Effects of TiC content and grain size on cutting performance of Al_2O_3-TiC ceramics tool

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ABSTRACT

Al_2O_3-TiC ceramics tools having 10-50mass%TiC and different grain size were prepared by hot-pressing, and the cutting performance of these tools was studied. The tool having 20-30mass%TiC content and the finest TiC grain size showed superior resistance to flaking and optimum cutting performance in turning test of alloyed tool steel.

INTRODUCTION

Al_2O_3-TiC ceramics tools exhibit higher hardness and toughness compared to pure Al_2O_3 ceramics tools, and offer advantages with respect to wear and fracture behavior in cutting performance. However, Al_2O_3-TiC ceramics tools are mainly used for cutting grey cast iron and have few applications for other work pieces.

In this paper, to study ways of increasing the applications of these tools, Al_2O_3-TiC ceramics tools having 10-50mass%TiC content and different grain size were prepared by hot-pressing, and the cutting performance of these ceramics tools for alloyed tool steel was investigated.

EXPERIMENTAL PROCEDURE

Al_2O_3 powder having particle sizes of approx. 0.3 and 0.8μm and TiC powder of approx. 0.8 and 1.5μm were used as raw materials. Various mixtures in the range of 10 to 50mass%TiC were prepared by ball-milling for 48hr. These mixtures were dried, filled into a carbon mold and hot-pressed using a high frequency induction furnace under a pressure of 20MPa in an Ar atmosphere for 1hr to produce $50\times50\times6mm^3$ plate. The mixture of fine Al_2O_3 and fine TiC (hereafter, referred to as F-F) was hot-pressed at 1723K, coarse Al_2O_3 and coarse TiC(C-C) was hot-pressed at 1973K, and both mixtures of fine Al_2O_3 and coarse TiC (F-C), and coarse Al_2O_3 and fine TiC (C-F) were hot-pressed at 1873K. The hot-pressing temperature was varied according to the mixtures type to suppress grain growth during sintering and to obtain significantly higher sintered densities.

Test pieces of $3\times4\times35mm^3$ were prepared from these plates by cutting and grinding using a #400 diamond wheel, and were offered for measurement of transverse-rupture strength (σ_m), Vickers hardness (Hv), fracture toughness (K_{IC}) and observation of microstructure. Measuring conditions were as follos : σ_m; the mean value of ten test pieces using the three points bending method, 30mm span, and 0.5mm/min cross head speed. Hv; the mean value of five points, 2N load. K_{IC}; the average of calculated values from length of indentation and cracking at five points using the microcrack-indentation method, 98N load.

In addition, cutting tools of ISO SNGN120408 inserts ($12.7\times12.7\times4.76mm^3$ prehoned $0.15mm\times-25'$) were prepared from the same plates, and the cutting performance was studied in turning alloyed tool steel (SKD11, ASTM HB). Cylindrical turning was performed twice for each cutting condition using a computer numerically controlled (CNC) lathe. The amount of flank wear (V_B) and crater wear (K_T), and cutting time to fracture of the ceramics tools were measured, and the wear mechanism was studied by SEM observation of worn structure. V_B was defined as the mean width of worn flank surface and was measured by optical microscope.

RESULTS AND DISCUSSION

Figure 1 shows microstructures of Al_2O_3-30mass%TiC specimens having various grain size. In this structure, the white phases with clear contrast are TiC and the grey phases are Al_2O_3, it is reasonable to assume. The F-F specimen shows the finest structure and the C-C specimen the coarsest structure. The Al_2O_3 grain size

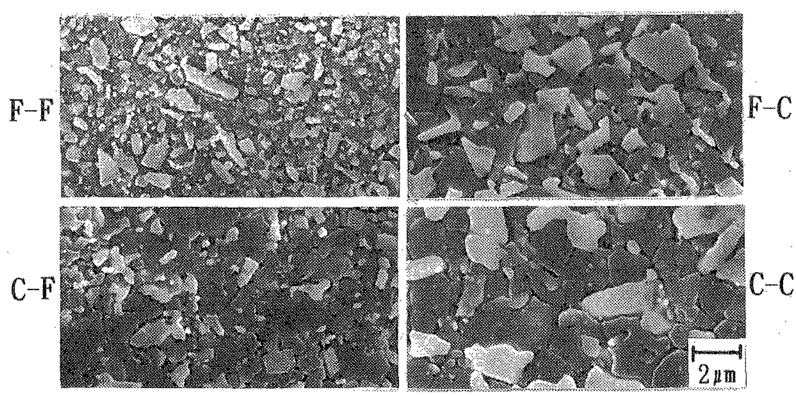

Fig.1 Microstructure of Al_2O_3-30%TiC specimen, after thermal etching.

)f the F-C and the TiC grain size of the C-F specimen are coarser than that of the ᶠ-F, because the hot-pressing temperature of the former was higher than that of the latter.

Table 1 lists the composition and several properties of various kinds of ceramics specimens. The mechanical properties of these specimens improved when the amount of TiC content was increased. Overall, F-F has higher σ_m and Hv than C-C, and C-F and F-C shows intermediate values between F-F and C-C specimens.

Table 1 Compositions and some properties of Al_2O_3-TiC ceramics specimens.

pecimen	TiC content (mass%)	Perticle size of rew material (μm) Al_2O_3	TiC	Hot-pressing temperature (K)	Grain size of ceramics (μm) Al_2O_3	TiC	Hardness Hv (Kg/mm^2)	T.R.S σ_m (MPa)	Fracture toughness K_{IC} (MPa·m$^{1/2}$)
ᶠ−F	10	0.3	0.8	1723	1.2	1.0	1950	900	3.0
	20	〃	〃	〃	1.0	〃	2000	950	3.5
	30	〃	〃	〃	〃	〃	2050	1000	4.0
	50	〃	〃	〃	〃	〃	2100	900	4.3
:−C	10	0.8	1.5	1973	3.0	2.0	1800	800	3.2
	20	〃	〃	〃	2.5	〃	1850	900	3.8
	30	〃	〃	〃	2.2	2.3	1950	900	4.3
	50	〃	〃	〃	〃	2.5	2050	900	4.6
‵−C	10	0.3	1.5	1873	1.4	1.8	1850	850	3.2
	20	〃	〃	〃	〃	〃	1900	900	3.8
	30	〃	〃	〃	1.2	2.0	1950	950	4.0
	50	〃	〃	〃	〃	〃	2050	900	4.5
:−F	10	0.8	0.8	1873	2.2	1.2	1900	800	3.1
	20	〃	〃	〃	〃	〃	1950	900	3.5
	30	〃	〃	〃	1.8	〃	1950	950	4.1
	50	〃	〃	〃	〃	〃	2050	900	4.5

T.R.S: Transverse-Rupture Strength

Next, the results of cutting)erformance are described. In turning ılloyed tool steel, tools often lemonstrate a short life time caused by shell-like fracture of the crater surface (hereafter, refered to as flaking [1]). Figure 2 shows an example)f flaking.

Figure 3 shows the effects of TiC content and grain size of Al_2O_3-TiC ceramics tools on cutting time to flaking in turning tests of alloyed tool steel. The C-C and the F-C tools with

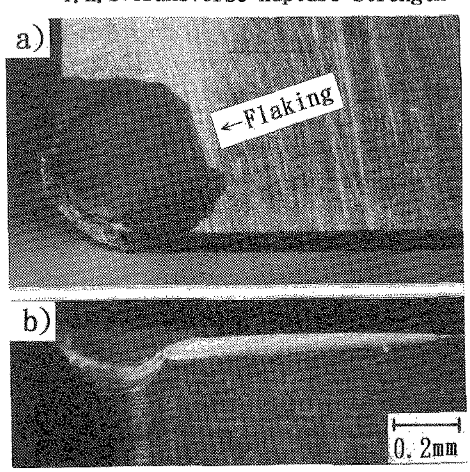

Fig.2 An example of flaking (indicated by arrow) occuing parallel to the crater surface. a)crater surface, b)flank surface.

coarse-grained TiC quickly suffer fraking irrespective of TiC content. However, the F-F and the C-F tools with fine-grained TiC had far longer tool life and flaking did not occur with 30%TiC after turning for 20min. Thus, it was found that the finer the TiC grain size, the larger the resistance to flaking.

Figure 4 shows the effect of grain size of Al_2O_3-30%TiC ceramics tools on flank wear in turning test of alloyed tool steel. The amount of flank wear of the F-F tool is smaller than that of the C-C tool.

Figure 5 shows a schematic drawing of crater and flank surfaces of F-F tool in turning test of alloyed tool steel for 20min. In this case, low speed and low feed rate (V=100 m/min, f=0.05m/rev) were selected to observe crater surface before flaking occurred. The X1-Y1, X3-Y3 and X5-Y5 curves show the worn state of Al_2O_3-10%TiC, 30%TiC and 50%TiC tools respectively. It is noted that the tool having higher TiC content showed larger crater wear and smaller V_B. The reason was considered as follows ; Since TiC is apt to react to the work piece ather than Al_2O_3, the tool having higher TiC content showed larger K_T caused by adhesive wear. In contrast, since softer Al_2O_3 tends to wear by abrastion rather than harder TiC, the tool with the higher TiC showed lower V_B caused by abrasive wear with hard particles such as Cr_7C_3 Mo_2C, and WC contained in the work

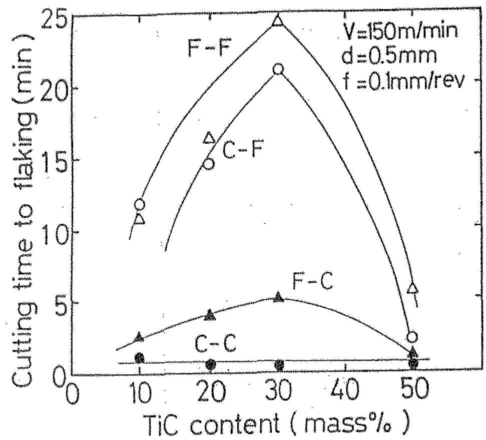

Fig. 3 Effects of TiC content and grain size of Al_2O_3-TiC ceramics tools on cutting time to flaking in turning test of SKD11.

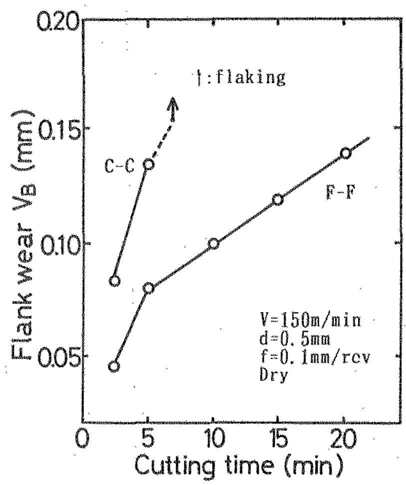

Fig. 4 Effect of grain size of Al_2O_3-30%TiC ceramics tools on flank wear in turning test of alloyed tool steel.

piece. Although a drawing of the F-C tool is omitted here, both K_T and V_B of the F-C tool were larger than those of F-F tool and the effect of TiC content is the same as that mentioned above.

Figure 6 shows the crater wear of Al_2O_3-30%TiC(F-F) ceramics tool in turning tests of alloyed tool steel for 5-20min. In this Figure, an arrow shows crack formation on the crater surface. It was noted that cracking was generated early in the cutting time and grew with increasing cutting time.

Figure 7 shows the relationship between cutting force and the V_B of commercial Al_2O_3-30%TiC tool in turning alloyed tool steel. Although

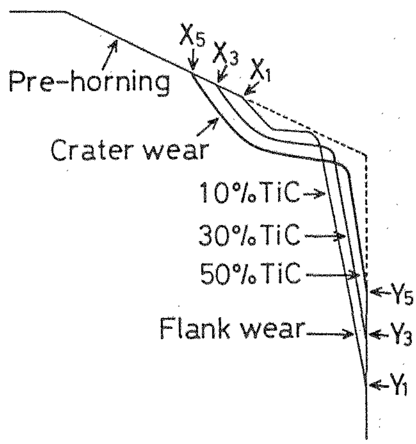

Fig. 5 Schematic drawing of crater and flank surface of Al_2O_3-TiC(F-F) ceramics tools in turning test for 20min. V=150m/min, d=0.5mm, f=0.1mm/rev, coolant, not used.

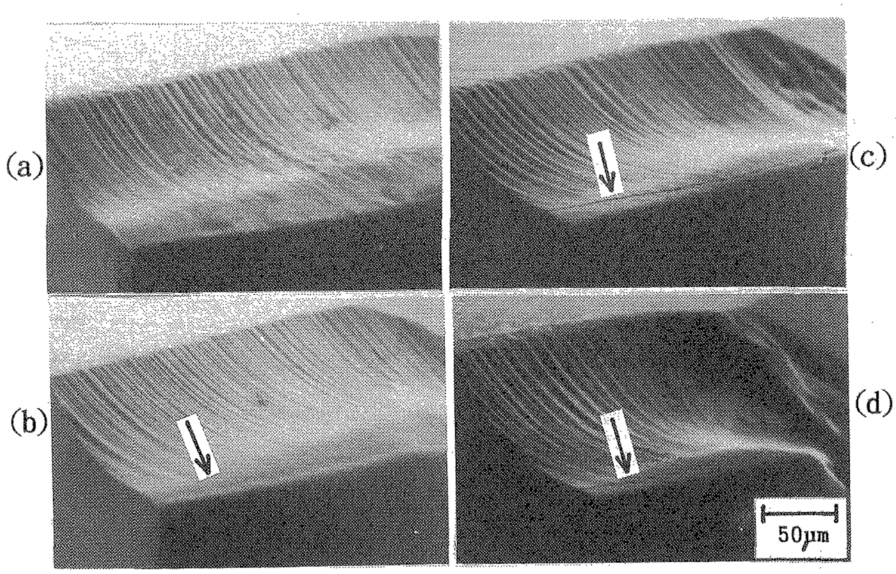

Fig. 6 Crater wear of Al_2O_3-30%TiC(F-F) ceramics tool in turning test of SKD11 for 5~20min. An arrow shows crack formation on crater surface. Cutting condition, the same as Fig. 3. a)5min, b)10min, c)15min, d)20min.

the principal force does not increase in spite of increasing V_B, both the axial force and the feed force quickly increase when V_B exceeds approx. 0.08mm. This fact means that the sum of the cutting force acts to shear the crater surface when V_B increases and as a result, flaking occurs from cracks on the crater surface as the fracture origin.

According to these mechanisms, it can be expected that the tools having fine TiC grain size and optimum TiC content show superior flaking resistance, because the finer the TiC grain size, the smaller the V_B, and the higher TiC content, the smaller the V_B but larger the K_T. The optimum TiC contents was expected about 30mass%.

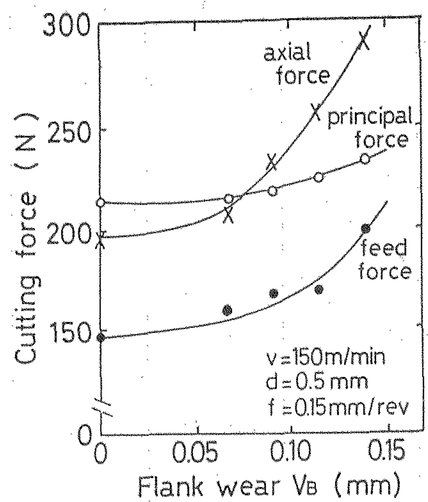

Fig. 7 Relation between cutting force and flank wear (V_B). Al_2O_3-30%TiC (F-F) commercialized tool is used.

SUMMARY

Al_2O_3-TiC ceramics tools having various TiC content and different grain size were prepared by hot-pressing, and the cutting performance using alloyed tool steel (SKD11) was studied. In turning alloyed tool steel, the tool with fine-grained TiC showed superior resistance to flaking and optimum performance was recorded with 30%TiC tool.

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