CHAPTER 3

EXPERIMENTAL PLAN

3.1 INTRODUCTION

The metal matrix composites has grown substantially in aerospace, automotive and electronics industries with a common goal of achieving higher strength to weight ratio, higher fatigue resistance and lower coefficient of thermal expansion. However, the final conversion of these composites in to engineering products is always associated with machining. A continuing problem with MMCs is that they are difficult to machine, due to the hardness and abrasive nature of the reinforcing particles (Paulo Davim, 2003). Selection of optimal machining conditions is a key factor in achieving this condition. In order to obtain a high quality surface finish with minimum power consumption the manufacturer has to set the input controllable factors at their optimum levels, with the minimum effect of uncontrollable or noise variables on the levels and the variability of the responses.

To attain the main objective of the present investigation, the experimental work has been conducted in the following sequence:

- Fabrication of Al-SiC\textsubscript{p} metal matrix composite bars of size 50 mm diameter and 300 mm in length for 10\% and 15\% volume fraction of SiC particulate reinforcement using stir cast method.

- Evaluation of chemical and mechanical properties of a fabricated MMC material.
• Selection of process parameters and their levels.

• Selection of a suitable orthogonal array for experimental design and corresponding process parameters and their levels.

• Turning of Al-SiC metal matrix composite bars using different process parameters.

• Evaluation of surface roughness and power consumption of above machining conditions.

• Optimization of process parameters using Taguchi method for single response criteria.

• Optimization of process parameters using multi-response optimization techniques.

• Comparison of results of various methods using the optimized parameters.

• To conduct Tool wear analysis at the optimal cutting conditions.

The detailed experimental procedures involved in each stage of the experimental work are briefed in the following sections.

3.2 FABRICATION OF MMC BY STIR CAST METHOD

Most of the methods used for the manufacture of metal matrix composites are expensive and require skilled complicated operations. The liquid phase routes are more similar to conventional casting process and are economical for the manufacture of metal matrix composites. In addition, these casting processes enable to fabricate large complex near net shaped components (Mohammed A. Taha, 2001; Basavarajappa et al 2006).
The metal matrix composites of A356 alloy reinforced with SiC\textsubscript{p} were prepared in a crucible furnace. The fabricated stir casting set up is shown in Figure 3.1. Easily producible SiC at particle size, which forms a good interface bond with matrix alloy, has been used as reinforcement material. Particles have been filtered to obtain a size of 30-60 \textmu m. The SiC\textsubscript{p} were pre oxidised at 650° C for 2 hours and poured into the liquid matrix stirred at a constant rate. The heat treatment was done in order to form a layer of SiO\textsubscript{2} on the SiC\textsubscript{p}, which improves the incorporation of the SiC\textsubscript{p} into the molten metal. The melt is stirred at a constant rate of 670rpm for 10 minutes, after the addition of SiC\textsubscript{p}. After the continuous stirring, the melt is poured into a permanent iron die mould to obtain composites of size 50mm diameter and 300mm length after the sprue pins were removed. No evidence of macro casting defects was seen. The matrix metal was also cast in the same process to standardize the casting process.

Magnesium is added to increase the wettability of the particulates. Magnesium, which improves the wettability of SiC\textsubscript{p} with the Aluminium melt, is lost from the melt by oxidation, during melting and stirring of the alloy. In order to compensate for this loss and maintain the wettability of the alloy, magnesium is added to the molten metal before the start of stirring.

Two different volume fractions 10\% and 15\% by wt\% of aluminium were fabricated. The average particle size of the SiC\textsubscript{p} is of 45 \textmu m sizes. The composites are henceforth referred as Al-SiC\textsubscript{p}(10p) and Al-SiC\textsubscript{p}(15p) respectively.
3.3 MICROSTRUCTURE ANALYSIS

The properties of the MMC depend not only on the matrix, particle, and the volume fraction, but also on distribution of reinforcing particles and interface bonding between the particle and matrix. The samples were sectioned and examined by SEM for metallographic examination. The optical micrograph of the aluminium metal matrix composite reinforced with 10 and 15 wt. % of SiC<sub>p</sub> [Al-SiC<sub>p</sub>(10p) and Al-SiC<sub>p</sub>(15p)] is shown in Figure 3.2 and Figure 3.3 respectively. The distribution of SiC<sub>p</sub> in these composites is uniform. For the microstructure of these composite specimens, no pores existed in these specimens due to the improvement of wettability when the Al-356 alloy was used. It indicate that no evidence of the presence of cavities neither at interfaces nor in the matrix was found with optical microscopy,
which indicates that a good bonding between the matrix and ceramic particulate was obtained by using the molten mixing method. The SiC particles are observed to be angular in shape. A careful examination indicates that apart from the large SiC particles, fine SiC particles less than 25 micron size are also present.

Figure 3.2  Microstructure of Al-SiC(10p) MMC

Figure 3.3  Microstructure of Al-SiC(15p) MMC
3.4 EVALUATION OF PROPERTIES

The base metal used in this investigation is A356 aluminium alloy. The chemical composition of the Al-SiC$_p$ (10p) and Al-SiC$_p$ (15p) composites is evaluated in weight percent and given in Table 3.1 and Table 3.2 respectively. Also the physical and mechanical properties of the fabricated Al-SiC$_p$ MMCs are evaluated and it is given in Table 3.3. It was noted that the hardness, density and tensile strength of Al-MMC increased by addition of SiC$_p$.

**Table 3.1 Chemical composition of Al-SiC (10P) –MMC**

<table>
<thead>
<tr>
<th>Reinforcement</th>
<th>%SiC</th>
<th>%Si</th>
<th>%Mg</th>
<th>%Fe</th>
<th>%Cu</th>
<th>%Mn</th>
<th>%Zn</th>
<th>%Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC -54 µm</td>
<td>10.00</td>
<td>7.77</td>
<td>0.63</td>
<td>0.15</td>
<td>0.16</td>
<td>0.09</td>
<td>0.08</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Table 3.2 Chemical composition of Al-SiC (15P) –MMC**

<table>
<thead>
<tr>
<th>Reinforcement</th>
<th>%SiC</th>
<th>%Si</th>
<th>%Mg</th>
<th>%Fe</th>
<th>%Cu</th>
<th>%Mn</th>
<th>%Zn</th>
<th>%Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC -54 µm</td>
<td>15.00</td>
<td>7.98</td>
<td>0.64</td>
<td>0.11</td>
<td>0.18</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Table 3.3 Physical and Mechanical properties of Al-SiC$_p$ MMCs**

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (gms/cm$^3$)</th>
<th>Tensile Strength (Mpa)</th>
<th>Hardness (BHN)</th>
<th>Modulus of Elasticity (Gpa)</th>
<th>% of Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-SiC$_p$ (10p)</td>
<td>2.65</td>
<td>280</td>
<td>100</td>
<td>90</td>
<td>1.3 - 1.9</td>
</tr>
<tr>
<td>Al-SiC$_p$ (15p)</td>
<td>2.76</td>
<td>285</td>
<td>110</td>
<td>90</td>
<td>1.3 - 1.9</td>
</tr>
</tbody>
</table>
3.5 SELECTION OF CUTTING TOOL

The particles used in the MMCs are harder than most of the cutting tool materials. This results in accelerated tool wear and premature tool failure. Conventional tool materials such as High-speed steel, coated and uncoated carbide tools sustained significant levels of tool wear after short period of machining. Most of the researchers reported diamond is the most preferred tool material for machining MMCs (Paulo Davim 2001).

Poly Crystalline Diamond (PCD) based materials for cutting tools are produced by sintering at high temperature and under pressure particle diamond crystals (grain size = 2-25microns) with a metallic binder, deposited on a hard metal substrate (tungsten carbide). Its hardness is extremely high and it is chemically inert to non-ferrous materials. Cutting tools made of PCD are produced by using three dimensions of diamond grain sizes such as fine, medium and coarse: fine grain is used for finishing operations and non-metal material cutting, medium grain for non-ferrous metal cutting and coarse grain for interrupted cutting operations like milling (D’Errico et al 2001). In this research work the cutting tool used for machining is PCD 1600 fine grade inserts. The details regarding the PCD tool dimension and its characteristics are given in Table 3.4.

<table>
<thead>
<tr>
<th>Insert</th>
<th>PCD 1600 grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate (for PCD)</td>
<td>Tungsten Carbide</td>
</tr>
<tr>
<td>Type</td>
<td>CNMA 120408</td>
</tr>
<tr>
<td>Nose radius</td>
<td>0.8 mm</td>
</tr>
<tr>
<td>Shank size</td>
<td>25*25 mm</td>
</tr>
<tr>
<td>Tool holder specification</td>
<td>PCLNR 25 25 M 12</td>
</tr>
<tr>
<td>Average particle size</td>
<td>4 microns</td>
</tr>
</tbody>
</table>
3.6 EXPERIMENTAL PROCEDURE

In the Al-SiC\textsubscript{p} MMC, the A356 aluminum matrix was experimentally found to contain 7.98\% Si and 0.64\% Mg apart from traces of other elements. Samples of the material Al-SiC\textsubscript{p} MMC in the form of cylindrical rods of 50 mm diameter and 300 mm length were fabricated using stir cast method (see figure 3.4). The experimental work was carried out on a medium duty CNC lathe. The average temperature of the environment was maintained at 25±3°C during machining. The machining tests were conducted under dry cutting process. The experimental set up for machining is shown in Figure 3.5. Each of the experiment was repeated thrice and average value of the responses was measured. Power consumption was measured with a set of watt meters as three-phase supply was used and their readings were added after multiplying by suitable multiplying factor to get power consumption in kilowatts (kW).

![Figure 3.4 Al-SiC\textsubscript{p} composite samples used as work pieces (50 mm Φ and 300 mm long)]
The machined surface was measured at three different positions and the average surface roughness ($R_a$) value in microns was taken using a Mitutoyo surf test (Make-Japan –Model SJ-301) measuring instrument with the cutoff length 2.5 mm as shown in Figure 3.6.

**Figure 3.5 Photograph of Experimental setup**

**Figure 3.6 Photographic view of stylus during surface roughness measurement**
For tool life assessment, a flank wear criterion of 0.3mm for one tool life was used. Flank wear was measured at machining interval of 15 minutes using a toolmakers microscope. The setup for tool wear measurement is shown in Figure 3.7.

![Photograph of tool maker’s microscope](image)

**Figure 3.7 Photograph of tool maker’s microscope**

Following the procedures laid down in this chapter, the optimization of process parameters using various methods for both single objective and multi response are discussed in the subsequent chapters.