TURNING OF BN FREE-MACHINING STEEL

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Abstract

This paper deals with the machinability of BN (Boron Nitride) free-machining steel in turning. Tested work materials were plane carbon steel JIS S45C and BN free-machining steel. The JIS S45C used as the standard. The tool wear in turning BN free-machining steel was smaller than that in turning standard steel. BN free-machining steel showed slightly lower cutting temperature and smaller cutting force to compare with standard steel at the tested cutting speeds. At the tool wear region of P grade carbide tool after turning BN free-machining steel at high cutting speed, Al and N were detected as a layer. It is thought that one of the main reasons of outstanding machinability of BN free-machining steel is the deposited layer containing Al and N acts as diffusion barrier at the tool-chip interface. In turning larger Al content BN added steel with higher Ti content cutting tool, the influence of BN addition on the tool wear reduction was more remarkable.

Key words: turning, carbide tool, cermet tool, tool wear, free-machining steel, belag, AlN

1 INTRODUCTION

In order to carry out efficient machining, several free-machining steels, which can be machined at higher cutting speed and show longer tool life by free-machining additives, have been developed and used for free machining stock such as screws and fasteners and many components of automobile.

As typical free-machining steel, leaded[1], sulfured [2][3] and calcium treated free-machining steel are widely known. About the effect of free-machining additives on the machinability and mechanical properties, lead acts as a lubricant between tool and work piece, resulting in longer tool life. Bismuth is also used as the substitute for lead. Enhanced manganese sulfur inclusion reduces transverse toughness and increases ductility. In the case of Calcium deoxidized steel [4], a complex oxide layer formed on the rake and flank face acts as the diffusion barrier between tool and work piece.

In the past few years, there has been an extensive effort to improve of machinability of work materials to increase productivity and to reduce the affection on natural environment. To satisfy these demands, various free-machining steels have been researched and developed [5]. There is BN free-machining steel which contains hexagonal boron nitride h-BN as one of them.

In this paper, Turning tests were performed by carbide tools and cermet tools to investigate the influence of h-BN on the machinability of steel. The tool wear, tool life, cutting force and others were investigated practically and these results were discussed.

2 EXPERIMENTAL PROCEDURE

Cutting tests were performed on mild carbon steel JIS S45C and several BN-free machining steels. The chemical compositions and hardness are listed in Table 1. The S45C was used for the standard. BN free-machining steels BN1-BN6 contained approximately 80 ppm of Boron, 150 ppm of Nitrogen but BN5 contained low Nitrogen (67ppm) and different levels of Al (BN1:0.02%, BN3; 0.009%, BN4;

Table 1 Chemical compositions of tested work materials

	Chemical compositions mass%							Hardness HB
	C	Si	Mn	S	Sol.Al	N	B	
S45C	0.43	0.25	0.73	0.018	0.020	0.0030	-	162
BN1	0.42	0.24	0.74	0.015	0.019	0.0150	0.0080	163
BN2	0.43	0.25	0.74	0.019	0.023	0.0130	0.0050	168
BN3	0.45	0.25	0.76	0.019	0.009	0.0163	0.0079	161
BN4	0.42	0.26	0.78	0.024	0.066	0.0167	0.080	158
BN5	0.41	0.26	0.77	0.023	0.076	0.0067	0.0086	145
BN6	0.41	0.25	0.76	0.021	0.111	0.0175	0.0077	155
S45C-AN	0.44	0.26	0.72	0.017	0.066	0.0155	0.0001	152

Table 2 Cutting conditions

Tool	Carbide K10, P10, P20, TiC Cermet, TiN Cermet
Cuttind speed	60 – 500 m/min
Feed rate	0.1, 0,2 mm/rev
Depth of cut	0.5, 1.0 mm
Coolant	dry

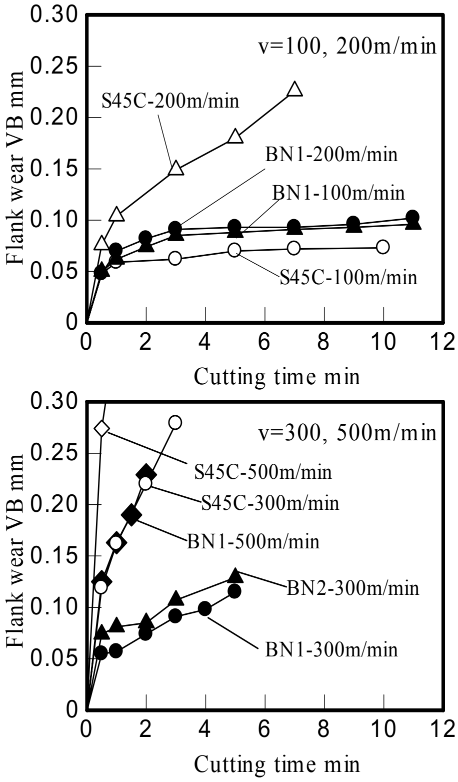

Fig. 1 Wear progress curves of carbide tool P20 in turning S45C and BN free-machining steels (d=0.5mm, f=0.1mm/rev, dry)

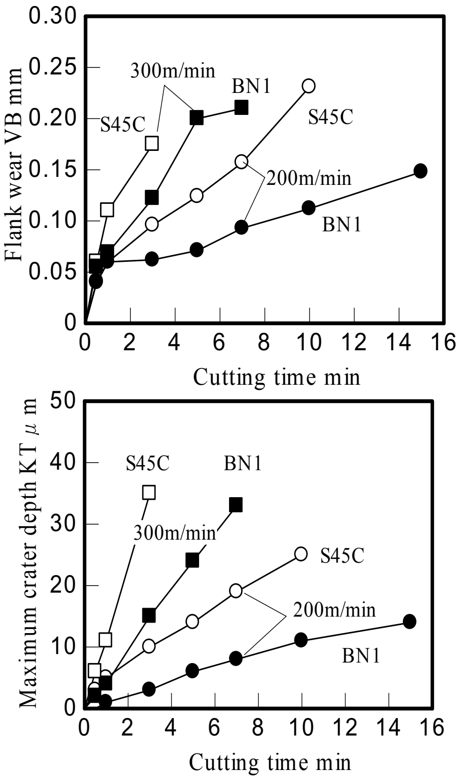

Fig. 2 Wear progress curves of carbide tool P30 in turning S45C and BN free-machining steels (d=0.5mm, f=0.1mm/rev, dry)

0.066%,BN5;0.076%, BN6; 0.111%). S45C-Al was Al enriched to compare with the standard (0.07% Al). S45C-AN was Al and Nitrogen enriched (0.07% Al and 150 ppm Nitrogen). All of these steels were normalized under the conditions of 850℃-2 hours.

Turning tests were carried out at the cutting conditions shown in Table 2. Tested tools were carbide tools (K10, P10, P20, P30), TiC cermet tool and TiN cermet tool. The forms of cutting tool were

SNGN120408 or SNMN120408. In turning, cutting was interrupted to measure the flank wear width by a micrometer-equipped microscope and the maximum crater depth by a surface roughness-measuring instrument.

3 RESULTS

Fig. 1 shows the wear progress curves of carbide tool P20 in turning S45C and BN free-machining steels. At the cutting speed 100 m/min there was no difference between these work materials. However at the cutting speed 200 m/min, BN free-machining steel caused smaller flank wear than that of standard steel. Even at the cutting speed 500 m/min, the flank wear width was smaller flank wear than that of standard steel. When turning with P20 (SNGN120408), the crater depth couldn't be measured for a chip bleaker. Then to investigate the influence of BN in work material on the crater wear, the experiment was also carried out using the throwaway chip with a flat rake face (SNMN120408). Fig 2 showed the wear progress curves of carbide tool P30 in turning S45C and BN free-machining steels at the cutting speed 200 and 300m/min. The flank wear in turning BN free-machining steel was smaller than that of standard steel same as the case of P20 (SNGN120408). At the cutting speed 300m/min, the maximum crater depth in turning standard steel increased rapidly from the cutting start and reached about 35μm at the cutting time 3min. On the other hand, the maximum crater depth in turning BN free-machining steel with 80ppm-Boron and 150ppm-Nitrogen increased gradually and reached about only 15μm at the cutting time 3min.

Fig. 3 shows the wear patterns of carbide tool P20 after turning S45C and BN free-machining steels. The Carbide tool after turning BN free-machining steel showed obviously smaller flank wear than that of standard steel.

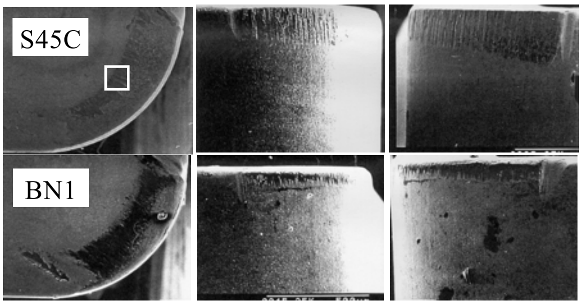

Fig. 3 Wear patterns of carbide tool P20 after turning S45C and BN free-machining steel BN1 (v=300m/min, d=0.5mm, f=0.1mm/rev. t=5min, dry)

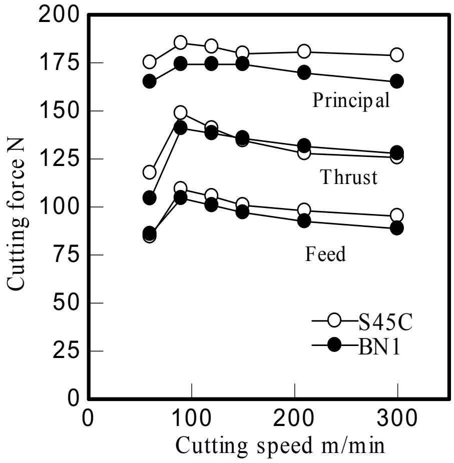

Fig. 4 Relationship between the cutting speed and cutting force in turning S45C and BN free-machining steel BN1(v=90-300m/min, d=0.5mm, f=0.1mm/rev, dry)

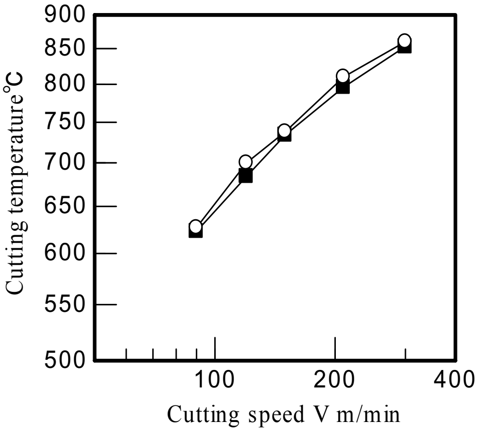

Fig. 5 Relationship between the cutting speed and cutting temperature in turning S45C and BN free-machining steel BN1 (v=60-300m/min, d=0.5mm, f=0.1mm/rev, dry)

Fig. 4 shows the relationship between the cutting speed and the cutting force in turning S45C and BN free-machining steels. The principal force, thrust force and feed force decreased with the increase of cutting speed over 100 m/min. In turning both steels at the cutting speed over 100 m/min, the cutting force decreased with the decrease of cutting speed. This suggests that the built-up edge was generated on the cutting edge. To compare with standard steel, BN free-machining steel showed slightly smaller principal, thrust and feed force at any cutting speed.

Fig. 5 shows the relationship between the cutting speed and cutting temperature in turning S45C and BN free-machining steels. As shown here, In turning any work materials, the temperature increased

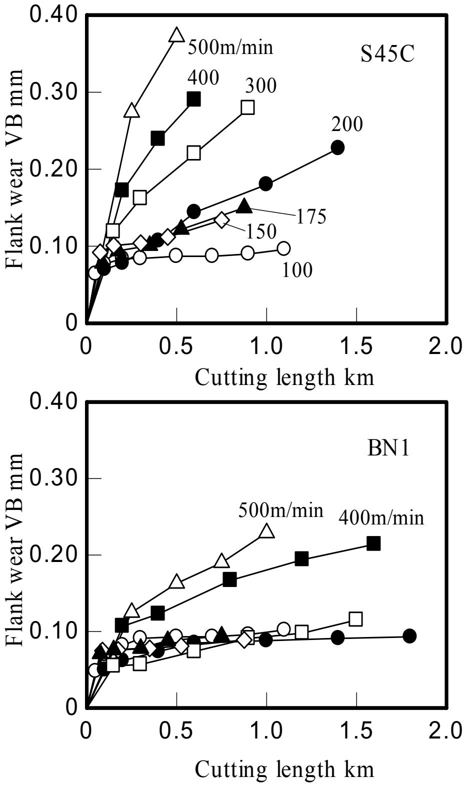

Fig. 6 Relationship between the cutting distance and flank wear in turning S45C and BN free-machining steel BN1 (P20, v=100-500m/min, d=0.5mm, f=0.1mm/rev, dry)

linearly with cutting speed on both logarithm graphs. To compare with standard steel, BN free-machining steel showed slightly lower cutting temperature at any cutting speed.

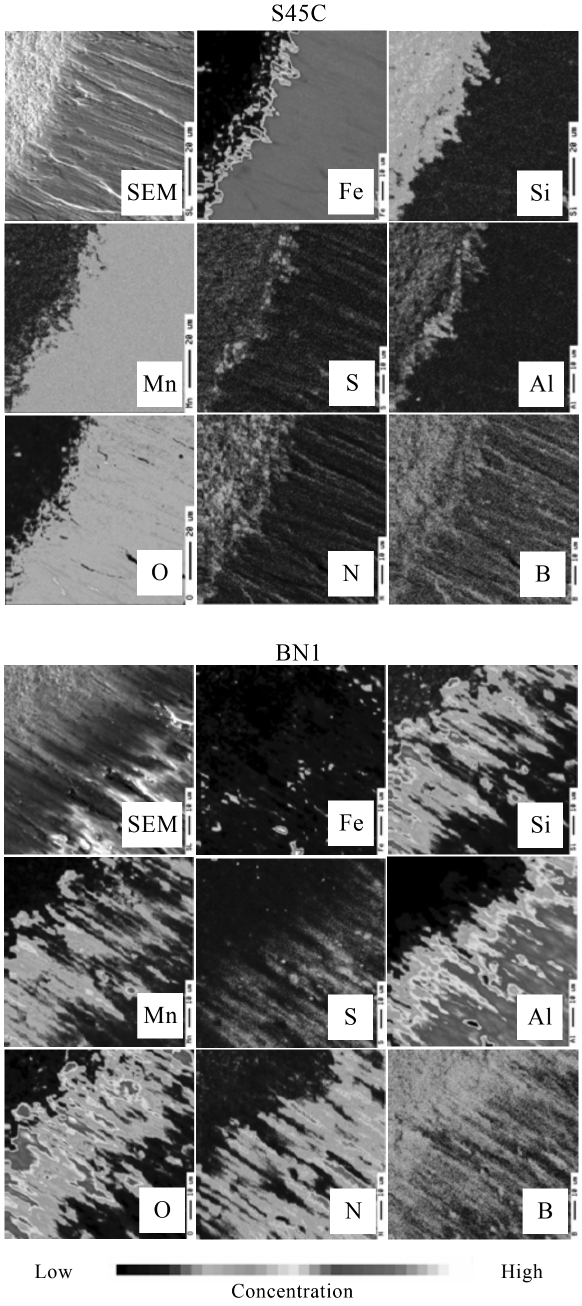

Fig. 7 Elements distribution on the rake face of carbide tool P20 after turning S45C and BN free-machining steel BN1 (v=300m/min, d=0.5mm, f=0.1mm/rev. t=5min, dry)

4 CONSIDERATIONS

Fig. 6 shows the relationship between the cutting distance and flank wear in turning S45C and BN free-machining steel BN1. It assumed that the tool wear was caused by only mechanical wear the wear progress rate against the cutting distance should be almost the same value. However in turning S45C at the cutting speed over 175m/min, the larger wear progress rate showed than that in turning at the cutting speed under 175m/min. This means that at the higher cutting speed the more thermal wear was caused [6]. On the other hand, BN1 showed almost the same wear progress rate at until 300 m/min and smaller rate than that of S45C at over 300m/min. Thus it is thought that the flank wear in turning BN1 was less caused by thermal wear than that of S45C. It is widely known these phenomenons are observed in turning calcium treated steel, which wear reduction mechanism is thought the deposited layer called “belag” act as diffusion barrier between the tool-work interfaces at the high cutting speed.

The distribution of the elements on the tool wear-out region after turning S45C and BN free-machining steel BN1 were analyzed by an Electron Prove Micro Analyzer (EPMA). Fig. 7 shows the elements

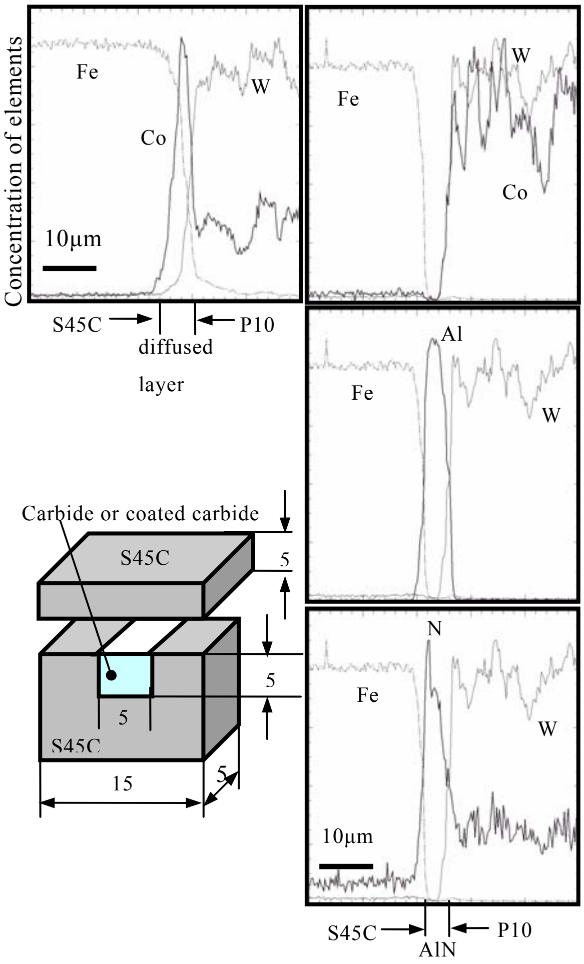

Fig. 8 Result of the line analysis of diffusion couples S45C-P10 and S45C-AlN-P10

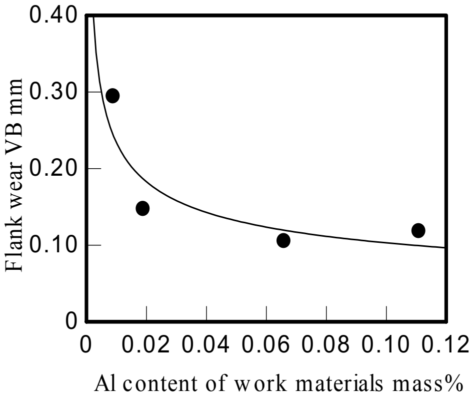

Fig 9 Relationship between Al content of BN free-machining steel and the flank wear width of carbide tool P20 in turning (v=300m/min, d=0.5mm, f=0.1mm/rev, dry)

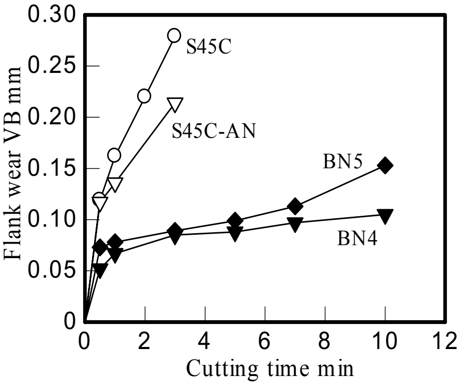

Fig. 10 Relationship between B, N content of work materials and the flank wear width of carbide tool P20 in turning (v=300m/min, d=0.5mm, f=0.1mm/rev, dry)

distribution on the rake face of carbide tool P20 after turning S45C and BN free-machining steel BN1. For S45C, most of the adhesion was Fe. In many cases Al is detected on the tool surface with Si and Ca as a compound oxide. However, in the case of BN1, the distribution pattern of Al extremely looked alike to that of Nitrogen. Thus it is thought that these Al and N adhere on the tool as a layer.

To clarify the reasons of the smaller tool wear in turning BN free-machining steel, the diffusion test was carried out. The couples were heated at 1200℃ for 30 min in a vacuum furnace and then cooled down in the furnace. The couples were sectioned to detect the defused elements by an electron probe micro analyzer. The result of the line analysis of diffusion couples were shown in Fig. 8. In the case of S45C-P10, which simulates turning plain carbon steel with carbide tool, cobalt in the tool diffused into the steel and iron in the steel diffused into the tool. It shows the inter-diffusion of the elements is the main cause of the crater wear at high cutting speed. In the case of S45C-AlN-P10, which simulates turning BN free-machining steels with carbide tool, no element diffused each other. This means that the AlN adhered on the tool act as a diffusion barrier between tool and work material. This must be the reason why BN free-machining steels cause smaller tool wear than that of standard steel.

From these obtained result in this research, it can be thought that the Al, B and N content in work material influenced on the tool wear in turning BN free-machining steels. Therefore, turning the work materials with different Al content were carried out. The rationship between Al content of BN free-machining steel and the flank wear width of carbide tool P20 in turning is shown in Fig. 9. The higher Al content BN added steel caused the smaller flank wear width. However, the influence was settled as for

Table 2 Chemical composition of tested cutting tools by EPMA analysis

	Chemical compositions %			
	W	Ti	Ta	Co
K10	63.5	-	0.6	5.3
P20-1	46.7	7.5	4.6	8.0
P20-2	48.4	9.4	4.6	5.0
P10-1	41.8	12.7	6.4	6.9
P10-2	36.8	13.7	7.1	7.6
TiN-Cermet	8.9	25.4	6.6	6.0
TiC-Cermet	2.1	33.8	5.7	0.7

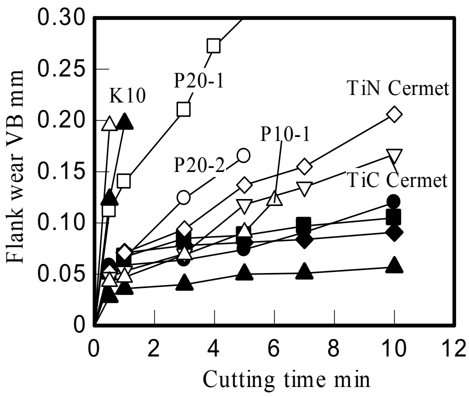

Fig. 11 Wear progress curves of tested tool with different Ti content in turning S45C and BN free-machining steel BN4 (P20, v=300m/min, d=0.5mm, f=0.1mm/rev, dry)

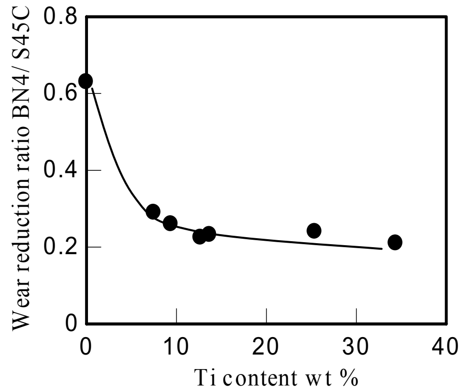

Fig. 12 Influence of Ti content of cutting tool on the tool wear reduction rate (P20, v=300m/min, d=0.5mm, f=0.1mm/rev, dry)

more than the constancy amount with the Al content.

The relationship between B and N content of work materials and the flank wear width of carbide tool P20 in turning is shown in Fig. 10. The Al content of S45C-AN, BN4 and BN5 were almost the same. However, N content of BN5 is lower than that of BN4 and B content of S45C-AN is almost no. The wear in turning S45C-AN and BN5 were larger than that in turning BN4. Thus, the appropriate B and N are also needed to obtain good machinability.

Moreover, it was thought the tool wear reduction depend on tool material like calcium treated steel, turning test was carried out with the tool of different Ti content. The chemical compositions of tested tools are shown in Table 3. The wear progress curves of tested tool with different Ti content in turning BN free-machining and S45C are shown in Fig. 11. The influence of Ti content of cutting tool on the tool wear reduction rate is shown in Fig. 12. The tool wear reduction rate was obtained by dividing the wear rate in turning BN added steel by that in turning S45C. The higher Ti contains of cutting tool shows higher wear reduction rate. The influence is settled as for more than the constancy amount with the Ti content. The cermet tool with highest Ti content in turning BN free-machining steel showed the smallest tool wear among the tested tools.

5 CONCLUSIONS

In order to clarify the machinability of BN free-machining steels in turning, Turning tests were performed by carbide tools and cermet tools. The tool wear, tool life, cutting force and others were investigated practically and these results were discussed. The results can be summarized as follows:

1) The tool wear in turning BN free-machining steel was smaller than that of standard steel.

2) To compare with standard steel, BN free-machining steel showed slightly lower cutting temperature and smaller principal, thrust and feed force.

3) At the tool wear region of P grade carbide tool after turning BN free-machining steel at high cutting speed. Al and N were detected by the pattern look alike very well. For S45C, Fe was detected through the tool wear region.

4) In turning larger Al content BN free-machining steel with higher Ti content cutting tool, the influence of BN on tool wear reduction was more remarkable.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of NKK BERS&SHAPES CO., LTD., which enabled this work to be carried out.

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