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EXPERIMENTAL INVESTIGATION OF SURFACE QUALITY IN TURNING OF TITANIUM ALLOY – A REVIEW

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ABSTRACT

Titanium and its alloys are considered as difficult-to-cut materials due to the high cutting temperature and the high stresses at and/or close to the cutting edge during machining. Titanium alloys present superior properties such as high strength-to-weight ratio and resistance to corrosion but, possess poor machinability. This restrict the industrial usage of Titanium Aloy.This paper studies difficulties in turning of Titanium alloy.

Keywords- *Turning, Titanium Alloy, Machinability.*

I. INTRODUCTION

Titanium and its alloys are considered as difficult-to-cut materials due to the high cutting temperature and the high stresses at and/or close to the cutting edge during machining. Titanium alloys present superior properties such as high strength-to-weight ratio and resistance to corrosion but, possess poor machinability.

By proper selection of the cutting parameters it is possible to improve the machinability of difficult to machine material. Specific cutting pressure can be used as one of the important process parameter to understand the status of the cutting edge. Any change in the specific cutting pressure can be attributed to the loss of form stability of the cutting wedge. The cutting force magnitude is found to be higher than feed force.

Chip compression ratio, shear angle, chip analysis are important from the metal cutting point of view to understand the machinability characteristics of any material. Microstructural analysis of the machined surfaces and chips indicated metallurgical phase changes as a result of cutting under dry conditions. Chip segmentation by shear localisation is an important process which is observed in certain range of cutting speeds. This phenomenon might be desirable in reducing the level of the cutting forces by improving chip's evacuation. The hydrostatic stress, shear stress and maximum principal stress distribution during the chip formation process at different cutting speed are different.

Surface roughness is greatly influenced by feed rate. Surface finish is also affected by cutting speed and depth of cut. However, effect of feed rate on surface roughness is more significant as compared to other cutting parameters. The quality of surface machined with the natural diamond tool was better than that with the other tools. Surface finish is found to be optimum in the cutting range of 45–55 m/min for the feed rate of 0.08 mm/rev and 0.5 mm.

The optimum quantity of lubricant with appropriate cutting conditions for achieving better machinability characteristics of a material. As a basic rule, a cutting fluid must be applied when machining titanium alloys.The correct use of coolants during machining operations greatly extends the life of the cutting tool. The developed high-pressure cooling technique provided significantly higher tool life and productivity than the currently used industrial practice while turning Ti–6Al–4Valloy. Tool life on high-pressure cooling with water-soluble oil improved at least by 250% over that in conventional wet environment. High-pressure cooling enables improvement in tool life and productivity by reducing the tool wear rate desirably and better surface finish on the machined material.

At any cutting condition, the cutting speed is the dominant factor in controlling tool life. Straight tungsten carbide tool had better wear resistance, when cutting titanium and its alloys, than the tungsten carbide-titanium carbide grades. The natural diamond tool exhibits an excellent cutting performance in machining titanium alloys when applying abundant coolant. Cutting tool materials undergo severe thermal and mechanical loads when machining titanium alloys due to the high cutting stresses and temperatures near the cutting edge, which greatly influence the wear rate and hence the tool life.

A small reduction in the cutting temperature due to cryogenic cooling enabled a significant improvement in the cutting force, surface roughness and tool wear. Cryogenic cooling by liquid nitrogen reduced the cutting temperature by 61–66% over wet machining. Cryogenic cooling decreased the cutting force by 35–42% over wet machining. Cryogenic machining reduced the surface roughness and tool wear to a maximum of 35% and 39% over wet machining respectively.

II. LITERATURE REVIEW

An attempt has been made to clarify some of the questions raised in the literature about the machining of titanium alloys .The experimental observations made in this investigation support some of the earlier findings and reinterpret others. The machining of titanium alloys is a classical case of distinct gross inhomogeneous plastic deformation involving periodic upsetting and intense shear localization in a narrow band. It is suggested that the continuous chipformation models, such as the classical Merchant-Piispanen model and the use of parameters derived from the model (such as the chip thickness ratio rand shear angle , should be discontinued in describing machining characteristics of titanium alloys. Efforts should be made to develop another set of appropriate parameters to describe the machining of titanium. This will aid the machine tool operator in optimizing the cutting process.[1]

Titanium and its alloys are considered as difficult- to-cut materials due to the high cutting temperature and the high stresses at and/or close to the cutting edge during machining. The high cutting temperature is due to the heat generated during machining (catastrophic thermoplastic shear process), the thin chips, a thin secondary zone, a short chip-tool contact length and the poor heat-conductivity of the metal, whilst the high stresses are due to the small contact area and the strength of titanium even at elevated temperature.

Straight grade (WC/Co) cemented carbides are regarded as the most suitable tool material available commercially for the machining of titanium alloys as a continuous operation. The C-2, identical to ISO K20, is the best carbide grade. High-speed steel tools are also very useful for some interrupted cuts, but the development of new tool materials is still required.Cutting tool materials undergo severe thermal and mechanical loads when machining titanium alloys due to the high cutting stresses and temperatures near the cutting edge, which greatly influence the wear rate and hence the tool life. Flank wear, crater wear, notch wear, chipping and catastrophic failure are the prominent failure modes when machining titanium alloys. Flank and crater wear may be attributed to dissolution-diffusion, attrition and plastic deformation, depending on the cutting conditions and the tool material, whilst notch wear is caused mainly by a fracture process and/or chemical reaction. As a basic rule, a cutting fluid must be applied when machining titanium alloys. The correct use of coolants during machining operations greatly extends the life of the cutting tool. Chemically active cutting fluids transfer heat efficiently and reduce the cutting forces between the tool and the workpiece.[2]

Straight-grade cemented carbides are suitable for use in the machining of titanium alloy Ti-6246. The wear resistance and cutting edge strength of an insert with finer grain size are superior to those of an insert with a coarser grain size. The dominant wear mechanisms of cemented WC/Co tools were dissolution/diffusion and attrition were at the cutting edge of the tools. The higher temperature observed, causing the plucking of pulling-out of carbide from the tool. Abrasion wear mechanisms dominated the wear type at the flank face and tool nose.Maximum flank wear was the factor controlling the toolife with all tested tools.The chip-breaker groove played an important role in the life of the tools. To maximise the utilisation of the chipbreaker groove, the correct cutting parameters and conditions have to be determined.[3]

A straight grade cemented carbides are suitable for use in Titanium alloy Ti-6246. The dominant wear mechanisms for cemented tools are dissolution and plucking at tool edge. Maximum flank wear at nose was more severe than flank and face wear. It always controlled the tool life[4]

The tests had as objective observes the behavior of the material, and the best cutting conditions were close to the suitable conditions for the tool manufacturer. However, it is possible to work in more severe conditions than the manufacturer's conservative conditions. Although few tests have been accomplished, it was possible to observe certain coherence in the behavior of the titanium in relation to the variations in the cutting parameters, in what concerns the wear presented and the respective roughness produced in the workpieces. This group to believe that the optimization procedures usually used for other alloys, based on the condition of maxim production through speed of maxim production (Vmxp) can be applied with success, what will be demonstrated so much with futures tests in the conditions of finish has mainly in the one of rough-heming.The alloy of titanium (Ti–6Al–4V) is a material of difficult machinability due to its properties such as high mechanical resistance, abrasivity besides the discharge chemical reactivity with the cutting tools to the temperature above 500 .C. However, the tests were accomplished the dry and the results were very satisfactory as it can be observed, coming to encounter with the current tendency of working with the low amount of cutting fluid or preferably the dry, due to the restrictions imposed by the current environmental legislation besides the economical factor (reduction of costs). [5]

Simulation of Ti–6Al–4V at three different cutting speeds is performed. The hydrostatic stress, shear stress and maximum principal stress distribution during the chip formation process at different cutting speed are obtained. Based on the analysis of the obtained simulation data, it is understood that:Chip formation in the cutting of Ti–6Al–4V is strongly influenced by crack initiation and propagation which results in discontinuous or serrated chip morphology.When cutting Ti–6Al–4V at low cutting speed, the chip obtained is discontinuous, while at high cutting speed the chip obtained is serrated.[6]

This study presents a new method for detecting the cutting tool wear based on the measured cutting force signals using the regression model and I-kaz method. The detection of tool wear was done automatically using the in-house developed regression model and 3D graphic presentation of I-kaz 3D coefficient during machining process. The machining tests were carried out on a CNC turning machine Colchester Master Tornado T4 in dry cutting condition, and Kistler 9255B dynamometer was used to measure the cutting force signals, which then stored and displayed in the DasyLab software. The progression of the cutting tool flank wear land (VB) was indicated by the amount of the cutting force generated. Later, the I-kaz was used to analyze all the cutting force signals from beginning of the cut until the rejection stage of the cutting tool. Results of the IKaz analysis were represented by various characteristic of I-kaz 3D coefficient and 3D graphic presentation. The I-kaz 3D coefficient number decreases when the tool wear increases. This method can be used for real time tool wear monitoring.[7]

The paper deals with finite element (FE) modelling of ultrasonically assisted turning (UAT). In this processing technology, high frequency vibration (frequency, f . 20 kHz; amplitude, a . 10_m) is superimposed on the movement of the cutting tool. Ultrasonic vibration yields for a nickel-base alloy Inconel 718 a decrease in cutting forces and working temperatures as well as a superior surface finish.The developed FE model allows transient, coupled thermomechanical modelling of both ultrasonic and conventional turning (CT) of elasto-plastic materials. The Johnson–Cook material model is adopted for Inconel 718 in simulations. Comparative analyses of temperature distribution in the cutting region and cutting tool are carried out for both turning schemes. Plastic strains during cutting and residual strains in the machined layer are analysed and compared with the results of nanoindentation tests of Inconel 718 specimens processed with and without application of ultrasonic vibration. Overall reduction in cutting forces and temperatures for ultrasonic turning in comparison to conventional turning is explained.[8]

The 3D finite element simulation of turning the CP Ti was validated by the comparison of cutting forces and chip thickness with reasonable agreement. Effects of cutting speed on peak tool temperature and tool cutting edge radius on forces, chip thickness, and tool temperature were investigated. The application of finite element simulation to study the chip curl was explored. Qualitative agreement on the type of chip curl and chip flow direction were achieved for turning with small depth of cut. The chip segmentation with shear band formation was investigated .The segment spacing in the finite element modeling was comparable to experimental measurements. The feasibility to use the finite element method to model the complicated 3D machining processes was demonstrated.[9]

High carbon steel as the tool material was found to contribute most to the variation in MRR and TWR. For Grit size factor, level 1 (mesh size 220) was identified as the most significant for its effect on the variation in MRR, TWR and surface roughness. For power rating factor, level 4 (400 W) has been most significant for MRR and TWR.[10]

The effects of different coolant supply strategies (using flood coolant, dry cutting, and minimum quantity of lubricant [MQL]) on cutting performance in continuous and interrupted turning process of Ti6Al4V are investigated. Based on the observation of the cutting forces with the different coolant supply strategies, the mean friction coefficient in the sliding region at the tool–chip interface has been obtained and used in a finite element method (FEM) to simulate the deformation process of Ti6Al4V during turning. From the FEM simulation and Oxley's predictive machining theory, cutting forces have been estimated under different coolant supply strategies and verified experimentally. used in the aerospace.[11]

The cutting force magnitude is found to be higher than feed force. Decrease in both cutting force and feed force is due to decrease in contact area and partly by drop in shear strength in the flow zone as the temperature increases with increase in speed. The cutting force and feed force values are found to be somewhat linear in the cutting range of 45–55 m/min at middle level of feed rate. Specific cutting pressure can be used as the one of the important process parameter to understand the status of the cutting edge. Hence, any change in the specific cutting pressure can be attributed to the loss of form stability of the cutting wedge.

Surface finish is found to be optimum in the cutting range of 45–55 m/min for the feed rate of 0.08 mm/rev and 0.5 mm.Turning at cutting speed of 45 m/min, 0.05 mm/rev and0.5 mm gave tool life of 337 s whereas at cutting speed of 55 m/min, 0.05 mm/rev and 0.5 mm the tool life was 282 s.The main type of wear is abrasion, microchipping and also some plastic deformation under dry cutting condition. The BUE formation was unseen for the selected machining parameters.[12]

The developed high-pressure cooling technique provided significantly higher tool life and productivity than the currently used industrial practice while turning Ti–6Al–4V alloy.Tool life on high-pressure cooling with water-soluble oil improved at least by 250% over that in conventional wet environment. The percentage benefit improved even further at higher combinations of process parameters. Similarly productivity enhancement has been very substantial, almost 50% increase as compared to conventional wet.High-pressure cooling with neat oil however did not provide substantial benefit on tool life and productivity.High-pressure cooling enables improvement in tool life andproductivity by reducing the tool wear rate desirably. This is achieved by efficient cooling of the machining zone.Water-soluble oil provides better cooling due to its higher momentum, better thermal conductivity and enhanced convective heat transfer coef.cient, providing higher tool life as compared to high-pressure neat oil. [13]

By proper selection of the cutting parameters it is possible to improve the machinability of difficult to machine material, Inconel 718 with high quality. [14]

Tests achieved have shown three main types of chips: Continuous chip at 50 m/min, Flow chip for speeds ranging around 100 m/min, and Shear localized chip starting from the transition speed of 125 m/min and above. The modification of the mechanism of chip formation is associated with the appearance of shearing instability. Chip segmentation by shear localisation is an important process which is observed within a certain range of cutting speeds. This phenomenon might be desirable in reducing the level of the cutting forces by improving chip's evacuation.

[15]

The selected parameters for study, namely chip compression ratio, shear angle, chip analysis, etc., are important from the metal cutting point of view to understand the machinability characteristics of any material and this is true with respect to Inconel 718 in high-speed machining considered in this work.[16]

At any cutting condition, the cutting speed is the dominant factor in controlling tool life. The application of MQL is not always effective in term of tool life and surface roughness. MQL is only effective at certain cutting speeds. In this experiment MQL is most effective at cutting speed of 135 m/min to get better tool life. High value MQL is less effective at high cutting speed due to the difficulty of the larger particle to penetrate into the cutting zone. Higher pressure is needed to ensure that the mist particle can penetrate into the cutting zone, when higher cutting speed is applied.Direct effect of cutting parameter on the surface roughness is not significant. Surface roughness is more dependent on the geometry of the cutting tool and the stability of the machine structure. However, effect of feed rate on surface roughness is more significant as compared to other cutting parameters.[17]

The present paper is an attempt to study the effect of machining parameters on the surface characteristics/quality of the machined part with respect to the specific cutting pressure, microstructural alteration and microhardness while high speed dry turning of superalloy Inconel 718. The present approach and results will be helpful for understanding the machinability and surface characteristics of Inconel 718 during high speed dry turning.[18]

To determine the optimum quantity of lubricant with appropriate cutting conditions for achieving better machinability characteristics of a material. Hence, an attempt has been made in this paper to enhance the machinability characteristics in high speed turning of superalloy Inconel 718 using quantity of lubricant, delivery pressure at the nozzle, frequency of pulses, direction of application of cutting fluid, cutting speed, and feed rate as the process parameters. Results indicated that the use of optimized minimum quantity lubrication parameters under pulsed jet mode leads to lower cutting force, cutting temperature, and flank wear. [19]

The machining of titanium and its alloys particularly for automotive use; the motivation for which was substantiated through fundamental cost models. The common problems encountered during titanium machining as well as standard and evolving techniques for improving machinability were discussed.

Additional factors that specifically affect the machinability of titanium for use from an automotive standpoint were introduced as well. Requiring special mention are the results from a controlled milling experiment on Grade 5 titanium, which introduced and validated a more accurate method for quantifying tool wear which was able to capture the effects of multiple standard tool wear parameters rather than just a flank wear measurement. This is expected to contribute to the reduction in the processing cost of titanium for automotive component manufacture.[20]

In general, tool wear was increased with increasing cutting speeds and cutting depths for both materials investigated as expected. The EDX analyses of the worn tools after machining of titanium alloy showed formation of built-up edges which consisted of tungsten and chromium. The map analysis of tungsten deposition indicated a deeper wear area. This observation can be explained by the high chemical reactivity and galling tendency of titanium at elevated temperature indicating that the temperature at the cutting insert was raised to more than 600°C.

No formation of built-up edges was found on the worn tools after machining of nickel-based superalloy which could be explained by the high chemical stability of alloy 625. After the EDX analyses Ni, Cr, Fe and Mo were present all around the worn surface.[21]

Titanium alloys present superior properties such as high strength-to-weight ratio and resistance to corrosion but, possess poor machinability. In this study, influence of material constitutive models and elastic–viscoplastic finite element formulation on serrated chip formation for modeling of machining Ti–6Al–4V titanium alloy is investigated. Temperature-dependent flow softening based modified material models are proposed where flow softening phenomenon, strain hardening and thermal softening effects and their interactions are coupled. Orthogonal cutting experiments have been conducted with uncoated carbide (WC/Co) and TiAlN coated carbide cutting tools. Temperature dependent flow softening parameters are validated on a set of experimental data by using measured cutting forces and chip morphology. Finite Element simulations are validated with experimental results at two different rake angles, three different undeformed chip thickness values and two different cutting speeds. The results reveal that material flow stress and finite element formulation greatly affects not only chip formation mechanism but also forces and temperatures predicted. Chip formation process for adiabatic shearing in machining Ti–6Al–4V alloy is successfully simulated using finite element models without implementing damage models.[22]

Cryogenic cooling by liquid nitrogen reduced the cutting temperature by 61–66% over wet machining. A small reduction in the cutting temperature due to cryogenic cooling enabled a signicant improvement in the cutting force, surface roughness and tool wear. Cryogenic cooling decreased the cutting force by 35–42% over wet machining. Cryogenic machining reduced the surface roughness and tool wear to a maximum of 35% and 39% over wet machining respectively.[23]

III. Conclusion

Although, due to poor machinability, Titanium alloys are not the preferred choice of engineering industry, but these alloys present superior properties such as high strength-to-weight ratio, resistance to corrosion and property to withstand high temperature making them popular.

In keeping mind the various cutting parameters like cutting speed ,depth of cut and feed rate a study of these parameters and optimizing these parameters can lead to improvement in machinability of Titanium alloys.

Low thermal conductivity makes them vulnerable due to high temperature in turning operation. Thus, investigations using different cooling medium may improve their machinability such as improved surface quality, reduced tool wear etc. Thus research paper is an attempt in this direction.

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