Study of the effects of cryogenic machining on the machinability of Ti-6Al-4V titanium alloy

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Abstract

Due to the chemical, mechanical and thermal characteristics inherent to titanium alloys, machining these materials is always considered very difficult. Cryogenic cooling using liquefied gases is one of the techniques used by many researchers to improve the machinability of different materials including titanium by reducing the cutting temperature and modifying the material properties of the workpiece and cutting tool. However despite the introduction of an industrial cryogenic milling system, in the context of machining of titanium, most cryogenic scientific studies are limited to turning operations. This paper is one of the first scientific studies on the cryogenic CNC milling of titanium alloys used in aerospace namely, Ti-6Al-4V (Ti64). A series of machining experiments have been conducted in order to study the effect of cryogenic cooling on the machinability of Ti64 titanium alloy in CNC end milling operations using TiAlN coated solid carbide cutting tools. These experiments showed that cryogenic cooling has resulted in 11% and 59% reduction in the surface roughness of the machined parts as compared to dry and wet conditions respectively whilst no major impact on the power consumption as a result of cryogenic cooling was recorded. In addition, the study of the cutting tools indicated that cryogenic cooling has significant potential to slow down the growth of tool wear resulting in longer tool life in comparison with conventional machining environments.

1 Introduction

Whilst titanium alloys are attractive materials to many industries such as aerospace, nuclear, gas turbine, biomedical, etc. due to their superior material characteristics such as high strength to weight ratio, high fracture toughness, high corrosion resistance, high biocompatibility, etc. [1], machining titanium is always considered to be very difficult. High cutting temperatures resulting in poor surface quality, rapid

tool wear, low productivity and high machining costs is an inherent characteristic of machining titanium [2]. Cryogenic cooling using super cold liquefied gases such as liquid nitrogen is one of the techniques used by many researchers in order to control the cutting temperature in machining heat resistant alloys such as titanium and austenitic steels [3, 4]. In turning Ti64, Dhananchezian and Pradeep Kumar [2] reported that cryogenic cooling has resulted in significant improvements in tool life and surface finish and reduction in the cutting temperature in comparison with wet machining.

Review of the wide range of literature on cryogenic machining, has shown that most studies in cryogenic machining of titanium are concentrated on turning operations. This paper is one of the very first scientific approaches to investigate the effects of cryogenic cooling on the machinability of the Ti64 aerospace grade titanium alloy in CNC end milling operations through the study of surface roughness, tool wear and power consumption.

2 Methodology and experimentation:

The workpiece material used for the experiments was Ti64 titanium alloy which is one of the most used titanium alloys in aerospace industries. This study was limited to the effect of machining environments and other machining parameters such as cutting speed, feed rates, depth of cut, etc. which were kept constant during the experiments as shown in table 1.

Table 1: Machining parameters used for experiments

Cutting Speed	Feed Rate	Depth of Cut	Immersion Rate
70m/min	0.030mm/tooth	1mm	50%

The proposed machining operation was end milling using a PVD TiAlN coated solid carbide end mill with positive rake. Three machining experiments have been conducted under three different environments namely, cryogenic and conventional dry and wet coolants. Power consumption, tool wear and surface roughness of the machined test parts was measured during and after the machining experiments.

3 Results and Discussion

Study of the surface roughness of the machined parts under three different environmental conditions indicated that the effect of cryogenic cooling on the surface roughness is significant as compared to dry and wet machining. As it is shown in figure 1-a, cryogenic cooling has resulted in 11% and 59% reduction in arithmetic surface roughness in comparison with dry and wet conditions respectively.

Statistical analysis of the power consumption of the machine tool during machining trials illustrated that cryogenic cooling has resulted in an average of 3% increase in the power consumption of the machine tool as compared to dry machining. This could be explained by increases in the workpiece material strength and hardness as a result of the cooling effect of spraying super cold liquid nitrogen in cryogenic machining. Power consumption in wet machining is significantly higher than cryogenic and dry machining. This is mainly attributed to the power consumption of the coolant pump of the machine tool. Eliminating the power consumption of the coolant pump indicated that using coolant in machining Ti64 titanium alloy has resulted in 2.5% increase in the power consumption of the machine which is statistically significant. This shows that the unfavourable cooling effect of the coolant in machining this alloy on the power consumption is more significant than the reduction in power consumption as a result of lubrication.

Investigation of the cutting tools during machining was conducted in equivalent intervals in order to monitor the tool wear as a result of machining. Whilst none of the cutting tools reached the end of their lives at the end of the experiments, the investigations revealed that cryogenic cooling has the potential to reduce the tool wear growth rate as compared to dry and wet conditions. A macroscopic study of the tools indicated that all cutting tools suffered from notching of the cutting edge while as it is shown in figure 1-b, a lower flank wear rate was observed on the cutting tool used for cryogenic machining. The wear mechanism of all cutting tools was abrasion while it was limited to the erosion of the coating for the tool used in cryogenic machining.

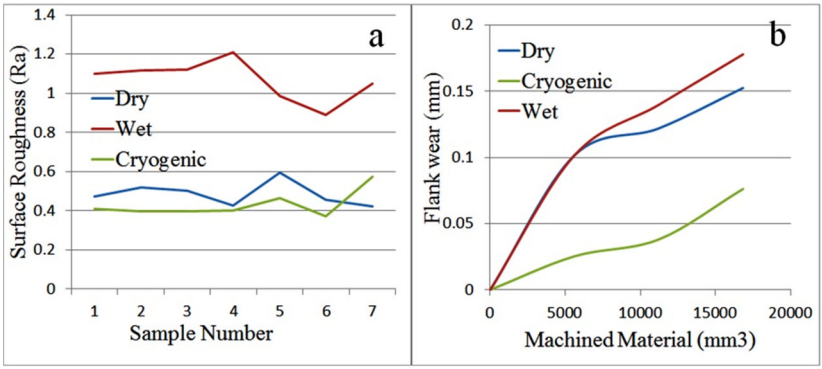

Figure 1: a) Comparison of surface roughness of the machined parts under three different conditions namely, dry, wet and cryogenic; b) Flank wear of the cutting tools used for cryogenic, dry and wet machining experiments

4 Conclusions

A series of machining experiments have been conducted in order to study the effect of machining environments namely, cryogenic, dry and wet on the power consumption, tool wear and surface roughness of the machined parts whilst other cutting parameters were kept constant.

Investigations revealed that cryogenic cooling has shown a potential to improve the machinability of Ti-6Al-4V alloy as compared to conventional machining techniques by producing relatively lower surface roughness and tool wear without major impacts on the power consumption of the machine tool.

References:

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