Tool Wear of Titanium/Tungsten/Silicon/Aluminum-Based-Coated Solid Carbide Thread Milling Cutters in Thread Tapping of Chromium-Molybdenum Steel

Tadahiro Wada and Koji Iwamoto

***Abstract*—Helical milling method with thread milling cutters in thread tapping is effective against problems associated with tapping chips. In this study, chromium-molybdenum steel (ISO 34CrMo4, AISI 4137) was helical milled with two physical vapor deposition (PVD)-coated cemented carbide end thread milling cutters in order to determine effective tool materials for tapping chromium-molybdenum steel. The coating films used were (Ti, W) N/ (Ti, W, Si) N and commercial (Ti, Al) N coating films. The inner layer of the (Ti, W) N / (Ti, W, Si, Al) N coating system is (Ti, W) N coating film, and the outer layer is (Ti, W, Si, Al) N coating film. In order to identify an effective tool material for thread tapping of chromium-molybdenum steel, tool wear was experimentally investigated. The following results were obtained: (1) In thread tapping of chromium-molybdenum steel at a cutting speed of 0.67 m/s, the tool wear width of the (Ti, W) N /(Ti, W, Si, Al) N-coated tool was smaller than that of the (Ti, Al) N-coated tool. (2) The mean value of the friction coefficient of (Ti, W, Si, Al) N was 0.564, and that of (Ti, Al) N was 0.817. (3) (Ti, W) N / (Ti, W, Si, Al) N-coated cemented carbide was an effective tool material for thread tapping of chromium-molybdenum steel.**

***Index Terms*—Tapping, helical milling, thread milling cutter, physical vapor deposition (PVD) coating system, tool wear.**

I. Introduction

In conventional tapping steels with machine taps, such as the spiral pointed tap, the spiral fluted tap, or the fluteless tap, the emission of chips has a large influence on tool damage of the tap. In particular, when tapping with taper pipe thread taps with a straight flute, the thickness of chips increases with the increase in tapping processing, these chips clog between the thread of the tap and the workpiece, and the thread of the tap very frequently causes tool breakage. It is considered that the helical milling method with thread milling cutters in thread tapping is effective against problems associated with tapping chips. Thread milling is a method for producing a screw thread by a milling operation [1]-[3]. Internal thread milling operation is possible for stable operation because chips are divided and chip clogging can be prevented. However, for internal thread tapping of chromium-molybdenum steel, there are no studies examining how to improve tool damage of pipe thread taps.

On the other hand, in order to improve resistance fractures of the thread milling cutter, cemented carbide, which has good fracture toughness, is often used as the substrate material for the tap. The physical vapor deposition (PVD) method is a widely used coating technology because of its lower treatment temperature, namely 470 K-870 K [4].

Recently, it has become possible to cut hardened steels with (Ti, Al) N-coated cutting tools. However, as machine parts are often cut at higher cutting speeds for mass production, tool materials must have excellent fracture toughness and wear resistance.

A titanium/tungsten-based coating film, namely (Ti, W)N coating film, has been developed [5]. A (Ti, W, Si)N coating film, which is a titanium/tungsten/silicon-based coating film, has also been developed [6]. Furthermore, titanium/tungsten/silicon/aluminum-based coating films, namely (Ti, W, Si, Al) N, (Ti, W, Si, Al) C, and (Ti, W, Si, Al) (C, N) coating films, have been developed [7]. And, compared with commercial (Ti, Al) N, the tool wear width of the (Ti, W) N/ (Ti, W, Si, Al) N-coated tool was smaller than that of the (Ti, Al) N-coated tool [8].

However, it is not clear whether these coating films are effective tool materials for helical milling with a thread milling cutter.

In this study, chromium-molybdenum steel was helical milled with two physical vapor depositions (PVD)-coated cemented carbide thread milling cutters in order to clarify effective tool materials for tapping chromium-molybdenum steel. The coating films used were (Ti, Al) N and (Ti, W) N/(Ti, W, Si, Al) N coating films. Tool wear was experimentally investigated.

II. Experimental Procedure

The work material used was chromium-molybdenum steel (ISO 34CrMo4, AISI 4137). The chemical composition of the chromium-molybdenum steel is shown in Table I. The tool material of the substrate was micro-grain cemented carbide, and two types of PVD-coated cemented carbide were used as shown in Table II. Namely, the coating films used were commercial (Ti, Al) N and (Ti, W) N/ (Ti, W, Si, Al) N coating films. (Ti, W) N/ (Ti, W, Si, Al) N comprises a multilayer coating system. The inner layer of the (Ti, W) N/ (Ti, W, Si, Al) N coating system is (Ti, W) N coating film, and the outer layer is (Ti, W, Si, Al) N coating film.

Fig. 1 shows a schematic view of thread tapping tests. The tapping tests were conducted on a vertical machining center (Type V7.5, Yamazaki Mazak Corporation). The driving power of this machining center is 5.5/7.5 kW and the

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maximum rotational speed is 4000 min-1. The thread tapping test was carried out under helical milling. In Fig. 1, the position of the thread milling cutter shown in Fig. 1(a) is the start position and the position shown in Fig. 1 (f) is the end position. At the first stage, the thread milling cutter moves while maintaining the clearance shown in Fig. 1(b). At the second stage, the thread is cut by the helical milling shown in Fig. 1(c). And the thread is milled in the circumference of the circle as shown in Fig. 1(d) and Fig. 1(e). At the final stage, the thread milling cutter removes the end position shown in Fig. 1(f).

TABLE I: CHEMICAL COMPOSITION OF THE WORKPIECE (ISO 34CRMO4) (MASS %)

C	Cr	Mo	Mn	Si
0.33-0.38	0.90-1.20	0.15-0.30	0.60-0.90	0.15-0.35

P: max 0.030, S: max 0.030

TABLE II: TOOL MATERIAL IN TURNING OF AISI D2

Tool type	Tool material
Coated tool	Substrate: micro-grain cemented carbide Coating layer: (Ti, Al)N, (Ti, W)N/(Ti, W, Si, Al) N

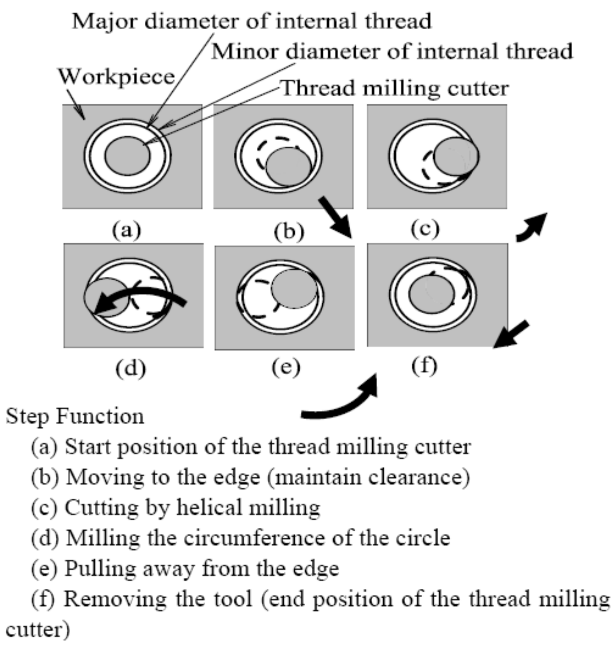


Fig. 1. Schematic view of the thread tapping.

Table III shows the specifications of thread milling cutter. Chromium-molybdenum steel was milled under the cutting conditions shown in Table IV.

The tool wear of the two kinds of thread milling cutters was investigated.

The friction coefficient was measured using a ball-on-disk tribometer (CSM Instruments), and the test conditions are shown in Table V.

III. RESULTS AND DISCUSSION

The chromium-molybdenum steel was milled with two kinds of coated solid carbide thread milling cutter. Fig. 2 shows the tool wear of the (Ti, Al) N-coated cutter after thread tapping of 200 thread holes. In this Fig. 2(a) photograph of the thread milling cutter for American taper pipe internal thread 3/8-18 NPT is shown. In this figure, the land is indicated above dotted line I-I, and the flute is indicated below dotted line I-I. Fig. 2(b) shows the details of A shown in Fig. 2(a). In Fig. 2(b), the land is indicated above dotted line I-I, and the flute is indicated below dotted line I-I.

TABLE III: SPECIFICATIONS OF THREAD MILLING CUTTER

Type of cutter	Thread milling cutter for American taper pipe thread (NC planet cutter)
Cutter size	Cutting dia. φ10mm×Max. tapping length 15.5 mm
Cutting face	Positive rake type (Rake angle: 5º)
Thread relief type	Eccentric thread (Relieved to cutting edge)
Flutes	Helix angle 28°, 4 flutes
Pitch	18 thread pitch/inch

TABLE IV: CUTTING CONDITION OF THE THREAD MILLING TEST

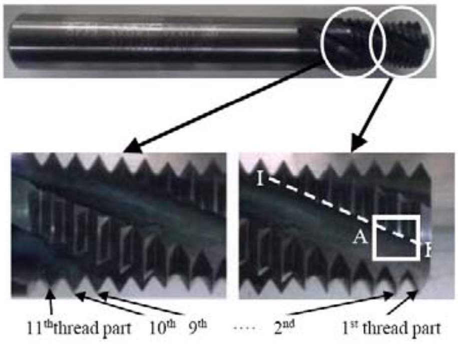
Cutting speed	0.67 m/s
Feed speed	49 mm/min (0.02 mm/tooth)
Cutting direction	Down cut
Tapping length	15 mm
Pre-drilled hole	φ14.5 mm (Without reaming before tapping)
Cutting method	Dry (blind hole down cut)

TABLE V: TEST CONDITIONS OF THE FRICTION TEST (BALL-ON-DISK TYPE)

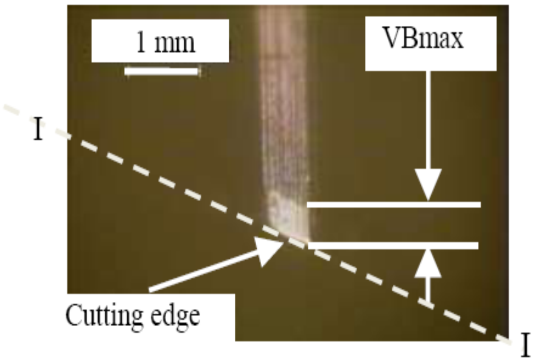
Material of ball	JIS SUJ2 (ASTM 52100) (Ball diameter: 6.00 mm)
Sliding length	1.74 km
Sliding speed	0.16 m/s
Normal load	1.00 N
Temperature	294 K
Humidity	55.0%
Atmosphere	Air

In all thread parts from the first thread part to the eleventh thread part, there is no remarkable failure such as flaking of the rake face on the cutting edge as shown in Fig. 2(a). And tool wear patterns in the case of the (Ti, W)N/(Ti, W, Si, Al)N-coated thread milling cutter, whose figure is not shown here, was similar to the tool wear in the case of the (Ti, Al)N-coated thread milling cutter as shown in Fig. 2. The main tool failure is flank wear as shown in Fig. 2(b). So, the maximum value of the flank-wear land was measured.

Fig. 3 shows the flank wear width of the two kinds of coated milling cutter after 200 holes of thread tapping. The number of thread parts of the thread milling cutter is four. This thread milling cutter has four lands per thread part, and eleven thread parts. Namely, the number of cutting edges of this thread milling cutter is forty-four. In this study, the maximum width of the flank-wear land of the second thread part and the ninth thread part is the designed "(VBmax)n." Here, the "n" of the subscript characters shows the number of cutting edges of the second thread part and the ninth thread part, and n is from one to four. In Fig. 3, "VBmax" is the maximum value of the four cutting edges of the second thread part and the ninth thread part. The V Bmax of the (Ti, W) N/ (Ti, W, Si, Al) N-coated thread milling cutter is smaller than that of the (Ti, Al) N-coated tools in both the second thread part and the ninth thread part.



(a) Photograph of the thread milling cutter for American taper pipe internal thread 3/8-18 NPT.



(b) Details of A shown in Fig. 2(a).

Land is indicated above dotted line I-I.
Flute is indicated below dotted line I-I.

Fig. 2. Tool wear of the (Ti, Al)N-coated cutter after thread tapping of 200 thread holes.

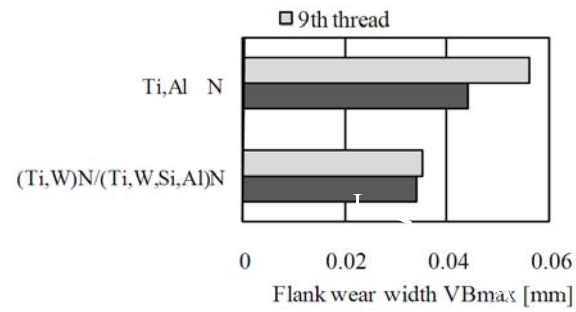


Fig. 3. Flank wear width of the second and the ninth thread part after thread tapping of 200 holes.

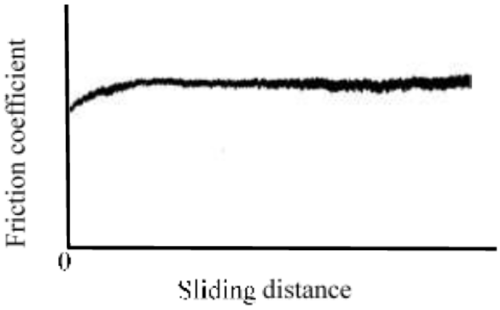
TABLE VI: CHARACTERISTICS OF THE COATING FILMS

Coating material	Thickness of film (μm)	Critical scratch load* (N)	Microhardness ($HV_{0.25N}$)
(Ti,Al)N	3.0	73	2710
(Ti,W)N/(Ti,W,Si,Al)N	3.5	>100	3200

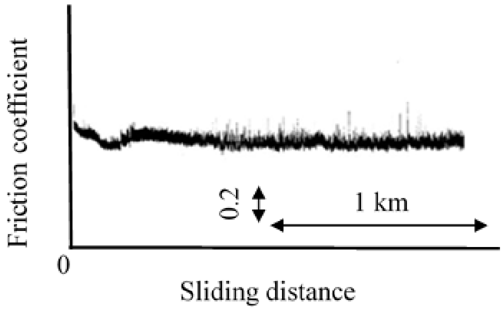
*: Measured value by scratch test

TABLE VII: MEAN VALUE OF THE FRICTION COEFFICIENT OF THE COATING FILMS

Coating film	Mean value of friction coefficient
(Ti, Al)N	0.817
(Ti. W, Si, Al)N	0.564



(a). (Ti, Al) N coating film.



(b). (Ti, W, Si, Al) N coating film.

Fig. 4. Relationship between sliding distance and friction coefficient under a sliding distance of 0 km to 1.76 km.

The film characteristics were then observed. Table VI shows the characteristics of the coating films [8]. Both the critical scratch load and the micro hardness of the (Ti, W) N/ (Ti, W, Si, Al) N-coated tool are larger than those of the (Ti, Al) N-coated tool. Therefore, it is considered that the tool wear of the (Ti, W) N/ (Ti, W, Si, Al) N-coated tool is the smaller because the (Ti, W) N /(Ti, W, Si, Al)N coating film has good wear resistance.

Furthermore, the friction coefficient was measured with a ball-on-disk tribometer. Fig. 4 shows the relationship between the sliding distance and the friction coefficient under a sliding speed of 0.16 m/s and a normal load of 1.00 N. The maximum sliding length is 1.74 km (1.09×10^4 s, 3.02 hrs.). The friction coefficient of the (Ti, W, Si, Al) N coating film shown in Fig. 4(b) is smaller than that of the (Ti, Al) N coating film shown in Fig. 4(a). Table VII shows the mean value of the friction coefficient of the (Ti, W, Si, Al) N coating film and the (Ti, Al) N coating film. The mean value of the friction coefficient of the (Ti, W, Si, Al) N coating film, 0.564, is smaller than that of the (Ti, Al)N coating film, 0.817.

As mentioned above, in order to improve the tribological properties of the coating films, the (Ti, W, Si, Al) N coating film was used. Therefore, it is considered that the tool wear of the (Ti, W) N/ (Ti, W, Si, Al) N-coated tool is the smaller because the (Ti, W) N/ (Ti, W, Si, Al) N coating film has the lower friction coefficient.

Finally, an accuracy inspection of the tapped internal thread was conducted with a taper pipe thread plug gauge (OSG Corporation). Fig. 5 shows the tapping number until thread failure. In the case of the (Ti, Al) N-coated thread milling cutter, the accuracy of the thread cannot be maintained above a tapping number of thread holes of 90. However, in the case of the (Ti, W) N/ (Ti, W, Si, Al)N-coated thread milling cutter, the accuracy of the thread is maintained until number of thread holes is 125. It is possible for the (Ti, W) N/(Ti, W, Si, Al) N-coated thread milling cutter to perform stable tapping for a long period.

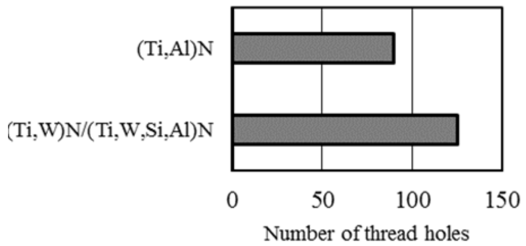


Fig. 5. Tapping number until thread failure.

IV. Conclusion

Helical milling method with thread milling cutters in thread tapping is effective against problems associated with tapping chips. In this study, chromium-molybdenum steel (ISO 34CrMo4, AISI 4137) was helical milled with two physical vapor deposition (PVD)-coated cemented carbide end thread milling cutters in order to determine effective tool materials for tapping chromium-molybdenum steel. The coating films used were (Ti, W) N/ (Ti, W, Si) N and commercial (Ti, Al) N coating films. The inner layer of the (Ti, W) N/ (Ti, W, Si, Al)N coating system is (Ti, W)N coating film, and the outer layer is (Ti, W, Si, Al) N coating film. In order to identify an effective tool material for thread tapping of chromium-molybdenum steel, tool wear was experimentally investigated.

The main results obtained are as follows:

- In thread tapping of chromium-molybdenum steel at a cutting speed of 0.67 m/s, the tool wear width of the (Ti, W) N/ (Ti, W, Si, Al) N-coated tool is smaller than that of the (Ti, Al) N-coated tool.
- The mean value of the friction coefficient of (Ti, W, Si, Al) N, which is the outer layer of the (Ti, W) N/ (Ti, W, Si, Al) N coating system, is 0.564, and that of (Ti, Al) N is 0.817.
- The (Ti, W) N/ (Ti, W, Si, Al) N-coated cemented carbide is an effective tool material for thread tapping of chromium-molybdenum steel.

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