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INFLUENCE OF CUTTING INSERTS IN MACHINING Al-Si ALLOY-BASED METAL MATRIX COMPOSITES

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ABSTRACT

To better comprehend the machinability studies during MMCs, the effect of cutting tool while machining MMCs, the cutting forces that induce and importantly the influence of cutting tool were carried out. Polycrystalline diamond (PCD) and uncoated tungsten carbide (K10) cutting tools were used to machine a eutectic (Al-12wt% Si alloy) and a hypereutectic (Al-17wt%Si) matrix material with Silicon Carbide (SiCP) and Aluminium Oxide (Al_2O_3P) in the particulate form at 0, 5, 7.5, and 10 volume percent volume fractions as MMCs. To further characterize the machinability of the composites, SEM analysis of chips created during machining and the cutting inserts was performed. Based on the results of the MMC machining operations, the Built-up Edge (BUE) development on the K10 insert has caused it to exert significantly higher cutting forces than the PCD. Machining of SiCp and Al2O3P reinforced Al-Si alloys utilizing K10 insert showed a comparatively bigger difference in cutting forces, indicating that the cutting forces exerted by PCD did not significantly alter with varied composite composition.

1. INTRODUCTION

The fluidity (A Kumar et al., 2020), higher specific strength, (Aqida S.N et al., 2003), superior workability (Amandeep Singh Wadhwa et al., 2023), castability (Aniban, N et al., 2002), etc., are just some of the reasons why alloys with some aluminum–silicon base is so often used in MMCs. Silicon carbide (SiCP) and aluminium oxide (Al_2O_3P) particles are the most used reinforcements for aluminium alloys in Particulate Reinforced Metal Matrix Composites (PMMCs). SiCP's strong strength (Balasivanandha Prabhu et al., 2006), elastic modulus (Conceiacao et al., 2002), low coefficient of thermal expansion (Branislav Sredanovic et al., 2022), and chemical inertness (Devaraj Sandiri et al., 2022) are among its many appealing properties. Its low density (3.1 gm/cc) is another perk. The inorganic compound Al_2O_3P, commonly known as -alumina, has a density of 3.69 gm/cc (Dipti Kanta Das et al., 2014), (Daulat Kumar Sharma et al., 2020) and is better suited for use in high-temperature applications due to its superior oxidation resistance (Fethi Khelfaoui et al., 2023), (H. D. Kumar, S. Ilangovan, N. Radhika. 2020) (Hiremath, Vijaykumar et al., 2016).

Less size SiCP reinforced AA6061 T6 composites by liquid metallurgy route (bottom pouring) mechanism was used to operate the flow of melt below of the crucible (Hung, N.P et al., (1995), (Ibrahim Ciftci et al., 2004), Jiang Rui-song et al., 2016). This addresses some of the

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challenges associated with stir casting, a process to develop PMMCs, including mixing of reinforcements, stirring of melt, incorporation of reinforcement particles, and transfer of the melt into the mould. The homogeneous distribution of reinforcement and, more crucially, the various mechanical and tribological properties are significantly impacted by the weight or volume percent of reinforcements, in addition to the process parameters (M. Kok, 2005), M. Kök et al., (2007) and (M Kok, 2009). At 25Wt% of SiC addition, Hardness and Impact strength values were 45.5 BHN and 36 N-m correspondingly, (Manoj Singla et al., 2009), and Minh Tuan Ngo 2023). This work was conducted on pure aluminium reinforced with SiC of volume fractions ranging from 5% to 30% through stir casting. While at 700 rpm stirrer speed and the impleller position at one tenth of the melt depth (Navin Kumar et al., 2020), it was found that the mechanical characteristics of 2618 Al alloy reinforced with silicon carbide decreased with increasing weight percentage of reinforcement and with reduction in its particle size (Narender Panwar et al., 2018).

Particulate Metal Matrix Composite (PMMC) machining is difficult because many reinforcement particles are harder than commonly used cutting tools like carbide tools and High-Speed Steel (HSS) (Quan Y M et al., 1999). This is because PMMCs constitute a hard reinforcement phase like SiC, Al_2O_3, etc. The capacity of Polycrystalline Diamond (PCD) tools to machine Al-SiCP MMCs has been brought to light by several studies. PCD tools are successfully suitable to machine SiCP reinforced MMCs (Reza Ghoreishi et al., 2018), and PCD is harder than commonly used reinforcement particles SiC/Al_2O_3, which typically do not experience any chemical interaction with working specimens. To determine the best tool material, tool geometry, and machining parameters for turning Al-20%SiC MMCs, a series of dry high-speed turning tests were conducted (S. Nguyen Hong et al., 2021). All the test tools exhibited flank wear as a result of abrasion, revealing abrasion as the mechanism of tool wear (Sakthivel, A et al., 2008). Tool wear, cutting forces, and surface roughness were studied and published as a function of machining time for A356/20/SiCP-T6 PMMC using a PCD insert (Sedat Ozden et al., 2007). Cutting forces were found to rise in tandem with flank wear of the turning insert, but feed and depth force remained constant. Cutting tool nose chamfering and flank wear were found to be the most common forms of wear while testing the machinability of Alumnimum 2024 composites supplemented with 30 wt% Al_2O_3 particles (S.I.A. Qadri et al., 2020). Multiple tool wear models were verified for use in milling cast and powdered aluminium alloys fortified with SiC particles. The research suggests that the best cost-effective method for machining SiCP reinforced MMCs is to do rough machining with uncoated WC inserts and then perform finishing operations with PCD tools (Strahinja Đurovic et al., 2022). According to the machinability tests conducted, coarse SiC particle reinforced composites produce both continuous chips and debris during machining, while fine SiC particle reinforced composites produce solely continuous chips (Sudheer Reddy et al., 2011).

Semi-continuous chips are created when SiC particles exist in the MMC, as discovered by the research team. Cracks in the chip's surface, along with shear stress and the creation of microscopic voids brought on by the stress increase at the particles' edges, are responsible for the mechanism by which chips form. Similar research (Tamer Ozben et al., 2008) found that whereas machining small SiC particles exclusively produce continuous chips, milling coarse SiC particle reinforced composites produced both chips and debris. Cutting forces in machining SiCP reinforced Al-Si alloys were found to be considerably greater compared to those of Al_2O_3P reinforced Al-Si alloys, as reported (Van Hung Pham et al., 2022) in the field of tribology and machinability. There is a follow-up to the work and results presented here in a subsequent study (Sudheer Reddy et al., 2011) and the same or similar description and data may be presented again with a different emphasis on topics such cutting tool micrographs. Therefore, the following works are reported, which indicate the variation of cutting forces in terms of percentage as compared with other material composition or process parameters, because there is a lack of research in the existing literature to correlate the effect of cutting tool on machining parameters.

2. EXPERIMENTAL DETAILS

The machining tests were conducted in a dry environment on a turning center using a cylindrical turning technique. Forces exerted during cutting were measured using a Kistler quartz 3-component dynamometer of type 9257B equipped with a multiple charge amplifier and a PC-based data-acquisition system connected to the turning centre. The dynamometer was used to determine the orthogonal components of the force. Two cutting tool materials, PCD and K10, were examined for this research due to the interest in learning the extent to which MMCs vary in their machinability. Cutting tools were chosen according to the properties of tool materials well-suited for MMC machining. Figure 1 depicts actual cutting inserts, and Table 1 lists the specifics of the commercial turning inserts that were employed for this study. All the test specimens were turned in a cylindrical fashion at a depth of cut of 0.2 mm and a feed rate of 0.1 mm/rev. The specimens for testing were machined at 75 and 118 metres per minute. The two speeds were selected from the range of values we could measure experimentally. The workpiece was machined using orthogonal methods, with only the primary force (that is, the force exerted by the cutting tool) considered. Fx is the cutting force (N), and its root-mean-square (RMS) value was measured using the testing apparatus.

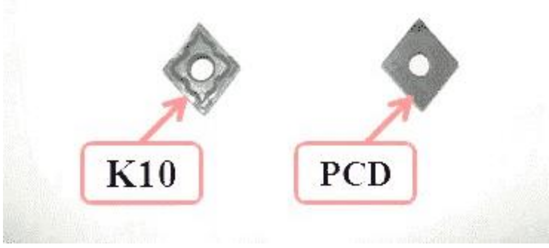

Figure 1. Cutting inserts used in machining MMCs

Table 1. Specifications of cutting inserts

CNMA 120404 LN -10 KP300		CNMG 120404 - ML K10	
C	Insert shape (80 Degree)		
N	Clearance angle (Zero Degree)		
M	Tolerance ± 0.08 to ± 0.18		
A	Type	G	Type
12	Cutting Edge Length (mm)		
04	Thickness (4.76 mm)		
04	Corner Radius (0.4 mm)		
LN - 10	Diamond length	ML	Geometry of chip breaker
KP 300	PCD Insert Grade of Taegutec	K10	Grade of uncoated carbide insert

3. RESULTS & DISCUSSION

In order to put the MMCs to use, machining is a necessary step. For this reason, conventional machining procedures were used to evaluate the machinability of the MMCs (Al-12% Si and Al-17% Si alloys reinforced with 0, 5, 7.5, and 10 vol% of SiCP and Al_2O_3P reinforcements, respectively) used in the present studies.

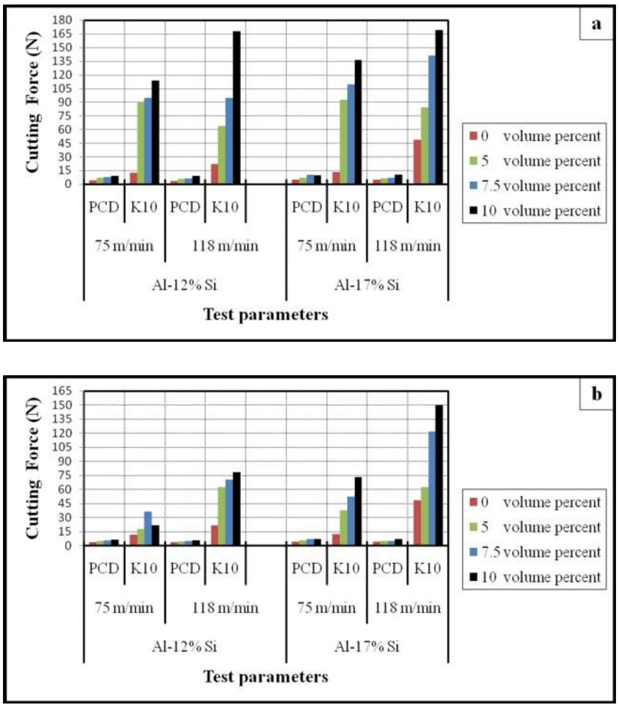

Figure 2. Variation in cutting forces during machining a) SiCp reinforced b) Al_2O_3P reinforced Al-12% Si and Al-17% Si alloys using PCD, K10 inserts at 75 and 118 m/min cutting speeds

Figure 2 displays the cutting forces caused by utilizing PCD and K10 cutting inserts at cutting speeds of 75 and 118 m/min on SiCP and Al_2O_3P reinforced Al-Si alloys, respectively. Furthermore, chips created during machining and the cutting inserts were analysed using SEM to provide a more in-depth understanding of the machining phenomenon. Some intriguing findings regarding the composites' machinability were uncovered by analysing the collected micrographs.

3.1 Influence of Cutting inserts on cutting forces in machining SiCP and Al_2O_3P reinforced Al-Si alloys at different cutting speeds

Similar reinforced Al-Si alloys were machined at the same cutting speeds to compare the impact of the insert on cutting forces. At 75 and 118 m/min, the cutting pressures exerted by the K10 insert were around 10 and 13 times, respectively, those utilising a PCD insert when machining different volume percent SiCp reinforced Al-12% Si alloys. In the case of SiCp-reinforced Al-17% Si alloys, the equivalent values were approximately 11 and 15 times, respectively. When milling Al_2O_3P reinforced Al-12% Si alloys with different volume percents at 75 and 118 m/min cutting speeds, respectively, the cutting pressures exerted by the K10 insert were around 4 and 11 times those of PCD. In the case of Al_2O_3P reinforced Al-17% Si alloys, the comparable values were roughly 7 and 16 times higher. Based on the results of the MMC machining operations, it is clear that the Built up Edge (BUE) development on the K10 insert has caused it to exert significantly higher cutting forces than the PCD. When the silicon content in the matrix alloy was hypereutectic, the effect of cutting tool material on the cutting forces created during machining of these composites was found to be more significant.

3.2 Influence of Reinforcements on cutting forces in machining Al-Si alloys using different cutting inserts and cutting speeds

Cutting forces induced in PCD machining of SiCp reinforced Al-12% Si alloys at cutting speeds of 75 and 118 m/min were found to be respectively 18 and 20% higher than those with Al_2O_3P reinforced Al-12% Si alloys of the same volume percent of reinforcement, as shown in Figure 2. However, at both cutting speeds, the cutting forces required to machine SiCp-reinforced Al-17% Si alloys with PCD were 30% higher than those required to machine Al_2O_3P-reinforced alloys. Similarly, when machining SiCp reinforced Al-12% Si alloys with K10, cutting forces were found to be 5 times and 37% greater than when machining Al_2O_3P reinforced Al-12% Si alloys at cutting speeds of 75 and 118 m/min, respectively. When using an Al-17% Si alloy as the matrix, the equivalent values were approximately three times as high, at 21%. When employing a K10 cutting insert, it was determined that the cutting force differential between SiCp and Al_2O_3P reinforced Al-Si alloys was relatively higher.

3.3 Influence of Cutting speed in machining SiCP and Al_2O_3P reinforced Al-Si alloys on cutting forces using different cutting inserts

Cutting forces decreased by around 10 and 9%, respectively, when machining SiCp reinforced Al-12% Si and Al-17% Si alloys with a PCD insert, and the cutting speed has been increased from 75 to 118 m/min. With Al_2O_3P reinforcement, the equivalent values were determined to be 11 and 10%. It was discovered that while machining MMCs using a K10 insert, the effects of cutting speed on cutting forces are distinct from those when using a PCD insert. When milling SiCp-reinforced Al-12% Si and Al-17% Si alloys with a K10 insert, the cutting forces rise by roughly 24 and 79%, respectively, when the cutting speed is increased from 75 to 118 m/min. Al_2O_3P reinforcement increased these values by a factor of 3 and 2, respectively. Built up Edge creation, caused by the disparity between the critical speeds of the two cutting tool inserts, may account for the observed increase in cutting forces caused by a change in speed during the machining of MMCs employing a K10 insert.

3.4 Influence of Silicon content of matrix on cutting forces induced in machining SiCP and Al_2O_3P reinforced Al-Si alloys using different cutting inserts and cutting speeds.

Cutting pressures increased during machining with PCD and K10 inserts at 75 and 118 m/min due to an increase of 5 weight percent of silicon content of matrix (Al-12%Si to Al-17%Si), as shown in Figure 2. When milling SiCP reinforced MMCs with PCD at 75 and 118 m/min cutting speeds, the cutting forces have risen by roughly 11 and 18%, respectively, with an increase of 5 weight percent of silicon content of matrix. When machining composites with a K10 insert, these numbers come out to around 19 and 51%, respectively. Similarly, while milling Al_2O_3P reinforced MMCs with PCD at 75 and 118 m/min cutting speeds, the cutting forces have increased by roughly 11 and 16%, respectively, with an increase of 5 weight percent of silicon content of matrix. When milling composites with a K10 insert, these values averaged out to around 94% and 71%, respectively. The cutting forces in machining with a K10 insert increased more than those with a PCD insert when the silicon content of the matrix material was increased in SiCP and Al_2O_3P reinforced Al-Si alloys. The percentage increase in cutting forces observed during machining of Al-12%Si MMCs with PCD and K10 insert at the cutting speeds used was greater than that observed during machining of Al-17%Si MMCs. For Al-Si alloys, PCD was shown to have a less percentage increase in cutting forces with change in volume percent of SiCp or Al_2O_3P reinforcement than K10.

3.5 SEM micrographs of Chips formed by machining MMC samples and Cutting Inserts

The chips created during the turning operation were analysed by SEM to better comprehend how the cutting tool material affected the mechanics of machining the MMC samples. The results of the microscopy analysis are discussed below. Figure 3 shows micrographs of chips that were smooth and lengthy after milling unreinforced Al-Si alloys with PCD and K10 inserts. When milling SiCP or Al_2O_3P reinforced alloys with PCD, the resulting chip pattern looks like figure 3 (a, c, e, g, i)—a very smooth material flow with tightly spaced chip pieces. This property observed with chips accounts for the improved surface smoothness, supporting the preceding findings. Nonetheless, as seen in Figure 3 (b, d, f, h, and j), when these composites were machined using K10, the chips generated showed somewhat loose packing of material. The chips made using the K10 insert have a typical tendency to stick and slip. The increased cutting forces and roughness of the machined surface may be the result of this phenomena. Following the machining process, scanning electron microscopy (SEM) was used to produce micrographs of the cutting edges of the inserts. These micrographs are displayed in Figure 4. Machining composites resulted in neither significant flank nor crater wear on the tool tip nor the cutting edge of the PCD insert. This was the case throughout the process. Nevertheless, as can be seen in Figure 4 (b), while milling Al_2O_3P reinforced Al-Si alloy, a little amount of material is smeared on the rake face of the PCD insert. This occurs because of the insert's rake angle. The tool wear that occurs during the machining of MMCs with a K10 insert can be seen in Figure 4 (c-d), and this wear tends to migrate towards the rack face as the process continues.

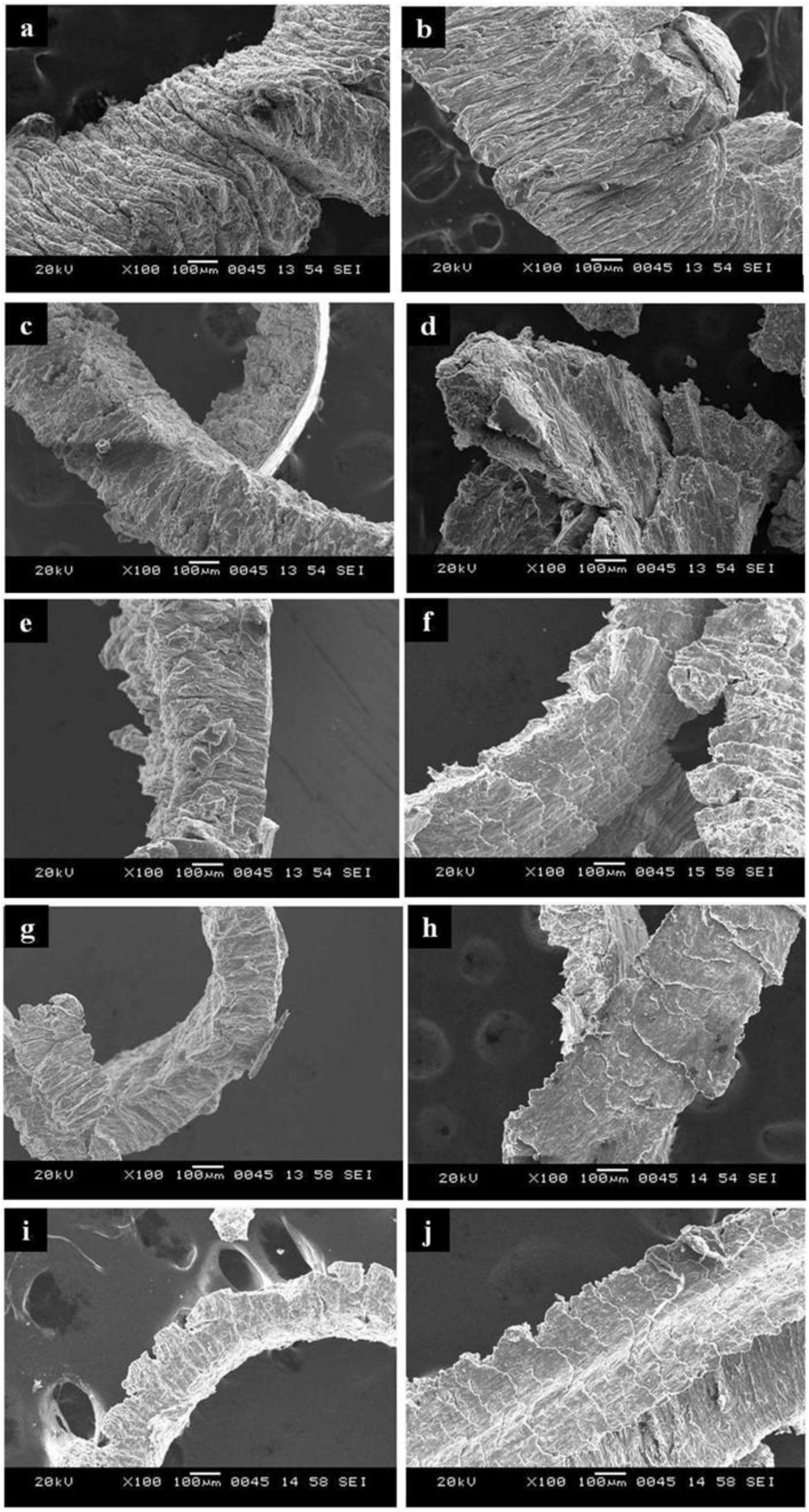

Figure 3. SEM Micrographs of turning chips pertaining to a) unreinforced Al-12% Si alloy machined using PCD b) unreinforced Al-12% Si alloy machined using K10 c) unreinforced Al-17% Si alloy machined using PCD d) unreinforced Al-17% Si alloy machined using K10 e) 5 volume percent SiCP reinforced Al-17% Si alloy machined using PCD f) 5 volume percent SiCP reinforced Al-17% Si alloy machined using K10 g) 5 volume percent Al_2O_3P reinforced Al-12% Si alloy machined using PCD h) 5 volume percent Al_2O_3P reinforced Al-12% Si alloy machined using K10 i) 5 volume percent Al_2O_3P reinforced Al-17% Si alloy machined using PCD j) 5 volume percent Al_2O_3P reinforced Al-17% Si alloy machined using K10

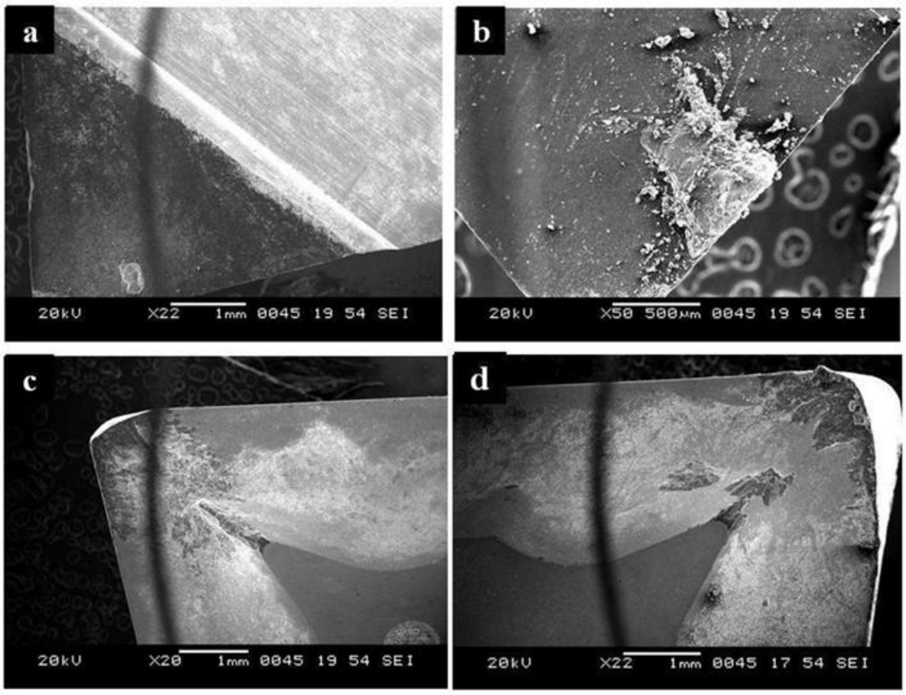

Figure 4. SEM Photographs of cutting inserts pertaining to a) PCD insert on machining SiCp reinforced Al-Si alloys b) PCD insert on machining Al_2O_3P reinforced Al-Si alloys c) K10 insert on machining SiCp reinforced Al-Si alloys d) K10 insert on machining Al_2O_3P reinforced Al-Si alloys

4. CONCLUSION

When machining MMCs with a PCD and K10 insert at the cutting speeds that were employed, the percentage increase in cutting forces was found to be greater in Al-12%Si MMCs than in Al-17%Si MMCs. This was due to the fact that the volume percent of reinforcements changed during the machining process. PCD was shown to have a smaller percentage increase in cutting forces with an increase in volume percent of either SiCp or Al_2O_3P reinforcement in Al-Si alloys compared to those with K10. This was found to be the case even though the percentage increase in cutting forces did occur. It was discovered that the effect of the cutting insert on the forces that were created during the machining of these composites was more obvious when the matrix alloy contained a silicon concentration that was hypereutectic. In the process of machining SiCp reinforced Al-12% Si and Al-17% Si alloys with a K10 insert, the cutting speeds were increased from 75 to 118 metres per minute, which resulted in a significant rise in the cutting forces, which were even greater with Al_2O_3P reinforced MMCs.

When SiCP or Al_2O_3P reinforced alloys are machined with PCD, the resulting chip pattern looks like a highly smooth material flow with closely spaced chip fragments. However, when these composites were machined with K10, the chips that were created had a rather loose packing of material and have exhibited a tendency to stick and slip. This tendency to stick and slip could be responsible for increasing the surface roughness, which in turn induces larger cutting forces.

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