CHAPTER 8

RESULTS AND DISCUSSION

8.1 INTRODUCTION

This chapter discusses the comparison of results obtained through various methods, the effect of cutting speed, feed rate and depth of cut on the surface roughness and power consumption of turning Al-SiC\textsubscript{p}(10P and 15P) MMCs. The optimized process parameter of turning of Al-SiC\textsubscript{p} MMCs is obtained by considering the merits and the demerits of the process parameter on the surface roughness and the input power of the process. Further the chapter addresses the tool wear analysis of PCD cutting tool, while machining Al-SiC\textsubscript{p}(10P) and Al-SiC\textsubscript{p}(15P) MMCs at the optimal levels of the machining parameters. The microstructures of the cutting tool wear pattern are clearly examined using scanning electron microscope (SEM) images and reported.

8.2 COMPARISON OF RESULTS OBTAINED THROUGH VARIOUS METHODS OF OPTIMIZATION

The initial settings chosen for the machining of Al-SiC\textsubscript{p}(10P) and Al-SiC\textsubscript{p}(15P) metal matrix composites were A\textsubscript{3}B\textsubscript{3}C\textsubscript{2}. The comparison of optimum factor levels of the machining parameters for each method are given in Table 8.1. The optimal factor settings for Al-SiC\textsubscript{p}(10P) MMC based on the selected techniques are A\textsubscript{1}B\textsubscript{1}C\textsubscript{2}(GRA), A\textsubscript{1}B\textsubscript{1}C\textsubscript{2}(DFA) and A\textsubscript{1}B\textsubscript{1}C\textsubscript{2}(WPCA). The optimal factor settings based on the selected techniques are A\textsubscript{1}B\textsubscript{1}C\textsubscript{2} for Al-SiC\textsubscript{p}(15P) MMC. As a result, the recommended machining conditions for
homogenised 10% and 15% SiC_p reinforced Al-MMC material would be the
selection of low cutting speed (75m/min) and feed rate (0.1mm/rev) and depth
of cut (0.6mm) for rough and medium turning process with PCD cutting tool
to obtain simultaneously better surface finish and minimum power
consumption as well as longer tool life.

Table 8.1 Comparison of Results (Optimum Parameter levels)

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Method</th>
<th>Optimum Parameter for Al-SiC_p(10P) MMC</th>
<th>Optimum Parameter for Al-SiC_p(15P) MMC</th>
</tr>
</thead>
</table>
| 1      | Taguchi Method (Minimization of surface roughness) | A_3B_1C_2  
A - 180m/min  
B - 0.1 mm/rev  
C - 0.6 mm  | A_3B_1C_2  
A - 180 m/min  
B - 0.1 mm/rev  
C - 0.6 mm |
| 2      | Taguchi Method (Minimization of power consumption) | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm  | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm |
| 3      | Grey Relational Analysis (GRA) | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm  | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm |
| 4      | Desirability Function Analysis (DFA) | A_1B_1C_2  
A - 120 m/min  
B - 0.1 mm/rev  
C - 0.6 mm  | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm |
| 5      | Weighted Principal Component Analysis (WPCA) | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm  | A_1B_1C_2  
A - 75 m/min  
B - 0.1 mm/rev  
C - 0.6 mm |
In the present investigation, comparisons of the optimum results are shown in Table 8.2.

Table 8.2 Comparison of performance characteristics for optimum values

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Method</th>
<th>Optimum performance for Al-SiC_p (10p) MMC</th>
<th>Optimum Performance for Al-SiC_p (15p) MMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taguchi Method (Single objective) Minimization of Surface roughness</td>
<td>Ra = 1.62 microns</td>
<td>Ra = 1.77 microns</td>
</tr>
<tr>
<td>2</td>
<td>Taguchi Method (Single objective) Minimization of Input power</td>
<td>Pc = 0.39 kW</td>
<td>Pc = 0.46 kW</td>
</tr>
<tr>
<td>3</td>
<td>Grey Relational Analysis (GRA)</td>
<td>Ra = 1.82 microns</td>
<td>Ra = 2.58 microns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pc = 0.39 kW</td>
<td>Pc = 0.46 kW</td>
</tr>
<tr>
<td>4</td>
<td>Desirability Function Analysis (DFA)</td>
<td>Ra = 1.82 microns</td>
<td>Ra = 2.58 microns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pc = 0.39 kW</td>
<td>Pc = 0.46 kW</td>
</tr>
<tr>
<td>5</td>
<td>Weighted Principal Component Analysis (WPCA)</td>
<td>Ra = 1.82 microns</td>
<td>Ra = 2.58 microns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pc = 0.39 kW</td>
<td>Pc = 0.46 kW</td>
</tr>
</tbody>
</table>

The optimum process parameter evolved in this investigation is A_1B_1C_2 for Al-SiC_p(10P) MMC and Al-SiC_p(15P) MMC with simultaneous minimization of surface roughness and power consumption. The confirmation experiment run was conducted by setting the optimum parameters and the surface roughness is evaluated as 1.82 microns and 2.58 microns for Al-SiC_p(10P) MMC and Al-SiC_p(15P) MMC respectively.

The optimum process parameter evolved with respect to minimization of the power consumption is A_1B_1C_2 for both Al-SiC_p(10P)
MMC and Al-SiC\textsubscript{P} (15P) MMCs. The confirmation experimental run was conducted by setting the optimum parameter as A\textsubscript{1}B\textsubscript{1}C\textsubscript{2}. The power consumed for Al-SiC\textsubscript{P}(10P) MMC and Al-SiC\textsubscript{P}(15P) MMC is 0.39 kW and 0.46 kW respectively.

8.3 EFFECT OF CUTTING SPEED

The cutting speed plays a significant role in affecting the machining performance of turning process. The cutting speed of the tool plays a major role in affecting the input power consumption of turning process. The input power is directly proportional to the cutting speed of the tool. Irrespective of the optimization methods used, the optimum level for cutting speed is observed as 75 m/min for multiple response optimizations.

- Change in the level of Cutting speed is greatly influences the power consumption. The average Pc value at 75m/min is 0.58 kW, at 120 m/min the Pc is 0.84 kW and at 180 m/min the Pc is 1.25 kW respectively.

- Change in the level of Cutting speed is slightly affecting the surface roughness for machining Al-SiC\textsubscript{P} MMCs. The average Ra value at 75m/min is 4.19 microns, at 120 m/min the Ra is 4.22 and at 180 m/min the Ra is 3.59 microns respectively.

- It was observed that higher cutting speeds provide for higher surface finish, but will lead to higher power consumption.

8.4 EFFECT OF FEED RATE

In the aspect of surface finish, it has been found that the feed rate is a more dominant factor than cutting speed. The higher the feed rate is the
worse the surface finish becomes, i.e. the surface roughness of the machined surface increases with increases in feed rate.

- Change in the level of feed rate is significantly affects the surface roughness response. The average Ra value at 0.1 mm/rev is 2.46 microns, at 0.2 mm/rev the Ra is 3.77 and at 0.3 mm/rev the Ra is 5.76 microns respectively.

- Change in level of feed rate affects the power consumption. The average Pc values at 0.1 mm/rev is 0.67 kW, at 0.2 mm/rev the Pc is 1.01 kW and at 0.3 mm/rev the Pc is 0.98 kW respectively.

- The optimum parameter level for feed rate is 0.1 mm/rev.

8.5 EFFECT OF DEPTH OF CUT

- Change in the level of depth of cut does not affect the performance measure of surface roughness (Ra) within the experimental region.

- It gives minimal effect on the surface roughness. The average Ra value at 0.3 mm of depth of cut is 4.19 microns, at 0.6 mm the Ra is 3.67 and at 0.9 mm the Ra is 4.12 microns respectively.

- Change in depth of cut affects the power consumption (Pc). The average Pc values at 0.3 mm of depth of cut is 0.92 kW, at 0.6 mm the Pc is 0.81 kW and at 0.9 mm the Pc is 0.93 kW respectively.

- The optimum parameter level for depth of cut is 0.6 mm.
8.6 EFFECT OF %REINFORCEMENT OF SiC\textsubscript{p}

While machining the work piece having 15% SiC reinforcing particles, more power is required than the work piece having 10% SiC reinforcing particles at the chosen cutting conditions. It was observed that more power was required to pull the reinforcing particles rather than cutting it. Power was generally more with increased reinforcing SiC particle percentage. Surface roughness slightly increases with increase of SiC particles for the same cutting conditions (Figure 8.1).

It is also observed that increase in percentage of reinforcing SiC has no improvement in their mechanical properties rather than increase in the surface roughness, power consumption and tool wear (Muthukrishnan et al 2008c). Based on the comparison of results from the various methods, the optimum parameters were obtained by analyzing the power consumption (Pc) and an average surface roughness (Ra) value of the machined component. Under this condition, the tool wear study was carried out for time duration of 60 min for analyzing the tool life of PCD inserts.

![Figure 8.1 Effect of %reinforcement of SiC particles](image-url)
8.7 TOOL WEAR ANALYSIS

Tool wear is one of the important factors for analyzing the machinability. From the literature, it is now well known that the primary wear mechanism in machining particulate reinforced MMC is abrasion by the reinforcing particles on the flank surface of the tool (Lane 1992; Tomac et al 1992). The main cause of tool failure is due to abrasion nature of hard reinforced SiC particles over tool insert. Hardness of the SiC particles is greater than PCD insert by three to four times. It is observed that more reasonable tool lives can be obtained by reducing the cutting speed to 50-200 m/min and, in this range life of 10-50min were obtained (Heath 2001).

The optimal machining parameters for Al-SiC$_p$(10p) and Al-SiC$_p$(15p) are A$_1$B$_1$C$_2$. Therefore, by setting these parameters as constant, tool wear study was carried out for 60 minutes duration. For the evaluation of tool life, a flank wear criteria of 0.3 mm was used. Tool makers microscope was used to measure the flank wear width and the same was measured at an interval of 15 min of machining. Parallel marks are seen on the flank face of tool after 15, 30 and 45 minutes duration respectively. Figure 8.1 shows the photographic view of the fresh PCD tool (1600 grade). Figure 8.2, 8.3 and 8.4 shows the progress of flank wear and tool failure pattern of PCD tool at the interval of every 15 minutes, while machining Al-SiC$_p$(10p) MMC at the optimal cutting conditions. It is found that the tool life of PCD withstands only about 45 to 50 minutes for both Al-SiC$_p$(10P) and Al-SiC$_p$(15P) MMCs.
Figure 8.2 Flank portion of a fresh PCD Tool

It is evident that, Parallel marks are due to the hardness of silicon carbide particles presented on the aluminum matrix. Main wear pattern observed on the cutting insert was the flank wear at the nose region. Two bodies and three body abrasive wear are also observed. Three body abrasive wear is caused by the released hard particles, entrapped between the tool and the work piece.

Figure 8.3 Photographic image of flank wear with BUE (After 15 min for Al-SiC_p(10P) MMC)
The examination of the worn tool under optical microscope revealed a relatively stable built-up-edge over the nose region (see Figure 8.3). This is expected because of the low cutting speeds at which experiments were conducted and the soft aluminium matrix, which adheres to the cutting edge at low temperature cutting. Even the hard, intermittent SiC\textsubscript{p} reinforcements did not disturb the relatively stable BUE. The optical inspection of the flank face of the cutting tool revealed the beginning of the flank wear. No substantial groove wear was observed. Also significant amount of de-brazing of the insert could be observed. This is due to the shock loads associated with machining of Al-SiC\textsubscript{p} MMC (Muthukrishnan et al 2008,a). It was observed that the composite having 15\% SiC reinforcing reached severe wear region after 45 min (see Figure 8.6), but 10\% of the SiC reinforcing composite was still in the steady wear rate. This was clearly understood that, the weight percentage of SiC particles on composite accelerated the tool flank wear (Xiaoping Li and Seah 2001).

![Figure 8.4 SEM image of flank wear with parallel marks (After 30 min for Al-SiC\textsubscript{p} (10P) MMC)](image)

Figure 8.4  SEM image of flank wear with parallel marks (After 30 min for Al-SiC\textsubscript{p} (10P) MMC)
Figure 8.5  SEM image showing flank wear marks (After 45 min for Al-SiC_p (10P) MMC)

Figure 8.6  SEM image of flank wear pattern (After 45 min for Al-SiC_p (15P) MMC)
8.7 SUMMARY

The effect of turning parameters on surface roughness, power consumption and tool wear is discussed. The summary is given below.

- The main wear pattern observed on the cutting insert was the flank wear at the nose region. This is due to abrasion nature of hard reinforced SiC particles over tool insert.

- It is found that the tool life of PCD withstands only about 45 to 50 minutes for machining both Al-SiC$_p$(10P) and Al-SiC$_p$(15P) MMCs.

- The examination of the worn tool under optical microscope revealed a relatively stable built-up-edge formation over the nose region.

- Input power consumed was more with increased reinforcing SiC particle percentage.

- The input power is directly proportional to the cutting speed of the tool. The optimum level for cutting speed is observed as 75 m/min.

- The surface roughness of the machined surface increases with increases in feed rate. The optimum parameter level for feed rate is 0.1 mm/rev. The optimum parameter level for depth of cut is 0.6 mm.

- Therefore, the optimal factor setting is $A_1B_1C_2$ for machining Al-SiC$_p$ MMCs for simultaneously achieving minimum surface roughness and power consumption.