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Chip Morphological Behaviour During Machining Of Ti-6Al-4V Using Refrigerated Soluble Oil

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Abstract -

Chips formed during machining are a vital instrument for the assessment both of machinability of material and the effectiveness of the machining method adopted. Various approaches have been proposed by researchers to make machining Ti-6Al-4V easier, ranging from reduction of cutting speed and feed rate to the use of coolant during machining. In this study, investigatation of the effect of refrigerated soluble oil on machinability of Ti-6Al-4V via monitoring of the chips formed during the various machining processes was carried out. The chips formed for various machining conditions were collected using a designed chip receptor medium and was analyzed using a metallographic microscope with an attached stylus. The experiment was planned using central composite designs (CCD) of the Response Surface Methodology (RSM) resulting in a 20 experimental run plan for dry and wet machining. Machining factors considered were cutting speed, feed rate, depth of cut and coolant temperature with corresponding values 40-120 m/min, 0.05-0.20 mm/rev, 0.2-1.0 mm and 5-11°C respectively. Responses monitored chip thickness, tooth profile and peak height. The effect of various factors on responses were discussed. Basically, results show that chip diameter increased with an increase in cutting speed. However, the sawtooth profile on chip reduced with an increase in cutting speed. It was therefore concluded that coolant temperature has an effect on chip morphology during machining of Ti-6Al-4V using refrigerated coolant.

Keywords: Chips, Machinability, Ti-6Al-4V, Soluble Oil, Refrigerated.

1. Introduction

Machinability, when defined in the terms of a material is as an indication of how easy or difficult machining the material can be. The machinability of a material may be assessed by tool life, limiting rate of metal removal, cutting forces, surface finish or chip shape [1]. Some engineering materials can be very difficult to machine, an example of which is Titanium alloy. These alloys however find a lot of application in many industries, due to their inmmense resistance to corrosion and unusual combination of high strength-to-weight ratio. The machinability of titanium alloys is however impaired by their high temperature chemical reactivity, extremely reduced thermal conductivity and modulus of elasticity [2]. However, machining titanium alloy is difficult because its' maintenance of high hardness at elevated temperatures, low thermal conductivity, low elastic modulus, and high chemical reactivity generally result in the low machinability of the alloy. These factors lead to degradation of surface integrity of machined parts caused by rapid tool wear [3]. Chip morphology is an important tool for investigating the

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machinability of Ti-6Al-4V and gaining better understanding of the fundamental phenomena governing machinability.The responses measured during such includes heat generated during the cutting process, vibrations mechanics of machining process, e.t.c [4]. Generally, the type of chip formed during machining is dependent on some determinants. This includes tool work piece thermal behavior and heat transfer, tool work piece friction behavior, the process parameters and properties of work piece and cutting tool material [5]. Several researchers have investigated machining performance during machining of Ti-6Al-4V with emphasis on roughness, cutting temperature and chip formation during the experimentation. [6] carried out an analysis of chip formation and microstructure when machining Ti-6Al-4V. They analyzed surface microstructure and studied chip types produced during using different cutting fluid supply systems at various machining conditions. The machining parameters used for the investigation were cutting speed (95 - 200 m/min), feed rate (0.10 - 0.105 mm/rev), depth of cut (1.3 - 5.0 mm). Chips were examined using a Leica S6D optical microscope to study their morphology (colour, shapes, structures, textures and geometry). From their results, chip saw-tooth height was relatively lower using the new cooling system. This they opined was as a result of the better fluid accessibility of the new system due to a higher fluid velocity of 10.83 m/s. [7] investigated the influence of tool wear on chip morphology while machining Ti-6Al-4V in dry condition. Machining factors used for the experiment include a varied cutting speed of 150.00 and 220 m/min and a constant depth of cut and feed rate of 1 mm and 0.208 mm/rev respectively. A tungsten carbide insert was used for the experiment and the analysis of the profile of the chips formed during the experiment was done using a scanning electron microscope. They reported that as the volume of material removed increased resulting from an increase in speed, there was an observable increase in chip length as the cutting speed increased.

[8] studied the formation of chip during the turning of aluminium metal matrix composites. They focused on how machining condition, tool wear and surface roughness affects chip geometry. Uncoated carbide insert was used as cutting tool and surface roughness was measured for various machining conditions. The machining parameters used were cutting speed (200 - 300 m/mins), feed rate (0.10 - 0.20 mm/rev) and depth of cut (0.5 - 1.5 mm). They reported the production of discontinuous chips at a (low) cutting speed of 200 m/mins. However with an increase in cutting speed to 300 m/mins, semi-continuous chips were formed. Generally, they observed that length of chip increased as feed rate increased when other parameters were kept constant. They therefore concluded that at low cutting speeds and high feed rates are unfavourable parameters for machining as the surface roughness was found to be larger.

[9] analyzed the mechanism for chip formation during machining of Aluminium/Silicon metal matrix composites. The process parameters used for the study were tool nose radius (0.4 - 0.8 mm), feed rate (0.05 - 0.20 mm/rev), cutting speed (40 - 120 m/min) and depth of cut (0.20 - 1.0 mm). Chip thickness and length was measured using a Nikon measure scope MM-22 at x50 magnification. Chip profile was examined using Scanning Electron Microscope (SEM) and Olympus optical microscope. It was reported that at a cutting speed of 40 m/min chips formed were segmented and needle type, however when cutting speed increased to 120 m/min, the chip formed were generally continuous and tubular in shape. It was reported that there was an increase in chip length with an increase in feed rate. [10] studied chip morphology during turning of AISI 301 using different biodegradable oils. The machining factors used during the investigation were spindle speed (80 - 260.00 rpm) and depth of cut (0.4 - 1.2 mm). The cutting fluids used during the experimental process were soluble, palm kernel and jatropha oils and chips formed were examined for various cutting speeds. Chip thickness was measured with a

micrometer. It was reported that continuous and ductile chips were formed only with the use of vegetable oils.

Experimental

Materials

A 100x20 mm Ti-6Al-4V alloy cylindrical bar was used as the experimental material. The work piece material was acquired from Shaanxi Titanium Aviation Material Company Limited, China. The chemical compositional analysis of the work piece (Table 1) was done using a MAXx LMM05 model of Ametek SPECTROMAX X Metal Analyzer (made in Germany) with a serial number 11000057.

Table 1: Chemical Compositional Analysis of Ti-6Al-4V

Element	Ti	Al	V	C	Fe	N	O	H
% Comp.	Balanced	5.99	3.97	0.03	0.10	0.01	0.104	0.005

Chip Analysis

Chip analysis was carried out using a MOTIC Optical Microscope Model 13007389 (Figure 1) to examine the structure of the chips formed during all the three machining conditions so as to ensure a clearer understanding of chip formation and impact on responses. The general physical appearance of the chips formed during each machining conditions were discussed.

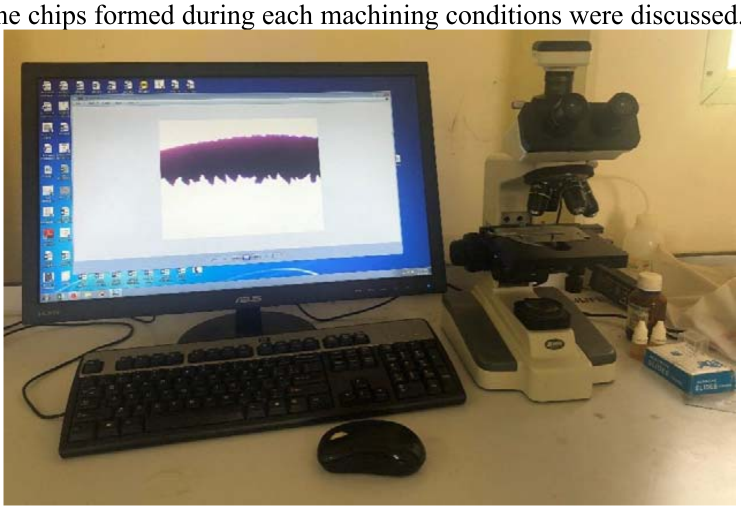


Fig 1: Motic Stereoscopic Optical Microscope (SOM)

Experimental Procedure

The Central Composite designs (CCD) of Design Expert version 10.0 was employed to design the procedure for the experiment. The four control factors selected were cutting speed (1178 – 1766 m/mins), feed rate (50 – 80 mm/rev), depth of cut (0.1 – 0.4 mm) and coolant temperature

(5 – 11^{o}C). An Orthogonal array of 20 runs were generated for the dry and wet machining process while a 30 run array was generated for the cooled machining process. A cooling system was developed to facilitate a reduction in cutting temperature during machining of Ti-6Al-4V. The coolant used was a N5 soluble oil.

Results and Discussion

Chip Morphology Analysis

The chips formed during machining of Ti-6Al-4V under each machining condition were collected and analyzed. The analysis was done for chips collected during dry, wet and cooled machining conditions. Figures 1 (a, b and c) show samples of chips produced during dry, wet and cooled machining respectively. Chips produced during cooled machining appeared shiny and were continuous. Continuous chips are produced when machining ductile materials at high speeds [8], however, its production during cooled machining of Ti-6Al-4V was as a result of the reduced temperature during cooled machining at high speed (1703.63 m/min). During dry machining, chips produced were burnt, brittle and discontinuous(Figure 1a). This could have resulted from the high temperature at the cutting zone. The absence of coolant during the machining operation resulted in the discontinuous chip-type formed during dry machining, this agrees with results of [11] who reported that discontinuous chips where formed during machining of Titanium alloy. Wavy and serrated chips of averagely 25 mm in length were obtained during wet machining. The chips were shiny and do not show any signs of burns when compared with the chips from dry machining (Figure 1b). The application of coolant during wet machining at room temperature resulted in the chip-type formed. This shows an improvement in surface roughness as the ease of removal of material has increased. The chips formed during cooled machining were ductile and continuous with an average length of 120.00 mm (Figure 1c).

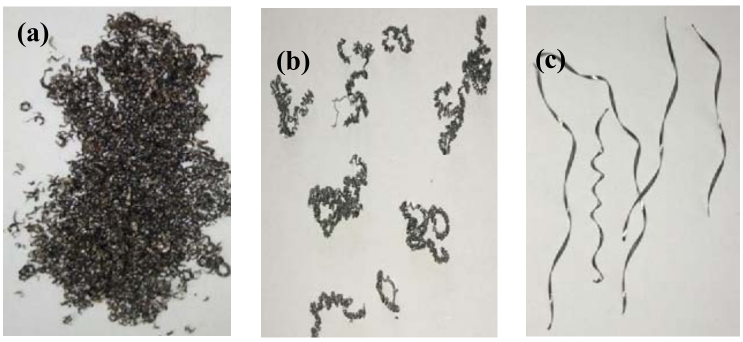


Fig. 2: Chips formed during machining of Ti-6Al-4V (a) Dry (b) Wet (c) Cooled

The ductility and continuous nature of the chips formed during cooled machining was due to the much reduced cutting temperature during cooled machining. The regulation of temperature at the cutting zone through the use of the developed Coolant Temperature Regulator (CTR) resulted in the changes in chip type as discussed above, this result agrees with [12] who reported that chip type had an impact on the quality of the machining process.

The analysis of chip-type formed was done at specific machining factors combinations to confirm if there were any changes in chip-type during machining at those runs. The observations were done by keeping two factors constant and varying a third factor. During dry and wet machining, the feed rate and depth of cut was kept constant (F = 60.00 mm/rev, Depth of Cut = 0.20 mm) while the cutting speed was varied (1044.37 m/min, 1374.00 m/min and 1703.63 m/min), but for cooled machining, the cutting speed varied were (982.00 m/min, 1374.00 m/min and 1766.00 m/min). It was observed that as cutting speed increased, the diameter of the spiral shape increased too, this result is in agreement with [13] and [14] who both reported that chip morphology changed as cutting speed increased during machining of Ti-6Al-4V. During wet machining, a chip-entanglement phenomenon was observed, the wavy chip formed curled around the workpiece, negatively impacting on machining efficiency and reducing surface integrity of the machined piece (Figure 2). A similar phenomenon was also reported by [13] and [15], without any solution proffered.

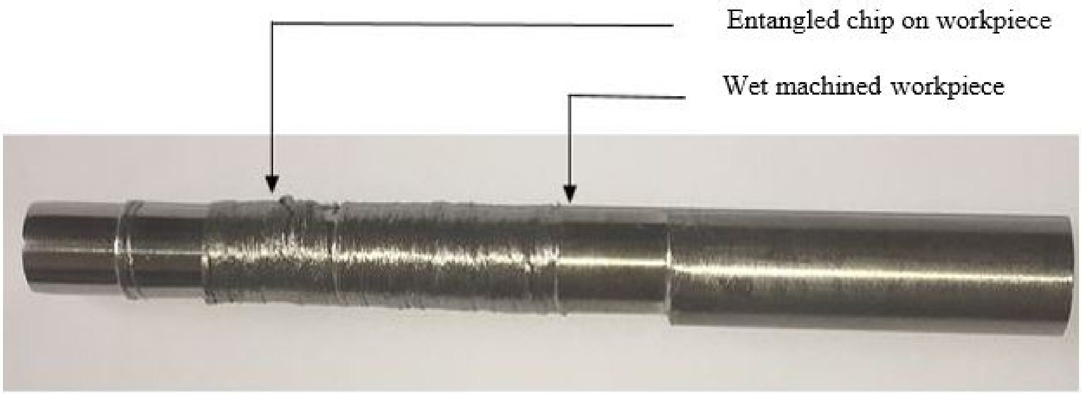


Fig. 3: Chip-Entanglement phenomenon during wet machining.

This occurred as a result of the high heat generated during machining as a result of increase in cutting speed (from 1044.37 to 1703.63 m/min). However, during cooled machining (Figure 3), the reduction of temperature at the cutting zone resulted in a much more efficient machining of workpiece as the chip-entanglement phenomenon was not observed despite the increase in cutting speed (from 982.00 to 1766.00 m/min). Hence, the use of the CTR to reduce the temperature at the cutting zone successfully solved the chip entanglement problem while machining Ti-6Al-4V.

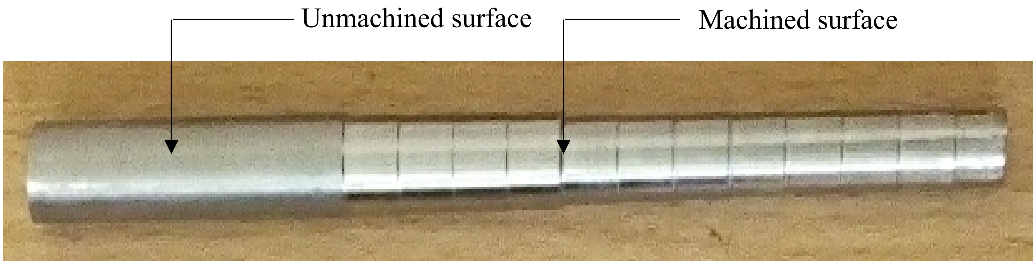


Fig. 4: Cooled Machined Sample of Ti-6Al-4V

Figure 4 shows the result of examination of the chip under light optical microscope at a magnification of forty (x40). From the figure, there was varying chip tooth for various machining condition. The chips produced during cooled machining were saw-tooth shaped (Fig 4a). The saw tooth shape was slightly obvious with chips produced during wet machining (Fig 4b) but was not observed at all during dry machining (Fig 4c). Hence only chips produced during cooled machining was clearly saw-toothed in shape.

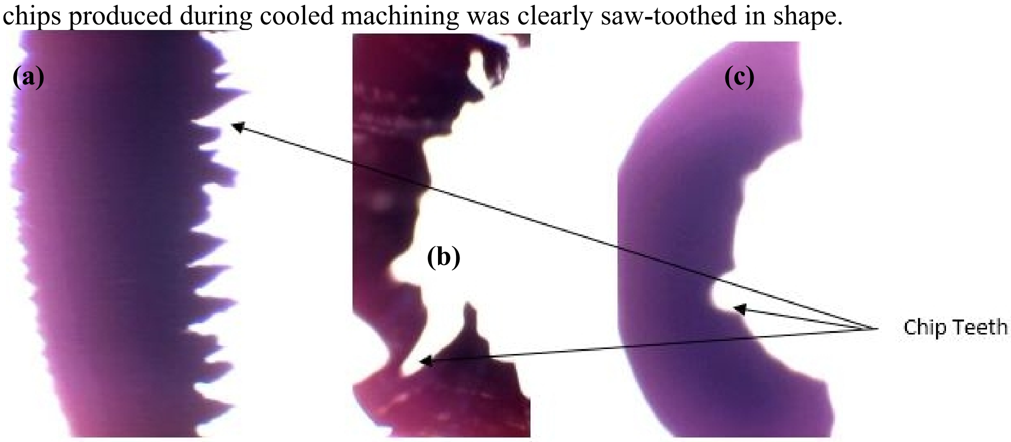
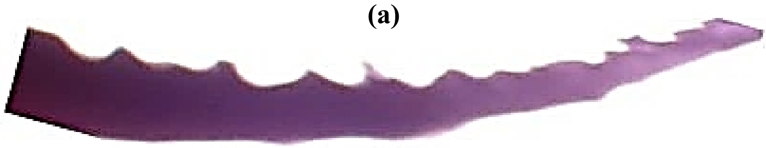


Figure 5: Chip teeth at x40 magnification (a) Cooled (b) Wet (c) Dry

Figure 5 shows chips produced during cooled machining at cutting speeds of 1703.63 m/min and 1178.00 m/min. It was observed that the saw-teeth noticed decreased as cutting speed increased. This can be explained by the increase in heat dissipation during machining. This agrees with a similar result for [13].

(a)



(b)

Figure 6: Chip teeth during cooled machining (a) V = 1178.00 m/min (b) V = 1703.63 m/min

Conclusion

In this study, chip morphological behavior during machining of Ti-6Al-4V using refrigerated soluble oil was examined. Experimental results obtained aided the drawing of the following conclusions;

1. As cutting speed increased, chip diameter also increased during the machining of Ti-6Al-4V;
2. Chip entanglement which reduces surface integrity during machining of Ti-6Al-4V can be reduced or eliminated with the use of refrigerated coolant (soluble oil).
3. The saw tooth noticed on chips reduced with an increase in cutting speed.
4. Chip morphology was affected by coolant temperature. Chips formed during refrigerated machining was ductile and continuous, hence Ti-6Al-4V's machinability could be improved if refrigerated soluble oil is applied as coolant during machining.

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