PERFORMANCE EVALUATION OF UNCOATED AND COATED CARBIDE TOOLS WHEN DRILLING TITANIUM ALLOY

ERWEEN BIN ABD. RAHIM

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ABSTRACT

Titanium alloys are widely used in the aerospace industry especially in airframes and engine components due to their high strength-weight ratio that is maintained at elevated temperature and their exceptional corrosion resistance. Nevertheless, titanium and its alloys are thought to be difficult-to-machine material due to their poor thermal properties and highly chemical reactivity. In this study, Ti-6Al-4V has been drilled using single-layer PVD-HIS-TiAlN coated carbide, Type A (T12-A) and Type C (T12-C and T13-C), multi-layer PVD-HIS-Supernitride coated carbide, Type A (S13-A) and Type C (S12-C and S13-C) and uncoated carbide Type B (U12-B and U13-B) and Type C (U12-C and U13-C) drills with different drill point geometry under various cutting speeds and constant feed rate. The tool performance, tool failure modes and tool wear mechanisms were analyzed under various cutting speeds. On the other hand, the cutting forces and the surface roughness were measured. In this study, Type C drills outperformed Type A and B drills in terms of tool life for almost all the cutting conditions tested. At low cutting speed of 25 m/min, the uncoated carbide tool of U12-C drills demonstrated the longest tool life, which resulted in low tool wear rate. The excellent improvement of both coated drills were mainly due to their ability of maintaining oxidation resistance and high hardness especially at elevated temperatures. On the other hand, poor performance of Type B drills was mainly due to premature tool failure caused by severe chipping and breakage. Non-uniform flank wear, chipping, cracking and catastrophic failure were the dominant failure modes of all tools under most cutting conditions tested. These failure modes were mainly associated with adhesion, diffusion and plastic deformation wear mechanisms. Based from the results obtained, it can be suggested that Type C drill was recommended and the lower cutting speed of 25 m/min should be employed in order to achieve high performance in drilling Ti-64.

ABSTRAK

Aloi titanium telah digunakan dengan meluas di dalam industri aero-angkasa untuk membuat kerangka pesawat dan komponen enjin disebabkan oleh nisbah diantara kekuatan-berat yang tinggi serta mampu bertahan pada suhu yang melampau dan tahan karat. Tambahan lagi, aloi titanium adalah sukar untuk dimesin kerana sifat termalnya yang lemah dan mempunya tahap tindak balas kimia yang tinggi. Di dalam kajian ini, Ti-6Al-4V telah digerudi menggunakan gerudi disalut selapis TiAlN pada karbida, Jenis A (T12-A) dan Jenis C (T12-C dan T13-C), disalut berlapis-lapis Supernitride pada karbida, Jenis A (S13-A) dan Jenis C (S12-C dan S13-C) dan karbida tanpa disalut, Jenis B (U12-B dan U13-B) dan Jenis C (U12-C dan U13-C) pada pelbagai halaju pemotongan dan kadar suapan malar. Prestasi mata gerudi, mod kegagalan mata alat, dan mekanisma kehausan mata alat telah dianalisa pada keadaan penggerudian yang basah. Daya pemotongan dan kekasaran permukaan pada dinding lubang juga telah diukur. Di dalam kajian ini, gerudi Jenis C adalah lebih baik jika dibandingkan dengan Jenis A dan B dari aspek jangka hayat gerudi tersebut bagi hampir kesemua keadaan pemotongan. Pada halaju pemotongan 25 m/min, gerudi karbida tanpa disalut, U12-C mempamerkan jangka hayat yang lama dan kadar kehausan mata gerudi yang rendah. Peningkatan prestasi bagi gerudi karbida yang disalut adalah disebabkan oleh keupayaan gerudi tersebut untuk menangani pengoksidaan dan mempunyai kekerasan yang tinggi pada suhu yang melampau. Prestasi yang buruk ditunjukkan oleh gerudi Jenis B adalah kerana kegagalan pra-matang disebabkan oleh sumbing yang ketara dan mata alat patah. Kehausan rusuk yang tidak seragam, sumbing, retakan dan kegagalan bencana merupakan mod kegagalan yang utama bagi semua mata alat pada hampir kesemua keadaan penggerudian. Mod-mod kegagalan ini boleh jadi berkaitan dengan rekatan, resapan dan perubahan bentuk plastik. Berdasarkan kepada keputusan yang dicerap, gerudi Jenis C telah disyorkan dengan halaju pemotongan pada 25 m/min bagi mencapai prestasi penggerudian yang optimum untuk menggerudi Ti-6Al-4V.

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α	-	Tool rake angle
b	-	Width of cut
β	-	Friction angle
C_T	-	Chisel edge wear (depth)
C_M	-	Chisel edge wear (width)
2d	-	Drill diameter
F_f	-	Component of parallel frictional force
F_p	-	Component of horizontal force
F_s	-	Component of horizontal shear force
F_t	-	Component of vertical force
i	-	Inclination angle
K_M	-	Crater wear
L	-	Lead length of the helix
M_w	-	Margin wear
N_f	-	Component of normal frictional force
N_s	-	Component of normal shear force
P_M	-	Chipping (width)
P_T	-	Chipping (depth)
2p	-	Drill point angle
R_a	-	Arithmetical mean deviation
R_{max}	-	Maximum height of the profile
R_z	-	Height of the profile irregularities in ten points
r	-	Drill radius
t_c	-	Undeformed chip thickness
V_b	-	Flank wear

$V_{b,max}$	-	Maximum flank wear
W	-	Web thickness
w	-	Outer corner wear
λ	-	Size of built-up edge
φ	-	Shear angle
σ_s	-	Normal stress
τ_s	-	Shear stress
ρ	-	Normalized radial coordinate
γ	-	Chisel edge angle
θ	-	Nominal clearance angle

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CHAPTER 1

INTRODUCTION

1.1 Background

Titanium is more and more often utilized in critical services in a wide variety of chemical, surgical, ship building and aerospace industry. Among the different alloys of titanium, Ti-6Al-4V is the most demanding due to its unique set of properties such as its high strength-to-weight ratio that can be maintained at elevated temperatures, corrosion and erosion resistance. However the material causes severe problems during the machining process. Ti-6Al-4V is notorious to machining due to its low thermal conductivity which causes high cutting temperature. At high temperature, it becomes chemically active and tends to react with most tool materials that are available today. Premature tool failure and inhomogeneous deformation by catastrophic shear are the consequence of the combination problem, which makes the cutting force fluctuate and causes tool wear, thereby aggravating tool wear and chatter. This poor machinability of titanium alloys has limited the cutting speed to less than 60 m/min in industrial applications (Komanduri and von Turkovich, 1981).

As pointed out by Siekmann (1955), machining titanium and its alloys will always be a problem no matter what techniques are employed to transform this metal into chips. Much previous researchers have been carried out to improve the machinability in machining of titanium alloys especially in turning (Komanduri and vonTurkovich,1981; Dearnley and Grearson, 1986; Ezugwu and Wang, 2000; Jawaid et al., 1999; Kitagawa et al., 1997) and milling (Ezugwu and Pashby, 1991; Ezugwu and Machado, 1988; Jawaid et al., 2000; Min and Youzhen, 1988; Sharif et al.,2000). In contrast, very little work has been conducted in drilling of titanium and its alloy especially on Ti-6Al-4V. Sakurai et al. (1991; 1992; 1996), Mantle et al. (1995), Arai and Ogawa (1997), Fujise and Ohtani (1998), Dornfeld et al. (1999), Lopez et al. (2000) and Syed et al. (2002) are among the researchers who investigated the drilling operation on titanium alloys.

Sakurai et al. (1991; 1992; 1996) studied the drilling process of Ti-6Al-4V using high speed steel drill with different cutting strategies (intermittently decelerated feed drilling, vibratory drilling and supplied with high pressure of coolant). They concluded that intermittently decelerated feed drilling have improved the tool life. Mantle et al. (1995) in their research found that the thrust force and torque for Ti-48Al-2Mn-2Nb was greater than Ti-6Al-4V using solid carbide drill. In another work, Arai and Ogawa (1997) had suggested that high pressure of coolant in drilling, can prolong the tool life. The comparison of cooling methods was performed by Lopez et al. (2000). They found that a significant improvement on tool life was achieved when applying high pressure internal cooling during drilling of Ti-6Al-4V.

As pointed by Fujise and Ohtani (1998), the rapid tool wear and the chip adhesion to the cutting edges which resulted in short tool life of high speed steel drill, was mainly due to the combination of heat generated and the concentration of thermal stress on the tool. Dornfeld et al. (1999) investigated the influences of related parameters of high speed steel and solid carbide drills on drilling burr formation and they proposed several basic burr formation mechanism during drilling Ti-6Al-4V. Syed et al. (2002) conducted several drilling experiments in Ti-6Al-4V using different tool geometries of solid carbide drills to determine the burr on the exit hole and hole surface roughness. They found that drill with two helical flutes produced poor results. Although there have been great improvement with regards to drilling of titanium alloy in the last decade, the most recent literatures revealed that the study on the effect of drill point geometry and tool coating is still limited and worth exploring. Therefore, considerable research effort in drilling of titanium alloy offers a significant potential in understanding the effect of the drill point geometry and coating performance.

1.2 Aims and Objectives

Drilling can be classified as a finishing process because most of the other machining processes like milling and turning were done first. Any failure during this process will cause a huge lost in terms of raw materials. This research is designed to evaluate the machining performance of uncoated WC-Co carbide tools, single layer PVD-HIS TiAlN coated carbide tools and multi layer PVD-HIS- Supernitride coated carbide tools as well as various types of drill point geometry when drilling Ti-6Al-4V. The specific objectives of this study are to:

a) establish acceptable cutting conditions for each type of carbide tool when drilling Ti-6Al-4V at various cutting conditions.
b) investigate the wear mechanism and tool failure modes of different type of carbide tools when drilling Ti-6Al-4V at various cutting conditions and various drill point geometries.
c) investigate the effect of various cutting conditions and various drill point geometries on tool life performance as well as the cutting forces.

investigate the effect of various cutting conditions and various drill point geometry on surface finish of the machined surface.