CHAPTER 6

DRILLING STUDIES OF ALUMINIUM ALLOY BASED METAL MATRIX COMPOSITES

6.1 INTRODUCTION

The drilling machine is one of the most important machine tools in industry. Although it is primarily designed to create a hole, it can perform a number of similar operations. In a drilling machine operation, a hole is generated by the rotating edge of a cutting tool known as the drill which exerts large forces on the work clamped on the table. As the machine tool exerts vertical pressure to start a hole, it is loosely called a drill press. Holes were drilled by Egyptians in 1200 B.C about 3000 years ago by bow drills. The bow drill is the mother of present day metal cutting drilling machine (Hajra choudhury et al, 2001).

Drilling constitutes about 40% of all metal cutting operations (Hamade and Ismail, 2005). Drilling is the most common process associated with the production of holes because of its simplicity, rapidity and economy. However, it is also one of the most complex cutting processes. Drilling is considered to be a complementary process of other more important processes, and yet 70% of the generated chip comes from this cutting technique (Rivero et al. 2006). Drilling is a pre-requisite and essential machining process which is used for all fastening / joining processes like riveting, to connect bolt and nuts, etc. The share of High Speed Steel (HSS) drills in the market is 30%. The schematic illustration of drilling processes is shown in Figure 6.1.
6.2 DRILLING STUDIES OF ALUMINIUM ALLOY BASED COMPOSITES

The wide scale introduction of Metal Matrix Composites (MMCs) will increase simultaneously with the development of technologies. MMCs are extremely difficult and complicated to machine due to the presence of hard ceramic particle reinforcement and extreme abrasive properties and also causes higher tool wear. With the projected widespread application of MMCs, it is absolutely essential to develop an appropriate technology for an efficient and cost effective machining process. Hole drilling of composite is more difficult than in metals, due to their relative low sensitivity to heat and their weakness in the through thickness direction.

Aluminium metal matrix composites are widely used for their favourable light weight, good mechanical properties, specific strength / stiffness and corrosion resistance properties. As a consequence of the wide range of applications of MMCs, the machining of these materials has become a very important subject for research. Despite the superior mechanical and
thermal properties of particulate metal matrix composites, their poor
machinability is the main deterrent to their substitution of metal parts.
Machining is a material removal process and therefore it is important for the
final fabrication stage prior to application. In composites, the particulates
which are reinforced with hard ceramic particles lead to severe tool wear and
large debonding / pull-outs on the machined surfaces. This leaves a lot of
porosity, scratches and voids on the machined surface.

6.3 DRILLING EXPERIMENTS

The drilling experiments on the plain LM24 aluminium alloy and
aluminium alloy - aluminium oxide / silicon carbide composites are
conducted with M2 grade 5 mm diameter High Speed Steel twist drills. The
specification of the drills used in the present work is ISO 235:1980. The
drilling experiments have been done with a different cutting speed of 10, 15
and 20 m/min. and with a feed rate of 0.1, 0.3 and 0.5 mm/rev on the
aluminium alloy based MMCs along with kerosene as a coolant.

The surface roughness $R_a$ of the machined hole surface is observed
using a stylus type surface roughness testing machine. For the repeatability of
results, all the experiments are conducted five times with the same machining
conditions and the average values are taken. The wear of the drills is
measured qualitatively using a toolmakers microscope.

6.4 SURFACE ROUGHNESS

The Mean (M), Standard Deviation (SD), Standard Error (SE) and the
upper and lower limits of Confidence Interval (CI) of the surface roughness,
$R_a$, in micron of the aluminium alloy and the aluminium alloy - aluminium
oxide / silicon carbide composite are presented from Tables 6.1 to 6.9. The
formulae used for the calculation are given as follows (Ronald et al (2002) and David L Streiner (1996)).

\[ X_i = \text{Value of the } i^{\text{th}} \text{ sample.} \]
\[ M = \text{Mean of } i \text{ values} = \frac{\sum (X_i)}{N} \]
\[ N = \text{Sample size.} \]
\[ SD = \left[ \frac{\sum (X_i - M)^2}{(N-1)} \right]^{1/2} \]
\[ SE = SD/(N)^{1/2} \]
\[ 95\% \text{ CI} = M \pm (1.96SE) \]

In all the conditions, the mean of surface roughness lies within the respective upper and lower limits of confidence for the plain LM24 aluminium alloy and the aluminium alloy - aluminium oxide / silicon carbide composite.
Table 6.1 Statistical analysis of surface roughness of drilled hole at cutting speed of 10 m/min and feed of 0.1 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness $R_a$, Micron</th>
<th>Mean $M$, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>95 % Confidence Interval Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.43 0.42 0.44 0.44 0.42</td>
<td>0.43</td>
<td>0.01</td>
<td>0.0044721</td>
<td>0.421279</td>
<td>0.438721</td>
</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>0.5 0.53 0.52 0.54 0.51</td>
<td>0.52</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.506211</td>
<td>0.533789</td>
</tr>
<tr>
<td>LM24 + 3% Al₂O₃</td>
<td>0.63 0.61 0.64 0.62 0.65</td>
<td>0.63</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.616211</td>
<td>0.643789</td>
</tr>
<tr>
<td>LM24 + 5% Al₂O₃</td>
<td>0.69 0.73 0.71 0.7 0.72</td>
<td>0.71</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.696211</td>
<td>0.723789</td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>0.62 0.6 0.62 0.6 0.61</td>
<td>0.61</td>
<td>0.01</td>
<td>0.0044721</td>
<td>0.601279</td>
<td>0.618721</td>
</tr>
<tr>
<td>LM24 + 3% SiC</td>
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<td>0.0158114</td>
<td>0.0070711</td>
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<td>LM24 + 5% SiC</td>
<td>0.8 0.84 0.82 0.83 0.81</td>
<td>0.82</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.806211</td>
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</tbody>
</table>
Table 6.2 Statistical analysis of surface roughness of drilled hole at cutting speed of 10 m/min and feed of 0.3 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness Rₐ, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>95 % Confidence Interval Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.87 0.9 0.9 0.91 0.87</td>
<td>0.89</td>
<td>0.0187083</td>
<td>0.0083666</td>
<td>0.873685 0.906315</td>
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</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>0.99 0.98 0.97 0.97 0.99</td>
<td>0.98</td>
<td>0.0044721</td>
<td>0.971279 0.988721</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM24 + 3% Al₂O₃</td>
<td>1.06 1.07 1.08 1.08 1.06</td>
<td>1.07</td>
<td>0.0044721</td>
<td>1.061279 1.078721</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM24 + 5% Al₂O₃</td>
<td>1.2 1.17 1.18 1.16 1.19</td>
<td>1.18</td>
<td>0.0158114</td>
<td>1.166211 1.193789</td>
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<td></td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>1.07 1.1 1.1 1.11 1.07</td>
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<td>0.0187083</td>
<td>1.073685 1.106315</td>
<td></td>
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</tr>
<tr>
<td>LM24 + 3% SiC</td>
<td>1.18 1.19 1.17 1.2 1.16</td>
<td>1.18</td>
<td>0.0158114</td>
<td>1.166211 1.193789</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>1.25 1.29 1.27 1.28 1.26</td>
<td>1.27</td>
<td>0.0158114</td>
<td>1.256211 1.283789</td>
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</tbody>
</table>
Table 6.3 Statistical analysis of surface roughness of drilled hole at cutting speed of 10 m/min and feed of 0.5 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness Rₐ, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>1.31 1.33 1.29 1.3 1.32</td>
<td>1.31</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.296211</td>
<td>1.323789</td>
</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>1.41 1.44 1.44 1.4 1.41</td>
<td>1.42</td>
<td>0.0187083</td>
<td>0.0083666</td>
<td>1.403685</td>
<td>1.436315</td>
</tr>
<tr>
<td>LM24 + 3% Al₂O₃</td>
<td>1.52 1.52 1.5 1.52 1.49</td>
<td>1.51</td>
<td>0.0141421</td>
<td>0.0063246</td>
<td>1.497667</td>
<td>1.522333</td>
</tr>
<tr>
<td>LM24 + 5% Al₂O₃</td>
<td>1.62 1.61 1.57 1.58 1.62</td>
<td>1.6</td>
<td>0.0234521</td>
<td>0.0104881</td>
<td>1.579548</td>
<td>1.620452</td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>1.53 1.54 1.5 1.49 1.49</td>
<td>1.51</td>
<td>0.0234521</td>
<td>0.0104881</td>
<td>1.489548</td>
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<tr>
<td>LM24 + 3% SiC</td>
<td>1.6  1.64 1.62 1.63 1.61</td>
<td>1.62</td>
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<td>0.0070711</td>
<td>1.606211</td>
<td>1.633789</td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>1.7  1.71 1.69 1.68 1.72</td>
<td>1.7</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.686211</td>
<td>1.713789</td>
</tr>
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</table>
Table 6.4 Statistical analysis of surface roughness of drilled hole at cutting speed of 15 m/min and feed of 0.1 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness $R_{\alpha}$, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.32 0.32 0.32 0.3 0.29</td>
<td>0.31</td>
<td>0.0141421</td>
<td>0.0063246</td>
<td>0.297667 0.322333</td>
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<tr>
<td>LM24 + 1% Al$_2$O$_3$</td>
<td>0.41 0.43 0.43 0.41 0.42</td>
<td>0.42</td>
<td>0.01</td>
<td>0.0044721</td>
<td>0.411279 0.428721</td>
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</tr>
<tr>
<td>LM24 + 3% Al$_2$O$_3$</td>
<td>0.5 0.5 0.51 0.52 0.52</td>
<td>0.51</td>
<td>0.01</td>
<td>0.0044721</td>
<td>0.501279 0.518721</td>
<td></td>
</tr>
<tr>
<td>LM24 + 5% Al$_2$O$_3$</td>
<td>0.61 0.58 0.58 0.62 0.61</td>
<td>0.6</td>
<td>0.0187083</td>
<td>0.0083666</td>
<td>0.583685 0.616315</td>
<td></td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>0.51 0.5 0.52 0.5 0.52</td>
<td>0.51</td>
<td>0.01</td>
<td>0.0044721</td>
<td>0.501279 0.518721</td>
<td></td>
</tr>
<tr>
<td>LM24 + 3% SiC</td>
<td>0.61 0.62 0.61 0.63 0.63</td>
<td>0.62</td>
<td>0.01</td>
<td>0.0044721</td>
<td>0.611279 0.628721</td>
<td></td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>0.7 0.72 0.68 0.69 0.71</td>
<td>0.7</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.686211 0.713789</td>
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</tr>
</tbody>
</table>
Table 6.5 Statistical analysis of surface roughness of drilled hole at cutting speed of 15 m/min and feed of 0.3 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness $R_{\text{a}}$, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.73 0.77 0.75 0.76 0.74</td>
<td>0.75</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.736211 0.763789</td>
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</tr>
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<td>LM24 + 1% Al$_2$O$_3$</td>
<td>0.85 0.87 0.86 0.88 0.84</td>
<td>0.86</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.846211 0.873789</td>
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</tr>
<tr>
<td>LM24 + 3% Al$_2$O$_3$</td>
<td>0.95 0.93 0.92 0.96 0.94</td>
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<td>0.0070711</td>
<td>0.926211 0.953789</td>
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</tr>
<tr>
<td>LM24 + 5% Al$_2$O$_3$</td>
<td>1.05 1.07 1.03 1.06 1.04</td>
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<td>0.0158114</td>
<td>0.0070711</td>
<td>1.036211 1.063789</td>
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</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>0.96 0.94 0.97 0.93 0.95</td>
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<td>0.0158114</td>
<td>0.0070711</td>
<td>0.936211 0.963789</td>
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</tr>
<tr>
<td>LM24 + 3% SiC</td>
<td>1.06 1.07 1.05 1.08 1.04</td>
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<td>0.0158114</td>
<td>0.0070711</td>
<td>1.046211 1.073789</td>
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</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>1.15 1.19 1.15 1.16 1.2</td>
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<td>0.0234521</td>
<td>0.0104881</td>
<td>1.149548 1.190452</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.6 Statistical analysis of surface roughness of drilled hole at cutting speed of 15 m/min and feed of 0.5 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness $R_n$, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>95 % Confidence Interval Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>1.09 1.07 1.11 1.1 1.08</td>
<td>1.09</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.076211</td>
<td>1.103789</td>
</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>1.21 1.19 1.22 1.18 1.2</td>
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<td>0.0070711</td>
<td>1.296211</td>
<td>1.323789</td>
</tr>
<tr>
<td>LM24 + 5% Al₂O₃</td>
<td>1.41 1.39 1.45 1.44 1.41</td>
<td>1.42</td>
<td>0.0244949</td>
<td>0.0109545</td>
<td>1.398639</td>
<td>1.441361</td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>1.31 1.27 1.29 1.28 1.3</td>
<td>1.29</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.276211</td>
<td>1.303789</td>
</tr>
<tr>
<td>LM24 + 3% SiC</td>
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<td>0.0070711</td>
<td>1.386211</td>
<td>1.413789</td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
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<td>1.51</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.496211</td>
<td>1.523789</td>
</tr>
</tbody>
</table>


Table 6.7 Statistical analysis of surface roughness of drilled hole at cutting speed of 20 m/min and feed of 0.1 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness $R_a$, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95% Confidence Interval Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.18 0.17 0.17 0.22 0.21</td>
<td>0.19</td>
<td>0.0234521</td>
<td>0.0104881</td>
<td>0.169548</td>
<td>0.210452</td>
</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>0.3 0.26 0.28 0.29 0.27</td>
<td>0.28</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.266211</td>
<td>0.293789</td>
</tr>
<tr>
<td>LM24 + 3% Al₂O₃</td>
<td>0.36 0.39 0.42 0.41 0.37</td>
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<tr>
<td>LM24 + 5% Al₂O₃</td>
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<td>0.47</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.456211</td>
<td>0.483789</td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>0.35 0.41 0.41 0.37 0.36</td>
<td>0.38</td>
<td>0.0282843</td>
<td>0.0126491</td>
<td>0.355334</td>
<td>0.404666</td>
</tr>
<tr>
<td>LM24 + 3% SiC</td>
<td>0.49 0.48 0.46 0.45 0.47</td>
<td>0.47</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.456211</td>
<td>0.483789</td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>0.62 0.61 0.61 0.56 0.55</td>
<td>0.59</td>
<td>0.0324037</td>
<td>0.0144914</td>
<td>0.561742</td>
<td>0.618258</td>
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</table>
Table 6.8 Statistical analysis of surface roughness of drilled hole at cutting speed of 20 m/min and feed of 0.3 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness Rₐ, Micron</th>
<th>Mean M, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95 % Confidence Interval Minimum</th>
<th>95 % Confidence Interval Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.54 0.58 0.55 0.56 0.57</td>
<td>0.56</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.546211</td>
<td>0.573789</td>
</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>0.7  0.66  0.68 0.69 0.67</td>
<td>0.68</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.666211</td>
<td>0.693789</td>
</tr>
<tr>
<td>LM24 + 3% Al₂O₃</td>
<td>0.81 0.77  0.8  0.78 0.79</td>
<td>0.79</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.776211</td>
<td>0.803789</td>
</tr>
<tr>
<td>LM24 + 5% Al₂O₃</td>
<td>0.91 0.9   0.88 0.86 0.85</td>
<td>0.88</td>
<td>0.0254951</td>
<td>0.0114018</td>
<td>0.857767</td>
<td>0.902233</td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>0.75 0.72  0.77 0.78 0.73</td>
<td>0.75</td>
<td>0.0254951</td>
<td>0.0114018</td>
<td>0.727767</td>
<td>0.772233</td>
</tr>
<tr>
<td>LM24 + 3% SiC</td>
<td>0.84 0.85  0.88 0.86 0.87</td>
<td>0.86</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.846211</td>
<td>0.873789</td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>0.99 0.95  0.94 0.98 0.99</td>
<td>0.97</td>
<td>0.0234521</td>
<td>0.0104881</td>
<td>0.949548</td>
<td>0.990452</td>
</tr>
</tbody>
</table>
Table 6.9 Statistical analysis of surface roughness of drilled hole at cutting speed of 20 m/min and feed of 0.5 mm/rev for the aluminium alloy based MMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface roughness $R_a$, Micron</th>
<th>Mean $M$, Microns</th>
<th>Standard Deviation, SD</th>
<th>Standard Error, SE</th>
<th>95% Confidence Interval Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain LM24 alloy</td>
<td>0.87 0.93 0.91 0.87 0.92</td>
<td>0.9</td>
<td>0.0282843</td>
<td>0.0126491</td>
<td>0.875334</td>
<td>0.924666</td>
</tr>
<tr>
<td>LM24 + 1% Al₂O₃</td>
<td>0.99 1.03 1.01 1.02 1</td>
<td>1.01</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>0.996211</td>
<td>1.023789</td>
</tr>
<tr>
<td>LM24 + 3% Al₂O₃</td>
<td>1.24 1.26 1.19 1.18 1.23</td>
<td>1.22</td>
<td>0.0339116</td>
<td>0.0151658</td>
<td>1.190427</td>
<td>1.249573</td>
</tr>
<tr>
<td>LM24 + 5% Al₂O₃</td>
<td>1.32 1.3 1.34 1.33 1.31</td>
<td>1.32</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.306211</td>
<td>1.333789</td>
</tr>
<tr>
<td>LM24 + 1% SiC</td>
<td>1.08 1.14 1.16 1.06 1.06</td>
<td>1.1</td>
<td>0.0469042</td>
<td>0.0209762</td>
<td>1.059096</td>
<td>1.140904</td>
</tr>
<tr>
<td>LM24 + 3% SiC</td>
<td>1.35 1.33 1.34 1.36 1.32</td>
<td>1.34</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.326211</td>
<td>1.353789</td>
</tr>
<tr>
<td>LM24 + 5% SiC</td>
<td>1.44 1.46 1.47 1.45 1.48</td>
<td>1.46</td>
<td>0.0158114</td>
<td>0.0070711</td>
<td>1.446211</td>
<td>1.473789</td>
</tr>
</tbody>
</table>
6.5 EFFECT OF SPEED AND FEED ON SURFACE ROUGHNESS

Surface roughness is one of the major characteristics in metal cutting that is measured in machining processes. Surface roughness and surface integrity are important performance measures which indicate the performance level attained by using the particular work material - tool material combination and the corresponding suitable feeds, speeds and depth of cut. The surface roughness of a machined product could affect functional attributes of several products. Contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating, and resisting fatigue.

The importance of considering surface roughness and surface integrity when machining aluminium MMCs arises due to the high thermal conductivity and low melting temperatures. The surface roughness of the aluminium alloy and aluminium alloy composite under different cutting speeds, different cutting feeds and the effect of aluminium oxide / silicon carbide particle reinforcement are presented from the Figures 6.2 to 6.7. The surface roughness decreases with the increase of speed and decrease of feed.

The cutting speed and feed affect the surface roughness. The decrease in surface roughness with the increase in cutting speed is attributed to the increase in the contact between the tool and workpiece, thereby resulting in increased cutting and burnishing effect between the tool and the drilled hole. The increase in surface roughness with the increase on feed is attributed to the decrease in the contact between the tool and workpiece, thereby resulting in decreased cutting and burnishing effect between the tool and the drilled hole. Machining with usage of coolant prevents the formation of built-up-edge of the drill tool and results in good surface finish.
Figure 6.2 Surface roughness vs Cutting speed at feed of 0.1 mm/rev for aluminium alloy - alumina MMCs

Figure 6.3 Surface roughness vs Cutting speed at feed of 0.3 mm/rev for aluminium alloy - alumina MMCs
Figure 6.4 Surface roughness vs Cutting speed at feed of 0.5 mm/rev for aluminium alloy - alumina MMCs

Figure 6.5 Surface roughness vs Cutting speed at feed of 0.1 mm/rev for aluminium alloy - SiC MMCs
Figure 6.6 Surface roughness vs Cutting speed at feed of 0.3 mm/rev for aluminium alloy - SiC MMCs

Figure 6.7 Surface roughness vs Cutting speed at feed of 0.5 mm/rev for aluminium alloy - SiC MMCs
6.6 EFFECT OF PARTICLE REINFORCEMENT ON SURFACE ROUGHNESS

The surface roughness increases with the percentage weight reinforcement of aluminium oxide / silicon carbide due to the increase in the amount of particles and higher hardness. The defects such as voids and cavities are formed on the surface due to tool – particle interactions, resulting pull-out / fracture and debonding of particles during drilling of MMC, which dominate the surface finish. The reinforcement particles in MMC increase tool - particle interactions and generate greater damage on the machined surface which causes inferior surface finish of the aluminium alloy - aluminium oxide / silicon carbide composites.

The surface roughness of the aluminium alloy - aluminium oxide / silicon carbide composite is higher than that of the plain LM24 aluminium alloy due to particle reinforcement and higher drill tool wear. The surface roughness of the aluminium alloy - silicon carbide composite is higher than that of the aluminium alloy - aluminium oxide composite. This is attributed to the higher tool wear of the HSS drill on machining the aluminium alloy - silicon carbide composite due to the higher hardness of the silicon carbide particles in the MMC.

6.7 EFFECT OF SPEED, FEED AND AMOUNT OF PARTICLE REINFORCEMENT ON DRILL TOOL FLANK WEAR

The optical microscopic studies are conducted qualitatively on the HSS drill due to very less tool wear. Three wear mechanisms on the HSS drills are adhesive wear, abrasive wear and diffusion wear. It has been observed that the harder aluminium oxide / silicon carbide particle in the MMC is harder than HSS and abrades the flank of the HSS drill during each cut. The maximum wear takes place at the outer edges of the tip and
minimum wear occurs at or near the point of the tip. This is because of the occurrence of the maximum rotational force and the maximum tip-to-workpiece contact, where as at the drill point less rotational force is expected by the tip. More over the force is pushing into the workpiece rather than cutting. The drill tool flank wear increases with the speed and the feed due to the temperature generated by friction and plastic deformation in the secondary shear zone. At lower cutting speeds and feeds, tool wear is not severe as the temperature is not significant. When the cutting speed and feed are increased, there is a transition in wear mechanisms from abrasion and adhesion, and also towards diffusion. The wear mechanisms on the HSS drills are adhesive wear, abrasive wear and diffusion wear. The rise in temperature adversely affects the wear resistance and hardness of the cutting tool. Increased heat causes dimensional changes in the workpiece part being machined, and also making control of dimensional accuracy difficult. The mean temperature in machining is proportional to the cutting speed and feed as follows:

\[
\text{Mean Temperature} \propto v^a f^b \quad \text{------------------------------------- (6.1)}
\]

where ‘a’ and ‘b’ are constants which depend on tool and workpiece materials, ‘v’ is the cutting speed and ‘f’ is the feed of the tool (Kalpakjian, 1995).

The HSS drill tool flank wear is higher in machining the harder aluminium alloy - aluminium oxide / silicon carbide MMCs than that of the plain aluminium alloy. The drill tool flank wear increases with the amount of percentage weight of particle reinforcement due to higher abrasion of increasing amount of hard ceramic particles in the MMCs. The tool wear is higher on machining aluminium alloy - silicon carbide composites than that of aluminium alloy - aluminium oxide composites due to higher hardness of the silicon carbide particles.
6.8 MICROSCOPIC STUDIES OF DRILLED HOLE SURFACES

The machined hole surfaces are analysed by using the optical microscope and the corresponding images are shown in the Figures from 6.8 to 6.15. Microscopic study of the drilled hole surface of aluminium alloy based MMCs shows the effect of particle on the surface of the composites.

Figure 6.8 Micrograph of drilled hole of aluminium alloy - 1% weight Al₂O₃ composite at cutting speed of 10m/min and feed of 0.1 mm/rev.

Figure 6.9 Micrograph of drilled hole of aluminium alloy - 1% weight Al₂O₃ composite at cutting speed of 15 m/min and feed of 0.1 mm/rev.
Figure 6.10 Micrograph of drilled hole of aluminium alloy - 1% weight Al₂O₃ composite at cutting speed of 20 m/min and feed of 0.1 mm/rev

Figure 6.11 Micrograph of drilled hole of aluminium alloy - 1% weight SiC composite at cutting speed of 10 m/min and feed of 0.1 mm/rev
Figure 6.12 Micrograph of drilled hole of aluminium alloy - 1% weight SiC composite at cutting speed of 15 m/min and feed of 0.1 mm/rev

Figure 6.13 Micrograph of drilled hole of aluminium alloy - 1% weight SiC composite at cutting speed of 20 m/min and feed of 0.1 mm/rev
Figure 6.14 Micrograph of drilled hole of aluminium alloy - 3% weight SiC composite at cutting speed of 10 m/min and feed of 0.1 mm/rev

Figure 6.15 Micrograph of drilled hole of aluminium alloy - 3% weight SiC composite at cutting speed of 15m/min and feed of 0.3 mm/rev

From the optical microscope images, the machined surface morphology is seen. The particle pullout and scratches made by the hard ceramic particles during machining of composites are identified. Further more, the machined
hole surfaces are analysed by using the Scanning Electron Microscope (SEM) and the corresponding images are shown in the Figures from 6.16 to 6.21.

**Figure 6.16a** SEM image of drilled hole of plain LM24 aluminium alloy at cutting speed of 15 m/min and feed of 0.1 mm/rev

**Figure 6.16b** SEM image of drilled hole of plain LM24 aluminium alloy at cutting speed of 15 m/min and feed of 0.1 mm/rev
Figure 6.17 SEM image of drilled hole of plain LM24 aluminium alloy at cutting speed of 20 m/min and feed of 0.1 mm/rev

Figure 6.18a SEM image of drilled hole of aluminium alloy - 5% weight Al₂O₃ composite at cutting speed of 15 m/min and feed of 0.1 mm/rev
Figure 6.18b SEM image of drilled hole of aluminium alloy - 5% weight Al₂O₃ composite at cutting speed of 15 m/min and feed of 0.1 mm/rev

Figure 6.19a SEM image of drilled hole of aluminium alloy - 5% weight Al₂O₃ composite at cutting speed of 20 m/min and feed of 0.1 mm/rev
Figure 6.19b SEM image of drilled hole of aluminium alloy - 5% weight Al₂O₃ composite at cutting speed of 20 m/min and feed of 0.1 mm/rev.

Figure 6.20a SEM image of drilled hole of aluminium alloy - 5% weight SiC composite at cutting speed of 15 m/min and feed of 0.1 mm/rev.
Figure 6.20b SEM image of drilled hole of aluminium alloy - 5% weight SiC composite at cutting speed of 15 m/min and feed of 0.1 mm/rev

Figure 6.21a SEM image of drilled hole of aluminium alloy - 5% weight SiC composite at cutting speed of 20 m/min and feed of 0.1 mm/rev
From the SEM images, plastic deformation, particle pullout and scratches made by the particles during machining are observed in the drill hole surface.

6.9 SUMMARY

The drilling tests have revealed that the surface roughness decreases with the speed and increases with the feed. The surface roughness values of the drilled hole surfaces of the plain LM24 aluminium alloy are lower than that of the aluminium alloy - aluminium oxide composite, which in turn is lower than that of the aluminium alloy - silicon carbide composite. The surface roughness increases with the increase of particle reinforcement. The surfaces of the entire drilled hole are of a high quality surface finish. The drill tool wear increases with the speed and the feed. The drill wear of HSS tool on drilling of the plain LM24 aluminium alloy is lower than the aluminium alloy - aluminium oxide composite, which in turn is lower than that of the aluminium alloy - silicon carbide composite.