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Machining of Sic – Metal Matrix Composite (MMC) by Polycrystalline Diamond (PCD) Tools and Effect on Quality of Surface by Changing Machining Parameters

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Abstract— In this paper, wear of polycrystalline diamond (PCD) cutting tools and the surface integrity during machining of SiC – Metal Matrix Composite (MMC) is discussed. An attempt is made to establish relation between the hardness of the tool and the flank wear. A newly developed PCD tool, which is superior in hardness with lower flank wear than the conventional tools is introduced. During machining with PCD tools, the severity of transfer material on the tools increased significantly with cutting distance and cutting speed. The superior surface finish obtained with the PCD tools cannot be merely explained by their low wear. The low degree of adhesion that these tools had with the work material appeared to be the main reason for the superior surface obtained at both low and high cutting speeds. At low cutting speed, when the use of coolant resulted in a marked reduction in the amount of work material on the machined work pieces, high Ra and P-V values can be obtained.

Key words: PCD Tools, SiC – Metal Matrix Composite (MMC), Machining of MMC, Tool Wear, Surface Roughness

I. INTRODUCTION

MMCs are increasingly being used in the aerospace and automotive industries, because of their improved strength and stiffness and reduced density over non-reinforced materials. Machining of MMC presents a significant challenge, because they consist of reinforcement materials that are significantly harder than the commonly used high speed steel (HSS) and WC tools. The reinforcement phase causes rapid abrasive tool wear and therefore the widespread usage of MMCs is significantly impeded by their poor machinability and high machining cost. While many engineering components made from MMCs are produced by the near net shape forming and casting processes, they frequently require machining to achieve the desired dimensions and surface finish. Too wear and surface integrity during machining of MMCs is major problems noticed. In most cases, the tool wear is due to abrasion by the hard reinforcement particles in the matrix material.

Following are the hard facts about abrasive wear concluded by researchers.

The abrasive wear of the tool is accelerated when the percentage of the reinforcement in the MMC exceeded a critical value which varied with the density and size of the reinforcement particles.

The BUE formed during machining can protect the tool from wear by abrasion. However, unstable BUE can cause tool chipping and thus result in a poor finish.

During machining the tool may fracture and pulled out the reinforced particles, resulting in a poor machined surface finish.

A superior finish can be obtained if the particles are cut directly.

Dislocation pile up in the matrix material that surrounds the rigid particles can result in the formation of cracks and voids.

PCD tools shows superior performance over carbide and alumina tools, both in wear resistance and the quality of the surface finish produced. This is because PCD tools are harder than the reinforced particles and do not have chemical tendency to react with MMCs.

PCD tools are better than WC tools in terms of wear resistance in machining MMC reinforced with Al2O3 or SiC, respectively. In machining carbon fiber reinforced plastics and MMC reinforced with SiC.

II. METHODOLOGY

In this paper, review of experiments is carried out to understand the performance of PCD tools in the machining of MMC. In particular, the wear of the cutting tools, and the surface and subsurface of the machined work piece are analyzed

Review on the wear of PCD tools in the machining of MMC is carried out by turning process using lathe machine. The MMC work piece is Al alloy reinforced with SiC (SiCMMC). The PCD tools used in this study are commercially available grades with ISO designation DCGW11T308 (nose radius = 0.8 mm, clearance angle = 7□). The properties of the MMC and cutting tools are shown in Tables 1 and 2 respectively.

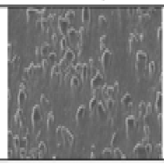
MMC	SiC - MMC
Matrix	9.27 Si, 0.15 Fe, 0.55 Mg, Al balance
Reinforcement	20 vol% SiC, Particle size 12.8 μm with aspect ratio 1.5:1
Microstructure	

Table 1: MMC Properties

Tool type	Grain size (μm)	Binder	PCD (Vol %)	Hardness (HV)	TRS[a] (kg/mm^2)	λ[b] (w/mk)
BN 100	3	TiN	85% CBN	4000-4500	80	217
BN 300	0.5	TiN	60% CBN	3300-3600	110 - 120	54
BN 600	0.5 & 4	Co	90% CBN	3900-4200	95 - 110	360
IZ 900	<0.5	Nil	>99% CBN	5100-5610	138	360-400
STANDARD	10	Co	75% PCD	7000-11000	80-90	2000

[a] Transverse rupture strength; [b] Thermal conductivity

Table 2: Properties of PCD Tools

The results are obtained with and without the application of coolant (a mixture of 1 part mineral oil and 20 parts of water). The depth of cut and the feed rate is kept constant for all the tests at 0.3 mm and 0.1 mm/rev respectively.

Machining is conducted at cutting speeds of 50 m/min and 400 m/min. The surface finish of the machined surface with the arithmetic mean deviation, *Ra and* measuring length, *lg*, of 5 mm is used as criterion for evaluating the surface finish.

III. DISCUSSION ON EFFECT OF PARAMETERS

A. *Flank wear*

Figs. 1 and 2 shows the change in the flank wear width and groove wear with cutting distance for PCD tools in the machining of SiC-MMC with and without coolant. It is found that increasing the cutting speed from 50 m/min to 400 m/min resulted in a significant increase in the flank wear. At both cutting speeds, the application of coolant can not reduce the flank wear (see Fig. 1). A correlation is found between the hardness of the tool and the flank wear. Among all the types of tools, IZ900 tool exhibits the lowest flank wear. PCD standard tool shows lower wear than all other tools. It is found that at 50 m/min, the application of coolant resulted in a significant increase in groove wear (see Fig. 2). At 400 mm/min, the use of coolant does not bring about a significant chance in the groove wear.

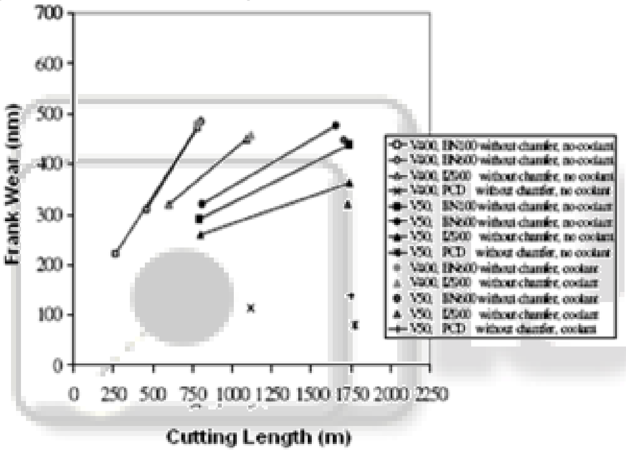


Fig. 1: Frank Wear of various PCD tools with different cutting speeds

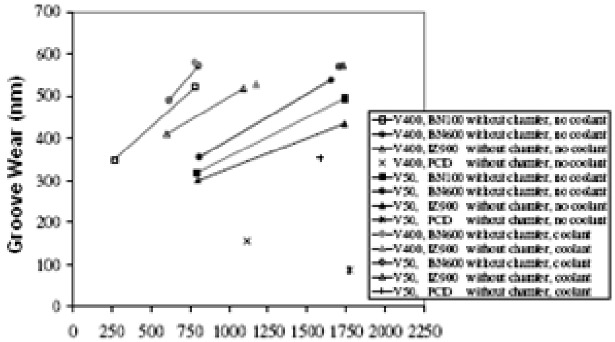


Fig. 2: Groove Wear of various PCD tools with different cutting speeds

B. *Built-up edge (BUE), Tool surface and Adhesion*

PCD tools possessing higher thermal conductivity, resulting in a lower cutting temperature and thus the degree of softening of the work material. It is found that the transfer onto the tool could be reduced significantly by applying coolant. Sodium hydroxide solution is used to dissolve the work material adhered onto the surface of the tools. After removal of the work material on the tool tips, high wear is noticed at the flank faces of the PCD tools used to cut the MMC.

Increasing the cutting speed from 50 m/min to 400 m/min leads to increase cutting temperature and thus a reduction in the strength of the work material. This reduce the severity of the abrasion and thus the tool become less susceptible to fracture. Furthermore, at 400 m/min, the high amount of work material adhered onto the tool protect the tool from abrasion. Also, the application of coolant reduce the flank wear.

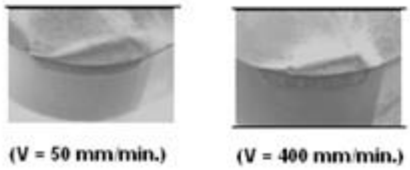


Fig. 3: SEM pictures of PCD tools used to machine SiC-MMC(X-100 after Etching) Machined surface

Fig: 4 shows the surface roughness obtained in the machining of SiC-MMC with PCD tools at 50 m/min and 400 m/min under dry condition. By increasing the cutting speed from 50 m/min to 400 m/min, significant increase in the flank wear is occurred due to an increase in the cutting temperature. Also due to heat generated during machining the tool becomes weak which leads a reduction of the wear resistance of the tool. During machining at 50 m/min with PCD tools, the surface roughness gradually increased as the cutting distance increased to 1770 m. At 400 m/min, a marked increase in the surface roughness is noticed observed as the cutting progressed. With PCD tool, the morphology of the machined surface of the MMC is observed to be essentially the same with the cutting distance.

It is noticed that the use of coolant resulted in an increase in the *Ra* value despite it had significantly reduced the amount of work material on the machined surface. During machining at a higher speed of 400 m/min with coolant, the work piece with higher ductility gives good surface roughness The improvement in the surface finish is due to reduction in the amount of built-up material. At 50 m/min, the lubricant could have played a more significant role in preventing the formation of BUE at the interfaces, resulting in a much lesser of amount of work material adhered onto the surface

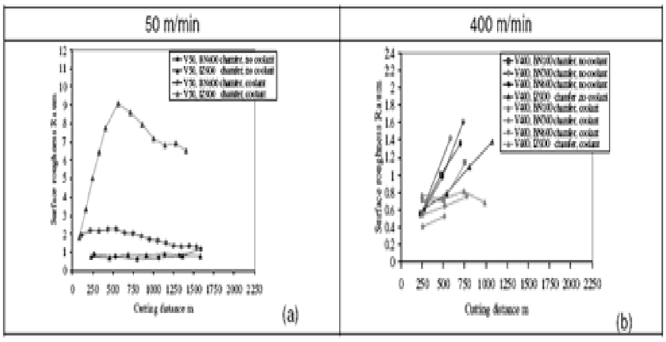


Fig. 4: cutting distance vs. Surface roughness at different speeds

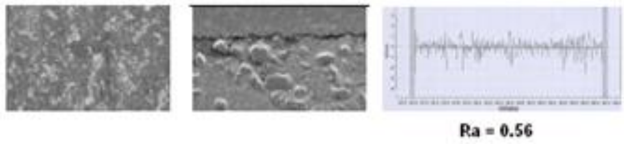


Fig. 5: SEM of machined surface roughness and its Ra value

IV. CONCLUSION

Effect of different parameters like; Flank wear, Built-up edge (BUE), Tool surface and Adhesion, machined surface by machining of MMC reinforced with SiC work pieces with various types of PCD tools at low and high cutting speeds are discussed. A correlation is established between the hardness of the tool and the flank wear. PCD tool shows higher wear resistance than all other traditional tools. During machining with PCD tools, the severity of transfer material on the tools increased significantly with cutting distance. The superior surface finish obtained with the PCD tools is superior. The intrinsic low adhesion property of these tools with the work material is the main reason for the superior surface.

Also, the use of coolant significantly reduces the amount of work material adhering onto the machined work piece which results in a deterioration of the surface finish. Measurement of the *Ra* value and SEM examination are essential to gain an important understanding of the morphology of the machined surface.

MMC has become increasingly important to many industrial areas, such as aeronautic, aerospace, sporting, automotive industries and bio-medical. High level research is essential to help the local industry to improve their capability in processing and machining advanced materials.

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