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Machining of Ti6Al4V using laser textured cutting tool under Ionic liquid (IL) lubrication condition

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Abstract
In the present work, the machining of Ti6Al4V has been conducted using plain and textured cutting inserts. For the current work, the uncoated carbide insert has been chosen as the cutting tool for the machining purpose. The textures over the cutting tool have been fabricated using a nanosecond Nd:YAG laser machine. The machining of Ti alloy has been conducted under the dry and Ionic Liquid (IL) based MQL environment. For the dry condition, three types of tools namely plain, textured (Tex), and textured filled with nano-graphene solid lubricant (Tex+SL) have been employed for the machining purpose. The use of the Tex+IL condition has reduced the cutting temperature by 17% as compared to the plain cutting tool. Moreover, the use of IL with the textured tool has also significantly reduced the adhesion of Ti over the tool rake surface.

Keywords: Ti6Al4V, Textured tools, Ionic liquid, Machining

1. Introduction

Titanium alloy Ti6Al4V has been used in various important sectors such as aerospace, biomedical, and defense fields due to superior mechanical and thermal properties [1]. However, due to high chemical reactivity and low thermal conductivity, the Ti6Al4V is considered a difficult to machine material, especially under the dry cutting environment [2]. Conventionally, Titanium is machined using mineral-based cutting fluids under flood conditions. These lubricants help in reducing the cutting forces and the cutting temperatures. However, the usage of mineral-based lubricants results in a significant rise in expenditures associated with the purchase, handling, and disposal. It has been estimated that 20% of the machining cost is attributed to mineral-based cutting fluids [3]. One possible way to improve the machining of Ti alloy is to use the textured tool in the cutting process. The use of surface-modified texture tools can considerably improve chip-tool friction. Moreover, the surface texturing parameters such as groove spacing, groove width, and groove aspect ratio could also modify the wettability behavior of the cutting inserts [4]. It is important to note that the sharp cutting edge of textured cutting inserts can act as secondary cutting edges during the machining process. This led to the derivative cutting of the chip back surface which unnecessarily increases the coefficient of friction and cutting zone temperature [5]. In this regard, Duan et al., [6] have used the femtosecond laser to create linear grooves parallel to the main cutting edge on the rake face of the tungsten carbide tool. The authors have found that the improper selection of cutting speed for the textured tool leads to additional cutting of chip bottom surface (derivative cutting phenomena) with the tool micro textures.

The efficacy of grooved tools could further be improved by using alternative cutting fluids such as Ionic liquids (ILs). The ILs are considered to have very high thermal stability. They are biodegradable, biocompatible, and eco-friendly. Babu et al., [7] have used Imidazolium-based IL for the machining of Inconel 825. The machining has been conducted between the cutting speeds of 80 m/min to 160 m/min. The IL-based lubrication condition significantly restricted the abrasion mark formation over the cutting tool.

In the present work, the machining of Ti6Al4V has been carried out using the laser-textured cutting insert under the IL-based lubrication environment. The use of IL mixed lubricant could reduce the cutting temperature and adhesion over the cutting insert.

2. Methodology

Ti6Al4V grade 5 cylindrical bars of 40 mm diameter and 250 mm length were used for experimentation. Textured and plain uncoated tungsten carbide cutting inserts (CNMA 120408 THMFX) with a nose radius of 0.8 mm and a rake angle of 0° were used. The C-type insert with an included angle of 80° has been used for experimentation.

An Nd-YAG nanosecond laser (make GSI lumonics, UK) system was used for the fabrication of textures. The micro-holes (dimples) of 50 µm diameter, 50 µm depth, and 200 µm pitch have been fabricated over the rake surface of the cutting inserts. The textures are aligned parallel to the main cutting edge.

Machining of the Ti6Al4V bar has been conducted under the dry and IL-based MQL environment. 1-Butyl-3 methylimidazolium hexafluorophosphate was chosen as the Ionic liquid. The close-up image of the setup used for the machining purpose has been given in Figure 1. The machining has been performed at the cutting speed = 110 m/min, feed = 0.12 mm/rev, and depth of cut = 0.5 mm. For comparison with IL condition, the machining with the plain cutting tool, textured cutting tool (Tex), and textured tool filled with nano graphene solid lubricant (SL) has also been conducted in the current study. The cutting temperature over the rake face during the machining has been recorded using the micro-epsilon infrared pyrometer. The pyrometer is directed towards the cutting zone for recording the temperature data. The adhesion over the cutting inserts after the machining has been studied using the elemental mapping technique (SEM: Zeiss Merlin Compact).

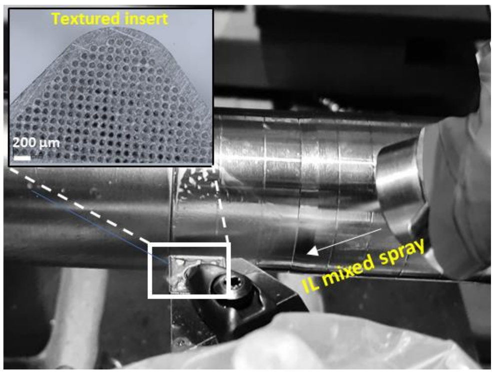

Figure 1. Close-up of machining setup used for experimentation.

3. Results and discussion

The cutting zone temperature under various conditions has been given in Figure 2. Due to the intimate contact under the dry condition the temperature of 545 °C has been recorded with the plain cutting tool. The machining of Ti6Al4V with the textured tool under the dry condition has reduced the cutting temperature to 530 °C. Further, the nano-graphene filled textured tool (Tex+SL) has reduced the cutting temperature to 512 °C. The reduction in the friction at the rake face due to the presence of nano-graphene solid lubricant is responsible for such a reduction in the cutting temperature. As compared to the plain tool, the use of IL with a textured tool reduced the cutting temperature by 17%.

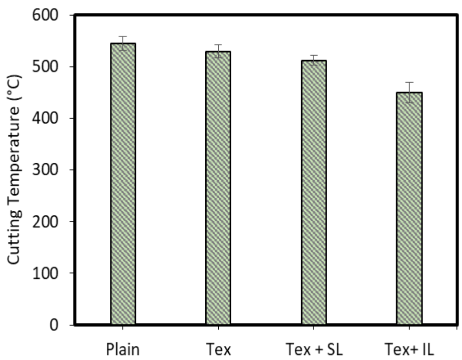

Figure 2. Cutting zone temperature recorded for different conditions.

The extent of Ti element transfer over the cutting inserts under various conditions has been given in Figure 3. Excessive adhesion of Ti element transfer over the plain cutting tool after the machining can be observed from the elemental mapping analysis. The traces of the Ti have been found to be up to 250 µm over the rake face of the plain tool under dry condition. However, the use of a simple textured tool reduced the extent of Ti transfer to 100 µm. The Tex+SL has also yielded the same kind of result in terms of Ti element traces. The maximum reduction in terms of Ti extent has been obtained with Tex+IL condition. The reduction in the derivative cutting phenomena due to the lubrication provided by the IL has reduced the Ti extent by 68% as compared to the plain condition.

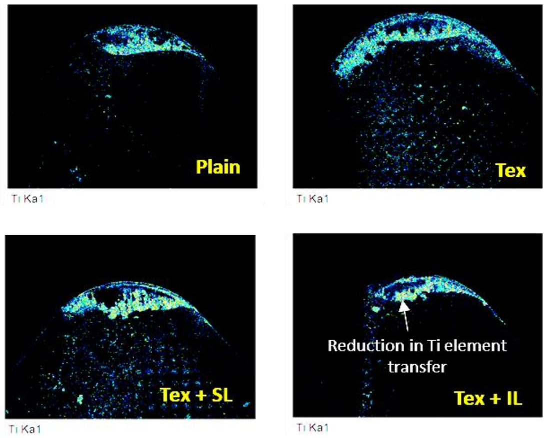

Figure 3. Elemental mapping of various cutting inserts after machining.

4. Conclusions

In the present study, the machining of Ti6Al4V alloy has been conducted using the plain and textured cutting insert. Machining has been conducted under both dry and IL-based lubrication modes. The following conclusions can be drawn from this work:

- The use of IL along with the textured tool reduced the cutting zone temperature by 17% as compared to the plain cutting tool.
- Excessive adhesion of the Ti element transfer layer has been observed for the plain tool under dry conditions.
- The textured tools filled with solid lubricant significantly reduced the cutting temperature.
- The use of Tex+IL condition has significantly reduced the Ti transfer layer over the tool rake face.
- As compared to the plain tool the use of IL with the textured tool reduced the Ti element extent effectively by 68%.

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