Thermal and Metallographic Investigation for H13A and AISI1050 using Vortex Tube Jet Assisted (VTJA) Machining

Balaji Nelge\textsuperscript{1*}, Kiran Devade\textsuperscript{2}, A.T. Pise\textsuperscript{3}, V.M. Kale\textsuperscript{4}

\textsuperscript{1*}Associate Professor, ICEM, Parandwadi, 410506, balaji.nelge@indiraicem.ac.in
\textsuperscript{2}Assistant Professor, ICEM, Parandwadi, 410506, kiran.devade@gmail.com
\textsuperscript{3}Dy. Director, DTE, Maharashtra, 411004, ashokpise@yahoo.com
\textsuperscript{4}Professor, ICEM, Parandwadi, 410506, vinayak.kale@indiraicem.ac.in

Abstract

Machining without the use of any cutting fluid is known as dry or green machining. It is becoming increasingly more popular due to concern regarding the safety of environment. Most industries apply cutting fluids/coolants when their use is not necessary. The coolants and lubricants used for machining represents 16–20\% of the manufacturing costs, hence the unnecessary use of these fluids should be restricted. Moreover there are certain materials that are considered as difficult to machine, for machining of such materials dry machining is advisable. An attempt is made here to carry out study with dry, wet as well as dry machining using cold air stream coming out of vortex tube, and the work piece is analyzed thermally as well as metallographic ally. The results are promising and have shown better results for cold air machining using vortex tube. The machining is performed using two grades of materials namely H13A, and AISI1050 with carbide coated tools, with depth of cut of 0.2 mm, Feed rate fixed at 0.5mm/rev and cutting speeds of 250,400,600 rev on semiautomatic lathe machine.

The tests are conducted with coolant, without coolant and with cold air stream as coolant. After the tests the thermal plots and metallographic study for hardness and surface finish have revealed that using cold air as coolant produces better surface finish while maintaining the tool tip and work surface at significantly lower temperatures. The same is being termed here as Vortex Tube Jet Assisted (VTJA) machining.

1 Introduction

Dry machining is ecologically advisable and it is being considered as a necessity for manufacturing industry now a days. Industries will be compelled to consider dry machining to enforce environmental protection laws for occupational safety and health regulations. The advantages of dry machining include: non-pollution of the atmosphere (or water); no residue on the swarf which will be reflected in reduced disposal and cleaning costs; no danger to health; and it is non-injurious to skin and is allergy free. Moreover, it offers cost reduction in machining. The earlier approach of machining advocates use of cutting fluids in the manufacturing industry. Since use of cutting fluids help: to remove the heat generated due to friction while machining; to enhance the cutting tool life, surface finish and dimensional tolerances and to prevent the formation of built-up edge along with transportation of chips. Coolants are essential in the machining of materials such as aluminum alloys and most stainless steels, which tend to adhere to the tool and cause a built-up edge. At the same time, the coolants produce problems in the working environment and also create problems in waste
disposal. Consumption of cutting fluids has been reduced considerably by using mist lubrication. However, mist in the industrial environment can have serious respiratory effects on the operator. The use of cutting fluids will be increasingly more expensive as stricter enforcement of new regulation and standards are imposed, leaving no alternative but to consider dry machining.

(Paul, Dhar, & Chattopadhyay, 2001) Suggested cryogenic cooling with AISI 1060 and resulted benefits in tool life and surface finish. Cryogenic cooling deals with providing liquid nitrogen jets at interface during machining. But the costs involved and oxidation factors are important and should be addressed. (M., List, Girot, & Coupard, 2003), suggested optimization in tool geometries for dry machining. The tool geometry needs to be changed for better performance in dry machining. (Kishawy, Dumitrescu, Ng, & Elbestedi, 2005) used MQL minimum quantity lubrication method for high speed machining of A356 aluminum alloy and concluded with unaddressed issues like machine reliability, tool wear and maintenance requirements. (List, et al., 2005) investigated wear behavior of tool in dry machining of aluminum alloy with cemented carbide inserts and concluded that built up edges are formed on the tool rake at low cutting speeds and tool wear is promoted because of this. At higher cutting speeds the tool wear is caused because of chemical action and diffusion. (Sanchez, Rubio, Alvarez, Sebastian, & Marcos, 2005) investigated effect of adhesion during dry machining of aerospace aluminum alloys, built up layer (BUL) lead to build up edges (BUE) and cause tool wear. Thus tool wear is unavoidable in dry machining and hampers surface finish. (Aoyama, Kakinuma, Yamashita, & Aoki, 2008) developed new lean lubrication method for near dry machining. Direct oil drop supply system (DOS) is implemented to overcome the disadvantage of MQL and achieved same machining performance as obtained in MQL (minimum Quantity Lubrication) method. This system leads to large consumption of cutting oil if diameter and frequency of drops is not optimized. (Courban, Kramar, Krajnik, Pusavec, Rech, & Kopac, 2009) used high pressure jet assisted machining (HPJA) for turning of Inconel 718. HPJA resulted in good chip breakability and reduction in built up edges.

Taking this approach into consideration and the technologies evolved so far as a substitute for wet machining are dry machining, mist lubrication we are proposing the cold stream of air coming out of vortex tube as a cooling media to assist machining of difficult to machine materials. This approach is VTJA vortex tube assisted machining. (Devillez, Coz, Dominik, & Dudzinski, 2011) performed dry and wet machining with carbide coated tools for surface integrity, and found that for the set test conditions dry machining with a coated carbide tool leads to potentially acceptable surface quality with residual stresses. Micro hardness values in the machining affected zone are of the same order than those obtained in wet conditions. (Hao, Gao, Fan, & Han, 2011) optimized the machining temperature while machining inconel 718 using PVD coated cemented carbide tool. (Wenlong, Jianxin, Hui, Pei, Jun, & Xing, 2011) used self lubricated tools for dry machining and found enhanced cutting performance with low friction coefficient and low flank wear. (Gomez, et al., 2012) performed dry machining with high silicon aluminum alloys for effects of surface pretreatments and adhesion. The result was to treat the carbide coated tools with diamond coating to form adherent layer so that wear is minimized. (Obikawa, Yamaguchi, Funai, Kamata, & Yamada, 2012) used air jet assisted machining (AJA) for machining of nickel based super alloy and concluded that air jet assisted machining can enhance the cutting tool life as compared to wet machining. (Kayank, Karaca, Noebe, & Jawahir, 2013) compared dry, preheated and cryogenic machining of NiTi memory alloys and cryogenic machining is concluded as the promising approach as cutting force reduces with cryogenic machining as compared to preheated and dry machining. The literature so far has shown that dry machining is accompanied with the problems of high tool wear, lower cutting tool life, and affects the surface integrity of the work piece. Several other methods are suggested such as self lubricated tools, cryogenic machining, near dry machining operation, minimum quantity lubrication, air jet assisted machining and High pressure jet assisted machining, we have proposed vortex tube jet assisted machining (VTJA).

2 VTJA

Vortex tube jet assisted machining utilizes high pressure air initially which is introduced at tool work piece interface through vortex tube. Vortex tube is a device capable of converting the high pressure jet of air into two streams viz. cold and hot stream based on the heat transfer principles. The hot stream of air escaping out of the vortex tube is allowed to escape into the atmosphere and the cold stream jet is directed to interface. Using vortex tube it is possible to produce cold air at near zero and below zero degrees. The air stream comes out at sufficient velocity and thus it helps to clean the swarf accumulated at the interface. This is a clean and cost effective solution to machining problems associated with dry machining of difficult to machine metals. From the discussion above it is clear that though number of different methods are suggested the cost effectiveness parameter of all the above methods is majorly governed by the rate of production and the volume of production.
required in the facility. If cryogenic machining is considered it adds to the cost of getting and utilizing the cryogenic fluids it needs changes to be made in the manufacturing setup. Minimum quantity lubrication (MQL) has to be ascertained from case to case basis. Using self lubricated tools is one of the options but needs specially ordered and manufactured tools. But VTJA being dependent on compressed air and compressed air can be made available easily in a manufacturing unit it is definitely a cost effective method. The vortex tube is a light and silent in operation it can be easily used without disturbing the manufacturing setup.

The vortex tube used for the experimentation is produced in house with following specifications. Table 1 shows the geometrical specifications of the vortex tube and Figure 2 shows the vortex tube geometry used for the experimentation. The vortex tube is used for pressures ranging from 2 to 5 bars and the set pressure for the machining conditions with vortex tube is 3 bar. At 3 bar it is possible to have cold stream of air coming out at 5°C.

Table 1 Vortex Tube specifications

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Dimensions and Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tube diameter entry</td>
<td>8mm</td>
</tr>
<tr>
<td>2.</td>
<td>Tube diameter exit</td>
<td>9mm</td>
</tr>
<tr>
<td>3.</td>
<td>Inlet nozzle diameter</td>
<td>2.5mm</td>
</tr>
<tr>
<td>4.</td>
<td>Cold orifice diameter</td>
<td>4mm</td>
</tr>
<tr>
<td>5.</td>
<td>Length of tube</td>
<td>49mm</td>
</tr>
<tr>
<td>6.</td>
<td>Cone Angle, $\phi$</td>
<td>5.71°</td>
</tr>
<tr>
<td>7.</td>
<td>Conical Valve angles</td>
<td>30°, 45°, 60°, 90°</td>
</tr>
<tr>
<td>8.</td>
<td>No. of entry nozzles</td>
<td>2</td>
</tr>
</tbody>
</table>

For the machining H13A aluminum and AISI1050 grade steel is used. The proposed conditions for machining were, depth of cut of 0.2 mm, Feed rate fixed at 0.5mm/rev and cutting speeds of 250,400,600 rev on semi-automatic lathe machine. It was proposed to carry out machining of these two grades of materials under Dry, Wet and VTJA conditions wherein dry condition means no use of cutting fluids, wet uses cutting fluids with water. And VTJA is without cutting fluid and with the cold stream of air. The tool used for machining is carbide coated tool.

3 Experimental Setup

The figure shows the actual setup for experimentation. The machine used for turning is HIMAC - Lx-175 all geared head lathe machine. The tool used for turning operations is a single point cutting tool and is hard enough to machine the material used for analysis. The tool make is WIDAX 16X16, TNMG, base of the tool is of dimension 16X16 and TNMG defines the shape of tool insert that is triangular. The material properties are as listed in the Table 2 below.

Table 2 Composition of the material used

<table>
<thead>
<tr>
<th></th>
<th>H13A</th>
<th>AISI1050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>0.55</td>
<td>0.5</td>
</tr>
<tr>
<td>Si</td>
<td>1.41</td>
<td>Mn</td>
</tr>
<tr>
<td>Ni</td>
<td>0.017</td>
<td>Si</td>
</tr>
<tr>
<td>Cu</td>
<td>0.017</td>
<td>S</td>
</tr>
<tr>
<td>Al</td>
<td>Balance</td>
<td>P</td>
</tr>
<tr>
<td>Fe</td>
<td>0.19</td>
<td>BHN</td>
</tr>
<tr>
<td>Zn</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>BHN</td>
<td>106</td>
<td></td>
</tr>
</tbody>
</table>
The material is tested at metasys material testing laboratory. The results of tests are discussed in the next section.

4 Results and Discussion

The machining tests are performed with the selected metals i.e. HE13A, AISI1050 and set depth of cut as 0.2 mm and cutting speeds of 250, 400 and 600 rpm. The feed rate is maintained as 0.5mm/rev with these set parameters the machining is conducted with instrumentation for temperature distribution along the surface of the work piece and the tool tip for different machining conditions. After the machining the work pieces were sent for surface roughness analysis and microstructure analysis to material testing laboratory. The results obtained are as follows.

4.1 Effect on temperature distribution for AISI 1050

After the machining of HE13A and AISI 1050 for temperature distribution along the surface at various cutting speeds the distribution is as shown in Fig.

It can be seen that wet machining of AISI1050 produces higher temperatures on the surface this is mainly because of the built up edge formation while machining and the ductility of AISI 1050 does not allow chip separation at the tool work piece interface. In contrast VTJA keeps the surface temperature on lower side as the cold air impinged on the surface helps the chip separation and built up edge formation is minimized. More or less similar results can be seen at higher cutting speeds of 400 and 600 rpm from the Fig.4 and Fig.5 below.

4.2 Temperature Distribution for HE13A

The temperature distribution for HE13A is shown in the Figure 6, Fig.7 and Fig. 8 for cutting speeds of 250,400 and 600 rpm respectively.
Figure 6 Temperature plot for HE13A

Temperature rise for HE13A at 250 rpm

Dry  Wet  VTJA

Temperature rise for HE13A at 400 rpm

Dry  Wet  VTJA

Temperature rise for HE13A at 600 rpm

Dry  Wet  VTJA

Figure 7 Temperature plot for HE13A

Figure 8 Temperature plot for HE13A

Fig. 7, 8, 9 shows that as the spindle speed i.e. the cutting speed increases the dry and wet methods of machining of HE13A take more or less same temperature with time. As compared to dry and wet, VTJA temperature distribution along work surface is near ambient conditions. Thus VTJA can become a promising method of cooling. For comparison metallographic properties like surface finish and micro structural changes are also considered.

4.3 Effect on Surface finish of HE13A and AISI 1050

Surface finish during machining is dependent on many parameters like cutting speed, feed, depth of cut, the cooling conditions provided, formation of built up edges, swarf removal, and the cutting tool geometry. The following Fig. 9 and Fig. 10 shows the effect on surface finish for all the machining methods employed.

Surface Roughness of HE13A

Figure 9 Surface finish of HE13A

Surface roughness of AISI 1050

Figure 10 Surface finish of AISI 1050

It can be seen that for HE13A wet machining provides good surface finish of average 1.126 microns. For AISI 1050 VTJA produces good surface finish of 1.353 microns as compared to wet and dry machining. The surface finish takes lower values at low speeds of cutting but at higher speeds i.e. 600 rpm the surface finish from Fig. 9 for HE13A and for AISI1050 VTJA produces good surface finish at lower speeds but surface finish decreases as speed increases. This may be because of

4.4 Effect on Microstructure of HE13A and AISI 1050 for dry machining
With the temperature distribution and surface finish the microstructure of all machined workpieces is also considered to compare the performance of wet, dry and VTJA machining process on HE13A and AISI 1050 the following Figures show the comparison of microstructure for all machined metals.

5 Conclusion

All above discussion with respect to thermal distribution, Surface finish and microstructure leads to following conclusions:
1. For AISI 1050 from temperature distribution it can be said that at all speeds of machining Vortex Tube Jet Assisted machining is able to keep the temperatures at interface near atmosphere and the surface finish obtained is in between 1 to 1.5 microns.
2. For HE13A also VTJA is able to keep the surface temperatures near ambient and the issues of built up edges is resolved, but at higher speeds it is seen that the surface finish obtained increases from 1.1 to 1.7 microns but this is acceptable.
3. Dry machining changes the microstructure at surface and tends to soften the material at higher speeds also the grain boundaries are showing precipitates of carbide thus leads to hardening of grain boundaries. With reference to all above discussion VTJA becomes a good alternative for machining of AISI 1050 and HE13A. Further to this it is possible to have metallographic study of tool and tool wear for wet and VTJA machining.

References


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