Tool Wear, Wear Mechanism and Dimensional Accuracy in Machining Al2124SiCp MMC using CBN and PCD Tools

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Abstract — The paper presents turning of Al2124SiCp (45%wt) Particulate Metal Matrix Composite using PCD, CBN-coated and CBN-uncoated tools. Tool wear, wear mechanism, surface roughness, and dimensional accuracy are investigated. Machining was performed at a feed rate of 8.3 mm/min with machining depth as 0.1, 0.2 and 0.3 mm, cutting speeds of 40, 60, 80 and 100 m/min, using High Precision Lathe Machine Model No: CG6125C having span 250 and length 500 mm respectively. Results reveal that Tool wear mechanism observed while using CBN-uncoated and CBN-coated were abrasion, adhesion, chipping and fracture. While using PCD tool wear mechanisms observed were abrasion, adhesion and chipping. On the type of wear, for PCD tool flank and crater wear were observed while for CBN tools flank wear was observed. PCD tool produced the best surface finish followed by CBN-coated while CBN-uncoated tool produced the worst surface finish. On dimensional accuracy it was observed that PCD has the lowest diameter error followed by CBN-coated while CBN-uncoated tool produced the worst surface finish. It is concluded that in machining Al2124SiCp (45%wt) Particulate Metal Matrix Composite PCD tools are the best followed by CBN-coated and finally CBN-uncoated tools.

Keywords — Tool Wear; Wear Mechanism; Surface Roughness; Dimensional Accuracy; Al2124SiCp MMC

I. INTRODUCTION

In recent years there has been an increase in the amount of composite materials whose matrix is metal in substituting monolithic materials in various uses as vehicle and sports related industry [1]. Metal Matrix Composites (MMCs) are endowed with superior qualities which include reduced weight and higher strength, elastic modulus, excellent wear resistance to abrasion [2]. However their full potential has not been realized yet over monolithic alloys. Key reason to this setback is their machinability which still poses a significant setback [3; 4]. Because of irregular nature of abrasive reinforcements of MMCs, their machining poses a challenge [5]. Presence of reinforcement phase causes rapid abrasive tool wear [5; 6]. Metal Matrix Composite parts are cast to close tolerances and brought to final dimensional requirements by machining [5; 7].

Cemented carbide tools, widely used in metal cutting wear rapidly while cutting particulate MMCs because of hard SiC particles present and surface produced is undesirable for specialized engineering work [5; 8]. In turning of MMCs poor surface is produced when coolant is used coupled with increased wear of the tool [6]. Through various researches diamond related cutting tools have been identified as the most effective and most preferred in machining Particulate MMCs [5].

Tool wear and breakage have been an issue with cutting tools since they were created. Tool wear weakens the cutting tool, increases the forces used in cutting and causes a lack of consistency in material removal. Parts and time lost to scrap and rework from tool wear are costly to manufacturing companies [9; 10]. Wear of cutting tools has been discussed by various authors who agree in principle that cutting tool wear constitutes abrasive, adhesive, diffusion, fracture and chipping mechanism of wear [9; 11].

Muthukrishnan N. et al [4] conducted experimental investigation involving turning of MMC (A356/SiC/10p). The researchers used PCD tool of grade 1500 and assessed surface finish, power consumption and tool wear.

Rajesh K. B. et al [12], studied effects of SiCp reinforcement to machining Al 7075 SiC (10%wt). The researchers assessed tool wear and surface finish in relation to feed, machining speed, and cut depth. Alakesh M. and Bhattacharayya B, [6] tested the ability to turn Al/SiCp (15%vol) using uncoated Rhombic carbide tool. The researchers observed that feed rate, turning speed and depth of cut had similar effect on part finish.

Dimensional accuracy in machining remains an important component in assessing quality related to a machined part. It can be resolved by measurements related to size and geometric or shape properties such as straightness, angularity, cylindricity and circularity. During machining, components actual size dimensions vary from those in design. This variation is referred to as dimensional error [13; 14]. Surface quality can be referred to as the condition of the machined surface which is generally explained as haphazard departure of variation from the nominal of a recurring surface. Surface texture is defined through the elements of roughness and waviness [13].

From literature involving turning particulate MMC, chips,
amount of reinforcement together with matrix material performance have an impact on the machining process. It is further observed that no literature is presented on machining Al2124SiCp (45%wt) PMMC using PCD, CBN-uncoated and CBN-coated to evaluate surface finish, wear mechanism and dimensional accuracy. This paper therefore seeks to assess tool wear, wear mechanism, surface roughness and dimensional accuracy while machining Al2124SiCp (45%wt) PMMC using PCD, CBN-coated and CBN-uncoated tools.

II. EXPERIMENTAL SET-UP

A. Component Design

Round bar of Al2124SiCp (45%wt) MMC 36.0 mm diameter and 78 mm long was used for this study. The reinforcement consisted of particulate SiC of grain size 5 to 8 μm diameter. The amount of SiC in the MMC constituted (45% wt).

B. Cutting Tools

Triangular shaped cutting tools consisting of CBN-coated, CBN-uncoated and PCD manufactured by Sumitomo Electric (Japan) were used. They consist of CBN-coated grade BNC 100 having relief angle of 00 and rake angle 00, CBN-uncoated of grade BN 700 having relief angle 00 and rake angle 00 and finally PCD of grade DA2200 having relief angle of 50 and rake angle of 100. The tools were mounted on PTTNR2525-33 tool holder.

C. Machining and Measurement Procedure

The machining of the particulate MMC was carried out at four machining speeds of 40, 60, 80, and 100 m/min using High Precision Lathe Machine Model No: CG6125C with a span radius 250 mm and length 500 mm. Feed rate was set at 8.3 mm/min and cut depths used were 0.1, 0.2, and 0.3 mm. No coolant was used during the cutting test. Cutting force was measured using three-component tool force dynamometer which was mounted on the cross slide of the high precision lathe machine. During the experiment TR200 portable roughness equipment manufactured by Time Group Inc Australia and Form Talyssurf PGI 1240 manufactured by Taylor Hobson Inc (USA) were used to measure work-piece surface finish The worn tool tips were observed under CCD camera and the flank wear was measured through use of integrated scale. Diameter error was measured using API tracker 3 Ultra-Portable Laser tracking System Model No: Tripod SC11032 which was placed 2.5 m from the work-piece.

III. RESULTS AND DISCUSSION

A. Tool Wear

During machining Al2124SiCp (45%wt) MMC under current conditions dominant wear mode physically observed was flank wear although negligible crater wear was also observed. Figure 1 shows effect of machining speed to tool flank wear of CBN-uncoated, CBN-coated and PCD tools while cutting Al2124SiCp (45%wt) MMC. At varying cutting speed and constant feed at depth of cut 0.1mm, 0.2mm and 0.3mm the maximum flank wear is as follows. At 0.1mm depth of cut, CBN-uncoated has the highest flank wear of 0.22mm followed by CBN-coated 0.15mm and finally PCD 0.01mm. At 0.2 mm depth of cut, CBN-uncoated has highest the flank wear of 0.28mm followed by CBN-coated 0.24mm and finally PCD 0.014mm. While at 0.3mm depth of cut maximum flank wear for the CBN-uncoated is 0.35mm, CBN-coated 0.31mm and PCD 0.016mm. It is observed that CBN-uncoated has the highest wear at all cutting speeds and corresponding depths of cut. Flank wear increased gradually for PCD tool as the machining speed increased as well as depth of cut at constant feed rate of 8.3 mm/min, however for CBN-uncoated and CBN-coated tools flank wear increase is not gradual but irregular.

The dominant wear mechanism for the tools is abrasion [5; 15], adhesion and chipping, however fracture is also observed. Figures 2, 3 and 4 show the various wear patterns on the three tools used in the experiment. From the images it can be construed that the dominant wear mechanism among all the tools is abrasion wear caused by hard SiC particles. Abrasion wear is commonly characterized by the presence of grooves parallel to the cutting direction on tool flank face [4]. Though CCD images of the tools were taken from the cutting tool rake, progressive wear of the cutting edge in this case is an indication of abrasive wear. CBN-uncoated tools showed
excessive flank wear at the same cutting time as compared to CBN-coated and PCD tools. Abrasive wear is evident in all the tools though it is more prevalent among CBN-uncoated and CBN-coated tools. As cutting speed increases, both the length and width of flank wear increases figure 2 revealed by the amount of flank wear. CBN-coated and CBN-uncoated tools show a relatively stable built up edge (BUE) figure 2 and 3 which enabled the tool to have longer life. However the BUE has an effect on the surface quality as some of the matrix material is deposited on the work surface hence lowering surface quality. It also causes adhesion wear of the tool as matrix material pulls out some tool material. Fracture wear of the tool is observed figure 3 (e) where the coating is fast worn out during machining. The presence of high percentage of hard SiC particles contribute to fast wear of the coating of CBN-coated. The worn tools reveal BUE on the cutting edge as shiny aluminum matrix material. Due to excessive tool wear for both CBN-coated and CBN-uncoated tools, cutting force is seen to increase as cutting progresses, however for PCD tool there no significant change in cutting force as machining progresses due to low wear effects.

For PCD tool figure 4 wear is quite minimal and the tool retains the cutting edge for a long time as compared to CBN-uncoated and CBN-coated tools. The mode of wear observed is abrasion and chipping of the cutting edge where chipping is shown by worn cutting edge in form of a rugged edge in the nose region. PCD tool wears through abrasion by the interaction of SiC and diamond particles [3]. Hardness of diamond is higher than that of SiC, therefore abrasion wear may be due to mechanical failure but not cutting at micro level [12]. This can be effective in two ways; two-body abrasion and three-body abrasion [4]. Rake face of PCD tool also encountered wear though minimal in form of crater wear figure 4(a, b). Chipping is also observed in PCD tool which shows the worn machining edge which appears as rugged edge figure 4(a, c). The impact between hard SiC particles and tool edge cause chipping wear of PCD tool [3]. Examination of the PCD tool revealed a relatively stable BUE at low cutting speed which is seen as a shiny part on the cutting edge. This cause adhesive wear of the PCD tool as matrix material pulls out some tool material [16]. However as cutting speed increased BUE disappeared with only traces of embedded matrix material. Comparing CBN-uncoated, CBN-coated and PCD tools it is observed PCD suffers lowest wear in the machining process and retains its cutting edge for a long time.

B. Surface Roughness

Figure 5 shows the effect of turning speed and depth of cut on surface finish while dry turning Al2124SiCp (45%wt) MMC using CBN-uncoated, CBN-coated and PCD tools. Cutting parameters considered included feed rate of 8.3 mm/min cut depth of 0.1 mm, 0.2 mm and 0.3 mm while cutting speed was varied from 40 to 100 m/min. From figure 5 it is seen that the value Ra for surface varies with machining speed. For CBN-uncoated and CBN-coated the value Ra increases with increase in machining speed. This can be attributed to rapid wear of CBN tools and the effect of BUE where matrix material get embedded on to the work surface hence lowering surface quality. Comparing CBN-uncoated and CBN-coated it is observed that CBN-coated
produced better surface finish than that of CBN-uncoated. However for PCD tool, the value Ra for surface is observed to reduce when machining speed is increased. This agrees with observations made by Muthukrishnan N. et al [5] in machining of PMMCs using PCD tools. It can be concluded that machining speed is important to ensure quality surface finish while using PCD tools. When turning Al2124SiCp (45%wt) at low machining speed BUE forms which lead to poor surface finish. When machining speed is increased BUE disappears and a corresponding decrease in chip fracture thus improving finish. For all the tools when depth of cut is increased, surface roughness Ra also increases. PCD tools performed better than CBN tools removing more material than CBN tools and also preserved surface of the work-piece during the entire cutting process.

The effect of cutting speed and depth of cut on diameter error in dry turning Al2124SiCp (45%wt) MMC using CBN-uncoated, CBN-coated and PCD tools is shown in figure 6. Cutting parameters considered included feed rate of 8.3 mm/min, 0.1 mm, 0.2 mm and 0.3 mm depth of cut while cutting speed was varied from 40 to 100 m/min. It is observed the general trend in diameter error increase with increasing cutting speed for CBN-uncoated and CBN-coated tools at the considered depths of cut. This increase in diameter error may be due to rapid wear of CBN tools causing decrease in depth of cut as cutting progresses. Further this may be due to the effect of BUE where matrix material get embedded on to the work surface hence lowering surface finish hence dimensional quality. Comparing CBN-uncoated and CBN-coated tools it is observed that CBN-coated tool produced a better dimensional quality than that of CBN-uncoated tool. It is observed that for PCD tool, diameter error is quite negligible and decreased as the cutting speed changed at the selected depth of cut. This can be attributed to wear resistance of PCD tools as well as reduction in BUE at high cutting speeds. At low cutting speed BUE causes matrix material to be deposited on to the work surface hence lowering surface finish hence dimensional quality. Comparing CBN-uncoated and CBN-coated tools it is observed that CBN-coated tool produced a better dimensional quality than that of CBN-uncoated tool. It is observed that for PCD tool, diameter error is quite negligible and decreased as the cutting speed changed at the selected depth of cut. This can be attributed to wear resistance of PCD tools as well as reduction in BUE at high cutting speeds. At low cutting speed BUE causes matrix material to be deposited on to the work surface hence affecting diameter. At high cutting speeds PCD tools produce better surface finish which is attributed to better dimensional quality. Thus cutting speed plays a crucial role in deciding dimensional accuracy while PCD tools are used. Comparing all the tools, increasing depth of cut causes a corresponding increase in diameter error. PCD tools performed better than CBN tools and maintained a good dimensional quality on the work-piece throughout the cutting process.

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### C. Dimensional Accuracy

Generally the quality of the machined components may be evaluated by important characteristics as dimensional accuracy as well as surface finish. Dimensional accuracy of machined components is established through measurement of size geometrical or shape properties such as straightness, angularity, cylindricity and circularity. However in most cases machined components actual size dimension differs from the designed size dimension [17]. This difference is known as size error and is often employed in verifying level of size dimension accuracy. In this experiment diameter error was assessed with reference to designed size as compared to machined size. Diameter error is chosen to assess dimensional accuracy in turning Al2124SiCp (45%wt) MMC. Diameter error refers to the deviation from designed size to the actual size. This quality aspect is vital of cylindrical parts required in fitting purposes [13].

### IV. CONCLUSIONS

Tool wear and wear mechanism of CBN-uncoated, CBN-coated and PCD tools in turning Al 2124SiCp (45%wt) Particulate Metal Matrix Composites were investigated.
Surface roughness and Dimensional accuracy were also investigated.

Tool wear mechanism observed while turning Al2124SiCp (45%wt) PMMCs using CBN-uncoated and CBN-coated were abrasion, adhesion, chipping and fracture. Tool wear mechanism observed while turning Al2124SiCp (45%wt) PMMCs using PCD were abrasion, adhesion and chipping.

Dominant type of wear observed for PCD tool were flank and crater wear while for CBN tools were flank wear.

PCD tool produced the best surface finish followed by CBN-coated while CBN-uncoated tool produced the worst surface finish.

On dimensional accuracy it was observed that PCD has the lowest diameter error followed by CBN-coated and lastly CBN-uncoated.

REFERENCES


