

REVIEW ON ABRASIVE JET MACHINING OF TITANIUM ALLOYS

Chandrakant Chaturvedi, Dr P Sudhakar Rao

¹ME Scholar, Mechanical Engg. Department, NITTTR, Chandigarh
Asst. Professor, Mechanical Engg. Department NITTTR, Chandigarh

Abstract :- Titanium alloy which comes under the category of very difficult to machine material by conventional machining processes because of its extremely short tool life. Titanium is a lightweight metal a widely used aircraft structural titanium alloy (Ti-6Al-4V) was machined with an abrasive water jet (AWJ) since other processes such as chemical machining have environmental legislative restriction and higher cost associated with waste disposal. Various parameters associated with abrasive waterjet machining while machining titanium alloy has been analyzed in this review and provision for further improvement has been considered.

Keywords: Titanium alloy, Abrasive water jet (AWJ), Control depth milling CDM

1. INTRODUCTION

Titanium is a light in weight metal that provides very good corrosion resistance, a high strength-to-weight ratio, and good high-temperature properties. Pure titanium is allotropic substance, with an HCP crystal structure (α phase) at low temperatures and a BCC structure (β phase) above 882° C. Alloying elements affects the strength of solid solutions and change the allotropic transformation temperature. Ti-6Al-4V which is the representative system of $\alpha+\beta$ alloys, most commonly used in the aerospace industry. It accounts for about 50% of total titanium production.[1]

Titanium and its alloys are classified as difficult-to-machine materials. The main problems in machining them are the high cutting temperatures and the frequent tool wear. Most tool materials wear frequently even at moderate cutting speeds. To minimize tool wear, current machining practice limits the cutting speed to less than 1 m/s. The machining characteristics of titanium and its alloys are summarized below.

1. Titanium and its alloys are poor thermal conductors. As a result, when machining titanium, it is difficult to dissipate the heat generated quickly; rather, most of the heat is concentrated on the cutting edge and tool face.
2. Titanium has a strong alloying tendency or chemical reactivity with the cutting tool material at operating temperatures. This is the reason for smearing galling, and welding, along with rapid wear or cutting tool failure.
3. During machining, titanium alloys exhibit thermal plastic instability which leads to unique characteristics of chip formation. The shear strains in the chip are non-uniform, they are localized in a narrow band that forms serrated chips.
4. The contact length between the chip and the tool is extremely short. This implies that the high cutting temperature and the high stress are simultaneously concentrated near the cutting edge (within 0.5 mm).

Titanium and its alloys represent the most challenging materials in machining. Many difficult-to-machine materials can now be machined at higher metal removal rates with advancement in cutting tool materials. None of these tool materials, however, seems to be capable of machining titanium because of their chemical affinities with titanium. New development in tool coating also does not help in machining of titanium. Titanium carbide and titanium nitride coatings are not suitable for machining titanium alloys because of their chemical affinities. Al_2O_3 coating has a lower thermal conductivity than the tungsten carbide inserts, which prevents heat dissipation from extremely concentrated high stress and high temperature at the cutting point. Thus, cryogenic machining, which can lower the cutting temperature and enhance chemical stability of the work-piece and the tool, can greatly increase productivity level in the machining of titanium and its alloys.[2]

Titanium alloy has many unique mechanical and physical properties such as high strength to weight ratio, high-temperature strength, and very good corrosion resistance. These are the major reasons that titanium alloys are used up to great extent, in aerospace engine components as well as for structural members. Other applications of titanium alloys include the chemical, electronic and biomedical industries. Among several alloys of titanium, Ti-6Al-4V is the most used structural alloy in the aerospace industry, providing 45 percent of the industry's total titanium alloy consumption. The superior mechanical properties that are beneficial for service conditions also limit the machinability of the titanium alloy. Since the first studies on the machining of titanium alloys in the 1950s, enormous effort has been focused on the development of improved machining methods for surface integrity and longer tool life. When machining titanium, the high strength induces very high cutting stress at a localized tool-workpiece contact and leads to a temperature rise. The machining-induced thermal energy is not effectively dissipated due to the adverse thermal properties of titanium. Therefore, the poor machinability of titanium alloys is mainly due to the high-temperature rise and rapid tool wear during

machining, which limits the cutting speed and tool life. Among the variety of cutting tools currently available, straight grade (WC/Co) cemented carbide tools are recommended to be the most suitable for continuous cutting and high-speed steel tools for interrupted cutting under the application of cutting fluid. At an elevated temperature, the titanium is chemically active with maximum tool materials; due to which, the tool wear is accelerated and resulting in short tool life. Also, inhomogeneous shear localization due to the serrated and unstable chip formation causes the resultant cutting forces to fluctuate. This, combined with the low elastic modulus of titanium, causes chatter and excessive deflection of the machined parts. However, the titanium alloys are still classified as one of the extremely difficult-to-machine.

Abrasive water-jetting (AWJ) is a technology for material removal, where abrasive particles are entrained into a jet of water which is accelerated to high velocities by use of high pressure more than 130 MPa. The particle-laden water jet strikes onto the surface of the workpiece and material is removed by an erosion process.[3] AWJ cutting is a relatively mature technology through cutting; however, the development of the method for controlled-depth milling (AWJ-CDM) is less well developed. AWJ-CDM has been shown to be suitable for processing of flexible structures and difficult-to-machine materials. However, it has been found that if the low traverse speeds and large grit sizes used for AWJ cutting are employed for CDM, the surface waviness and roughness of the component may be very high of the order of millimeters. There has, however, been some success reported in the literature in achieving a depth tolerance of ± 0.025 mm and a surface waviness of 50 μ m using AWJ CDM on aluminum alloy.

The traverse speed of the jet over the workpiece also has a strong influence on its surface finish. Low traverse speeds result in irregular surface morphology of the milled area but that despite this, lower surface roughness values are observed. It is observed that low surface roughness values require a high number of particle impacts per unit area; such conditions result from lower traverse speeds, higher abrasive flow rates or by use of a smaller mixing tube to orifice ratio. Surface waviness is reduced with the increase of traverse speed up to 0.01 ms⁻¹ (600 mm in⁻¹) but that further increases in traverse speed yield only small improvements. However, to achieve surface uniformity (i.e. a low surface waviness) the traverse speed must exceed a higher critical value (0.016 ms⁻¹ (960 mm min⁻¹)).[4]

AWJ-CDM shows some promise as a method for shaping materials and structures that are difficult to machine by conventional processes. However, as seen, the MRR and the surface finish and tolerances of the machined component depend critically on several processing variables, amongst them abrasive grit size and jet traverse speed.

Grit embedment and the surface characteristic is a problem for the service life of component manufactured by AWJ-CDM, especially in case of fatigue failure. The effects of milling parameters (namely jet-workpiece traverse speed, jet impingement angle, milling direction, and grit size) on the surface morphology and degree of grit embedment are investigated for the milling of a titanium alloy (Ti-6Al-4V) with garnet grit.[5] Up to 40% of the area of a milled surface has been shown to consist of embedded grit. Grit embedment can be minimized either by milling with a high jet traverse speed at low impingement angles or by low-speed milling at jet impingement angles up to 45° in the backward direction only. However, even in the best cases, 5% of the area of a milled surface was composed of embedded grit.

While considering nature of grit embedment, it was found that whole grit particles are not embedded but only shed up-to small fraction of particle size depth and a non-imbedded portion of particle size is broken away by the subsequent impact. Grit size has only a small influence on the level of grit embedment. It is reasonable to assume that the degree of grit embedment will be a function of both the number of particles striking unit area and the tendency for an individual particle to embed.[6] However, the level of grit embedment will not increase linearly with particle dose (number of particles impacting per unit area) since as the dose becomes greater, some embedded particles will be removed by the later impacts (this has been demonstrated to be the case in milling with a high jet traverse speed. For the same abrasive mass flow rate, the dose of particles (measured by particle number rather than mass) impacting the surface will be larger for the smaller sized grit. Whilst it is not clear exactly what parameters control grit embedment into a surface, it is reasonable to assume that particles that penetrate deeper into the workpiece will have a higher tendency to embed.

2. LITERATURE REVIEW

Sr no	Name of author	Title	Year	The methodology used / Parameter analyzed	Results and discussion
01	Shane Y. Hong, Irel Markus, woo-Cheol jiong[1]	New cooling approach and tool life improvement in cryogenic machining of titanium alloy ti6al-4v	2001	Temperature effect on material properties and cooling considerations. New economical cryogenic cooling approach Design Implementation	Economical cryogenic machining approach uses the minimum amount of liquid nitrogen through micro-nozzle between chip breaker and tool rake. This approach provides the best tool life than any other machining method.
02	YW Seo, M Ramulu and D Kim [2]	Machinability of titanium alloy (Ti-Al-4V) by abrasive waterjets	2003	Titanium alloy Ti-6Al-4V, was AWJ machined under a variety of experimental conditions. The conditions included a pressure of 138±207 MPa, garnet size of mesh 50±100	The transverse speed of .7mm/s was found to be the most appropriate speed for the best surface finish. Material removal in the AWJ cut has been observed to occur by ductile shearing and by abrasive scooping and the ploughing action of the

				and the standoff distance of 1.0 ± 4.0 mm at a traverse speed of 0.7 ± 2.4 mm/s at a constant flow rate of 10 grams/s. Profiles of machined surfaces, kerf geometries and microstructural features of the machined surfaces were analyzed using surface profilometry, SEM and EDX system.	abrasive particles. The machined surface with features at the jet exit exhibited basically the similar ductile shearing and abrasive scooping action, even in the wavy/groovy patterned rough cutting region.
03	G. Fowler, P.H. Shipway and I.R. Passby[5]	A technical note on grit embedment following abrasive water-jet milling of titanium alloy	2005	Single passes of the jet were used at low traverse speeds whereas at higher traverse speeds where the amount of material removed per pass was low multiple passes were employed.	Multiple passing of jet over workpiece has no effect on surface morphology. Grit embedment is higher in forward milling while it is lower in backward milling. With a higher jet, transverse speed milling direction does not influence grit embedment.
04	G. Fowler, P.H. Shipway and I.R. Passby[6]	Abrasive water-jet controlled depth milling of Ti-6Al-4V alloy – an investigation of the role of jet–workpiece traverse speed and abrasive grit size on the characteristics of the milled material	2005	Effect of transverse speed, milling direction, grit size and no of passes were considered for examination while machining titanium alloy with AWJ-CDM.	Surface waviness increase with no of passes while surface roughness is independent of the same. Higher transverse speed results in lower material removal rate. The MRR, surface roughness and waviness were lower for smaller grit.
05	Ahmet Hascalik, Ulas Caydas, and Hakan Gurun[4]	Effect of traverse speed on abrasive waterjet machining of Ti-6Al-4V alloy	2007	Machined under varying traverse speeds of 60, 80, 120, 150, 200, and 250 mm/min by abrasive waterjet (AWJ) machining.	In this paper, the author identified three zone IDR (initial damage region) which is at a shallow angle of attack, SCR (smooth cutting region) which is at large angle of attack, RCR (rough cutting region) jet upward deflection zone. The traverse speed appears to be a significant parameter on the depth of the SCR.
06	G. Fowler, P.H. Shipway and I.R. Pashby[6]	The effect of particle hardness and shape when abrasive water jet milling titanium alloy Ti-6Al-4V	2009	Process parameters under investigation were traverse speed, shape, and hardness of the abrasive particles.	1. With an increase in particle hardness material removal rate and surface roughness increases. 2. Surface waviness is not affected by shape and particle hardness.
07	MC Kong and D Axinte[7]	Response of titanium aluminide alloy to abrasive waterjet cutting: geometrical accuracy and surface integrity issues versus process parameters	2009	Geometrical accuracy, surface texture, and surface morphology are analyzed with newly defined width to nozzle ratio and depth to thickness ration along with the ability of AWJ to machine Ti-Al alloy.	The cutting parameters to obtain the best kerf in terms of geometrical accuracy and surface quality has been found ($P \frac{1}{4} 50$ kspi, $MRR \frac{1}{4} 220$ mm ³ /min, $AFR \frac{1}{4} 0.773$ kg/min, $SOD \frac{1}{4} 1$ mm). These combinations can achieve satisfactory results:
08	F. Boud, C. Carpenter J. Folkes, P.H. Shipway [8]	Abrasive waterjet cutting of a titanium alloy: The influence of abrasive	2010	- Cutting was performed at two jet-traverse speeds of 50 and 400 mm min⁻¹. - The tests were run on a	The cutting efficiency and degree of grit embedment were near about the same for the five abrasive types utilized, despite their different

		morphology and mechanical properties on workpiece grit embedment and cut quality		commonly utilized aerospace titanium alloy, namely Ti-6Al-4V, with a Vickers hardness of 330 kgf mm ⁻² . • The titanium plate had a thickness of 14 mm. • Five garnet abrasives, all with the same nominal size range of 80 mesh, were employed. • The five abrasives were all from different source.	morphologies (associated with the different sources of the grits), hardness and fracture loads.
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3. CONCLUSIONS

Considering the difficulties while machining titanium alloy by the conventional machining process. AWJ machining has become a significant process to machine such alloy, however, there are some problems associated with it i.e. grit embedment, surface waviness, lower material removal rate which provide us with a way for improvement in nearby future. Apart from that some conclusions which were observed during the review of these papers provided below

1. Material removal in the AWJ cut has been observed to occur by ductile shearing and by abrasive scooping and the ploughing action of the abrasive particles.
2. Multiple passing of jet over workpiece has no effect on surface morphology. Grit embedment is higher in forward milling while it is lower in backward milling. With a higher jet, transverse speed milling direction does not influence grit embedment.
3. Surface waviness increase with no of passes while surface roughness is independent of the same. Higher transverse speed results in lower material removal rate.
4. The MRR, surface roughness and waviness were lower for smaller grit.
5. The traverse speed appears to be a significant parameter on the depth of the SCR.

4. FUTURE SCOPE

AWJ machining has become a significant process to machine titanium alloys. However, there are some problems associated with it i.e. grit embedment, surface waviness, lower material removal rate which provide us with a way for improvement in nearby future.

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