An Experimental Study on Turning of AL6063 Under Cryogenic Pre Cooled Condition.

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Abstract

One of the major issues faced while machining Aluminium and its alloys is built up edge and hence reduced tool life and surface finish. Turning temperature and friction have to be reduced to avoid sticking and built up edges. This work deals turning of AL 6063 rod at two environments a) Pre cooling to sub zero temperature using dry ice and b) Dry turning at room temperature. Depth of cut is kept constant at 2.5mm. Turning inserts CNMG 120408 MP TT 5100 and CCGT 120408 FC K10 - 1 were used. Cutting speeds of 70, 110, 175 m/min and feed rates of 0.2, 0.315 and 0.4 mm/rev were used. The surface roughness, \( Ra \), \( Rz \), & material ratio \( M_{r1} \) & \( M_{r2} \) tool wear are measured. Increase in productivity and cost saving were evident while using CNMG 120408 MP TT 5100 under pre cooled turning environment.

Keywords: Dry Ice, Al 6063, Pre cooling, Cryogenic, Surface roughness \( Ra \), \( Rz \), turning, Material ratio, \( M_{r1} \), \( M_{r2} \), productivity.

1. Introduction.

Aluminium alloy 6000 series is used in aerospace industry to make light load components, hydraulic, oil and fuel system components [1]. Machining Aluminium and its alloys is a challenge due to built up edge which reduces surface finish and tool life. The presence of Silicon and Magnesium in Al 6063 alloy leads to difficulty in turning at higher cutting speeds and feeds necessitating the use of a turning insert with high top rake angle. But, high top rake angle does not ensure a good surface finish at a higher cutting speed and feed due to sticking and built up edges. Hence, friction and temperature between work piece and turning insert has to be reduced. Yakap Yilder & Muammer Nalbant [2] reviewed many cooling strategies during machining process and reports that tool life and surface finish can be improved through reduction of cutting temperature at cutting zone. J. Kouam et al [3] proved that semi dry lubrication is very effective while turning Al 6063 – T6 rod at lower feed rates than wet and dry turning in terms of surface roughness. R.J.Kiran et al [4] cooled the oil – water mixture to 0°C to reduce surface roughness while turning AISI 1016 steel. P.Vamni Krishna and D.Nageswara Rao [5] mixed graphite and boric acid in in SAE 40 oil and obtained reduced surface roughness and tool wear. Shanmugam Murugappan & Sanjivi Arul [6] pre cooled EN8 steel rod before turning to reduce surface roughness. Low alloy Hardenled 41Cr4 steel is pre cooled in a similar method by using liquid nitrogen to achieve low surface roughness value along with good service properties [7]. Apart from using various cooling agents, different methods of applying cooling agent during turning are followed by researchers. Vishal S. Sharma et al [8] used special nozzles to mix and supply the coolant. Yakap Yildiz & Muammer Nalbant [2] listed indirect cooling methods such as pouring cryogenic coolant over work piece just before turning, pouring over chip to improve chip breakability and supplying cryogenic coolant through tool holder. In this work dry ice is used as a pre cooling agent to cool the work piece before
finish or semi finish turning of AL6063 work piece of small to medium diameter to reduce friction produced between tool and work piece. Aluminum becomes more ductile at a temperature around -50°C [9]. This work takes advantage of increased ductility of Aluminum alloy at sub zero temperatures by pre cooling it to improve surface roughness characteristics. This work replaces the special purpose insert CCGT 120408 FC K 10 – 1 with positive top rake angle with less costly general purpose insert CNMG 120408 MP TT 5100 under dry ice cooled environment to reduce cost of production and to improve productivity.

2. Experimental Set up

Al 6063 (HE 9 grade) 50mm diameter rods were procured and cut into 220mm long pieces and the faces were turned and held between head stock and tail stock as shown in Fig 1a. The work pieces were then kept in a thermally shielded cooling chamber containing dry ice at -77°C as shown in the Fig.1b for 36 hours. The work piece temperature was found to be -50°C +/- 2°C before the turning operation. This increase in temperature from -77°C is due to a) effect of room temperature, b) due to time lost in moving work piece from cooling chamber to lathe, and setting operation in lathe. The Room temperature was measured as 26°C. The experiments were carried out for 9 different combinations of speed and feed (refer Table.1). Totally 36 experiments with constant depth of cut of 2.5 mm were carried out for each condition as shown in Table.2. Three trials were carried out to assess the variability in turning and cooling environment.

![Fig. 1 (a) Work piece held in Lathe; (b) Dry ice chamber.](image)

Table.1 Specification of Machine, Tool, Speed and Feed

<table>
<thead>
<tr>
<th>Specification</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turning Environment</td>
<td>Room Temperature</td>
</tr>
<tr>
<td>Machine</td>
<td>Kirloskar Turn Master 35 Centre Lathe</td>
</tr>
<tr>
<td>Tool Holder</td>
<td>PCLNR 2525 M12</td>
</tr>
<tr>
<td>Insert</td>
<td>CNMG 120408 MP TT 5100 (General Purpose Insert)</td>
</tr>
<tr>
<td>Tool, Work Piece Temperature in Degree Celsius</td>
<td></td>
</tr>
<tr>
<td>Cutting Speed (m/min)</td>
<td>70</td>
</tr>
<tr>
<td>Tool</td>
<td>G - DIC</td>
</tr>
<tr>
<td>Work Piece</td>
<td>55 - 45</td>
</tr>
<tr>
<td>Tool</td>
<td>S - DIC</td>
</tr>
<tr>
<td>Work Piece</td>
<td>55 - 75</td>
</tr>
</tbody>
</table>

3. Measurement

3.1 Surface roughness characteristic Measurement

Surface roughness values Ra, Rz and material ratio M_r1 and M_r2 were measured. TESA Make Rugosurf10G surface roughness tester was used to measure the surface roughness. The cut off and traversing length of 0.8mm and 4.0mm is selected respectively. Surface roughness (Ra) was measured near the end portion of turned length only, since the difference between surface roughness values Ra at the start of turning and at the end of turning was of less than 0.05μm.

3.2 Temperature measurement

The temperature of work piece and tool (at top rake surface very close to chip flow) were measured using K-type thermocouple and handy digital read out and listed in Table.3. A thermocouple was fixed on the insert using a paste before each turning operation. Another thermocouple was manually touched over the work piece by inserting through a small tube fixed on the tool post which moves along with the tool. P.VamsiKrishna and D.Nageswara Rao [5] used similar method to measure the temperature at the bottom of insert. The measured temperatures are used to indicate the difference of temperature between dry ice cooled and room temperature turning and do not represent tool- work piece interface temperature at cutting zone.
4. Results and Discussions:

4.1 Surface Roughness Ra.

The ideal surface roughness Ra value was calculated using equation (1), where \( f \) is feed rate in inches/revolution and \( r \) is tool nose radius in inches [10].

\[
\text{Ideal Surface Roughness Ra} = \frac{0.0321 f^2}{r} \quad (1)
\]

The variation in three trials in terms of surface roughness Ra, Rz and Mr1, Mr2 found to be within +/- 2%. The mean values are plotted in the graph.

Fig.2 shows that at lower cutting speed, general purpose insert produces ideal surface roughness values under dry ice cooled environment. Also at higher feed rates, both at DIC and RMT general purpose insert gives better surface roughness value than special purpose insert.

Fig.3 shows that at a cutting speed of 110 m/min, General purpose insert gives lower surface roughness Ra values than ideal Ra values at low feed rates and very near to ideal Ra values at higher feed rate. However general purpose insert under dry ice cooled environment yields better Ra value than special purpose insert under room temperature environment at higher feed rate of 0.4 mm/rev. But there is no substantial difference at lower and medium feed rate.

Fig.4 shows at a cutting speed of 175 m/min general purpose insert under room temperature environment gives a better surface roughness value than any other environment. Special purpose insert under dry ice cooled environment gives surface roughness values as similar as G- DIC environment at lower and higher feed rates.

But tool wear is substantial as shown in Fig.5 in case of general purpose insert at room temperature environment at 175 m/min even though it yields lower surface roughness value than any other environment. One common phenomenon found from Table.3 and Fig.2 to 4, is that whenever the work piece temperature is around or lesser than 10°C then lower surface roughness Ra values is achieved. While using special...
purpose insert CCGT 120408 FC K10 – 1 due to positive top rake angle more heat is produced. This phenomenon confirms with FEM analysis and study done by Hendri Yanda [11] on rake angle effect.

4.2 Surface Roughness Rz

Fig.6 shows Surface roughness Rz values vs. feed rate for cutting speed 70 m/min. The trend found to be very similar to Surface roughness Ra values. At 110 & 175 m/min cutting speed the trends of Rz values are similar to trends of Ra values. The ratio of RZ/Ra found to be in between 3.85 to 4.96. At lower feed rates the ratio is on higher side at 4.96 and for higher feed rates on lower side at 3.85. The Rz/Ra ratio is lesser by 3 % to 8 % in dry ice cooled turning environment than room temperature turning environment while using special purpose insert. This shows that height of peak and valleys are less. There is no appreciable difference between special purpose insert and general purpose insert in terms of Rz/Ra ratio for any turning environment.

4.3 Material ratios Mr1 and Mr2

ISO 13565 –1/2/3 defines Mr 1 is material ratio in % which separates protruding peaks from core roughness profile and Mr2 is material ratio in % which separates valleys from core roughness profile [12]. Higher value of Mr1 is not desirable as it reduces the load bearing area and in turn reduces the load bearing capacity[13]. It also aids in quick wear during sliding function and abrasiveness when work piece is used with seals [14]. The Fig.7 to 10 shows Mr1 and Mr2 values in % for different turning environment as given in Table 2.

The Fig.7 shows that using a general purpose insert in dry ice cooled turning environment reduces the Mr1 values by 2 to 3 % at 0.2 mm/rev feed rate. However at higher feed rates for any cutting speed dry ice cooled environment is not effective in terms of reduction of Mr1. Fig.8 shows that while using a special purpose insert at lower cutting speed of 70m/min, Mr1 decreases by 2 to 10%.

Higher or lower value of Mr2 is desirable or undesirable depends upon functionality. Lower value of Mr2 represents an increased valley depth which assists in lubrication retention where as higher value of Mr2 represents a reduced valley depth which assists in increasing load bearing area [13]. Fig.9 & 10 shows Mr2 Values for different speed, feed rate combinations under different turning environments. The figures help in selecting right combination according to functional requirement of turned work piece.
4.5 Productivity and cost analysis

The feed rate is dominant factor in achieving lower value of surface roughness Ra while turning aluminum alloy [15]. Contour plots are made for surface roughness Ra versus cutting speed in m/min and feed rate in mm/rev using distance method with power 2. Contour plots are useful in finding out achievable surface roughness under given cutting speed and feed rate. They also help in finding out selectable feed rate for a given cutting speed in different turning environments to achieve a desirable surface roughness. Shanmugam Murugappan & Sanjivi Arul [6] used similar method to analyze the productivity improvement during turning of EN8 steel rod under pre cooled condition.

**Table 4 Selectable feed rate for given Ra and Speed**

<table>
<thead>
<tr>
<th>SL No</th>
<th>Desirable surface roughness Ra (μm) to be achieved</th>
<th>Cutting Speed (m/min)</th>
<th>Selectable Feed rate (mm/rev)</th>
<th>% change in Selectable Feed rate (mm/rev) for DIC (Dry Ice cooled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>70</td>
<td>0.270</td>
<td>0.210</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>110</td>
<td>0.280</td>
<td>0.295</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>175</td>
<td>0.260</td>
<td>0.275</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>110</td>
<td>0.345</td>
<td>0.345</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>70</td>
<td>0.355</td>
<td>0.240</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>175</td>
<td>0.330</td>
<td>0.330</td>
</tr>
</tbody>
</table>

The total cost per part is addition of costs of raw material, setup, material handling, machining and tool [16]. To analyze cost aspects of using general purpose insert in dry ice cooled environment over using special purpose insert in room temperature environment, the cost of machining and tool are considered where as other costs are common. Fig 12 & 13 shows that the machining cost will come down when turning is carried in between 70 to 80 m/min due increase in selectable feed rate and in turn increase in productivity while using dry ice along with general purpose insert. The cost of dry ice and its transportation is 1 $ per kg in India. The increase in coolant cost due to usage of dry ice is offset by the tool cost as cost of general purpose insert in India is 15 per cutting edge where as special purpose insert is 95 per cutting edge. Hence in terms of cost economics, at 70 to 80 m/min a) due to productivity increase and b) less cost per cutting edge using dry ice along with general purpose insert is beneficial. Whereas at medium and higher cutting speeds (above 80 m/min) cost benefits depend on size of the work piece as cooling cost is directly proportional to work piece weight.

5. Conclusion

The experiments were carried out under two different environments namely dry ice cooled and room temperature. In each environment two different inserts were used namely general purpose insert CNMG 120408 MP TT 5100 and special purpose insert for aluminum turning CCGT 120408 FC K10 -1. Experiment carried out in 3 different cutting speeds and feed rates having 9 combinations. Totally 36 experiments were carried out for one trial. Three trials were conducted and mean values are plotted as graph.

General purpose insert under dry ice cooled environment gives ideal or near to ideal surface roughness Ra values.
General purpose insert under dry ice cooled environment gives Lower Ra values for any cutting speed.

Special purpose insert is effective under dry ice cooled environment only at higher cutting speeds.

Tool wear is dominant in room temperature environment while using both types of inserts.

Rz values have a similar trend with respect to Ra values for any turning condition. The ratio of Rz/Ra is lower at higher feed rates and vice versa. The ratio is also less by 3 to 8% while using special purpose insert under dry ice cooled environment.

$M_{41}$ values are lesser by 2 to 3% at lower feed rate while using general purpose insert where as it is lesser by 2 to 10% at lower cutting speed while using special purpose insert.

General purpose insert under dry ice cooled environment gives higher productivity at lower cutting speed of 70 to 80m/min.

In terms of cost economics, at lower cutting of 70 to 80 m/min, General purpose insert under dry ice cooled environment is beneficial where as it is lesser by 2 to 10% at medium and higher cutting speed, cost benefits depend on size of the work piece as cooling cost is directly proportional to work piece weight.

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References


