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Influence of dimple and spot-texturing of HSS cutting tool on machining of Ti-6Al-4V

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ABSTRACT

Machining of titanium alloys using high speed steel (HSS) tools is difficult due to their lower thermal conductivity which increases temperature of the HSS cutting tools thus accelerating their wear. Texturing on rake face of a cutting tool has recently emerged as a promising and environment friendly method enhancing removal of heat from the machining zone. This paper reports study on influence of spot and dimple textures by micro-plasma transferred arc powder deposition (μ-PTAPD) process on rake face of the HSS cutting tools. Experiments were conducted to study effects of μ-plasma power, powder flow rate and exposure time on dilution of spot-textures by making spots of Stellite powder on the HSS tool and to identify their optimum values for making an array of spots on rake face of the HSS tool. Similarly, effects of μ-plasma power and exposure time on diameter, depth, and aspect ratio of dimples were studied to identify their optimum values for producing an array of dimples on rake face of the HSS tool. Spot-textured, dimple-textured, and non-textured HSS tools were used in turning of Ti-6Al-4 V alloy and their performance was compared in terms of machining forces, flank wear, tool temperature, chip shapes, and surface roughness of the turned workpiece. Use of spot-textured HSS tool resulted in least values of cutting and thrust forces, chip-tool contact length, tool temperature, flank wear, adhesion of the workpiece material to the tool, and average surface roughness of the turned workpiece than the dimple-textured and non-textured HSS tools at different cutting speeds. Performance of the dimple-textured HSS tool was better than the non-textured tool in these aspects. Spots helped in formation of segmented chips by reducing curling radius of chips whereas non-textured and dimple-textured tools formed continuously curling ribbon-like chips. Spots also act as fins which enhance heat loss to the machining environment and helping in reduction of tool temperature. This study proves that spot-texturing of rake face of HSS tool by μ-PTAPD process is an economical, effective and environment friendly method to improve machining of titanium alloys.

1. Introduction

Use of titanium alloys has been increasing continuously due to their some unique properties such as biocompatibility, higher strength-to-weight ratio, excellent corrosion resistance, and higher fracture toughness. They are commonly used for various applications in the field of biomedical engineering (i.e. medical prostheses, dental implants, orthopedic implants and endodontic instruments), aerospace engineering, automobile engineering, marine applications, power generation, sports accessories, oil and gas extraction, and in making jewellery (Li et al., 2017). Conventional machining of titanium alloys is very difficult due to (i) their lower thermal conductivity which causes transfer of approximately 80% of heat generated during its machining to the cutting tool increasing its temperature (Pramanik and Littlefair, 2015), (ii) sticking tendency of the chips to the cutting tool. This adhered material is easier to tear off under a combination of high temperature, pressure and sliding speed which accelerates wear of the cutting tool (Sun et al., 2015), and (ii) their higher hot strength (i.e. ability to maintain their strength at higher temperature) which increases machining forces. The combined effect of higher machining forces and higher tool wear deteriorates surface finish of the workpiece (Gupta and Laubscher, 2017). Therefore, there is a strong need to evolve different inventive machining approaches for titanium alloys which will help in efficient removal of heat from the machining zone, reduce machining forces and adhesion of the removed material to the cutting tool, improve surface finish and allow the use of higher cutting speeds. Several strategies have been used to enhance machining of titanium alloys. This include use of cutting fluids and advanced tool materials, changing tool geometry, optimization of the machining parameters, chip breaking, and using different machining environments. Bermingham et al. (2012) compared the influence of high-pressure emulsion cooling and cryogenic cooling on chip morphology

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Table 1
Chemical composition of T-42 grade HSS tool and Ti-6Al-4 V by wt.%.

Chemical composition of T-42 grade HSS tool (wt. %)											
Elements	Co	W	Cr	Mo	V	C	Ni	Si	Mn	P	S	Fe
Composition	9.15	8.68	4.1	3.23	3.12	1.35	0.36	0.22	0.2	0.3	0.35	Bal.

Chemical composition of Ti-6Al-4 V (wt. %)											
Elements	Al	V	C	O	N	H	Fe	Cu	Sn	Y	Ti
Composition	6.17	4.02	0.02	0.13	0.022	0.005	0.04	0.12	0.10	0.004	Bal.

Table 2
Mechanical properties of Ti-6Al-4 V.

Ultimate tensile strength (MPa)	Elongation (%)	Hardness (HV)	Thermal conductivity at 20 °C (W m^{-1} K^{-1})	Density (g cm^{-3})
800–890	16	341–357	6.8	4.50

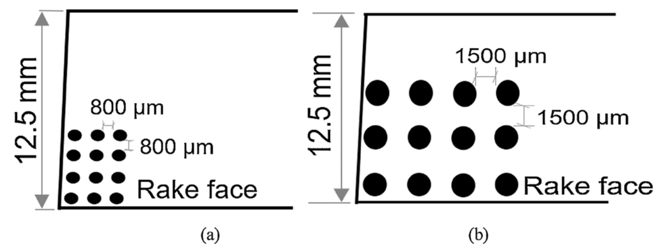

Fig. 2. Schematic of array of the (a) dimple textures and (b) spot textures on rake face of the HSS cutting tool.

and tool life in machining of Ti-6Al-4 V. They found that high pressure water based emulsion cooling offers better tool life than cryogenic cooling and observed various changes in chip morphology. da Silva et al. (2013) investigated wear mechanism and life of cutting tool made of polycrystalline diamond in machining of Ti-6Al-4 V at high speed and supplying coolant at high pressure. Their results showed that high pressure of coolant reduces the adhesion tendency of chips and improves the tool life. Mia and Dhar (2018) studied the influence of using duplex jets to supply high-pressure coolant on the machining zone temperature and machinability of Ti-6Al-4 V. They found enhancement in heat dissipation and reduction in machining forces, surface roughness and tool wear.

Texturing of the cutting tools has recently emerged as a promising and environment friendly method for effective heat removal from the machining zone. Wei et al. (2017) have reported that texturing of the cutting tools can enhance performance in machining of different materials by reducing the machining zone temperature, decreasing machining forces, and improving wear resistance of the cutting tool. Zhou et al. (2011) mentioned that surface texturing is an emerging method for improving tribological properties of the materials. Ling et al. (2013) used diode laser for micro-texturing on margin of the drill bits and compared the performance of textured and non-textured drill bits by drilling a series of holes in a titanium plate. Their results showed that

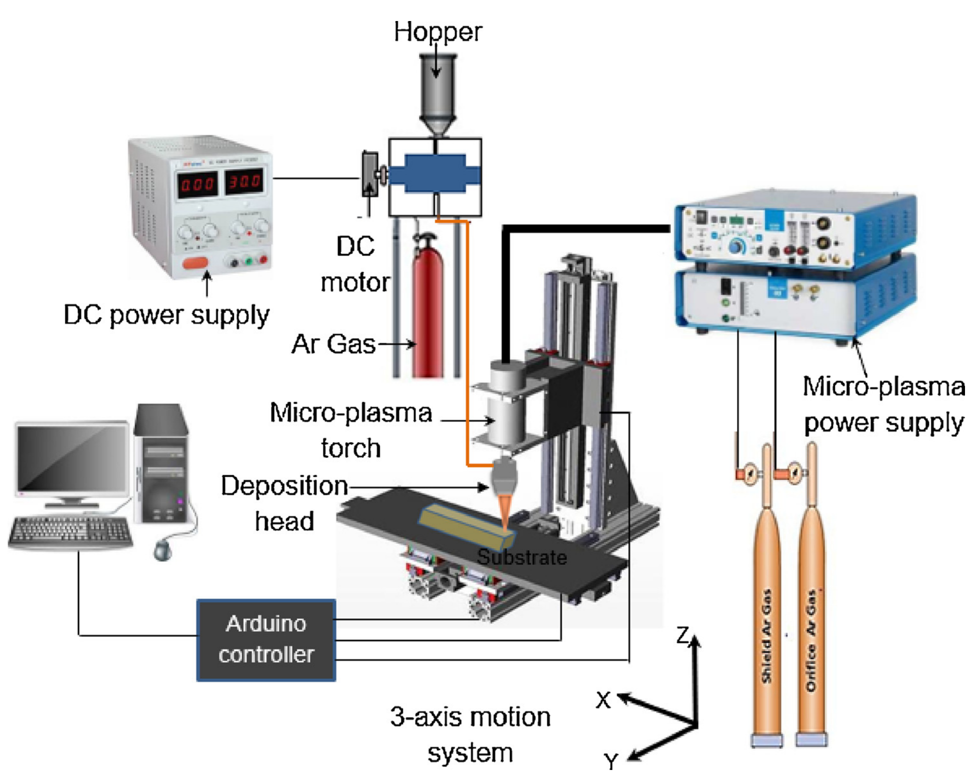

Fig. 1. Schematic of experimental apparatus of μ-PTAPD process used in texturing of HSS cutting tool.

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