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Review on HSM of Titanium Alloys in Aerospace Industry

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Abstract

Despite of good strength-to-weight ratio and superior corrosion resistance of titanium alloys, it is very difficult to machine them due to their poor machinability. Productivity and efficiency of the titanium alloys can be improved by means of high speed machining tools. Eventually, it is a much needed technology to complement the advancements in aerospace manufacturing applications. A bulk of literature is accounted for the purpose that simply suggest that different methods are being employed by researchers to improve the machinability of Titanium alloys in numerous aerospace as well as other engineering applications. In the present paper, a brief review is made on several past research works related to enhancement of conventional machining of titanium alloys and it was affirmed that HSM is one of the most preferable techniques to serve the purpose.

Keywords: titanium, high-speed machining (HSM), machinability, aerospace applications, corrosion, thermal conductivity

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INTRODUCTION

Significant advances have been made in understanding the behavior of engineering materials, when machining at higher cutting conditions from practical and theoretical standpoints. With the very nature, aerospace applications demand parts, which are both extremely strong and very light. Titanium remains one of few metals that have the capability of meeting high standards that is required in modern aerospace applications.

In the paper by Mustafizur Rahman et al., it has been discussed regarding the HSM of titanium alloys, that on machining titanium alloys with conventional tools. The tool wear rates progress fast, and it is generally hard to achieve a cutting speed of over 60m/min. Different types of tool materials, such as and cubic boron nitride (CBN) and ceramic, diamond, are highly applicable with titanium alloys at higher temperature. Although binder-less CBN (BCBN) tools that do not have any sintering agent, binder, or catalyst, have a remarkable larger tool life than conventional CBN inserts even at high cutting speeds. In order to find more sensitive understanding of high speed machining (HSM) of titanium alloys, the generation of mathematical models is needed. The models are also an important to predict the machining parameters for HSM.

Nabhani conducted turning tests on rolled and annealed TA48 (Ti-5Al-4Mo-(2-2.5) Sn-(6-7) Si-2Fe max: 0.015H, 0.5O, 0.05N) using PCBN, Polycrystalline Diamond (PCD) & Coated WC at a surface sped of 75m/min, feed rate 0.25 mm/rev, depth of cut 1.0 mm without cutting fluid. They investigated tool/workpiece interaction, wear rate, and performance using quick-stop tests. Plastic deformation of carbide tools under compressive stress was observed close to the cutting edge at high temperatures. The performance of carbide tools was not effective as the coated layers were rapidly removed during machining, leaving the tungsten carbide substrate open to cratering. The PCBN and carbide tools had the same wear mechanisms, while the lowest wear rate and best surface finish was observed in PCD when compared with other two inserts.

Like all steels and aluminum grades have identical machining characteristics, Ti-alloys of different grades i.e. commercially pure and various alloys do not have same machining characteristics. Ti inhibits dissipation of heat with in the work piece itself because of low thermal conductivity. The study of HSM Ti-alloys by conventional machining approached as an appearance of crystal structures of Ti at the atomic level.

(a) Hexagonal; close packed.
(b) Cubic, body centered milling and turning.

These level of structures are considered, and important findings are sorted. Finding for the most efficient combination of tool, workpiece materials, turning and milling strategy for the particular application, machining parameters, and specific analyses are considered.

Characteristics of Titanium Alloy

The characteristics of titanium alloys make them the preferred choice for use in the aerospace industry. Because of this, the aerospace industry is among the largest purchases industries of titanium products and raw titanium – purchasing around 11% of all titanium alloys.

- Lightweight, yet strong, uniquely versatile metal
- High strength and low weight, hence, more specifically, low weight-to-strength ratio.
- Low weight leads to low density
- Low thermal expansion rate

Significance of Titanium in Aerospace Applications

In aerospace industry applications, it has a unique problem and titanium is a uniquely qualified solution. Over the course of an aircraft's lifespan – anywhere from 20 to 50 years or more, use of titanium has eventually improved the aircraft's performance. Its significance is discussed in detail in the following:

- Decreased fuel use results in considerable decreases in overall operational costs. Use of titanium in aircraft can also increase that aircraft's range while decreasing its fuel use.
- The lighter an object is, the easier it is to make it airborne; simultaneously, cargo passengers require protection from the high speeds and altitudes, so strength is also an important factor. High strength allows it to be used to reduce the weight of an aircraft without sacrificing the aircraft's structural integrity. A light aircraft is required less fuel to fly, required for less refueling stops and subsequently longer periods spent in continuous flight.
- In addition, titanium is also highly resistant to corrosion. When titanium is exposed to pure oxygen or air at high temperatures, titanium forms a passive oxide coating. The coating continues to increase often reaching thickness of 25 nm up to 4 years after the treatment. These passivating layers

protect the titanium from other forms of corrosion and oxidation.

- Thermal expansion described the tendency of a material to change its volume, shape, and area because of changes in temperature. The thermal expansion of a material can be weaken it, create cracks, cause deformation, or cause it to fail or break overall. Naturally, titanium has a low-thermal expansion rate, making it an ideal material for the use in aircraft that experiences a great temperature changes at different climates and different altitudes.

HIGH SPEED MACHINING

High speed machining (HSM) is one of the procedures expected for lower costs, delivering efficiently, shorter lead and production times, and better quality build products. HSM in practice has been carried out by enhancing the spindle designs, control systems and tools. Efficiency and productivity of the machining process can be improved by exploring feed rates in accordance with cutting velocity leading to high chip-removal rates with small tool diameters.

HSM is also defined as the high productive rate, high rotational speed (n), high cutting speed (v), high speed, high feed (f), and feed. HSM is not only simply feed essentially and high cutting speed, but also process where the operations are performed with very specific methods and production equipment like machining components of all sizes from roughing to finishing, identifying as high productive machining. Low-cutting forces are involved in HSM, ensuing stress free components, high-quality surface finish, burr free edges as well as productivity increment.

Since eight years, there is an outstanding progress in machining of the Ti-alloys for different applications. Machining of Ti alloys can be done by conventional processes, such as turning, milling, tapping, grinding, drilling, and sawing and also by non-conventional processes, such as water jet machining, electric discharge machining, chemical milling, and ultrasonic machining. In conventional machining (CM), hogging is very light, that is, the material extraction rate is less as the spindle speeds are low, and the amount of cutting time will be high.

HSM of Titanium Alloy

Although titanium is considered to be the most suitable material for aerospace applications, it elucidates many engineering challenges for its effective utilization. The tool wear, surface finish, material removal rate, and overall cost are the major challenges in titanium machining. In order to meet these challenges conventional high speed machining is one of the solutions to produce more durable and quality products.

REVIEW OF THE WORKS ON ENHANCEMENT OF HSM OF TITANIUM ALLOYS

In the study of Chakradhar Bandapalli et al., here is discussed to find the most efficient combination of tool, milling strategy, machining parameters, workpiece materials, etc. for the particular application. This work is carried out by various researchers whom are studied in the field of conventional machining of titanium alloys considering only milling and turning operation, and important findings are narrated.

In the study of Ezugwu, paper presented an overview of major advances in machining techniques, which have resulted to increase the steps in productivity; therefore, lower manufacturing cost without adverse effect on the surface finish, circularity, surface integrity, and hardness variation of the machined component.

Narutaki et al. performed turning tests on alloys Ti-6Al-4V (α+β) & Ti-5Al-2.5Sn (β) with cutting speeds 0.5 to 5.0 m/s, feed 0.1 mm/rev, depth of cut 0.5 mm, and cutting fluid of soluble type and found that for both the work pieces, natural diamond tool is exhibited an excellent cutting performance compared to other tools such as straight tungsten carbide (WC-K10), cemented TiN, coated TiC, CBN tool, pure aluminum oxide type of ceramic, and sintered diamond. It has been claimed that cutting force for Ti-alloy was to be about one half of that of a carbon steel (0.45%C), and cutting temperature was to be about 2500C higher than that of carbon steel due to low-thermal conductivity and density of Ti-alloys.

In Yanga et al.'s study, the developed 3D transient finite element model for a moving Gaussian laser heat source to predict the depth of the heat-affected zone (HAZ) and temperature distribution in Ti-6Al-4V alloy workpiece is identified. The temperature profile and depth of HAZ strongly depend on the parameters of laser beam. Close agreement was shown between the thermal model simulations and the results produced by experimental work.

Huang, Li, Sun, & Ge used solid cemented carbide end mill for down milling operation on Ti-6Al-4V by varying cutting speeds from 80 to 360 m/min, constant feed per tooth 0.08 mm/tooth, axial depth of cut 20 mm and radial depth of cut 0.5 mm under dry cutting conditions. Machining chatter was investigated with variable pitch end mill through signal analysis method and compared at stable and unstable milling processes and found that chatter occurs because of milling speeds and impact forces that increases strain hardening grate of the workpiece and thermal softening with increasing milling temperature. Optimal cutting speed was achieved at 160 m/min achieving good machined surface quality and smaller milling force at this cutting speed.

In the study of Niu et al., it is performed that the end milling using Ti-6Al-4V (ASTM Grade 5) and Ti-6Al-4V extra Low Interstitial (ELI) (ASTM Grade 23) in Beta Annealed (BA), JHP 70 HPM Tribon end mill on Ti-alloys, and Mill Annealed (MA) heat treatment conditions with three different cutting speeds 50, 100 and 150 m/min; depth of cut (2 mm) as kept constant, the feed rate (0.04 mm/tooth), and flood coolant was used during machining. Effect of cutting speed on the surface integrity and fatigue property of both alloys at a stress level of 600 MPa was investigated and no clear relationship was found between cutting speed and surface roughness and also there was no measurable influence on the fatigue life of either alloy.

CONCLUSION

Improvements achieved from research and development activities in the area of high speed machining have particularly enhanced the machining of difficult-to-cut nickel base and titanium alloys, which have traditionally exhibited low machinability due to their peculiar characteristics like high strength at elevated temperature, poor thermal conductivity, resistance to wear, and chemical degradation. A good understanding of the cutting conditions, processing time, cutting tool materials, and functionality of the machined component will lead to efficient and economic machining of titanium-based superalloys. HSM of Ti-alloys could be done by using advanced cutting tools inserts like BCBN, PCBN, PCD and Cemented Carbide tools.

More efforts should be kept in improving conventional machining because nonconventional machining is not suitable for mass production. Though much work was already carried out regarding the machining of Ti-alloys, still more attention is to be given to other machining parameters for cost efficient machining of Ti-alloys considering optimization techniques, statistical methods and simulations. In order to have advancement in this process, innovation and development of tool materials and tool geometry should be considered by industries and researchers as the machining of Ti-alloys is mainly dependent on the tribological aspects like wear and the coolant. The tool wear determines the tool life which is essential for mass production, cost reduction and without uninterrupted cutting.

New spindle designs and milling cutters should accomplish tool inserts having shapes like round, pentagonal, hexagonal, hectagonal and octagonal cornered. Coolants play the important role for improving the tool conditions as the heat dissipation while machining Ti-alloys is less because of low thermal conductivity.

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