EFFECT OF MACHINING PARAMETERS ON THE TOOL WEAR AND SURFACE ROUGHNESS OF AL-AIN MMC IN END MILLING MACHINING

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ABSTRACT

The machinability of MMCs have been extensively focused and investigated by the scientific community not only due to their superior mechanical properties but also because of the potential application in automotive and aerospace industries. Since these materials are classified as difficult-to-machine material due to the hardness and abrasiveness, the selection of particles reinforcement’s volume and selection of cutting tools are essential in order to obtain better surface finish and reduce tool wears. In this paper, attention is focussed on the experimental study of 5% aluminium nitride (AlN) reinforced aluminium MMC manufactured via stir casting method and been heat treated purposely to increase the mechanical properties. Cutting tool insert used for this end milling experiment was single layer coated carbide. Machining parameters; cutting speed, feed rate and cutting time are considered and the machining characterization; flank wear and surface roughness are examined. Furthermore, some solutions to reduce tool wears, and obtain better surface finished are discussed.

Keywords: Metal matrix composite (MMC); Aluminium nitride (AlN); tool wear; surface roughness.

1. INTRODUCTION

An aerospace and automotive industry is going through tremendous evolution in introducing new generation materials having low density and very light weight with high strength, hardness and stiffness. Material matrix composites (MMCs) are designed to suit the requirements. These materials are new generation of composite materials which combines the tough metallic matrix with a hard ceramic. The reinforcement of ceramic material in metallic matrix will affect the properties of these materials; high in strength, hardness, wear resistance and strength to weight ratio are the properties that makes these materials as a potential in automotive and aerospace industries (Kennedy et al., 1997).

The structure and properties of MMCs are affected by the type and properties of the matrix, reinforcement, and interface. Aluminium, titanium and magnesium are the various types of lightweight materials commonly used as matrix phase and aluminium and its alloys are the most popular. Ceramic reinforcements mostly used are silicon carbide and aluminium oxide (Seeman et al., 2010). However, others ceramic are also capable of being used as reinforcement particles such as boron nitride and aluminium nitride. Compared with other ceramic materials, Aluminium Nitride (AlN) is one of the lowest densities, high specific modulus, and lowest thermal expansion. Its thermal expansion 4.6 x 10-6 m/ºC was close to Si offer a potential use for both monolithic and composites materials (Kuramoto et al., 2003).

MMCs are classified as difficult-to-machine material. The difficulty in machining these materials is one of the major problems that are preventing its wide spread in engineering application (Cronjager et al., 1992; Schwartz et al., 1997). It is due to the hardness and abrasiveness of the materials. To overcome or minimized the problems, attention should be given to the volume of particles reinforcement and selection of cutting tools in order to obtain lower surface roughness and tool wear.

Among the different forms of tool wear, flank wear is the significant measure because it affects the
dimensional tolerance of workpieces. The main wear mechanism of the tools which had been investigated by the researchers was abrasion wear of the tool face. This is due to the reinforcement particles, with the greatest wear on the flank face of the tool (Pedersen et al., 2006). Flank wear occurs due to the rubbing of the tool along the mechanical surfaces of workpiece material, caused by abrasive, diffusive, and adhesive wear mechanisms (Reddy et al., 2009).

In machining of MMCs, flank wears of cutting tool (VBmax) increases with the increase in the cutting speed (Seeman et al., 2010). At lower cutting speed, tool wear is reduced, which can be attributed to formation of larger size unstable BUE due to high contact pressure and friction. The different abrasive wear grooves on the flank face can be seen while turning Al/SiCp metal matrix composite material at low cutting speed (50 m/min). This phenomenon happened due to the abrasive nature of the hard SiC particle present in the workpiece materials. In the meantime, when the cutting speed increased to 150 m/min, abrasive and adherence of work material on to the flank face is seen which is mainly due to the generation of high contact pressure and temperature between work and tool (Seeman et al., 2010). Flank wear also increases with the increase of feed (Sornakumar et al., 2010) and depth of cut (Schwartz et al., 1997).

In meantime, surface roughness of machined material plays an important role in the evaluation of machining accuracy. Many factors affect the surface condition and machining parameters such as cutting speed, feed rate, and depth of cut have a significant influence. When machining Al₄Ti₅O₁₃ particle-reinforced aluminium alloy composites with different cutting tool, it was found that the surface roughness increased with increasing volume fraction of particles (Sahin et al., 2002). Surface roughness value increased with increasing of cutting speed. This is due to the generation of narrow grooves on the workpiece. With the increasing of cutting speed, the cutting temperature increased and leads to weaken the binding between the particles and alloy matrix. It tended to move them rather than cutting or breaking. Therefore, the particles are generated grooves on the surface of the workpiece when the tool edge came in contact with hard and brittle particles (Reddy et al., 2008).

Cutting tools based on polycrystalline diamond (PCD) had also been used successfully for machining MMCs. PCD showed better wear resistance and produced better surface finish than carbide or alumina tools (Muthukrishnan et al., 2008). With diamond tools, the tool wear is very low but the price is very high and the shaping of the tool is very limited (Kök et al., 2010).

In this paper, attentions are given to the machinability of 5% AlN reinforced aluminium MMC machined by end milling process and using single layer coated of cutting insert. Machining characterization is focused in term of tool flank wear and surface roughness of workpiece material.

2. METHODOLOGY

2.1 Materials

The reinforcement material in the experiments was 5 wt% of AlN and was reinforced with aluminium silicon (Al-Si) alloy as a matrix. Table 1 shows the chemical composition of Al-Si alloy. This composition was determined by Glow Discharge Profiler (Model-Horiba Jobin Yyon). The mean size of the reinforcement particle was <10 μm and the purity of >98%. The machined material was fabricated through stir casting method as shown in figure 1. Heat treatment was conducted to increase the mechanical properties.

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt%</th>
<th>Element</th>
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<tbody>
<tr>
<td>Fe</td>
<td>0.42</td>
<td>Sn</td>
<td>0.016</td>
</tr>
<tr>
<td>Si</td>
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<td>Co</td>
<td>0.004</td>
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<tr>
<td>Zn</td>
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<td>Ti</td>
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<tr>
<td>Mg</td>
<td>0.0107</td>
<td>Cr</td>
<td>0.008</td>
</tr>
<tr>
<td>Cu</td>
<td>0.02</td>
<td>Al</td>
<td>Balance</td>
</tr>
<tr>
<td>Ni</td>
<td>0.001</td>
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</tbody>
</table>

Fig. 1 Stir casting process in producing machined material
2.2 End Milling Experiment

Machining tests was conducted by using single layer of coated carbide (P10); ISO catalogue no: ADKT103504PDFRLC milling tool insert (The PVD TiB2 coating) on the tool body diameter Ø12mm. The machining experiment was conducted in DMC635V eco DMGECOLINE vertical milling machine at dry cutting conditions. The cutting speed used was 200 and 250m/min with a various feed rate; 0.2, 0.6, 0.8, and 1.0mm/tooth and a constant depth of cut of 1mm. The flank wear was measured using a Three Axis Travelling Microscope. Surface roughness of the machined surface was observed using Roughness Tester Mpi mahr Perthenometer.

3. RESULT AND DISCUSSION

3.1 Effect of Machining Parameters on Flank Wear (VBmax)

The effect of time on wear has three stages: initial, steady-state, and worn-out regions. The experiment was done in a constant cutting speed (s); 250m/min. In fig. 2, an increase of flank wear is observed which only takes 0.5min (30sec) to wear when the feed rate (f) fixed to f=1.0mm/tooth. For f=0.2mm/tooth, flank wear is the least range. It shows a better tool life with insert still in a good condition even with the machining time exceeding 2.5min. For f=0.6mm/tooth and f=0.8mm/tooth, the three stages that shows the effect of time on wear can be seen clearly. It started with the increasing of flank wear until reached 25sec and gone through steady state region for a certain period of time. When the VBmax is around 0.15mm, it wears sharply after 25sec leaving steady state region.

![Fig. 2 Effect of feed rate (f) and machining time (t) on flank wear (VBmax)](image)

From the observation, it is clear that the flank wear (VBmax) increases with the increase in feed rate (f). The increasing of feed rate may increase the flank wear due to BUE formed on flank face that changes the geometry of the tool (Seeman et al., 2010) (Hung et al., 1996).

Figure 3 indicates the flank wear (VBmax) at different cutting speed (s); 200 and 250m/min. The increase of cutting speed by 25% is intentionally used to observe the VBmax towards machining time. The experiment was done in a constant feed rate (f); 0.8mm/min. It is clearly shows that the flank wear (VBmax) is increases with increase of cutting speed. The values of VBmax when machining time exceeds 0.75min (45sec) are approximately similar for cutting speed 200 and 250m/min. But as the machining time is increased, the tool wear for cutting speed 250m/min unfortunately goes up to 0.33mm. In a mean time, for cutting speed 200m/min, the values of tool wear remains within steady-state region even with the machining time exceeding 1.5min (90sec).

![Fig. 3 Effect of cutting speed (s) and machining time (t) on flank wear (VBmax)](image)

It can be concluded that as the cutting speed is increased, abrasive and adherence of work material on to the flank face is seen clearly. This phenomenon happens mainly due to generation of high contact pressure and temperature between work and tool; the main wear mechanism of carbide tool is abrasive and adhesive wear (El-Gallab et al., 1998) (Seeman et al., 2010).

3.2 Effect of Machining Parameters on Surface Roughness (Ra)

To study the effect of cutting speed and machining time on surface roughness (Ra), the experiment was done in a constant feed rate (f) 0.8mm/tooth and depth of cut 1mm. From fig. 4, it shows that as the cutting speed (s) increases, the roughness decreases. This is due to the fact that the BUE vanishes and chip fracture
also decreases. (Palanikumar et al., 2007). With the increasing of cutting speed, the cutting temperature increased and leads to weaken the binding between the particles and alloy matrix (Seeman et al., 2010). It tended to move them rather than cutting or breaking. Therefore, the particles are generated grooves on the surface of the workpiece when the tool edge came in contact with hard and brittle particles (Seeman et al., 2010).

![Surface roughness, Ra (µm)](image)

**Fig. 4** Effect of cutting speed (s) and machining time (t) on surface roughness (Ra)

From Figure 5, the increase in feed rate (f) increases the surface roughness (Ra) and the value of surface roughness (Ra) is low at low feed. This is because of the increase in maximum chip thickness due to the increase in feed rate, which results in an increase of surface roughness (Reddy et al., 2008).

![Effect of feed rate (f) and machining time (t) on surface roughness (Ra)](image)

**Fig. 5** Effect of feed rate (f) and machining time (t) on surface roughness (Ra)

4. **CONCLUSION**

The experiment results of end milling on of AlN reinforced aluminium metal matrix composite (MMC) using coated carbide insert (P10) were presented. The effect of cutting speeds and machining time on tool wear and surface roughness was measured.

The flank wear (VBmax) increased with the increases of feed rate (f) and decreased when the value of feed rate is lower. The increasing of feed rate may increase the tool wear due to BUE formed on flank face that changes the geometry of the tool. When the values of cutting speed were varied, it is clearly shown that increase in cutting speed will increase the flank wear (VBmax). As cutting speed is increased, abrasive and adherence of work material on to the flank face is seen clearly. This is due to generation of high contact pressure and temperature between work and tool.

The surface roughness (Ra) increases with the increase in feed rate (f) and decreases with the decrease in feed rate (f). This is because of the increase in maximum chip thickness due to the increase in feed rate, which results in an increase of surface roughness. The situation is different with the variation of cutting speed (s). As cutting speed increased, the surface roughness is decreased and vice versa. This is due to the; increasing the cutting speed will increase the cutting temperature and leads to weaken the binding between the particles and alloy matrix. It tended to move them rather than cutting or breaking.

**REFERENCES**


155