Investigation on Tool Wear During Micro End Milling Of Ti-6Al-4V

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Abstract

Titanium and its alloys are very difficult to cut because of low thermal conductivity, high toughness, high chemical reactivity, spring back action, strain hardening under normal cutting conditions, etc. hence, tools get worn out very soon and cause poor surface finish and inaccurate geometry. Cutting parameters such as depth of cut, cutting velocity and undeformed chip thickness contribute a lot to the quality of the final geometry produced and tool shape. AlTiN coated tungsten carbide micro end mill cutter with two flutes were selected for this study in order to investigate the tool wear and its effect on surface roughness, width of slot cut and tool cutting edge radius. In order to investigate the effect of cutting edge radius, a feed rate of 4 µm per tooth was used. Experiments were carried out on Ti-6Al-4V titanium alloy using micromachining centre. Condition of tool, slots and surface roughness were analysed using 3D Optical profiler.

Keywords: Ti-6Al-4V, MicroEnd Milling,Surface Finish, Slot Width, Cutting Edge Radius, Tool Wear Criterion

1. INTRODUCTION

Over last decade demand of miniaturised components has been increased because of applications of micro components in aircraft structural components, submarine heat exchanger components, turbine blades, electronic, biomedical, automobile industries, etc. Miniaturisation of components is attracting both consumers and manufacturers as small parts hence, small products, are easy to handle, carry, consumes lesser space and ergonomically more competent. Manufacturing of smaller components requires lesser raw material, smaller and lighter machines which consumes less power, and smaller machines have smaller rotating and reciprocating components which leads to lesser inertia and balancing challenges. These days' micro components are being used in biomedical implants, fluidic micro channels, micro nozzles, micro moulds, optical lenses, small batteries, turbine blades, hardware components, etc.

Since the ancient times, people do research for the purpose of inventing war machines and later those technologies get absorbed into industrial and domestic uses also, for making day to day life easy and comfortable. Also, because of requirement of micro components in aeroplanes and space crafts, same are getting much importance these days.Oliaei et al. [1] conducted experiments in which circular pockets were micro-milled using uncoated Tungsten Carbide tools. Flank wear, edge rounding and reduction in tool diameter were the main types of wear.Li et al. [2] conducted experiments in which 0.1 mm diameter, two fluted, Tungsten Carbide micro end mills used, in dry machining conditions. Surface roughness has been used for this purpose.

Rashid et al. [3] conducted turning experiments for investigating all kinds of wear mechanisms possible while machining Ti-6Al-4V alloy using uncoated Tungsten Carbide tools in dry conditions. For crater wear, abrasion, adhesion, attrition and diffusion wear mechanisms were found to be more responsible. Clear evidences of tool weakening effect of plastic deformation of cutting edgeshave been given. Also, Zhu et al. [4] investigated tool wear mechanism during end milling of the Ti-6Al-4V alloy [illegible]

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[illegible] this was high tool wear. As cutting vibrations increases, itincreases friction between tool rake face and chip. Swain et al. [5] did an experimental investigation in which they micro end milled Nimonic 75 alloy using uncoated TC and AlTiN coated TC tools for analysing machining characteristics. Chipping and flank wear were found to be main reasons for tool failure. For both, uncoated and coated micro tools, flank wear was found to have a direct relation with feed rates and cutting speeds. Also, they found that coated tool produces fewer burrs.

Chae et al. [6] surveyed the mechanical micro machining and also its application. Specially micro-milling has been focused.Bhuiyan et al. [7] and Bhuiyan et al. [8] conducted turning experiments and used acoustic emission device and accelerometer device for tool wear and surface roughness monitoring in dry conditions. Together these two devices can capture the entire range of signals which get generated from the machining zone, hence, they comprise a band pass filter. It was found that the vibration components in X, Y and Z directions increased with the increment of the feed rate, the depth of cut and the cutting speed respectively.

Wang et al. [9] conducted experiments and investigated cutting tool wears and breakages, and the effect of diameter of tool, tool angle, cutting force, tool extension length and vibrations on the tools. The rack face wear, flank wear, breakage and micro-chipping were found as the main wear patterns on the tools. Vipindas et al. [10] conducted experimental study and found that for the machining of the Ti-6Al-4V alloy using 1000µm micro end mill, the size effect region comes out as feed per tooth below 1µm feed per tooth.

Tool wear study on micro end mill tools is limited in the literature due to expensive tools and non-availability of measurement capabilities. Along with this, tool wear study found mainly concentrated on uncoated tungsten carbide tools.The objective of this work is to perform tool wear study during micro end milling of Ti-6Al-4V alloy. Effects of tool wear on geometry of the slot produced, burr formation, change in surface roughness and cutting edge radius have been studied along witheffect of minimum uncut chip thickness on tool wear during micro end milling of Ti-6Al-4V alloy.

2. EXPERIMENTAL WORK

2.1 Workpiece Material and Tool

Ti-6Al-4V is one of the titanium alloy, which is widely being used in many fieldssuch as fabrication of aircraft structures, turbine blades, medical implants, etc., because of itssuperior properties such as resistance to heavy loads, great resistance to corrosion, lightness, highspecific ultimate tensile strength, bio-compatibility, low thermal and electrical conductivity, andgood thermal stability because of its moderately high melting point. In this study Ti-6Al-4V was selected as the workpiece material. Table 1 shows the physical properties of the Ti-6Al-4V material.

AlTiN coated 2 fluted tungsten carbide micro end mill cutter with 1000 µmdiameter was used in this study for experimental investigations. Cutting edge radius was measured in the range of 3 – 3.5 µm. This was done by fitting a circle to the SEM image of the cutter edge and radius of the circle was taken as the cutting edge radius of the tool

Table 1

Mechanical and thermal properties of Ti-6Al-4Valloy

Property	**Value**
Density (g/cm^3)	4.43
Thermal conductivity (W/mK)	6.7
Vickers hardness	340
Specific heat (J kg $^{-1}$ K $^{-1}$)	526
Melting Point (^{o}C)	1650
Elasticity modulus (GPa)	114
Tensile strength (MPa)	950

2.2 Experimentalsetup

The tool wear experiments have been conducted on the DT-100, MIKROTOOLS Pte Ltd, Singapore, micro machining centre, shown in Fig1 (a). 3D Optical profiler (AliconaInfiniteFocus G5) was used for analysing tool wear, slot width and surface roughness of the machined surface (Fig. 1b).Tool and machined slots were analysed at regular interval to monitor tool condition. Table2 shows the experimental conditions selected for this study. A feed rate of 4 µm feed per tooth, which is close to but more than the cutting edge radius of the tool, was selected. Reason for this is, as tool gets wear out cutting edge radius of the tool increases, this would result in influence of cutting edge radius effect on tool wear and other machining performances. Since maximum spindle speed of the machine is 5000 rpm cutting speed is limited to 15.7 m/min.

(a) (b)

Fig.1.Experimental setup(a) Micro machining centre DT-100 (MIKROTOOLS Pte Ltd, Singapore), (b) 3D Optical profiler

Table 2

Experimental details

Sl. No.	Particular	Description
1	Make of machine	MIKROTOOLSPte Ltd, Singapore
2	Model	DT-110
3	Micro end mill dia.	1000µm
4	No. of flutes	2
5	Cutting speed	15.7 m/min (5000 rpm)
6	Depth of cut	0.1 mm
7	Feed per tooth	4 µm

3. RESULTS AND DISCUSSIONS

The experiments were carried on until tool got worn out completely. For ensuring complete wearing out of tools, the tools were examined using 3D Optical profiler for their flank wears at major cutting edge.Fig. 2 shows the progress of the flank wear with respect to cutting length.From this figure it can be seen that with 4 µm feed per tooth tool got worn out after approximately 1000 mm length of cut.Itcan be noticed that flank wear corresponding to 1000 mm length of cut is in the range of 20 µm, which can be considered as tool wear criteria during micro end milling of Ti-6Al-4V. Fig. 3 shows the condition of the tool after 10, 220, 620 and 1100 mm length of cut.

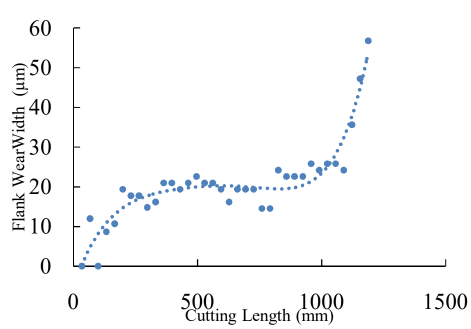

Fig. 2. Variation of flank wear with cutting length at major cutting edge (for first flank surface) for 4 µm feed pertooth

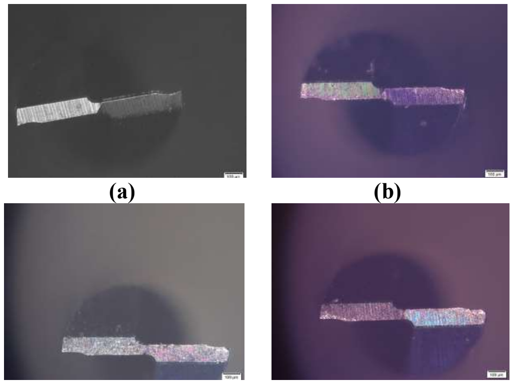

Fig. 3.Condition of the tool after (a) 10 mm, (b) 220 mm, (c) 620 mm and (d) 1100 mm length of cut

3.1 Effect of Tool Wear on Cutting Edge Radius

The sharp cutting edges of fresh tool, gets ground up during machining, and finally results in tool with larger cutting edge radius. Due to change in cutting edge radius, tool geometry changes and affects machining factors like, cutting forces, surface finish, slot width, etc. So, it becomes very important to study effect of tool wear on tool cutting edge radius. Fig.4 shows variation of cutting edge radius with cutting length for 4 µmfeed per tooth. It can be noticed that during initial stages of machining, cutting edge radius increases and decreases few times before finally increases. This may be due to repeated breaking, wearing and regrinding action of the tool wear at the cutting edge. Latter this effect has been correlated with the results of surface roughness.

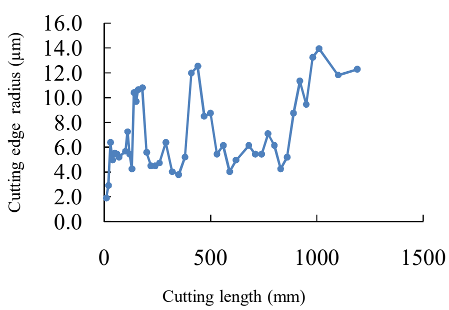

Fig. 4.Variation of cutting edge radius with cutting length for 4µm feed per tooth tool

3.2 Effect of tool wear on surface finish

Fig. 5 shows the variation of surface roughness with cutting length. It can be noted that initially surface roughness value decreases, reaches a minimum value and then increases. This could be explained based on the finding of Aramcharoen andMativenga [11]. It was reported that during micro end milling minimum surface roughness appears when feed per tooth becomes equal to the cutting edge radius [11]. During initial stages of machining cutting edge radius increases due to the tool wear and when cutting edge radius becomes equal to feed per tooth optimum surface roughness appears. Further increase in cutting edge radius due to tool wear results in increase of surface roughness due to ploughing effect.

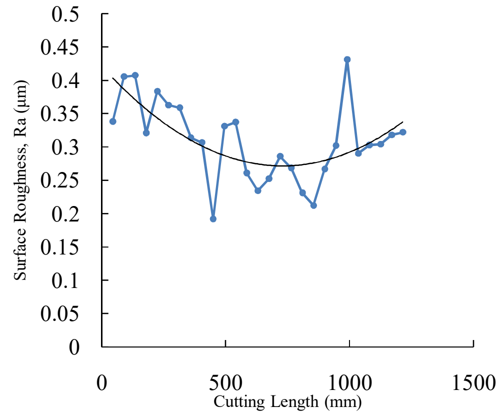

Fig. 5.Variation of Ra valuewithcutting length for 4µmfeed per tooth

3.3 Effect of Tool Wear on Slot Widths

Due to rubbing action during machining, some material from the cutting edges gets worn out. This leads to decrement in the tool cutting edge radius, which in turn produces the slots with lesser widths. During measurements it was found that the slot width is having a decreasing trend as tool gets worn out from cutting edges. This is evident fromFig.6 for 4µm feed per tooth. The ordinate shows slot width value in micro meters and abscissa shows cutting length in millimetres.

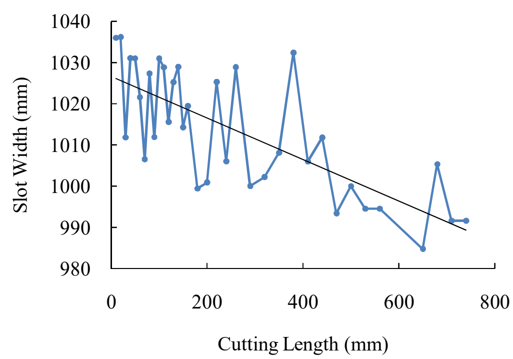

Fig.6.Variation ofslot width withcutting length for 4 µm feed per tooth

4. CONCLUSIONS

1) Toolcutting edge radius was found to be increasing and decreasing during initial stages of machining. This could be due to the repeated breaking, wearing and regrinding action of tool wear at the cutting edge.
2) Variation of surface roughness was found to be decreasing initially until cutting edge radius of the tool becomes equal to the feed per tooth due to tool wear. Thereafter surface roughness increases.
3) Slotwidths were found to decrease continuously, this was due to the fact that when tool wear happens from the cutting edges, effective diameter of tool decreases due to removal of material from cutting edges.

4) In case of 4 µm feed per tooth tool encounters its failure region after approx. 1000 mm length of cut.
5) From Fig. 2 it can be observed that a flank wear in the range of 20 µmcan be considered to be tool failure criteria while micro end milling of Ti-6Al-4V.

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