Comparison of machining performance between cutting tap and rolled tap in tapping of Inconel 718 superalloy

Masahiro MIZUNO[1, a *], Yuma KOSEKI[1, b], Nobuhito YOSHIHARA[1, c], Naohiro NISHIKAWA[1, d] and Toshirou IYAMA[1, e]

[1] Iwate University, 4-3-5 Ueda, Morioka, Iwate 020-8551 JAPAN

[a] m.mizuno@iwate-u.ac.jp, [b] t2416016@iwate-u.ac.jp, [c] yosihara@iwate-u.ac.jp, [d] nkawa@iwate-u.ac.jp, [e] iyama@iwate-u.ac.jp

Keywords: Rolled tap, Cutting tap, Roll form Tapping, Cut tapping, Inconel 718

Abstract. There is a strong demand for ways to prevent tap breakage in tapping of Inconel. Since tapping operation is normally performed at the final stage of manufacturing process, the economic loss due to tap breakage is extremely high in particular in the machining of difficult-to-machine materials such as Inconel. Tap breakage easily occurs in tapping of Inconel due to its inferior chip discharge performance as well as severe tool wear. In this study, we focused on the rolled tap which doesn't generate chips, and compared with the cutting tap in terms of processing torque, crystal grain structure and mechanical strength of processed internal threads, and so on. It was clarified that the increase rate of tapping torque with increase in the number of tapping is relatively small when a rolled tap is used and the mechanical strength of the internal threads processed with a rolled tap becomes higher.

Introduction

Inconel alloys are widely used for high-temperature applications such as jet engines, gas turbines, chemical processing devices, etc., because of their excellent oxidation and corrosion resistance at high temperatures.

There is a strong demand for ways to prevent tap breakage in tapping of Inconel. Since tapping operation is normally performed at the final stage of manufacturing process, the economic loss due to tap breakage is extremely high in particular in the machining of difficult-to-machine materials such as Inconel. Tap breakage easily occur in tapping of Inconel due to its inferior chip discharge performance as well as severe tool wear. Many researchers have been working on the study on machining of Inconel [1] [2] [3]. However, there are only a few studies on tapping of Inconel [4].

In this study, the authors focused on the roll form tapping which doesn't generate chips, and compared with the cut tapping in terms of processing torque, crystal grain structure and mechanical strength of produced threads, and so on.

Experimental details

Experimental set up. Inconel 718, which was heat-treated as per the standard schedule including solution treatment at 980°C/1h and water quenching, was used as workpiece material. The nominal size of the internal thread produced in the experiment was M3×0.5 (JIS). The pilot drilling was performed with straight shank drills (SAITO SEISAKUSHO, V-ADS series). The base material is tungsten carbide and the coating material is TiAlN. The drills have a point angle of 118 degrees and a helix angle of 30 degrees. In pilot drilling, water-insoluble cutting fluid (TAIYU, HF-160) was used. Roll form tapping experiment was performed with a rolled tap (YAMAWA, SURZ G5 M3X0.5 B) made of powdered high speed steel. The tool has three straight flutes to facilitate the supply of lubricant to the rolling contact area. The number of chamfered threads of the tool is two. Cut tapping experiment was performed with a spiral fluted tap (YAMAWA, ZEN-B P2 M3X0.5) made of powdered high speed steel. Both of the numbers of the flutes and the chamfered threads of the tap are three. Roll form tapping and cut tapping were performed under the presence of lubricant paste (TRUSCO, CP-1).

Pilot drilling and tapping were carried out using a vertical machining center (MORI SEIKI, FRONTIER m1). Tapping torque was measured with a magnetostrictive torque sensor (SAN-E TEC, CTS005). The output signal was taken into a personal computer via an AD converter (CONTEC, AIO-160802AY-USB). The hardness of pilot hole surface was measured with a Vickers hardness testing machine (AKASHI, MVK-A). The strength of processed internal threads was evaluated using a tensile tester (SHIMADZU, AG-X PLUS). Electron Backscatter Diffraction (EBSD) analysis by a field emission scanning electron microscope (JEOL, JSM-7001F) was applied to investigate the metal grain structure and the grain strain distribution of the surface layer of the drilled holes and the tapped threads.

Experimental methods.

Measurement of the Vickers hardness of pilot hole surface. In order to investigate the change in the Vickers hardness of pilot hole surface with a progress of drill wear, one hundred pilot holes with a depth of 9 mm were drilled using a single drill with a diameter of 2.76 mm at a step feed of 0.8 mm. The drilling conditions are shown in Table 1. After drilling, the workpiece was sliced by wire electrical discharge machining and the Vickers hardness of each hole surface was measured at the three points shown in Fig. 1.

Measurement of tapping torque. For each roll form tapping experiment and cut tapping experiment, 100 pilot holes with a depth of 9 mm were prepared using a single drill. The diameter of the pilot drill used for roll form tapping experiment was 2.76 mm and that used for cut tapping experiment was 2.60 mm. The drilling conditions were the same as shown in Table 1. In both tapping experiments, only the firstly drilled 20 holes and the lastly drilled 20 holes were used. It can be assumed that the lastly drilled 20 holes have a thicker work-affected layer on their surfaces than the firstly 20 holes due to the progress of drill wear. A new tapping tool was used for each tapping for the firstly 20 holes and the lastly 20 holes. The tapping was performed in three steps while measuring tapping torque. Each step-feed was 3 mm/3 mm/2 mm and the total tapping depth was 8 mm. The tapping conditions are shown in Table 2 and Table 3.

Evaluation of the strength of internal threads. The shape of the test pieces prepared for evaluating the strength of internal threads is shown in Fig. 2. The thread length was 1 mm. The fundamental machining conditions to make the internal threads were the same as shown in Table 1, Table 2 and Table 3. A threaded mandrel made of high speed steel was prepared and screwed into the internal thread to be evaluated. They were put into a special holder having shanks as shown in Fig. 3, and then set on a

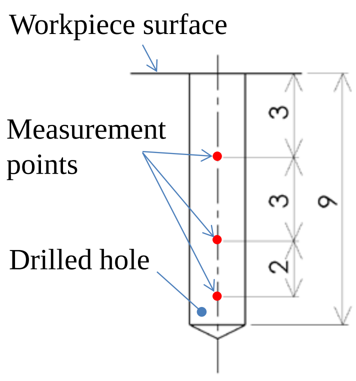


Fig. 1 Measurement points of Vickers hardness

Table 1 Drilling conditions

Tool diameter (mm)	2.60/2.76
Rotation speed of tool (rpm)	1380
Feed rate (mm/min)	15.0
Step feed (mm)	0.8

Table 2 Tapping conditions for roll form tapping experiment

Rotation speed of tool (rpm)	100
Nominal diameter of pilot hole (mm)	2.76
Tapping depth (mm)	8
Step feed (mm)	3/3/2

Table 3 Tapping conditions for cut tapping experiment

Rotation speed of tool (rpm)	106
Nominal diameter of pilot hole (mm)	2.60
Tapping depth (mm)	8
Step feed (mm)	3/3/2

tensile tester. The tensile speed was set at 1.0 mm/min. The load when the internal thread was broken was evaluated. The evaluation experiments were conducted three times under the same conditions.

Observation of the metal grain structure and the grain strain distribution of the surface layer of the drilled holes and the tapped threads. Specimens for EBSD analysis were prepared as follows. Firstly, drilling or tapping was carried out under the machining conditions as shown in Table 1, Table 2 and Table 3. Secondly, the workpiece was cut so that the cut plane includes the axis of the drilled hole or the threaded hole by wire electrical discharge machining. Thirdly, the cut plane was finished by sanding, buffing and ion milling.

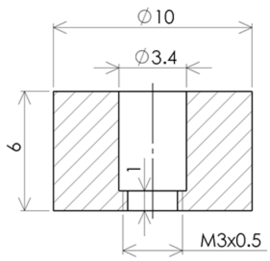


Fig. 2 Shape of the test piece prepared for evaluating the strength of internal threads

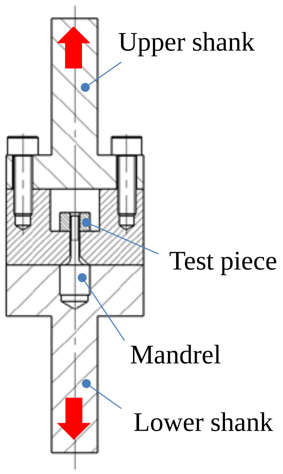


Fig. 3 Method for evaluating the strength of internal

Experimental results.

Relationship between the number of drilling and the Vickers hardness of pilot hole surface. Figure 4 shows the relationship between the number of drilling and the Vickers hardness of pilot hole surface. The Vickers hardness of pilot hole surface was increased from 350 to 550 in 100 times of drilling. The microscope images of the cutting edge of drill before and after 100 times of drilling are shown in Fig. 5. We can see a severe wear in the cutting edge after 100 times of drilling. Figure 6 shows the EBSD KAM maps of the surface layer of the 21st and the 80th drilled holes. The KAM maps are drawn using a blue-green-yellow-red color scheme, indicating relative level of the grain strain with blue being lowest and red highest. The thickness of the work affected layer of the 80th drilled hole is about twice of that of the 21st drilled hole. The authors consider that the Vickers hardness of pilot hole surface is increased with the increase of the thickness of work affected layer due to the progress of tool wear.

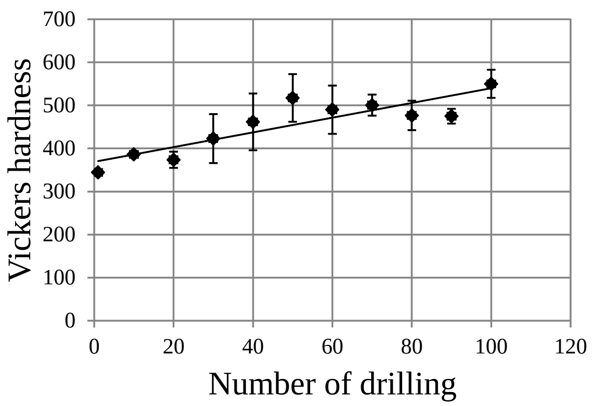
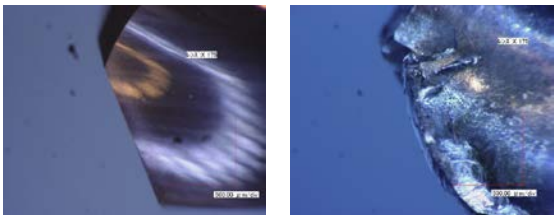


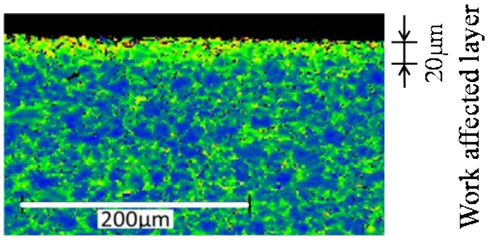
Fig. 4 Relationship between the number of drilling and the Vickers hardness of pilot hole surface.

Change in tapping torque. Figure 7 shows an example of the change in tapping torque in three-step feed. We

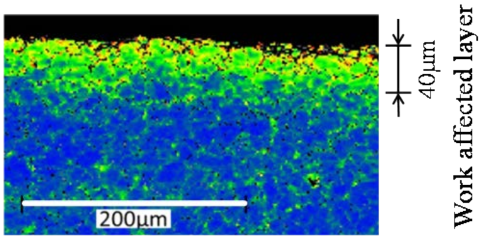


(a) Initial (b) After 100 times of drilling

Fig. 5 Microscope images of the cutting edge of drill before and after 100 times of drilling



(a) The 21st hole



(b) The 80th hole

Fig. 6 EBSD KAM maps of the surface layer of drilled holes.

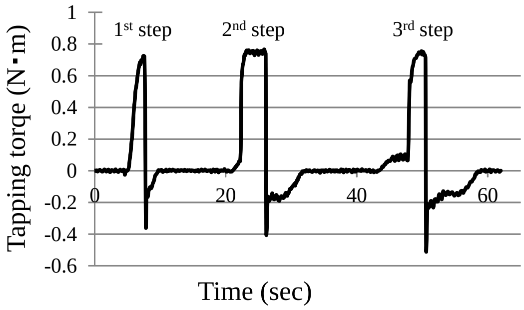
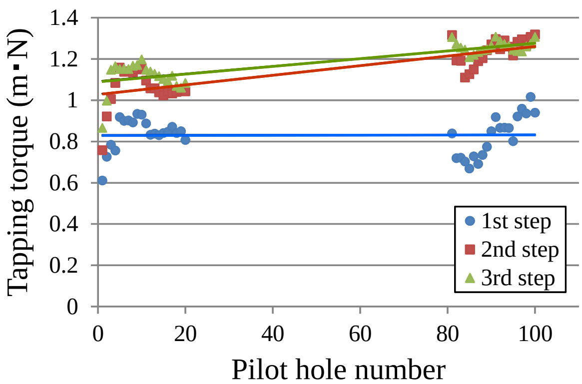


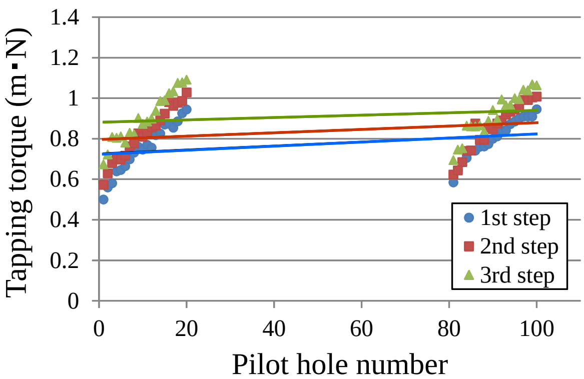
Fig. 7 An example of the change in tapping torqe in three-step feed

can see three peaks in this figure. Figure 8 shows the relationship between the pilot hole number and the peak value of the tapping torque in each step feed. In the cases of both roll form tapping and cut tapping, the tapping torque is slightly higher in tapping of the pilot holes of number 81-100 than those of 1-20 in spite of a new tool was applied for each. It might be caused by the increase in the thickness of work-affected layer and the reduction of pilot hole diameter due to tool wear. In addition, we can see a steep increase in the tapping torque in cut tapping. The microscope image of the cutting edge of cutting tap after the first tapping process is shown in Figure 9. Chipping of the cutting edge occurred at this early stage. On the other hand, a clear appearance change was not observed in the rolled tap after 20 times of tapping process.

Comparison in strength of the internal threads processed with a rolled tap and a cutting tap. Figure 10 shows the average breaking loads of the



(a) Roll form tapping



(b) Cut tapping

Fig. 8 Relationship between the pilot hole number and the peak value of the tapping torque in each feed step.

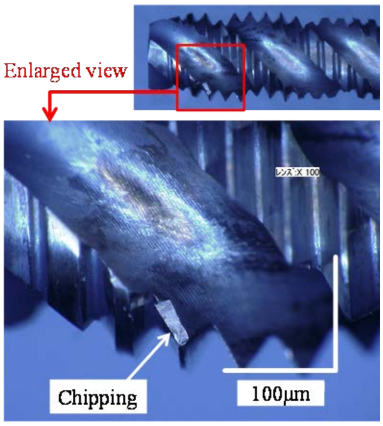


Fig. 9 The microscope image of the cutting edge of cutting tap after the first tapping process.

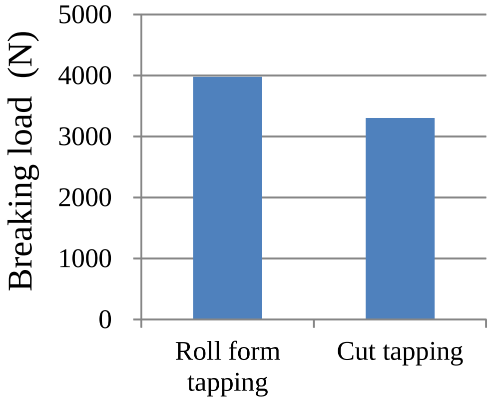
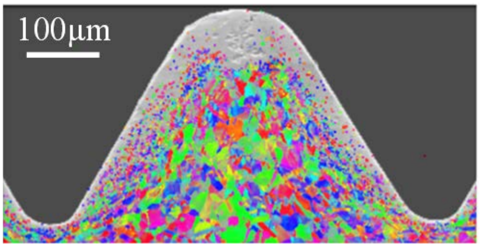
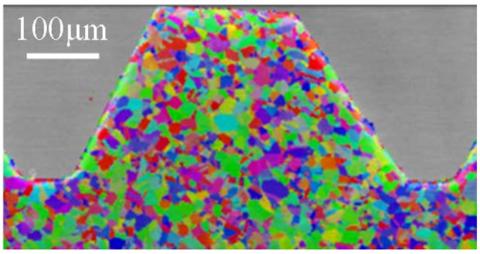


Fig. 10 Comparison in strength of the internal threads machined with a rolled tap and a cutting tap.

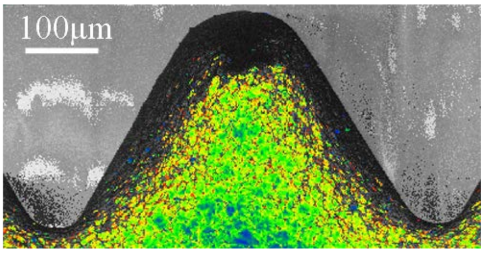


(a) Processed with a rolled tap

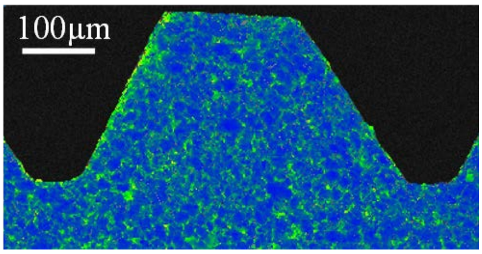


(b) Processed with a cutting tap

Fig. 11 IPF KAM maps on a cross section of the threads processed with a rolled tap and a cutting tap.



(a) Processed with a rolled tap



(b) Processed with a cutting tap

Fig. 12 EBSD KAM maps on a cross section of the threads processed with a rolled tap and a cutting tap.

internal threads processed by roll form tapping and cut tapping. The standard deviation in three times of test was 15 N for the thread processed by roll form tapping and 38 N for that by cut tapping. The internal thread processed by roll form tapping has about 20 % higher strength, compared with that processed by cut tapping. The authors conjecture that the processing quality of a rolled tap is stable because the standard deviation of the breaking load of the internal thread processed with a rolled tap is very small.

The metal grain structure and the grain strain distribution of the surface layer of tapped threads. Figure 11 shows the EBSD IPF maps on a cross section of the threads processed with a rolled tap and a cutting tap. Figure 12 shows their EBSD KAM maps. It is found from Fig. 11 that the metal grains near thread surface are refined by the roll form tapping. And it is found from Fig. 12 that a large compression strain is remained in the thread processed with a rolled tap. The authors consider that the high strength of the internal thread processed with a rolled tap is brought by both of the refinement of the metal grains near the thread surface and the compression strain remained in the threads.

Conclusions

The authors compared the roll form tapping with the cut tapping in terms of processing torque, crystal grain structure and mechanical strength of produced threads, and so on. The obtained results are summarized as follows.

(1) The Vickers hardness of pilot hole surface is increased with the increase of the thickness of work affected layer due to the progress of tool wear.
(2) Tapping torque is affected by the progress of a pilot drill wear.
(3) The tapping torque in cut tapping increases steeply due to the chipping of the cutting edge.
(4) The internal thread processed with a rolled tap has about 20 % higher strength, compared with that with a cutting tap.
(5) The processing quality of a rolled tap is stable, compared with that of a cutting tap.
(6) The metal grains near thread surface are refined by the roll form tapping.
(7) A large compression strain is remained in the thread processed with a rolled tap.

References

[1] A. Çelik, M. S. Alağaç, S. Turan, A. Kara, F. Kara, Wear behavior of solid SiAlON milling tools during high speed milling of Inconel 718, Wear 378-379 (2017) 58-67.

Reference to a book:

[2] A. Shokrani, V. Dhokia, S. T. Newman, Hybrid Cooling and Lubricating Technology for CNC Milling of Inconel 718 Nickel Alloy, Procedia Manufacturing 11 (2017) 625-632.

[3] G. R. Mettam, L .B. Adams, An Experimental Investigation on Cryogenic Milling of Inconel 718 and its Sustainability Assessment, Procedia CIRP 14 (2014) 529-534.

[4] A. Mizobuchi, M. Masuda and H, Tasuku, Influence of Tapping Conditions and Tool Geometries on Tool Life in Tapping of Inconel 625®, Key Engineering Materials 407 – 408 (2009) 33-36.