

Influencing the Process Stability for Tapping Through and Blind Holes by Taps with Radial Lubricant Supply



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Abstract The large number of drills and taps in automotive power train components make these processes to a considerable machining step. Due to the fact that hypoeutectic Al-Si alloys tend to adhere on the tool surface, the machinability of these alloys is challenging. In times of modern light-weight design, every gram counts. Therefore material, which is not necessarily needed, is removed from these components, designwise. One result of such steps is an increased number of clearance holes at the power train components. The requirements of short cycle times due to cost reasons induce the manufactures to machine blind holes and clearance holes with one tapping tool to reduce the non-productive time of tool changes. These tools normally have a centred internal coolant supply providing sufficient chip evacuation. Especially the adhesion of Al has a negative influence on the chip transportation and leads to an increase of stochastic inclinations of clogging the chip flute. In course of the present work, it is shown that this tendency increases when the chips are not properly flushed out of the flutes. Obviously this process instability increases when machining clearance holes by tools with a centred internal coolant supply. Sandvik also detected this problem and patented a tapping tool with a central bore and radial coolant channels for every flute in the area of the tool chamfer. According to this idea a tool was designed by finite element method for mechanical structure. Also fluid dynamic studies have been created to determine the lubricant flow. With prototypes of such a tapping tool, cutting tests were performed in Al-Si alloys compared to conventional tapping tools.

Keywords Tapping · Chip removal · Coolant supply

1 Introduction

The high number of required connecting components along the automotive power train components make internal thread tapping to one of the most demanding

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machining operations. If process instabilities occur, the result is usually a tool failure and the consequence is tap breakage. Due to the fact that the workpiece material encloses the tool, a fracture results in a clogged borehole with the broken tool consisting of hard material. From an economic point of view such an incident is a disaster as thread tapping operations are nearly amid the final machining processes. So there are two costly decisions to make: re-working or rejecting the work piece. Nevertheless many other issues are also associated with the process stability like the dimensional accuracy, thread form errors and surface roughness of thread forms. These failures are usually detected by the quality check after the machining or during the assembling.

The influence of the machine tools is in addition also to be considered. Here the synchronous interaction between the rotation of the spindle and the axial motion of the feed axis is fundamental [1]. Especially when the revolution speed and the feed rate decelerate, subsequently stop, and after that accelerate in the reverse direction. During this section of the process, the rotational speed and the feed rate have to be tuned accurately.

The importance of the knowledge about the tapping process fundamentals, which are related to the chip formation, the chip transportation and the tribological behaviour of the work-piece/tool system are rather complex. The chip formation itself is dependent on the number of cutting lands, the chamfer length/angle, the pitch, the rake angle and optionally the angle of helical flute. All these parameters entail that every chamfered cutting edge has a different nominal width of cut and also the radial diameter at the gate part is changing constantly with the pitch [1].

Moreover, the aspect of the machined material is also evident. The objective of this study is to determine the indicators for the process stability of the thread tapping process in hypoeutectic Al-Si alloys. Particularly Aluminium with its tendency of adhering at the cutting edge and the rake face is influencing the chip formation in a negative way, as due to an occurring build up edge (BUE) the cutting edge is not geometrically defined anymore [1]. Besides Aluminium is also responsible for so-called build up layers (BUL) in the rake face [4]. Here are also the tribological interactions between work piece material, tool material/coating and the metal fluid aspects responsible [5]. This fact is also influencing the chip transportation and evacuation in a stochastic manner, because chips can adhere to such BUL.

2 Tool Failures in Thread Tapping Processes

One major issue for designated tool failures is the chip evacuation. Previous studies have also indicated that clogged flutes are very common [6]. The chips are pressed in the flutes to a conglomerate and act like a barrier, which clamps the tool in the borehole. In the worst-case scenario, the tapping tool cannot resist and a tool breakage is the result.

This phenomenon leads in both major process steps, during the forward chip formation process (FCFP) as well as in the backward tool removing process (BTRP),

to tool breakages. During the FCFP the risk of clogging chip flutes increases with the borehole depth because the removed material is rising with the depth and if there is the tendency of clogged flutes, additional chips cause pressure against the affected lands until the critical load is exceeded. Throughout the BTRP the problem occurs directly after the change of the rotary motion of the spindle. The chip conglomerate runs the risk of being pinched between the lateral surface of the bore and the relief of the tool. In Fig. 1 such an incident is depicted (Fig. 2).

Apart from adhesion wear, another factor typically influencing process stability is the tribological wear. This phenomenon typical occurs at the flank and depends on the frictional conditions, hence on pressure as well as on the temperature between the tool and the workpiece. In previous studies, this effect was primarily related to thread forming [5], but it is also crucial in thread tapping because of the enclosed

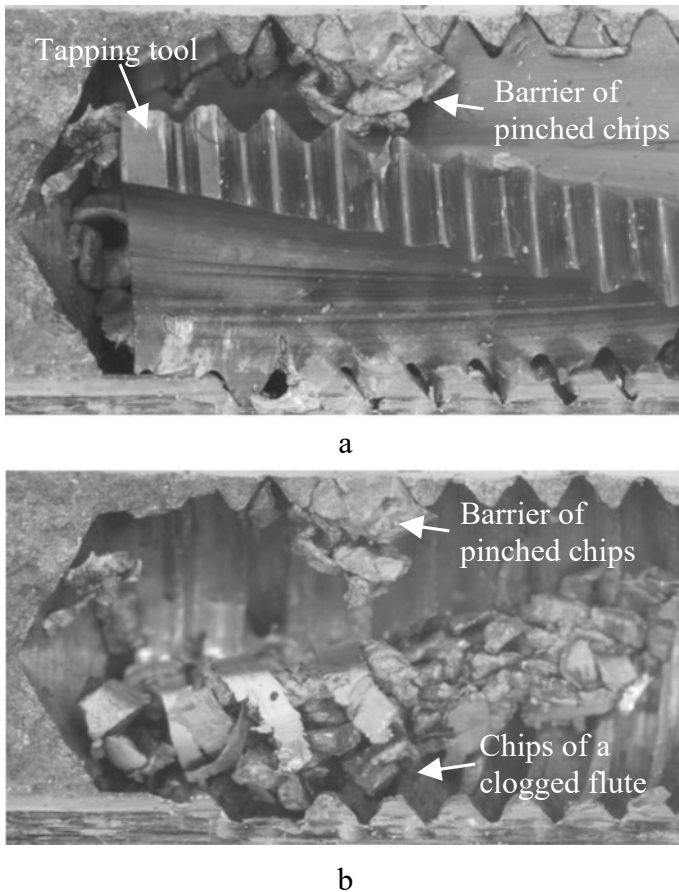
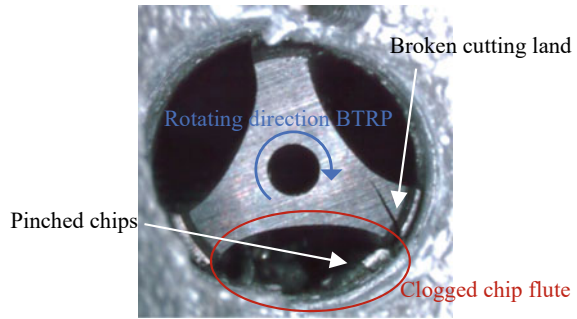


Fig. 1 Sliced workpiece with tool failure, with **a** tapping tool and **b** removed tool

Fig. 2 Broken tapping tool in a through hole



frictional interaction between the tool flank and the workpiece. Thus this process is in general sensitive towards the interaction of the tribological pairing [5].

Apart from application errors like inaccurate tool clamping, wrong borehole diameters/depths or machine codes, the clogged flutes are the reasons for tool failures.

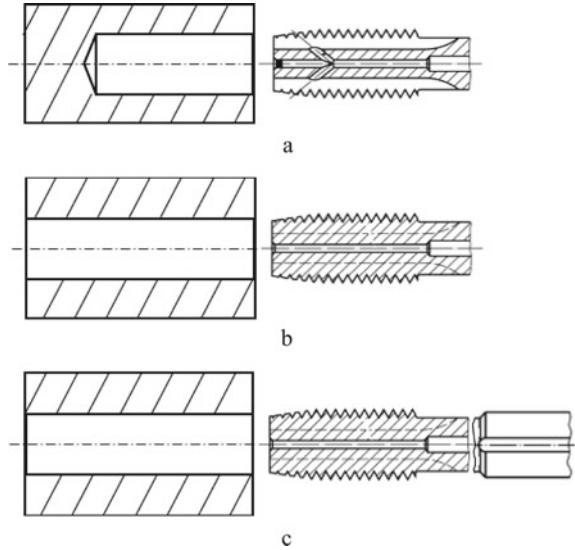
2.1 Improved Tribological Interaction and the Chip Transportation in Tapping Through and Blind Holes

There are several approaches to improve the interaction between the contact partners, namely the workpiece, the tool, the coating and the metalworking fluid (MWF). In previous works the interactions between MWF and tapping tools have been evaluated [5, 7]. Also several different coatings on HSS or tungsten carbide tools have been tested [1] and [2].

For through holes and blind holes there are different approaches to design tool geometry for tapping tools. On the one hand, for the through holes, spiral point taps with straight flutes are recommended. Here external nozzles provide the MWF supply. In addition, axial grooves along the tool shank or internal supply with radial outlets to flush the chips through the holes are common. On the other hand for blind holes the chips have to be evacuate in the opposite tool feed direction. Therefore, spiral flutes are applied and the MWF supply is realised by axial internal coolant holes.

All these cooling strategies show weaknesses when machining through holes and blind holes with one tool. Using spiral point taps is not satisfying as the removed chips are tempted into the blind hole (see Fig. 3a). Subsequently the chips will act as a barrier and as a consequence as a mechanical punch if the tap clearance is not long enough. By machining through holes with internal coolant supply there is no sufficient support of the fluid (see Fig. 3b) and with rising machining depths also the risk of tool failure increases. Therefore, it is very common to make a compromise and apply an internal coolant supply (axial) and additional grooves along the tool shank (see Fig. 3c). However, when machining through holes, this is also not very suitable because the MWF is not transported to the effective working area.

Fig. 3 MWF supply **a** internal radial, **b** internal axial, **c** internal axial and grooves along the tool shank [8]



2.2 Improved Metalworking Fluid Supply for Tapping Through and Blind Holes

Supplying the effective working area with MWF is the aim in thread tapping to improve the process stability and the tool life. Sandvik also sees this as a fundamental aspect and thus they patented (Fig. 4) a tapping tool where the coolant flows out of the axially running cooling channel and is diverted radially outwards at a diversion element [9]. This provides an appropriate MWF supply for machining blind holes as well as for through holes.

Based on this patent and on the DIN 4000–80, tapping tools were designed to improve the coolant supply (Fig. 5). FEM and CFD simulations based on measurements of equivalent machining tests have evaluated the tools.

Fig. 4 Patent form Sandvik with diversion element [9]

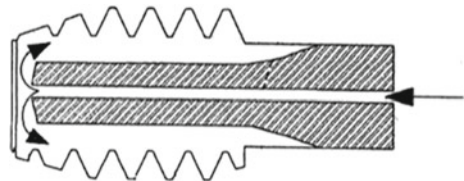
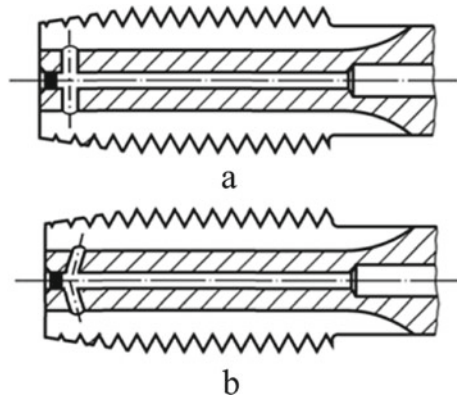


Fig. 5 Tool with rectangular radial outlets (a), tool with inclined radial outlets (b)



3 Experimental setup

3.1 Pre-experiments of Thread Tapping in Hypoeutectic Al-Si Alloy with a M6 Tungsten Carbide Tapping Tool

All experiments were performed on a horizontal milling machine (DMG-Mori NHX 9000) with a constant feed rate of 1 mm/rev and a cutting speed of 49 m/min. A rigid clamping chuck was used in order to avoid the damping of the effect of the feed force. This feed force (F_z) and the forward/backward torque M_z were measured by a piezoelectric dynamometer with four 3-component force sensors (Type: Kistler 9129AA: X, Y, Z \pm 10 kN). In Fig. 6 the so-called measurement workpiece can be seen.

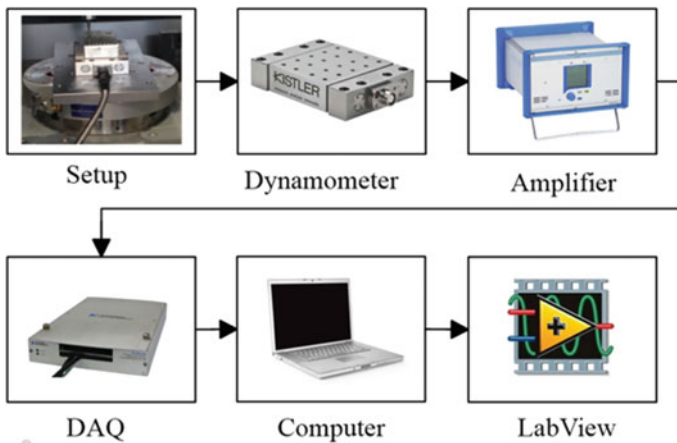
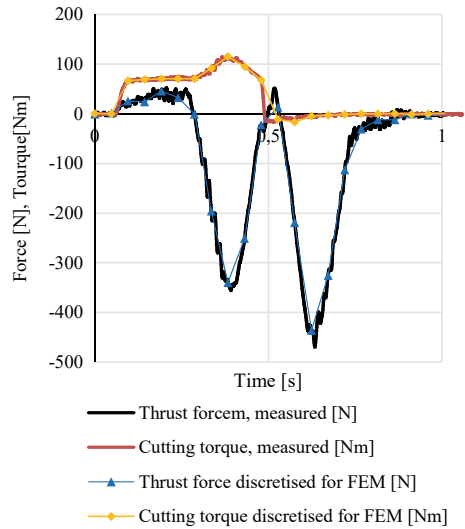


Fig. 6 Measurement chain

Fig. 7 Measurement of thrust force and cutting torque



In Fig. 7 a typical signal of the process forces is shown. The average cutting torque during the FCFP ranges between 0.7 and 1.2 Nm and the absolute values of the thrust force is between 400 and 500 N. These measured values are representative for a new tool. According to these measurement signals, a discretisation was performed to get the loading cases of the thrust force and the cutting torque for the following FEM simulation.

The tapping operations were conducted with internal MWF supply. Additionally, a measurement of the flow rate has also been performed, as can be seen in Fig. 8. Therefore, a tapping tool with an internal supply diameter of 1 mm was clamped in a chuck and the internal fluid supply was turned on with an adjusted capacity of the pump up to 30 bar. The mean value of the measured flow signal was around 1.66 L/min, as can be seen in Fig. 9.

In addition to the flow rate measurement, machining tests were made with different pumping capacities. Therefore the conventional tapping tool with internal coolant supply was used with the same parameters as in the pre-experiments. The main focus

Fig. 8 Measurement of the flow rate



Flow sensor

Tool with 1 mm ϕ of internal supply

Fig. 9 Signal of flow sensor at 30 bar pumping capacity with

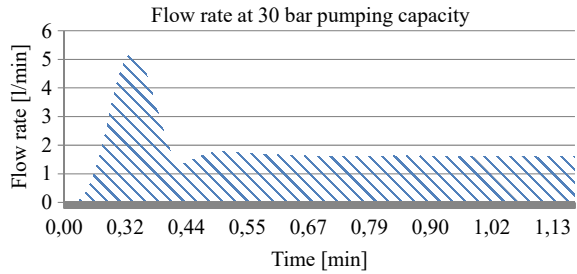


Fig. 10 Chips dimensions with no MWF supply



here was also on the chip formation process and if the chip dimension relates to the flow rate. Thus the chips have been collected during the machining process and were analysed with a microscope. During the first setup no MWF supply was purchased. The following pumping capacities were designated at 20, 40 and 80 bar. According to the measurements the adjusted pumping capacities resulted in 1.19, 1.91, and 2.65 L/min of average flow rate (Fig. 10).

As it can be seen in Figs. 11, 12 and 13, no significant difference can be seen concerning the dimensions. The type of chips most often observed in the different experiments were the discontinuous chips. Additionally, also spiral-helical chips occurred when no MWF supply was provided.

3.2 FEM Simulation of Tapping Tools with Improved MWF Supply

For the FEM simulation the signals of the cutting force measurement have been discretised. Based on this evaluation two load cases have been defined. The first one is based on the measurements and is equivalent to the process forces using a new tool. The other load case represents a worn tool, therefore the discretised values have

Fig. 11 Chips dimensions
with MWF supply of
1.19 L/min (20 bar)



Fig. 12 Chips dimensions
with MWF supply of
1.91 L/min (40 bar)



Fig. 13 Chips dimensions
with MWF supply of
2.65 L/min (80 bar)



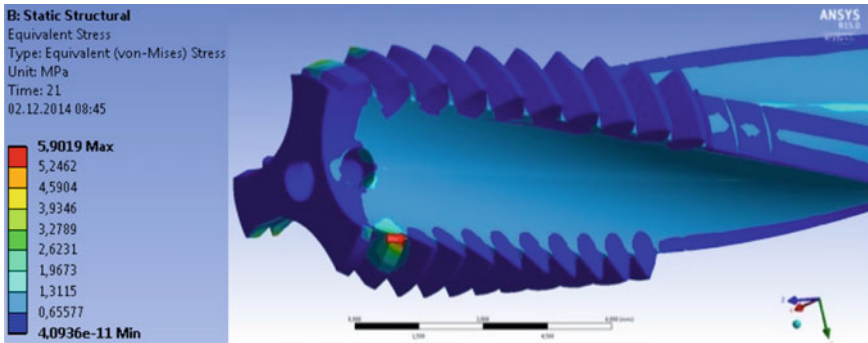


Fig. 14 FEM simulation

been multiplied by the factor 1.3 according to the empirical analytical approach for the cutting force calculation from Victor and Kienzle [10]. The aim of the FEM simulation is predicting the behaviour of the adopted tool regarding realistic load cases, e.g. to determine the influence of the sectional weakening of the core diameter. Hence, several simulations with a variety of different positions of the radial outlets were calculated. The positions were displaced along the z-axis. In addition the angle of the chip flow in the rake face, depending on the rake angle γ_p , the angle of helical flute γ_f and the chamfer angle κ_r was considered that the outlets are not positioned directly where the chips are passing by.

To get realistic results of the FEM simulation, the contact width of the thrust force and the cutting torque were set equal to the depth of cut (Fig. 14).

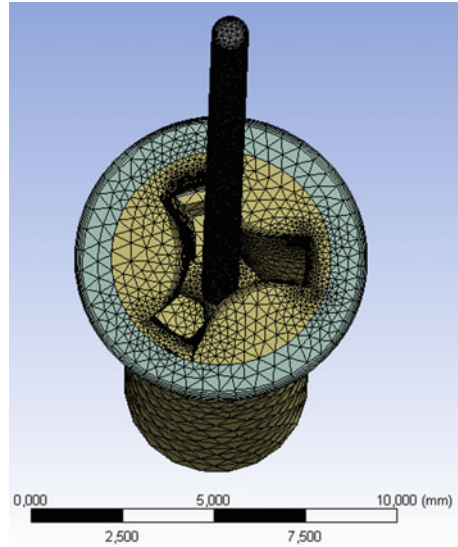
3.3 *CFD Simulation of Tapping Tools with Improved MWF Supply*

The diameter of the radial outlets were determined to provide the same flow rate of the MWF as the conventional M6 tapping tool and the applied axial coolant supply. In according to the FEM simulation the diameter of the coolant outlets were determined to guarantee the tool stability and the flow rate of 1.66 L/min (Figs. 15 and 16).

3.4 *Experiments of Thread Tapping of Through Holes and Blind Holes with M6 Tungsten Carbide Tapping Tools*

After the simulation and evaluation of the results two different types of the adopted coolant supply tools were manufactured. The radial outlets have been eroded with a

Fig. 15 Control volume of CFD simulation with inflated mesh



electric discharge machining (EDM) drilling machine and the internal axial coolant was clogged at the tool tip, as the coolant flows out of the radial outlets. All experiments have been performed with the same process parameters as the pre-experiments mentioned in Sect. 2.1. For evaluating the process stability, the experiments were performed with conventional tapping tools and the tools with improved MWF supply. Each tool has to perform 1.100 threaded holes and the performances of the tools were compared.

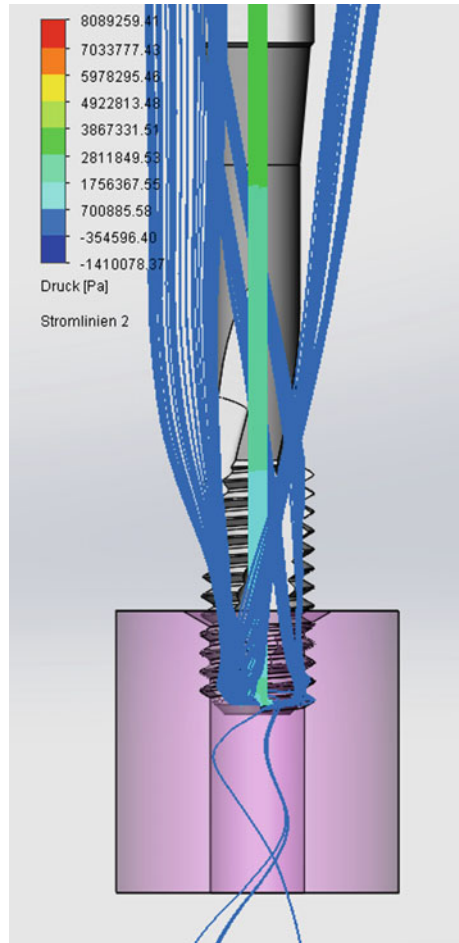
The rectangular workpiece was the same hypoeutectic Al-Si alloy as in the pre-experiments, with dimensions of $370 \times 420 \times 30$ mm and two times 1.100 holes were arranged. In the first experiment setup tapping drill holes were arranged alternatingly, namely through holes were followed by blind holes. Thus, there were 50% blind holes and 50% through holes in one experimental setup.

The focus of the second experiment setup was shifted slightly to through holes. More specifically, three through holes were followed by one blind hole. Hence, there were 75% through holes and 25% blind holes in the second experimental setup.

4 Results and Discussion

In the first experimental setup, the distribution of through holes and blind holes was equal and so a tool had to perform 1.100 threads. The process was performed for all tools in the same conditions. In this first experimental stage both types of tapping tools performed without any conspicuousness. Thus all tools managed the quantity

Fig. 16 CFD simulation



of 1.100 taps with appealing quality. The machined threads were checked with a thread gauge (Fig. 17).

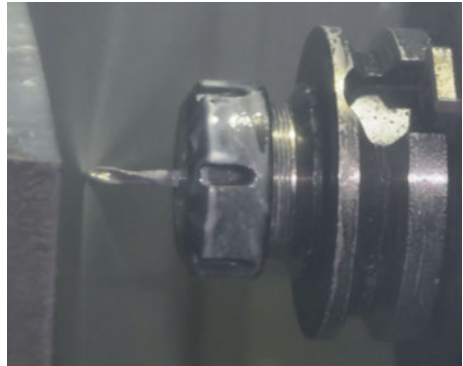
After the first experimental stage, the tools had to perform again 1.100 thread holes. The distribution of the thread holes and the blind holes was about 75–25%.

The conventional M6 tungsten carbide tapping tool with the axial coolant supply showed here process instabilities. The first conventional tool was able to perform 106 thread holes, thereupon a tool failure occurred. This incident encountered while machining a through hole. The experiment was re-performed with a new conventional tool. Here again a tool failure was observed after 506 thread holes. In addition, this failure also occurred during machining a through hole. The workpiece with the broken tools was analysed in the same way as in Fig. 2. Here also the reason for the tool failure was insufficient chip evacuation. The chips acted as a barrier the tool could not overcome and a broken tool was the result.

Fig. 17 MWF supply is insufficient for through holes

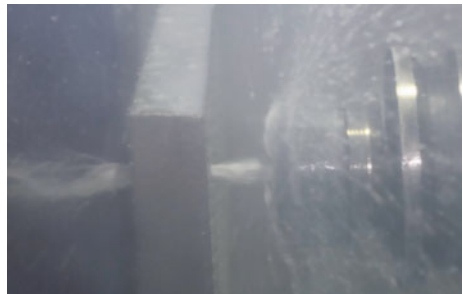


Fig. 18 MWF supply with radial outlets



Subsequently, the machining test were performed with the tools with adopted MWF supply. Opposed to the conventional tapping tools both types of the adopted tools had no problems to perform the required quantity of 1100 thread holes. With respect to this performance, the argument for the adoption of the coolant supply is significant (Fig. 19).

Fig. 19 MWF supply during machining with adopted tool



5 Conclusion

The influence of the process stability in thread tapping of through holes and blind holes has been investigated.

The following conclusions can be drawn from this study:

1. One major issue for tool failures is the chip evacuation. Clogged flutes are very common [6] and the chips are pressed in the flutes to a conglomerate and act as a barrier, which clamps the tool in the borehole. In the worst-case scenario, the tapping tool cannot resist and a tool breakage is the result.
2. If no MWF supply is purchased, spiral-helical chips occur in addition to the discontinuous chips. Apart from that, different flow rates or pumping capacities do not show a significant impact on the chip formation.
3. Machining through holes and blind holes is very challenging because the metal-cutting fluid supply needs to be sufficient for chip evacuation. Therefore a tool with adopted coolant supply is needed.
4. A tool with adopted coolant supply was designed. The demands for the tool stability and the coolant flow rate were simulated via FEM and CFD using empiric values, obtained by previous measurements.
5. The tool with adopted coolant supply showed outstanding performances in machining through holes and blind holes. Here the performance was, 50% higher than with conventional tools.

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