspect of the corrosion resistance as well.

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