Title: FUNDAMENTAL TOOL WEAR STUDY IN TURNING OF Ti-6Al-4V ALLOY (Ti64) AND NANO-ENHANCED MINIMUM QUANTITY LUBRICATION (MQL) MILLING

Scheduled Date of PhD Defense: 1/9/2015
Scheduled Time of PhD Defense: 3.00PM
Scheduled Location of PhD Defense (Building & Room #): 3540 Engineering Building
Full name: Trung Kien Nguyen
PID: A45082194
Email: nguye279@msu.edu
PhD Degree Major: Mechanical Engineering
Advisor: Dr. Patrick Kwon

Abstract

Titanium (Ti) alloy, in particular Ti-6Al-4V (Ti64), has been widely used in a variety of industries such as automobile, aerospace, chemistry, biomedicine and other manufacturing industries because of their desirable and unique mechanical properties. The well-known properties of Ti alloys include light-weight, excellent strength even at elevated temperatures, resistance to corrosion and biocompatibility, which cannot be collectively and comprehensively satisfied by any other alloys in some applications. In machining of Ti alloys, however, the low thermal conductivity and high hardness exposes cutting tools to high temperatures and cutting forces, which often fracture the cutting tools catastrophically. More importantly, the high chemical solubility of cutting tools causes the high chemical wear leading to accelerated wear on cutting tools, especially when cutting at high speeds. Polycrystalline diamond (PCD) and uncoated
carbide tools are the most widely used tool materials for machining Ti alloys. The coated carbide tools, which are extremely successful for most other alloys, are completely ineffective in extending tool life in machining Ti alloys. In order to find the main reason for this puzzling behavior, this study revisits the fundamental wear mechanisms in rake and flank faces using PCD and carbide tools in dry turning of Ti64 alloy. The original microstructure of work material was characterized using Orientation Image Microscope (OIM) with Electron-Backscattered Diffraction Scan (EBDS) to explain the correlation of the wear pattern with the observed microstructure. Based on the microstructure and the tool wear patterns, this study claims that wear damages are caused primarily by the heterogeneity coming from not only the presence of both \( \alpha \) (hexagonal closed packed) and \( \beta \) (body centered cubic) phases but also the hard orientation of the \( \alpha \)-phases. In addition to the heterogeneities, the adhesion layer detaching parts of the tool material also contributes to flank wear.

This thesis also considers improving tool life by adopting new lubrication techniques. In particular, Minimum Quantity Lubrication (MQL)-based machining process was chosen as it has many merits over not only conventional flood cooling machining but also dry machining. However, few disadvantages make the MQL-based machining process impractical to be adopted in many industrial production settings. More specifically, the cutting speed in a typical MQL process is restricted because the MQL process does not allow efficient cooling of cutting tools in more aggressive cutting conditions. At high cutting speeds, for example, a minute amount of oil used in MQL will simply evaporate or disintegrate as soon as the oil droplets strike the tools already heated to high temperatures. Solid lubricants in a platelet form have been mixed with
MQL oils to mitigate this major deficiency of MQL process. This study distinguished the platelets into nano-platelets and micro-platelets depending on the thickness of platelets. Many micro-platelets are available commercially. However, for nano-platelets, exfoliated Graphite nano-platelet (xGnP) and XGS® hexagonal Boron Nitride (XGS®hBN) produced by XG Science, Inc. (Lansing, Michigan) were used. These platelets were mixed into a typical vegetable oil used in MQL process. When the mixture of oil and these platelets are applied, the platelets are expected to provide additional lubricity even after the oil droplets have been disintegrated at high temperature. Thus, the enhancement achieved by adding these platelets allows us to expand the processing envelope of MQL. In this research project, a comprehensive study on the effect of the diameter and thickness of platelets was carried out. Firstly, the comparison between micro and nano-platelets enhanced MQL oils with varying contents was studied with a tribometer test (ball-on-disc setup) in a reciprocating motion in order to understand the changes in the friction and wear behaviors. The tribometer test showed that the nano-platelets were much more effective than the micro-platelets in reducing wear without altering the friction behaviors. Secondly, in the MQL ball mill experiment of steel AISI 1045, the micro-platelets present in MQL oil increased the tool wear, even compared to the traditional MQL with pure oil only. Thus, the thickness of the nano-platelets is an important characteristic in enhancing MQL-based machining. Finally, the nano-platelets enhanced MQL was applied in milling Ti-6Al-4V. The results showed that the presence of nano-platelets in the MQL oil decreased the tool wear and improved the tool life compared to traditional MQL with pure oil as well as dry machining not only by
providing lubricity at high temperature cutting condition but also by reducing the micro-chipping and tool fracture caused by the impact in milling process.