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INFLUENCE OF THE INFEEED METHOD ON TOOL LIFE AND SURFACE FINISH IN AUSTENITIC STAINLESS STEEL THREAD MACHINING

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Abstract. Among the machining processes, threading is one of the most difficult to perform due to complicated chip removal and lubrication in the cutting zone. In addition, the feed rate must be synchronized with the rotation of the spindle. The tool has to advance a distance equal to the pitch of the thread to be cut per revolution of the spindle. This work presents experimental results of thread machining of austenitic stainless steel 304, applying the three possible infeed methods like radial, flank and incremental infeed. The evaluation takes in consider the workpiece surface finishing, chip formation and tool life. The results indicated a longer tool life for incremental infeed and better surface finishing for the flank infeed. The radial infeed was the worst situation in terms of tool life and surface finish, although this is the most used infeed method in the industrial environment.

Keywords: Thread machining, infeed, stainless steel.

1. INTRODUCTION

Many are the methods used in the industries for joining parts. Soldering, brazing, welding or riveting may permanently join the parts of an apparatus, or demountable such as screws, rivets, pins or retaining rings may join them. Threaded fasteners are used to join parts that must be frequently disassembled. They have the possibility of assembling and disassembling a set quickly and safely without the need for adjustments.

There are various methods for generating screw threads, the main ones are rolling and cutting. Threads of metal fasteners are usually created on a thread rolling machine. Thread cutting, as compared to thread forming and rolling, is used when full thread depth is required, when the quantity is small, when the blank is not very accurate, when threading up to a shoulder is required, when threading a tapered thread, or when the material is brittle (Koepfer, 2003; Smith, 1989).

Considering the limitation of thread rolling and the development of exotic materials, thread machining is gaining more application. It can be said that, among the machining processes, threading is one of the most difficult to perform due to complicated chip removal and lubrication in the cutting zone, moreover the feed rate must be synchronized with the rotation of the spindle.

The high degree of complexity in the manufacture of threads on CNC lathes can be justified by controlling the items as well as the characteristic parameters of a thread, like pitch, diameters and angles. Faced with such challenges, as well as the search for optimized results, several researchers devoted much time to study this process (Ezugwu and Okeke, 2001; Ezugwu, *et al.*, 1999; Gunay, 2016).

Another justification for the present study has been the increasing need for machining of materials considered to be difficult machinability, such as stainless steels (Mahdavinejad and Saeedy, 2011; Manera, *et al.*, 2010). AISI 304 stainless steel is applied in welded constructions in aerospace structural components, aircraft fittings and components for severe chemical environments (Mahdavinejad and Saeedy, 2011). Machining of AISI 304 is more complex compared to the machining of other low-alloy steels due to some characteristics such as low heat conductivity, high deformation hardening and mechanical and microstructural sensitivity to strain and stress rates (Mahdavinejad and Saeedy 2011; Akasawa *et al.*, 2003; Kopak and Sali 2001).

There are three CNC machining infeed methods (radial, flank and incremental) as shown in figure 1. Infeed method dictates how the tool entries in the workpiece to create the thread form.

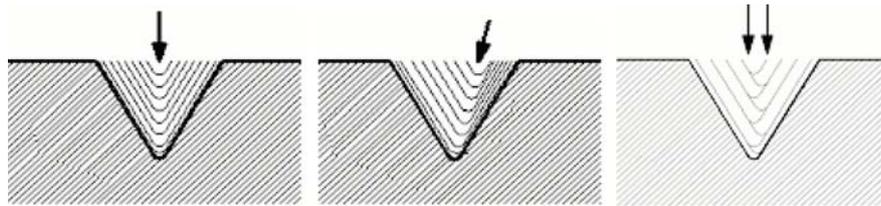


Figure 1. Infeed methods - Radial, Flank and Incremental. (Smith, 1989; Nalbant, *et al.*, 2008; Khoshdarregi and Altintas, 2015)

In the thread cutting the feed rate must be synchronized with the rotation of the spindle. The tool has to advance a distance equal to the pitch of the thread to be cut per revolution of the spindle. The generation of the fillet occurs by chip removal. This fact causes concentrated generation of effort and heat due to the friction between part, tool and chip.

The radial infeed is the most common method, where the threading insert is fed at 90° to the workpiece rotational axis. Since the tool is fed perpendicular to the workpiece centerline radially, a chip is removed from both sides of thread flanks and a V-shaped chip is formed (Smith, 1989).

Flank infeed is often known as the “half-angle screw cutting technique”, mainly utilized on a conventional lathe. The left-hand flank is formed by the tools “V” form geometry while the right-hand thread flank is generated by successive passes, as the tool is fed down the face at half the thread included angle. Chip control is improved with all flank infeed techniques over “plunging”, enabling over chip to be vectored away from the previously cut surface (Smith, 1989).

In the incremental infeed the tool cutting edges alternate their cutting positions, especially in the lateral (right and left) until the final height of the fillet is reached. Once the depth of cut has been properly distributed at each increment and once the cutting position of the edges has been alternated while one works, the opposite side receives a better volume of cooling thereby minimizing the influences of the normal high temperatures in this machining operation (Smith, 1989).

This work presents experimental results of thread machining of austenitic stainless steel ASTM A276/16 – 304 austenitic stainless steel, applying three possible infeed methods such as radial, flank and incremental infeed. The evaluation takes in consider the workpiece surface finishing, chip formation and tool life.

2. MATERIALS AND METHODS

The machined material was ASTM A276/16 - 304 austenitic stainless steel. The M16 X 2.5 thread was machined using the three infeed methods (radial, flank and incremental). Thread compliance was checked with a nut used as a template. Table 1 shows the chemical composition of the workpieces, which were taken from the same manufacturing batch. Figure 2 shows a machined sample.

Table 1. Chemical composition of ASTM materials

C	Cr	Mn	Mo	N	Ni	P	S	Si
0,024	18,25	1,570	0,500	0,085	8,040	0,037	0,028	0,280



Figure 2. Machined sample.

The class M cemented carbide tools with PVD TiN coating GC 1020 was used for the experiments. The parameters used are shown in table 2, based on the radial infeed method.

Table 2- Machining parameters

Application	Vc (m/min)	Height of fillet (mm)	Number of passes (radial)	Number of passes (flank)	Number of passes (incremental)
1 - Usually factory	80	1,60	14	16	18
2 - Catalog recommendation	120	1,60	10	-	-

During the process, strategic stops were made in order to observe general aspects of the thread and the tool and to collect of chips for analysis. The experiments were carried out until the tool fracture, and until then it was possible to perform the axle and nut assembly. The experiments were carried out on a CNC lathe Hyundai-KIA Machine SKT160A Siemens command with the initial possibility for radial and flank infeed method, special parameterization for incremental infeed was required. The machine tool (figure 3) and an optical microscope were used.



Figure 3. CNC lathe.

For the results and discussions presented in item 3, basic parameters indicated by manufacturers were used: cutting speed 120 m/min and number of passes 10.

3. RESULTS AND DISCUSSIONS

Figure 4 is associated with radial infeed, in which the tool moves perpendicular to the workpiece. At each pass occurs the increase of the depth of cut increasing the area of the primary and secondary shear planes indicating the need for greater shear strength. In this case, it was difficult to evacuate the chip, which, despite its small size, tends to embed itself between the part and the tool, increasing the temperature at the cutting edges. It is observed in figure 4a that the substrate was exposed, as a function of the loss of the coating of the tool. In this way there were pronounced flank and crater wear that resulted in total collapse of the tool. The loss of coating has resulted from the abrasion mechanism associated with high strength and hardening tendency of the material. In addition, the high ductility of the material provided the formation of the built-up edge that also contributes to the end of the tool life. Figure 4b shows vibration marks and blue colored surface indicating high temperatures in the machined thread.

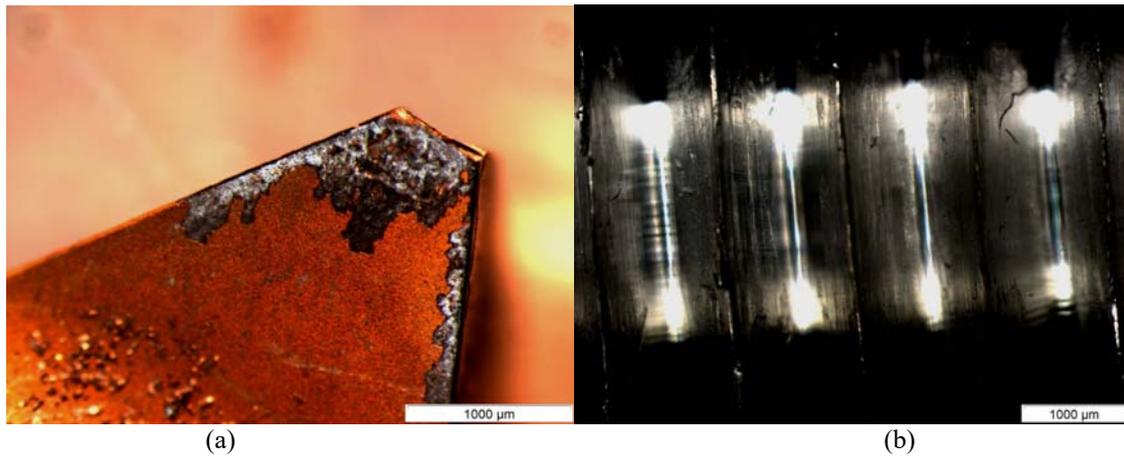


Figure 4. Radial infeed results (a), worn tool, (b) thread surface finish.

Figures 5a and 5b are associated with the flank infeed. In this case the chips were vectored away from the previously cut surface, what contributed to the reduction of built-up edge formation. There is also a reduction of the sliding friction regions along the tool-chip contacting surface minimizing the possibility of vibration. Figure 5a shows that wear occurs mainly on one side of the insert nose, keeping the other one practically intact. This result is expected, once only one side of the insert nose is subjected to high heat and pressure. The gradual increase of the tool-workpiece contact area and the suitable chip flow when flank infeed technology is applied resulted in better surface quality (figure 5b) in comparison to the radial one. A better surface finish contributes to lower occurrence and propagation of corrosion.

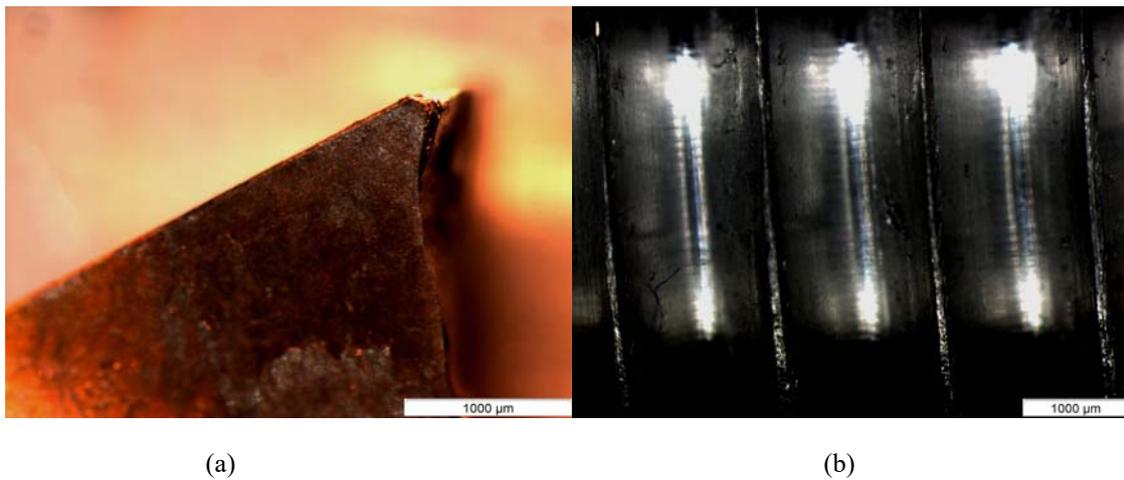


Figure 5. Flank infeed results (a), worn tool, (b) thread surface finish.

Figures 6a and 6b are associated with incremental infeed method. Similar wear is observed on both sides of the tool, what is justified by the alternating tool displacements (right and left to final thread height).

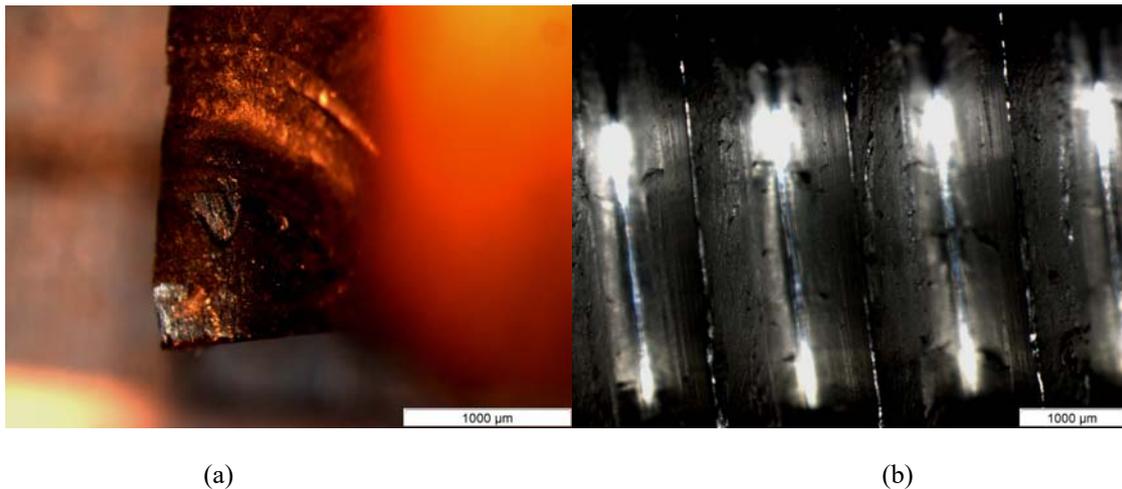


Figure 6. Incremental infeed results (a), worn tool, (b) thread surface finish.

As a consequence of the fact, the formation of short chips of easy flow with considerable reduction of the built-up edge was verified. In addition to flank wear, crater wear can be also observed in Figure 6a. The incremental infeed requires special programming of the CNC and an extra pass for finishing the thread. The influence of the final pass that contributed to the formation of a minor root radius can be observed in figure 6b. The effect of the high temperature on the crest of the thread is also observed (blue colored surface), but the overall surface finish was acceptable.

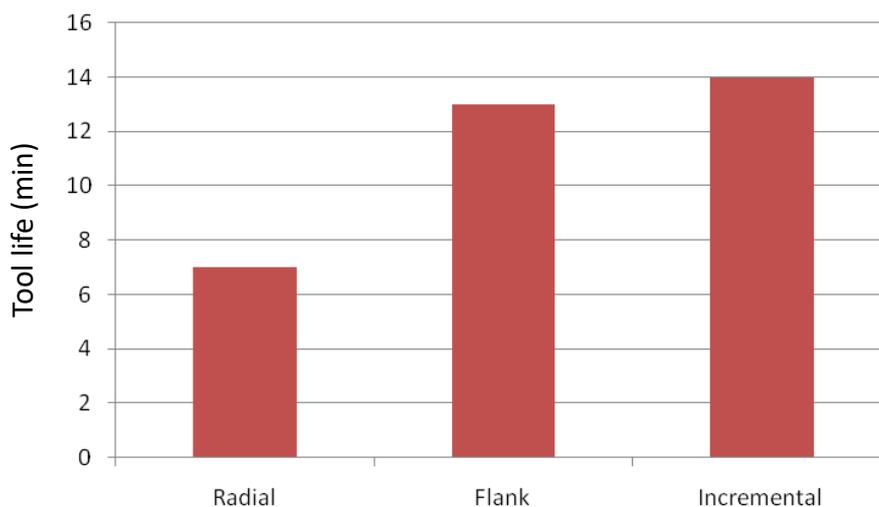


Figure 7. Tool life in function of the infeed method.

The lowest tool life resulted from radial infeed (7 min). This method form chip that is difficult to break, thus chip flow can be a problem resulting in built-up edge. Moreover, both sides of the insert nose are subjected to high heat and pressure. Tool life was similar to flank (13 min) and incremental (14 min) infeed methods. Flank infeed promotes suitable chip removal that contributes to the reduction of built-up edge formation. However, only one side of the insert nose cuts the workpiece and consequently there is a more pronounced wear rate on this cutting edge. Incremental infeed forms short chips of easy flow with reduction of the built-up edge. It also presents a uniform wear on the both sides of the insert nose.

4. CONCLUSIONS

Radial infeed resulted in the shortest tool life. In this case, the chip tends to embed itself between the part and the tool, increasing the temperature at the cutting edges. The loss of coating has resulted from the abrasion mechanism associated with high strength and hardening tendency of the material. Built-up edge also contributed to the end of the tool life.

Tool life was similar to flank and incremental infeed methods. Flank infeed promotes suitable chip removal that contributes to the reduction of built-up edge formation. However, only one side of the insert nose cuts the workpiece and consequently there is a more pronounced wear rate on this cutting edge. The gradual increase of the tool-workpiece contact area and the suitable chip flow when flank infeed method is applied resulted in better surface quality in comparison to the others.

Incremental infeed forms short chips of easy flow with reduction of the built-up edge. Similar wear was observed on the both sides of the insert nose. The final pass contributed to the formation of a minor root radius and a good surface finish.

5. ACKNOWLEDGEMENTS

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