MACHINING OF TI6AL4V ALLOY USING NOVEL BONDLESS DIAMOND LAYERED GRINDING WHEEL FOR PRECISION GRINDING

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Abstract- Now being tried out for grinding Ti alloys which find increasing use in new applications. Grinding of this material is difficult and cryogenics using liquid nitrogen is a good way of extending the life of the wheel and enhancing its performance. While machining the Ti alloys, the cutting zone temperature is so high (reduction of temperature of cutting zone, favorable change in the chip-grinding grit interaction and the use of novel bondless diamond layered grinding wheel). Our bondless diamond wheels have been a success giving nanometric finish. The major task of this paper is “Cryogenic high speed grinding of Ti alloys” with the new wheel.

Keywords- Novel bondless, Diamond Layered Grinding Wheel, Ti6Al4V, Precision Grinding.

I. INTRODUCTION

Introductory work on turning and drilling of Ti alloys was carried out, these results helped in formulating conditions for grinding. However machining Ti alloys is a challenge and grinding even more so. Ti alloys have a low thermal conductivity and become hard at -50°C and cutting forces increase. It was also found that the micro hardness increased from 312.8 Vickers (load of 1 kg) to 419.3, indicating sign of hysteresis. Hysteresis has been reported at elevated temperatures of 650°C. The grinding temperature could reach this figure but then diamond graphitizes at this temperature. Hysteresis is probably due to the delivery system of the liquid nitrogen that requires elaborate design and development for which the time were inadequate, increasing tool life during turning Ti-6Al-4V using round tee-lock CNMG insert. Using cBN tool for turning with dry environment the speed: 60, 90 and 120, feed: 0.1 and 0.3 rpm and DOC: 0.05, 0.15 and 0.3 mm. Finally the creation of bondless diamond grinding wheel has shown success during different environments.

Grinding Ti alloys which find increasing use in new applications. Grinding of this material is difficult and cryogenics using liquid nitrogen is a good way of extending the life of the wheel and enhancing its performance. In recent work on cryogenic grinding of Ti alloys has been done by researchers at IIT Kharagpur-India and they used specially designed bonded CBN wheels.

Our bondless diamond wheels have been a success giving nanometric finish. The term binderless is technically incorrect as the method of fabrication has to be sintering whereas our method is Chemical Vapour Deposition on caribide substrate and the word bondless is correct. In any case the word used for joining abrasives is bonding not binding. Cryogenic high speed grinding of Ti alloys with the new wheel. This has just been completed and the results are a mix of mostly positive conclusions. Quantifying ductile area on a aspheric and plano surfaces using bondless and bonded wheel and discussed together with novel wheel, spherical chip and critical depth of cut, work with the new wheel was initially on the Pentium III chip and later on Si and glass, these materials did not pose any serious challenge though surprisingly the chip packaging on the Pentium III chip produced excellent results.

Figure 1. Microstructure of alpha-beta Ti-6Al-4V alloy

Ample research has been done to improve the machinability of titanium. The problems that arise during machining of titanium are attributed to the high chemical activity to elements that are used in tooling materials. Also, their poor thermal properties (thermal conductivity for Ti, k=5.8W/m.K as opposed...
to carbon steel, $k=51.9\text{W/m.K}$) as well as their mechanical properties in terms of high temperature strength and low elastic modulus contribute to these difficulties which are characterized by a high specific energy and a high grinding zone temperature.

Due to adverse environmental impact caused by the use of metalworking fluids, modern manufacturing practices have pushed towards dry or minimum quantity lubrication machining. Among potential alternative solutions, the use of cryogenic gases as cutting and grinding fluids, i.e. carbon dioxide, $\text{CO}_2$ and liquid nitrogen, $\text{LN}_2$ have been known since the early 1950’s. Reports showed that using liquid nitrogen as a coolant improves the grindability of steel in respect of contact zone temperature, grinding forces as well as surface integrity. The importance of cryogenic work is demonstrated in a special issue edited by Stevenson in which the work of Philopovic & Stevenson, Adler et al, Wakabayashi et al, Paul and Chattopadhyay and Hong are highlighted. Experimental Procedure

The grinding experiments were conducted on VR1 Mill-TB CNC machining centre is shown in Figure 1. Experiments were conducted at low speeds (5000 and 8000 rpm) at a high speed (140,000 rpm) on VMC. The Ti slab mounted on a Kistler dynamometer and the grinding wheel of 12 mm diameter mounted on the collet of the jig grinder, which is attached to the spindle of VR1 Mill-TB machine. The jig grinder attachment is removed for low speeds.

At the speed of 5000 rpm ($V=3\text{ m/s}$) the diamond wheel with stainless shaft worked well when machining Ti alloy. When the speed was increased to 8000 rpm ($V=5\text{ m/s}$) the wheels with the carbide shaft worked better, rigidity of the grinding wheel was improved by using K type tungsten carbide shaft instead of a stainless steel one used earlier. It improved rigidity is essential for high speed machining of Ti alloys as shown in Figure 3.

![Figure 3 Bondless diamond grinding wheels with different shaft material](image3)

A Kistler dynamometer is shown in Figure 3. With a 20 mm Ti alloy slab mounted on it eleven surfaces were ground with full and partial immersion and these can see in Figure 4.

![Figure 4 Ti alloy slab positioned on a Kistler dynamometer](image4)

Machining at very high speeds 140,000 rpm ($V=88\text{m/s}$) require a very rigid wheel. The stainless steel shaft worked well when machining the Si die and the chip packaging of Intel’s Pentium III chip and also when machining optical glass. Balancing of the wheel becomes important. Use of carbide shafts of a composition that matches the substrate of the wheel helped to bring about a large increase in rigidity.

<table>
<thead>
<tr>
<th>Parameter of machining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work material</td>
</tr>
<tr>
<td>Ti-6Al-4V alloy</td>
</tr>
<tr>
<td>Grinding wheel</td>
</tr>
<tr>
<td>Monolayer of diamond on a tungsten carbide substrate</td>
</tr>
<tr>
<td>Diameter</td>
</tr>
<tr>
<td>12mm</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>5mm</td>
</tr>
<tr>
<td>Cutting speed</td>
</tr>
<tr>
<td>8000rpm (low speed)</td>
</tr>
<tr>
<td>150000rpm (high speed)</td>
</tr>
<tr>
<td>Feed</td>
</tr>
<tr>
<td>0.1mm/min</td>
</tr>
</tbody>
</table>
Experiments at high speeds with carbide shafts could not be conducted as the supplier for special services could not deliver them in time for this report.

However at low speeds the carbide shafts performed well from the point of view of surface roughness (Ra=0.2µm) when used with emulsion based water coolants. During cryogenic grinding the finish was not as good and the cutting forces were higher due to the elevation of hardness of the Ti alloy.

A 20 mm Ti alloy slab mounted on it eleven surfaces were ground with full and partial immersion and these can see in Figure3. Experiments at high speeds with carbide shafts conducted, low speeds the carbide shafts performed well from the point of view of surface roughness (Ra=0.2µm) when used with emulsion based water coolants and 11 ground surfaces. Table2 shows measurement values of surface finish-parallel lay and force with friction values. During cryogenic grinding the finish was not as good and the cutting forces were higher due to the elevation of hardness of the Ti alloy.

Throughout this experimental procedure only liquid nitrogen, LN₂ was used as the source of cryogenic lubrication although some researchers prefer the idea of using carbon dioxide, CO₂ gas coolant. For comparison purposes, data is used from research done using carbon dioxide as lubricating coolant as well as liquid nitrogen.

<table>
<thead>
<tr>
<th>Groove</th>
<th>Shaft type</th>
<th>Environment</th>
<th>speed (rpm)</th>
<th>depth of cut (mm)</th>
<th>feed rate (mm/min)</th>
<th>Ra (µm)</th>
<th>Rq (µm)</th>
<th>Rmax (µm)</th>
<th>Wt (µm)</th>
<th>Ave. Tangential Force (N)</th>
<th>Ave. Feed Force (N)</th>
<th>Shaw Friction Coeff</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>s.steel</td>
<td>coolant</td>
<td>5000</td>
<td>0.05</td>
<td>0.1</td>
<td>0.285</td>
<td>0.35</td>
<td>1.82</td>
<td>3.95</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
</tr>
</tbody>
</table>

Figure 5. Grinding wheel setup for low speeds (8000 rpm)
The chip was produced using emulsion based coolant which is unlikely to appear in cryogenic LN₂ grinding as the material becomes brittle due to immense decrease in surface temperature that allows easier chip breaking and extended tool life. The efficiency in terms of tool life in parting/grooving and threading is illustrated in Figure 8, and cryogenic
CO₂ applied at a rate of about 6g/s is a competent coolant for threading as well as for parting/grooving stainless steel. Although carbon dioxide has certainly lengthened tool life, however surface finish was not improved and grinding forces was not reduced.

II. RESULTS AND DISCUSSIONS

Tangential force comparison under different conditions of grinding (surfaces 5-11).

From Figure 6, surface 5 and 11 produced the best surface finish using cryogenic as lubrication during the grinding experiment.

Surface 5 is produced from low speed grinding (8000rpm) with the wheel mounted onto a carbide shaft whereas surface 11 experimented with a high speed jig grinder rotating at 150,000rpm uses a stainless steel shaft. Surface 5 and 11 also produced the best flatness under cryogenic grinding condition at low and high speed respectively, the highly ductile titanium alloy produced a moderately long chip which is undesirable because it wears out the cutting tool rapidly.

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![Figure 6 Values of surface roughness for each immersion](image)

![Figure 7. Efficiency of cryogenic CO₂ with respect to the water based coolant in terms of tool life in parting/grooving and threading.](image)

White bars indicate neat CO₂; grey bars CO₂ with vegetable oil and dark bars CO₂ plus chlorinated mineral oil. Cryogenic grinding with a novel bondless diamond wheel has shown significant success in terms of improved surface finish, roundness/flatness, tool life, and tolerances. of equal interest is hydrodynamic action of LN₂ in pin and disc studies put forward by Hong and his implementation in machining applications is needed.

CONCLUSION

The bondless diamond grinding has been a big success for machining IC chips for failure analysis and for grinding of optical glass. The bondless diamond wheel machines Ti alloys with conventional coolants quite well.

Bonded grinding wheels made of cBN (cubic boron nitride) which is another super abrasive next only to diamond, result in increase of force and wear. Cryogenic bondless diamond grinding of Ti alloys resulted in excellent surfaces finish in the nanometric range at low speeds.

Cryogenic grinding hardens the Ti alloy and apparently hysteresis occurs which is not good for fatigue applications. This needs more investigation.

REFERENCES


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