Surface Treatment of High Speed Steel Tools

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ABSTRACT

This paper reveals to cutting performance on 3 kinds of high speed steels throw away tips (including made by powder metallurgical process), which are compared surface treated tips by means of the coating process PVD-TiN (physical vapor deposition by the arc ion plating method) with untreated conventional tips. The results are as follows: "X" tips by name have the highest hardness and performance on continuous cutting than the others, but they have the lowest toughness and larger chipping on intermittent cutting. The effects by PVD-TiN distinguish into each substrate materials, as "X" tips are hard to recommend appropriate uses.

Hence, it is found that the selections of materials for cutting mode are ever important.

Keywords: powder metallurgical high speed steel, throw away tip, PVD-TiN, cutting mode

1. Introduction

In the recent machinning industries are exposed severely for the cost reductive competition and overseas shift caused by the strong yen rate. According as the diffusion of various surface treatmen technologies, which have been applied to high speed steel tools as a indispensable way of improvement on their cutting performances. [1] In this research, the cutting performances of tools with 3 kinds of high speed steels throw away tips (as shown in Fig. 1), were discussed during the continuous and intermittent cutting. Throw away tips were made by powder metallurgical process or conventional melting process, and the most of them had thin film TiN by optimum coating process of PVD (physical vapor deposition by the arc ion plating method). [2] While, they were compared to untreated commercial throw away tips.

2. Experiments

Experiments are practiced with the work materials to continuous cutting life test on their cylindrical

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surface and to intermitent cutting wear test on the cylinder with groove at the point of cutting edges. Each material tips are finished by grinding, which dealt with surface treatment PVD-TiN and without treatment are made both, then all tips are tested.

3. Chemical Composition of Testing Materials

The chemical composition of testing materials are as shown in Table 1, therein upper two are made by powder metallurgical process with sinter and"X" has less Mo contents than "H", but larger W contents 2 times than "H".The bottom"K" is made by usual melting process and as a whole has less contents than the powder metallurgical others because such enriched high alloy elements could not be melt together uniformly in the melting and casting processes. [3],[4]

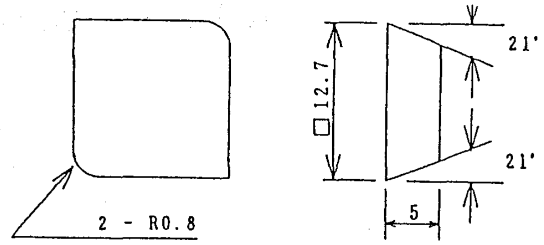

Fig. 1 Tip geometries

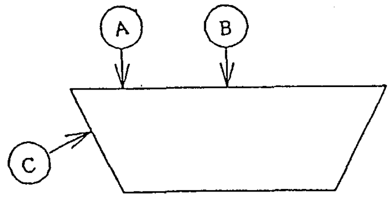

Fig. 2 Measured position

in Table 2, therein shown Rockwell hardness of each material together. Further, in this table"n"is the number of samples, "$\overline{X}$" is the mean value, and "R" is the range of hardness scatter.

5. Surface Treatment

All sample are surface treated by means of PVD-TiN (request Japan Adcoating Inc. by the arc ion plating method). At the 3 position of each sample

Table 1 Chemical composition of the testing materials (wt.%)

Material	C	Si	Mn	P	S	Cr	Mo	W	V	Co
Powder metallurgy H	2.26	0.33	0.30	0.023	0.027	4.10	6.83	6.75	6.40	10.40
Powder metallurgy X	2.15	0.30	0.27	0.023	0.006	4.10	5.85	14.22	5.48	11.65
Melting K	1.40	0.32	0.26	0.019	0.011	3.98	3.37	8.84	3.75	11.65

4. Heat Treatment

Heat treatment are operated by oil quenching and tempering in the air, those conditions are shown

as shown in Fig. 2, coated film thickness is measured by DENSOKU industry Inc. with beta-ray film thickness meter BTC-55. These results are shown in Table 3. Thickness on near part of the cutting edge are almost uniform for all materials. [5]

6. Cutting Conditions

6.1 Cutting Machine

Experimental cutting test are performed by LS type universal lathe with KOPP stepless speed speed changer, which made by OHKUMA Inc.

6.2 Work Materials

Work materials to be cut are the machinery structural alloy steel SCM 440 (hardened and tempered). Applied diameter and hardness for each cutting mode are shown in Table 4.

6.3 Cutting Mode and Tool Life Criterion

(1) Cutting speed and tool life criterion

Cutting test are performed on the continuous and intermittent cutting at various speed, thereby respective tool life criterion are defined as shown in Table 5.

(2) Depth of cut "d" and feed rate "f"

d = 1.5 mm, f = 0.2 mm/rev. : constant value

(3) Cutting fluid

Cutting fluid are applied all cutting conditions, but pouring quantity are 1.5 l/min.for continuous cutting, and 1.0 l/min. for intermittent cutting. The brand of cutting fluid is"Custrol HYSOL-X", which is a water soluble type.

(4) Work material for intermittent cutting

Shematic view of the work material with tool for intermittent cutting, is shown in Fig. 3.

Table 2 Heat treatment and hardness:(HRC)

Material	Quenching (oil)	Tempering	Hardness(n=5)	
			$\bar{X}$	R
H	1190℃ 45 sec	560 ℃ 90 min 3 times	67.8	0.4
X	1210℃ 45 sec		70.1	0.3
K	1220℃ 45 sec	540 ℃ 90 min 3 times	68.0	0.6

Table 3 Coated film thickness unit in μm (n=15)

Material		Top surface (near edge)		Flank (near edge)
		A (Cutting edge)	B	C (Cutting edge)
H	$\bar{X}$	2.25	1.70	2.02
	R	0.74	0.29	1.28
X	$\bar{X}$	2.29	1.93	2.32
	R	0.60	0.53	1.04
K	$\bar{X}$	2.42	1.84	2.06
	R	0.69	0.21	0.79

Table 4 Work materials: SCM440(hardened and tempered)

Cutting mode	Work diameter (mm)	Hardness (Hs)
High speed continuous cutting	φ 147~120	41~38
Low speed continuous cutting	φ 130~110	38~36
Intermittent cutting	φ 146~136	42~40

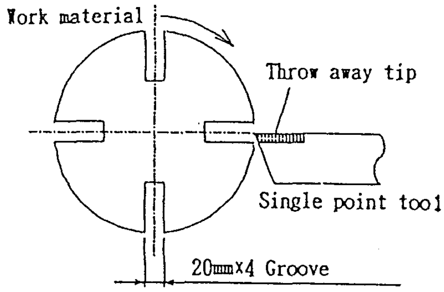

Fig. 3 Schematic view of intermittent cutting

Table 5 Cutting speed and tool life criterion

Cutting mode		Cutting speed	Tool life criterion
Continuous cutting	High speed cutting	45, 50, 55 (m/min) Without treatment tip	During time: The cutting edge to be damaged perfectly
		55, 60, 65 (m/min) TiN treatment tip	
	Low speed cutting	25 (m/min)	Flank wear after the defined time cutting
Intermittent cutting	Low speed cutting	15 (m/min)	Flank wear after the defined time cutting and fracture

7. Results

The obtained test results are as follows.

Table 6 During time : The cutting edge to be damaged perfectly:(min) n=3

Cutting speed (m/min)	Without treatment						Surface treatment (PVD-TiN)					
	H		X		K		H		X		K	
	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R
45	12.73	9.78	16.54	16.03	11.57	7.03						
50	4.73	3.53	6.97	1.86	3.84	1.48						
55	2.21	1.30	3.87	1.61	3.31	1.36	7.35	1.14	11.77	3.81	12.15	1.10
60							4.96	1.86	7.14	3.25	6.46	2.43
65							2.86	1.27	3.34	0.72	3.79	0.35

7.1 High speed continuous cutting

From this test, the obtained during time that the cutting edge to be damaged perfectly, are shown in Table 6. As for during time of without treatment in Table 6, "X" have superior values than the others, exept the dispersion at 45 m/min. While those with surface treatment have no superiority, rather "K" by melting process have long time and little dispersion. Tool life rate comparison with "H"= 100, are shown in Table 7. Further, relations between these tool life (T) and cutting speed (V), V - T curves i.e. both logarithmic representations are shown in Fig. 4, 5.

Table 7 Tool life rate compared with H

Cutting speed (m/min)	Without treatment			Surface treatment (PVD-TiN)		
	H	X	K	H	X	K
45	100	130	91			
50	100	147	81			
55	100	175	150	100	156	161
60				100	145	131
65				100	117	133

In those, the upper placing curve showed long life and usefulness as "X". But, it is thought that the effect of surface treatment was tangled to add to material characteristics. "X" and "K" show more better tendency at high speed range than "H", but the effect of surface treatment are larger than the difference of material composition. As a whole, the effect of surface treatment on same material showed so long life 3 - 4 times of without those at cutting speed 55 m/min.

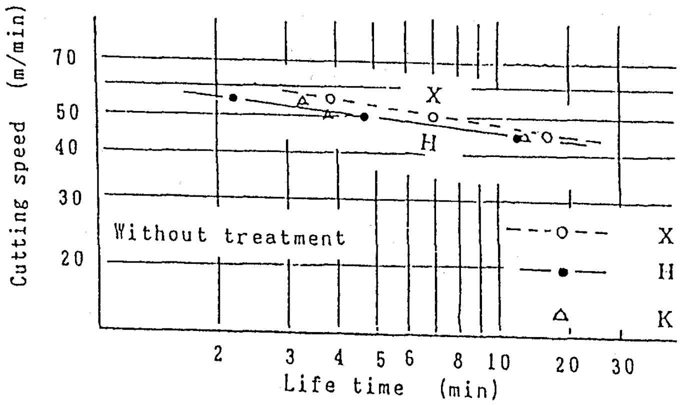

Fig. 4 V-T curve (Without treatment)

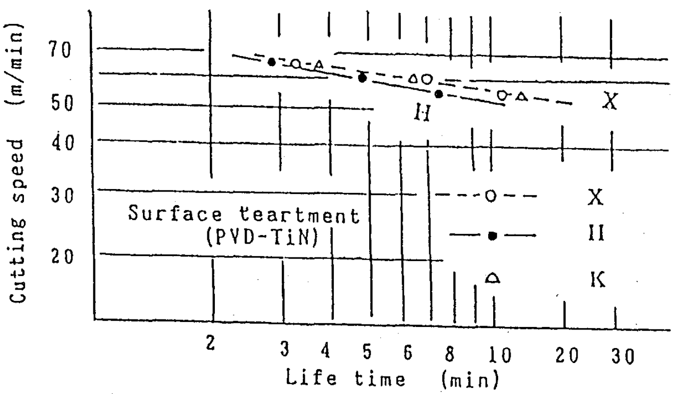

Fig. 5 V-T curve (Surface treatment)

7.2 Low speed continuous cutting

Low speed continuous cutting are carried out at the same cutting speed 25 m/min over all. The flank wear VB are measured by Carl Zeiss type universal measuring microscope at each definite cutting time. For reference, the crater wear KT (depth of the maximum crater) are measured after the cutting time 30 min as above. These data are shown in Table 8, 9 respectively.

Table 8 Flank wear quantity after the defined cutting time:VB(μm) n=3

Cutting time (min)	Without treatment						Surface treatment (PVD-TiN)					
	H		X		K		H		X		K	
	X̄	R	X̄	R	X̄	R	X̄	R	X̄	R	X̄	R
1	126.7	35	56.7	15	105.0	65	Abrasion isn't recognized.					
3	153.3	25	73.3	10	140.0	40	(ditto)				46.7	5
5	185.0	30	116.7	30	181.7	40	40.0	20	33.3	15	46.7	20
7	193.3	55	126.7	15	198.3	70	43.3	30	36.7	5	56.7	30
10	228.3	45	158.3	10	255.0	85	53.3	30	38.3	5	58.3	25
15	263.3	50	210.0	30	306.7	75	58.3	25	56.7	15	66.7	20
20	291.7	45	270.0	25	380.0	90	58.3	25	66.7	5	70.0	25
30	415.0	130	378.3	30	535.0	60	63.3	30	75.0	10	73.3	15
40							73.3	35	85.0	20	80.0	20

For visual research, the relations between cutting time and flank wear VB are illustrated in Fig. 6. There are large differences in VB and KT between with and without surface treatment. After mere 1minute cutting, any flank wear of without treatment can be seen clear, but can not be recognized and measured in case of with treatment. The appearance of the cutting edges after 10 minutes cutting, are shown in photograph Fig. 7. As regarding the adhesive wear appearance, the difference whether surface treat or untreat are found distinctly, then the difference of materials are little. As seen each photograph, upper side show KT and lower side show VB, and the both wear trace are distinct in without treatment. But the surface treatment wear are little and can not be measured. The flnk wear of "X" are least on both tests with and without treatment tips, as they increase in the order of "H", "K". The effect of surface teatment appeared during low cutting speed so 25 m/min clearly. As shown in photograph Fig. 8, the flank wear of without treatment tips become to 0.38 - 0.54 mm after 30 minutes cutting, while the wear of with treatment tips exceed largely confining within 0.1mm, for all various differences of substrate materials, such as seen in Fig. 7.

Table 9 Crater wear quantity after 30 minutes cutting : KT(μm) n=3

Cutting time (min)	Without treatment						Surface treatment (PVD-TiN)					
	H		X		K		H		X		K	
	X̄	R	X̄	R	X̄	R	X̄	R	X̄	R	X̄	R
30	169.7	46	143.3	4	140.7	7	Wear little and can not be measured					

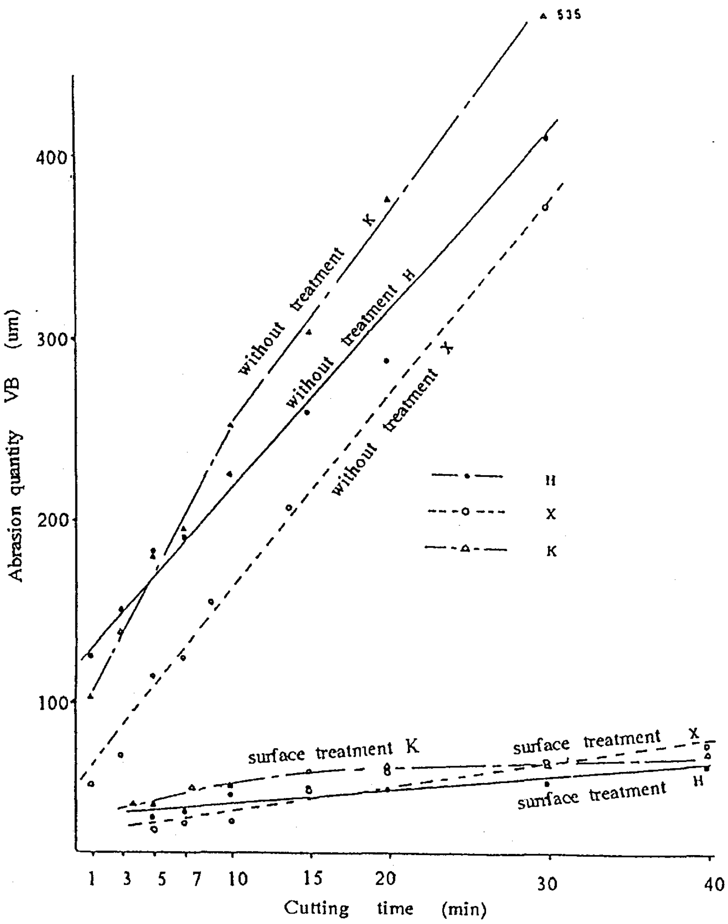

Fig. 6 Relations between cutting time and flank wear (Low speed continuous cutting)

7.3 Low speed intermittent cutting (15 m/min)

Low speed intermittent cutting are carried out at the cutting speed 15 m/min and flank wear VB are measured by the same procedure above, at each definite cutting time. Table 10 are shown these VB, which caluculated with adjacent 2 measured values, because dispersion of them are large. The shockness on the point of cutting edge at touching instance are severely, hence large fracture or chipping often occure. Table 11 are shown the occurence conditions of the fracture or chipping. Hence the results of inttermitent cutting test are by contraries to the case of continuous cutting. "X" is very brittlest, so not put up for this use. As regarding the difference between "H" and "K", the surface treatment make fracture tendency improved clearly. Thus, the effect of surface treatment are clear in the

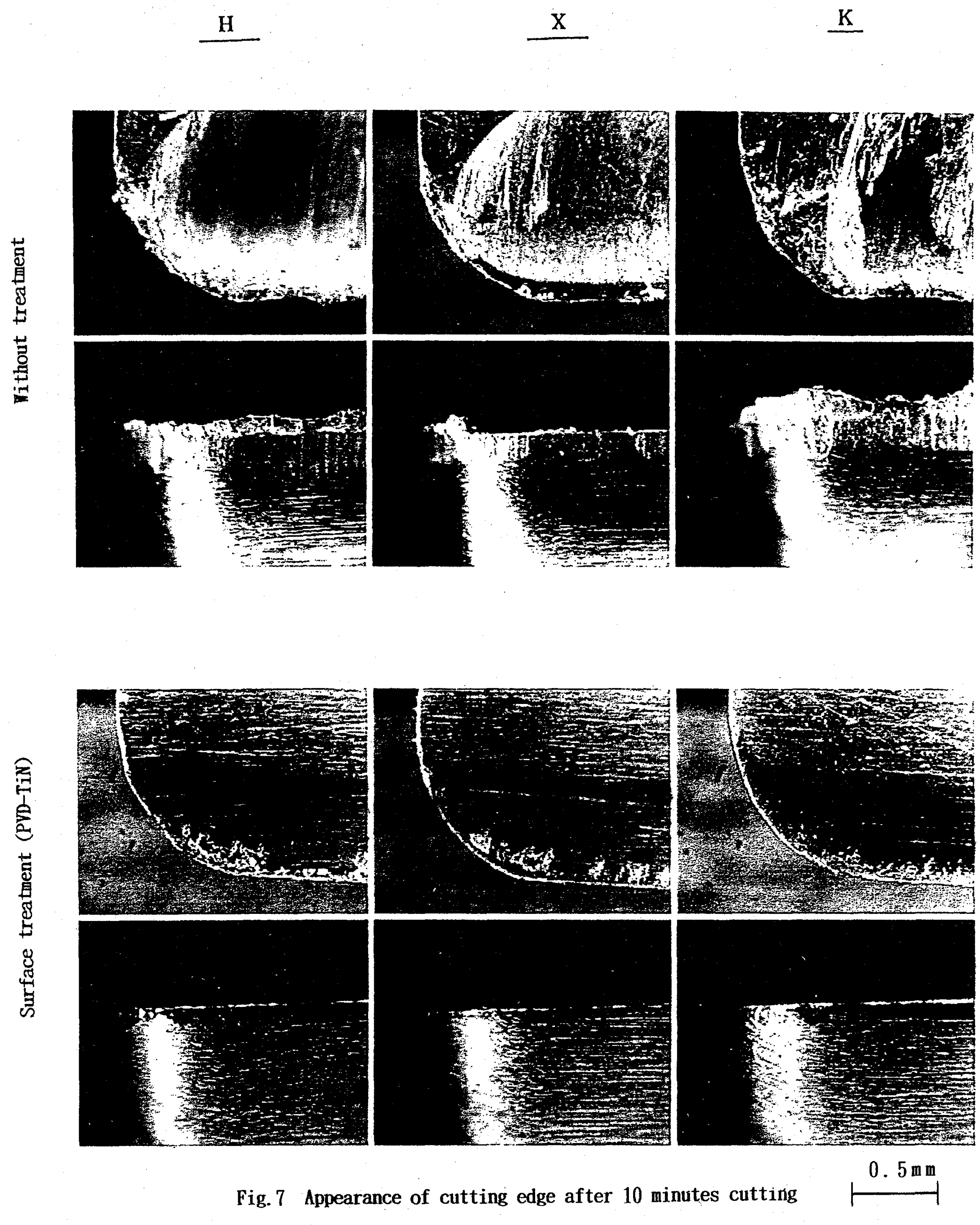

Fig. 7 Appearance of cutting edge after 10 minutes cutting

(Low speed continuous cutting)

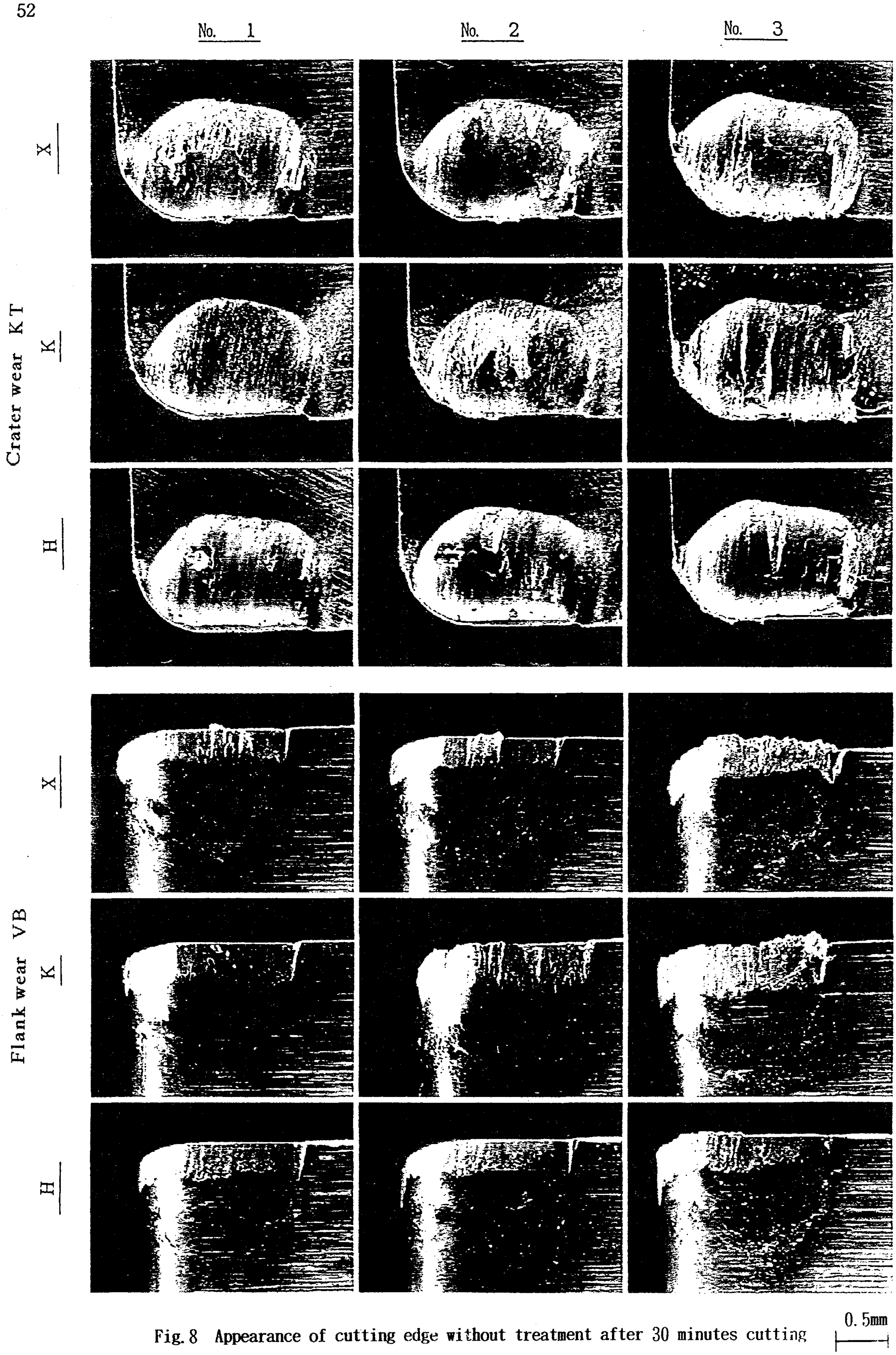

Fig. 8 Appearance of cutting edge without treatment after 30 minutes cutting

(Low speed continuous cutting)

Table 10 Flank wear quantity after the defined cutting time :VB(μm)n=3

Cutting time (min)	Without treatment						Surface treatment (PVD-TiN)					
	H		X		K		H		X		K	
	X̄	R	X̄	R	X̄	R	X̄	R	X̄	R	X̄	R
1	97.5	5	812.5	5	117.5	5	55.0	5	50.0	10	65.0	0
3	192.5	25			145.0	0	85.0	5	80.0	0	95.0	0
5	272.5	35			202.5	35	90.0	0	87.5	5	97.5	5
7	287.5	35			n=1 240	—	112.5	5	90.0	0	100.0	0
10							120.0	10	180.0	160	117.5	5
15							107.5	15	n=1 100	—	122.5	5
20							107.5	15			132.5	15
25							110.0	10			137.5	5

clear in the same way as the continuous cutting even the intermittent cutting, and they are larger than the distinction of substrate materials. The appearance of cutting edge after 3 minutes start on cutting, are shown in photograph Fig. 9. Therefrom it can be seen that chipping happen to all without treatment tips, in special all "X" tips chipped in the first 1 minute extremely, and are unusable already. On the contrary, the surface treatment tips have no fracture all this materials. As regards the surface treated "K", it is not recognized as large fracture even after 25minutes cutting, and it is evaluated so the most available material that it can be use for surface treatment. However, considering abrasion quantity "H" are favorable, so it is smaller than the others.[6]-[9]

Table 11 The occurrence condition of the fracture (with n=3, from the test start)

Cutting time (min)	Without treatment			Surface treatment (PVD-TiN)		
	H	X	K	H	X	K
1	○○○	×××	○○○	○○○	○○○	○○○
3	○○○		×○○	○○○	○○○	○○○
5	○○○		○○	○○○	×○○	○○○
7	○○○		×○	○○○	○○	○○○
10				○○○	○○	○○○
15				×○○	×○	○○○
20				○○		○○○
25				○○		○○○

Notes)○ The tip that large fracture didn't occur.
× Large chipping (>0.3mm) appeared tip.

8. Conclusion

To investigate the cutting performance and usage of the commercial cutting tools, tests were carried out

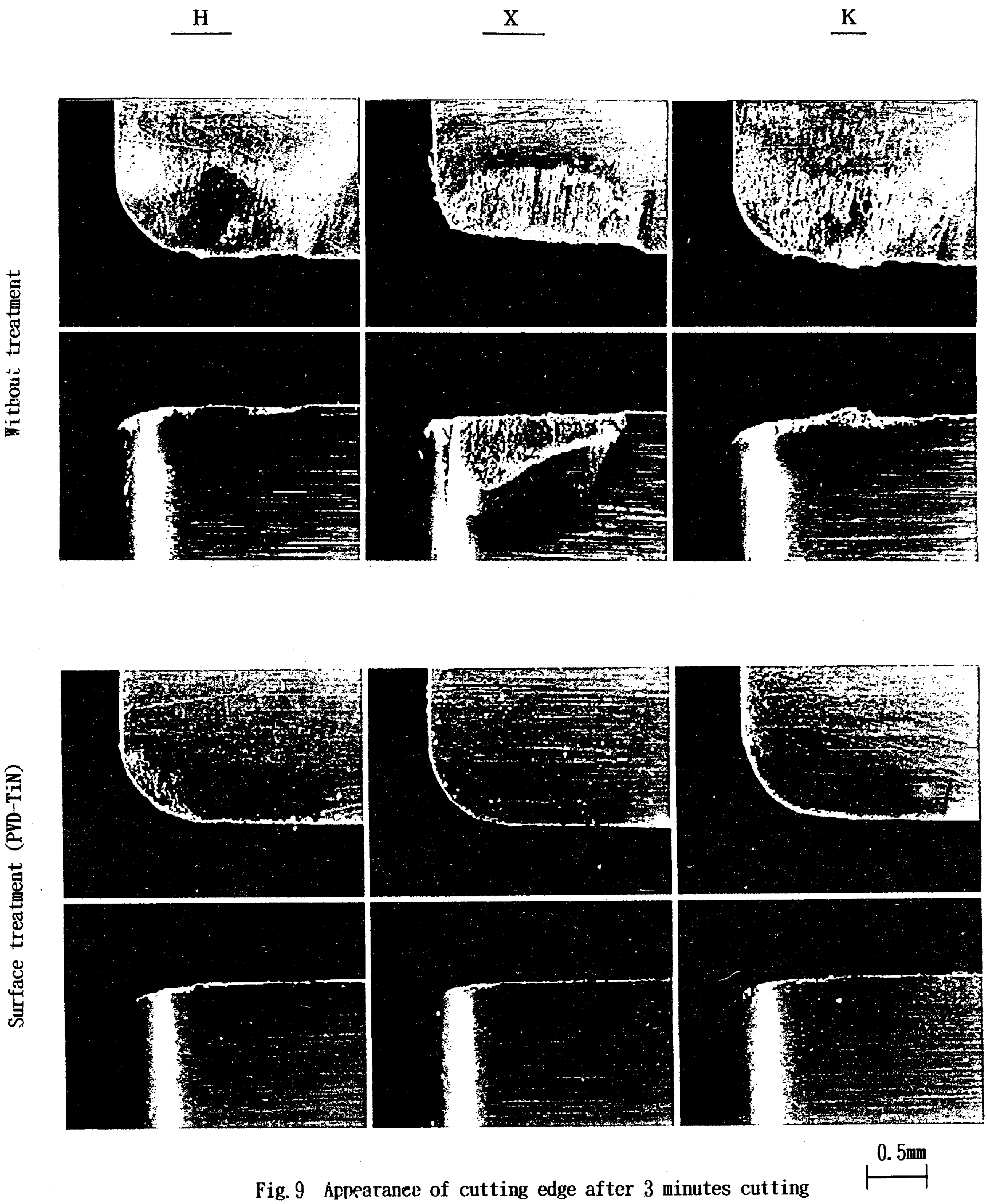

Fig. 9 Appearance of cutting edge after 3 minutes cutting

(Low speed intermittent cutting)

during various cutting modes. The cutting tools were used 3 kinds of high speed steels with throw away tips,which were made by powder metallurgical process or conventional melting process. Then the most of them had about 2 μm thickness TiN by means of the optimum surface coating process PVD, which was applied arc ion plating. Experiments were practiced using the hardened and temperd work material SCM 440. Obtained results are as follows:

(1) The hardness by quenching and tempering of powder metallurgical throw away tips so-called "X" is highest, because it have high alloy (W, Mo) elements much more than the others, therefor highest heat resistance and longest tool life on the continuous cutting.

(2) In case of intermittent cutting "X" is very short in life and brittlest than others, so not put up for this use. Because it have high alloy elements excessively, and breakable complex carbides are much more formed.

(3) The improvable effect of surface treatment PVD-TiN are large about overall cutting test, and it is proved that they exceed the differences in the raw character of testing materials.

(4) It could not be covered even surface treatment PVD - TiN, that the most high alloyed powder metallurgical tips "X" are brittle and unuseful in the intermittent cutting with considerable shock.

Acknowledgment

The auther would like to thank heartily Director of the NIPPON KOUSHUHA KOUGYO Inc. K.SHIWAKU for financial support, and T.IIDA for carrying out experiments and good cooperation.

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