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Design Review and Analysis of Titanium Alloys and its Cutting Parameters for High Speed Precision Machining

Mr.C.Manivel, Ms.Malarvizhi, Dr.L.Savadamuthu

Abstract— *Aerospace, automotive and biomedical parts manufacturers widely use titanium metal matrix composites because of their high specific strength and exceptional resistance to corrosion. The machinability of metal-titanium matrix composites is the biggest threat because their low thermal conductivity and elastic modulus are bigger challenges to overcome; it also acquires high hardness at high temperature with high chemical reactivity.*

This study covers the analysis of the machinability parameters of the processing of metal titanium matrix composites and focuses on the optimization of the machining process. Potentially improved parameters are cutting and machining forces, alloy chip formation and cutting temperature reduction. The CNC milling process of Ti-6Al-4V alloy parameters has been determined and studied in detail for optimization

Keywords— *Aerospace, automotive , biomedical parts, metal-titanium matrix etc.*

I. INTRODUCTION

The machinability of titanium metal matrix composites will be the biggest challenge to tackle and researchers from industry and academia have repeatedly shown this on reputable magazine. Selecting the correct cutting speed, feed rate and depth of cut determines many parameters of the cutting dynamics of all machining parameters.

The main objective of the paper is to understand the impact of changing machining environment on different aspects of titanium alloy machining. Some other parameters such as rake angle, tool wear rate, type of cutting tool, type of coating on the cutting edge, thermal conductivity of cutting material, lubricating fluid and lubricant flow rate, forming pattern chips, the influence of the alloying elements and its crystal structure Unlike other ferrous and non-ferrous materials, the hardness of the material is not an indicative parameter for optimal planning for cutting parameters. In-depth studies on the experimental results of diamond milling of metals such as aluminum, stainless steel, etc. is considered to determine the parameters of titanium metal matrix composites.

Homogeneous crystalline material forms single crystals, showing that shear force fluctuations depend on frictional conditions during cutting. Therefore, a polycrystalline material with such a strong crystalline texture also requires special attention to machinability studies. It is understood that the dynamic behavior of various forces and signals is affected by the type, location and configuration of the wear mode. Simulation of high-speed dry machining of Ti-6Al-4V alloy shows that shear fluctuations can be caused by chip fragmentation.

Reducing vehicle mass and thus fuel consumption is one of the most important goals of automotive materials research. Titanium alloys are promising automotive materials due to their excellent strength-to-weight ratio, high corrosion resistance, and ability to maintain strength at elevated temperatures.

However, titanium alloys have limited applications in the mainstream automotive segments due to their higher processing costs. Titanium alloy properties such as poor thermal conductivity, low modulus of elasticity, ability to maintain strength at high temperatures, and reactivity with tool materials increase the machining cost of titanium alloys. Significant research has been done to reduce titanium alloy processing costs through advancements in materials and tool geometries, new lubricant formulations and lubrication techniques, coatings and modifications. of the machining environment indicates that studies on the machinability of titanium materials, Taguchi technique in machining optimization, response surface method in machining optimization, measurement of surface roughness Surface and cutting temperatures are widely discussed.

II. TITAN PROCESSING STUDIES

The demand for machining titanium alloys has increased in recent years. To understand and approach the current research situation in titanium alloy machining, a literature review was performed. This study focuses on the machining properties of titanium. In general, it is necessary to finish machining a titanium part, due to the requirements for dimensional accuracy, surface quality, and material consistency. Machining of titanium alloys poses a significant problem due to its poor machinability (Klaus Gebauer 2006, Komanduri & Reed 1983 and Awopetu et al 2005). Titanium's low machinability has led many large companies to invest large sums of money in

Mr.C.Manivel, Assistant Professor, Nehru Institute of Engineering & Technology, Coimbatore, Tamilnadu, India

Ms.Malarvizhi, Assistant Professor, Rathinam Technical Campus, Coimbatore..Tamilnadu, India

Dr.L.Savadamuthu, Professor, SNS College of Technology, Coimbatore, Tamilnadu, India

developing techniques to minimize machining costs. Machao & Wallbank (1990) and Ramesh et al (2008) considered that tool manufacturers are looking for new tool materials that can extend tool life in the face of such a challenge.

It should be noted that the first literature on machining titanium alloys was presented by Siekmann (1955). It has been shown that machining titanium and its alloys will always be an issue, regardless of the technique used to chip the metal. Komanduri & Von (1981) have shown that the machining difficulty of titanium alloys is always true when it comes to tool materials. While improving machining speed will greatly help in increasing material utilization, it should be noted that this is only one of many factors that affect material utilization. Other things, including material costs, must also be considered in any particular application.

Alpha-beta alloys details, Ti-64 accounts for about 45% of total titanium production, non-alloy grades about 30% are presented by several researchers. Komanduri et al. (2005) presented new observations on the chip formation mechanism to increase productivity when machining titanium and reported interesting findings towards the goal. Hartung et al (1982) studied turning tests on Ti-64 with conventional cemented carbide Carboloy 820 and Kennametal K68. They analyzed and proposed that the wear rate of the tool material, which maintains a stable reactive layer, is limited by the diffusion rate of the tool components from the tool chip interface. Diffusion flux correlates well with the observed wear rate. Bhaumik et al (1995) developed a boron nitride-cubic boron nitride (wBN-cBN) composite tool by high pressure/high temperature sintering for machining Ti-64 alloy. In their investigation, they showed that this composite tool could be economically used to machine titanium alloys.

Tool failure modes and wear mechanisms of both tools were tested under different cutting conditions. The performance of uncoated and multilayer CVD coated carbide alloy tools was analyzed for tool life and surface finish. It has been observed that most studies have focused on instrument temperature or surface roughness. No comprehensive analysis is underway to evaluate titanium machining performance.

Nurul Amin et al (2007) listed several applications of titanium in many fields such as refineries, surgical applications, chemical industry, food industry, automotive and marine applications. Titanium is the best material in these industries due to its outstanding mechanical properties, heat resistance and corrosion resistance. Titanium has a density of only about 60% of steel, has a strength far superior to many steel alloys. However, titanium causes many machining difficulties. It has low electrical conductivity and so the heat from cutting does not dissipate quickly. This results in heat concentration on the cutting edge and thus significantly limits the machinability of this material.

III. METHODS

Milling is one of the most widely used machining operations in the manufacturing industry. The situation becomes very difficult to handle when hard materials have to undergo milling. The possibility of tool wear and surface roughness damage increases with high cutting forces and high temperatures at the interface of the cutting tool and workpiece.

Experimental data show that cryo-cooling is more durable than dry-cooling and conventional cooling and provides the best results for tool life, surface finish workpiece, productivity with the least environmental impact, lowest energy costs and lowest machining costs.

A. PROBLEM STATEMENT

A literature review of recent articles found that the following are the parameters that can be determined by the case study method, Cutting speed, Feed rate, Direction depth of cut, Frictional tool wear, Chip microstructure, Machine influence, Increasing cutting speed causes a linear increase in the frequency of the dynamic force, but the corresponding amplitude varies inversely during dry grinding of Ti-6Al-4V alloy, vibration during machining. These parameters should be considered for high-speed machining operations, and the machinability of titanium metal matrix composites is generally governed by the parameters listed. An objective case study was performed to determine the parameters in a standard machine tool. The machinability of metal titanium matrix composites is significantly worse than that of other materials. The behavior of materials in high-speed milling operations is being studied; Material structure should be checked after machining. Surface roughness is a measure of the technological quality of the product and affects the production cost and product quality. Therefore, industries always choose to maintain good quality of machined parts.

B. RESPONSE SURFACE METHODOLOGY IN MACHINING

The response surface method is an economical method used to predict the optimum conditions for machining. Response surface methodology method is highly reliable, practical and relatively easy for usage. More researchers investigated surface finish using this response surface methodology, Taraman (1974), Sundaram and Lambert (1981). Choudhary and Baradie (1997), Mital and Mehta (1998), Kopac et al (2002) demonstrated the usage of response surface methodology in developing surface roughness prediction model

Sulaiman et al (2014) investigated the turning parameters for Titanium alloy using Response surface methodology. Due to the low machinability conditions, the machining of Titanium material is difficult. Response surface method with Box-Behnken design method was adopted to study the effect of cutting parameters (cutting speed, feed rate and depth of cut) against the responses (surface roughness, tool life etc.). RSM analysed that the cutting speed have the greatest influence on tool life followed by feed rate and depth of cut. Feed rate is found to be great influencing parameter in analysis of surface roughness.

Dass and Chauhan (2013) investigated the effect of tool material on the machinability of Titanium alloy using response surface methodology. The cutting parameter selected for the investigations are cutting speed, feed rate, depth of cut, approach angle. Comparison on two different cutting materials inserts, viz, polycrystalline diamond and cubic boron nitride with 47 ` similar tool geometry for similar machining operations are carried out for the investigations. Response surface methodology with central composite design is employed to evaluate the objective function. It is concluded that the approach angle is the dominant factor in evaluation of surface roughness in machining process.

Dureja et al (2014) investigated surface roughness and tool wear in hard turning of AISI steel with coated carbide cutting tool using Response surface methodology. Desirability function module in Response surface methodology is applied to obtain the optimal set of input parameters for minimization of tool life and surface roughness. These results are also compared with Taguchi technique and the results of the RSM and Taguchi technique is found to be in close proximity.

C. OVERVIEW OF SURFACE ROUGHNESS AND CUTTING TEMPERATURE MEASUREMENT

Mustafizurahman et al (2006), Ramesh et al (2008), Ezugwu et al (1997), Ozel et al (2010) experimented several experiments to determine the importance of surface roughness and wear rate in a machining operation. It is discovered that high wear rate may lead to an uneconomical machining and eventually poor surface finish will be obtained on the surface of the work piece. The wear rate of titanium machining is controlled using CBN as tooling material. Nouari and Ginting (2006) investigated the performance of alloyed cutting tool while machining pure titanium material and studied the wear mechanism of the tool. Due to the properties of low thermal conductivity and high thermal conductivity, the machining of titanium is always considered to the difficult- machine material, Ezugwu and Wang (1997). The adhesion of the titanium material on to the cutting tool leads to premature tool failure and poor surface finish. Also titanium material exhibits high strength at elevated temperatures and low modulus of elasticity, which makes the material difficult-tomachine, Hong (1993). The importance of surface finish is highlighted by Karmer and Harthung (1981) as it will bring out improved strength properties, corrosion and thermal resistance.

Jawahir and Wang (2007), Jawahir et al (2003), Wang et al (2007) have used several optimization techniques for turning operations. It is deliberated that selection of proper process parameters will give the optimum cutting conditions and good surface finish. Also proper selection of cutting parameters improves machinability, tool life, reduces tool wear, decreases cutting forces and improve material removal rate. The performance of surface roughness and tool life of machining operations are defined by the machining parameters like feed rate, cutting speed and depth of cut, Yang and Tarng (1998).

Byrne (1987), Stephenson et al (1991) used thermocouple method of measuring the cutting temperature to measure the mean temperature over the entire cutting area. Thermocouples are rugged and inexpensive transducers used to measure the cutting temperature over a wide range of temperature. Temperature measurement using natural thermocouple relies on the principle that when metals are in contact, a small voltage is produced and this change is voltage is directly proportional to the change in temperature of metal in contact. If these two metals are considered as the tool and workpiece, then temperature can be measured on the border surface between the tool and the workpiece. The disadvantage of this method of temperature measurement is that the coolant or the lubricants cannot be used. Reichenbach (1958) demonstrated the use of infrared thermography to measure the cutting temperature. Photoconductive cells are used to measure the face temperature of a cutting tool in a shear plane in metal cutting operation. Investigators used an infrared sensitive photographic plate to measure the cutting temperature. This method is used to measure the cutting temperature in tool chip interface of a single point cutting tool during an orthogonal cutting process. Wang et al (1996) and Yourong et al (1998) determined the distribution of temperature during turning operation on the rake and flank faces of two ceramic cutting tools using infrared method of temperature measurement.

IV. CEMENTED CARBIDE

A. CARBIDE TOOL

Cemented carbide is a hard material used extensively as cutting tool material, as well as other industrial applications. Carbide tools can withstand higher temperatures at the cutter-workpiece interface than standard high-speed steel tools (which is a principal reason for the faster machining)

Carbide (or more specifically tungsten carbide and titanium carbide) is a very common material on any sort of cutting tool: For example, saw blades, lathe bits, drill bits, router bits and dental drilling tips are generally made of carbide. Carbide is so popular in these sorts of tools because it stays sharper longer than most other materials. Additionally, some ball-point pens use carbide balls because it helps the pen last longer.

With something like a carbide-tipped saw blade, the main body of the blade is made of steel. The small tips of carbide are brazed on to the body. A good carbide tip might hold an edge ten to twenty times longer than a tool steel tip.

Carbide is much denser than both steel and Titanium. Its finished product is often polished and finished with harder abrasives such as diamonds. It's truly a versatile and durable material.

Carbide tipped tools retain their cutting edge hardness at high machining temperatures generated by high cutting speeds and feeds that reduce machining cycle time. Carbide tipped tools improve surface finish and hold size far longer for better quality. With the right machine and the right tooling, hard-turning offers an economical and cost-saving alternative to conventional machining techniques such as grinding. The granulated mixture is poured into a die cavity and pressed. It gives a moderate strength like that of chalk. Next, the pressed compacts are placed in a sintering furnace and heated at a temperature of about 1400°C, resulting in cemented carbide.

Carbide is very strong and resists being cut by lower grade metals such as high- speed steel. Most cutters such as saw blades are made from HSS metals or made from carbide.

Fig 1.CARBIDE TOOL

B. VERTICAL MILLING MACHINE

Milling is the process of machining using rotary cutters to remove material by advancing a cutter into a work piece. This may be done varying direction on one or several axes, cutter head speed, and pressure. Milling covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes for machining custom parts to precise tolerances.

Milling can be done with a wide range of machining tool. The original class of machine tools for milling was the milling machine (often called a mill). After the advent of Computer Numerical Control (CNC) in the 1960s, milling machines evolved into machining centers: milling machines augmented by automatic tool changers, tool magazines or carousels, CNC capability, coolant systems, and enclosures. Milling centers are generally classified as vertical machining centers (VMCs) or horizontal machining centers (HMCs).

The integration of milling into turning environments, and vice versa, began with live tooling for lathes and the occasional use of mills for turning operations. This led to a new class of machine tools, multitasking machines (MTMs), which are purpose-built to facilitate milling and turning within the same work envelope.

In the vertical milling machine the spindle axis is vertically oriented. Milling cutter are held in the spindle and rotate on its axis. The spindle can generally be lowered (or the table can be raised, giving the same relative effect of bringing the cutter closer or deeper into the work), allowing plunge cuts and drilling. There are two subcategories of vertical mills: the bed mill and the turret mill.

- A turret mill has a fixed spindle and the table is moved both perpendicular and parallel to the spindle axis to accomplish cutting. Some turret mills have a quill which allows the milling cutter (or a drill) to be raised and lowered in a manner similar to a drill press. This provides two methods of cutting in the vertical (Z) direction: by raising or lowering the quill, and by moving the knee.
- In the bed mill, however, the table moves only perpendicular to the spindle's axis, while the spindle itself moves parallel to its own axis.

Turret mills are generally considered by some to be more versatile of the two designs.

A third type also exists, a lighter, more versatile machine, called a mill-drill. The mill-drill is a close relative of the vertical mill and quite popular in light industry; and with hobbyists. A mill-drill is similar in basic configuration to a very heavy drill press, but equipped with an X-Y table and a much larger column. They also typically use more powerful motors than a comparably sized drill press, most are multi-speed belt driven with some models having a geared head or electronic speed control. They generally have quite heavy-duty spindle bearings to deal with the lateral loading on the spindle that is created by a milling operation. A mill drill also typically raises and lowers the entire head, including motor, often on a dovetailed (sometimes round with rack and pinion) vertical column. A mill drill also has a large quill that is generally locked during milling operations and released to facilitate drilling functions. Other differences that separate a mill-drill from a drill press may be a fine tuning adjustment for the Z-axis, a more precise depth stop, the capability to lock the X, Y or Z axis, and often a system of tilting the head or the entire vertical column and power head assembly to allow angled cutting-drilling. Aside from size, the principal difference between these lighter machines and larger vertical mills is that the X- Y table is at a fixed elevation; the Z-axis is controlled by moving the head or quill down toward the X,Y table. A mill drill typically has an internal taper fitting in the quill to take a collet chuck, face mills, or a Jacob’s chuck similar to the vertical mill.

The milling process removes material by performing many separate, small cuts. This is accomplished by using a cutter with many teeth, spinning the cutter at high speed, or advancing the material through the cutter slowly; most often it is some combination of these three approaches. The speed and feed used are varied to suit a combination of variables. The speed at which the piece advances through the cutter is called feed rate, or just feed; it is most often measured as distance per time (inches per minute [in/min or ipm] or millimeters per minute [mm/min]), although distance per revolution or per cutter tooth are also sometimes used.

As material passes through the cutting area of a milling machine, the blades of the cutter take swarfs of material at regular intervals. Surfaces cut by the side of the cutter (as in peripheral milling) therefore always contain regular ridges. The distance between ridges and the height of the ridges depend on the feed rate, number of cutting surfaces, the cutter diameter. With a narrow cutter and rapid feed rate, these revolution ridges can be significant variations in the surface finish.

Fig 2.VERTICAL MILLING MACHINE

C. SURFACE ROUGHNESS TESTER

Surface roughness is an important parameter used to determine the suitability of a surface for a particular purpose. The irregularities on a machined surface impact the quality and performance of that surface and the performance of the end product. Rougher surfaces typically wear more quickly than smoother surfaces and are more vulnerable to corrosion and cracks, but they can also promote adhesion. A roughness tester, also referred to as roughness gauge or roughness meter, is a portable device that is used to quickly and easily measure the surface roughness (surface finish) of an object.

Typical roughness testers provide a linear roughness measurement, tracing a mechanical tip along a surface to measure roughness along an arbitrary line. More sophisticated versions provide an areal roughness measurement,

which measures an area of the surface using non-contact methods, such as lasers, optics, interferometers, and more, to give finer resolution and wide area measurements. For this discussion we will focus on portable roughness testers and linear roughness measurement.

Roughness values are typically reported in Ra, which is the average absolute deviation from a central line of a surface; Rq, which is the root mean square of the deviation, and numerous other values that measure peak heights and depths of valleys. For most applications Ra and Rq provide an adequate indication. For specially designed surfaces, the other parameters may be more appropriate.

Roughness testers can measure several predetermined lengths. Shorter distances are used to measure finer surfaces, while longer lines are traced for rougher surfaces. It is good to ask about the different options available when considering a roughness tester.

Some roughness testers have an interchangeable stylus or probe for measuring different shapes, offsets, and curves. To measure either the inner diameter or an outer diameter, make sure the roughness meter under consideration can meet your requirements.

If you prefer either empirical or metric, some roughness testers are able to display the results of the surface finish in either micro-inches or micrometers, saving you the step of having to convert it manually.

Fig 3. SURFACE ROUGHNESS TESTER

V. TITANIUM ALLOYS

A. MICRO ANALYSIS OF TITANIUM ALLOY

Titanium alloys are commonly used in micro tools for surgery as well as in small size biomedical implants such as miniature Left Ventricular Assist Device (LVAD), finger joint replacements and small bone implants. Titanium alloys are considered as difficult to machine materials due to their thermo mechanical properties. Prediction of the temperature fields in the workpiece and the tool during micro milling of Titanium is vital. The temperature in the machining not only affects the tool wear, but also directly influences the residual stresses, 3D distortions and the dimensional accuracy of micro parts. A simple analytical result is derived to relate these two expressions. Using this solution, the long time creep response has been predicted reasonably well from the constant strain rate results for the two alloys studied. Relative to other metals, it is shown that titanium alloys exhibit exceptionally low values of strain hardening. Optical microscope observations of slip line evolution have been used to relate the deformation mechanisms to the macroscopic behavior. Operative slip systems, as well as dislocation distributions and morphologies, are also presented for the first time following creep of a single- phase α microstructure in Ti–6Al.This article presents a finite element model to predict tool and workpiece temperature fields in the micro milling process of Ti- 6AL-4V under various cutting conditions. Temperature simulations are validated by thermocouple measurements in the micro milling of Ti–6Al–4V.

It was noticed that the cooling rate from the range and ageing conditions had an effect on the microstructure parameters, volume fraction and chemical composition of the , and has a significant effect on the mechanical properties of the alloys tested.

B. CHEMICAL ANALYSIS OF TITANIUM ALLOY

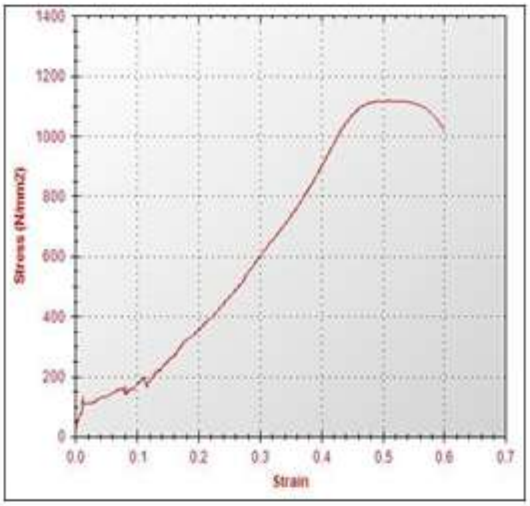
Transformation processes have been studied using continuous high energy X- Ray Diffraction (XRD) and electrical resistivity for two different states of the metastable phase. Microstructures have been observed by electron microscopy. Different transformation sequences are highlighted depending on both heating rate and chemical composition of the metastable phase. At low temperatures and low heating rates, the hexagonal phase is first formed as generally mentioned in the literature. Increasing the temperature, XRD evidences the formation of an orthorhombic phase , which evolves toward the hexagonal pseudo compact α phase. For higher heating rates or for richer composition in β-stabilizing elements of the β-metastable phase, ω phase may not form and α'' forms directly and again transforms into α phase. A direct transformation from β-metastable to a phase is observed for the highest heating rate. The formation of the metastable and phases clearly influences the final morphology

It has a chemical composition of 6% aluminium, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the remainder titanium. The Ti- 6Al-4V alloy is an titanium alloy that exhibits high strength, low density, and good corrosion resistance. It is one of the most commonly used titanium alloy. The joining of C/C and TiB whisker (TiBw) reinforced Ti-6Al-4V composite by brazing is more effective by using a brazing material consisting of Cu–Ni alloy and TiB2 than one consisting of only the Cu–Ni alloy. The shear joint strength is 56% higher for the former. The TiB2 particles in the brazing material react with Ti, which diffuses from the TiBw/Ti-6Al-4V composite, resulting in the formation of TiB whiskers in the brazing layer. The in situ synthesized TiB whiskers are uniformly distributed in the joint and provide reinforcement and decreased residual thermal stress.

C. HARDNESS TEST IN TITANIUM ALLOY

In the hardness tests of the titanium alloy Ti6Al4V, the Vickers method was used. It involves squeezing a diamond pyramid with a square base and an angle of 136 ° between opposing walls into the metal. The hardness parameter is the ratio of the load to the surface side of the permanent imprint. Metallographic analyzes carried out after heat treatment show slight differences compared to the original Ti6Al4V microstructure. As-build elements show a martensitic microstructure and are characterized by a higher yield point, tensile strenght from heat-treated elements, but the elongation is lower . By the use of heat treatment, e.g. aging, a material with increased mechanical parameters can be obtained . One of the most frequently carried out heat treatment processes on elements made by additive manufacturing technology is hot isostatic pressing (HIP). Structural elements made with AM technologies and later processed with HIP show very different microstructures. This difference is not so high in the hardness test, but it has a significant impact on the mechanical properties. Martensitic microstructure allows as build samples to achieve higher strength and yield point values. While the higher ductility of the α + β microstructure helps the sample after HIP treatment to obtain higher elongation. High tensile strength is given to metastable α-martensite by a shorter effective slip length compared to microstructure . Higher elongation as well as lower yield point and tensile strength of HIP-treated elements result from the more plastic β phase and more number of independent slip planes compared to the α phase .

In addition to the material's microstructure, roughness and surface defects also affect the material mechanical properties . Hot isostatic pressing (HIP) reduces porosity and most preferably affects the mechanical properties and fatigue life of elements manufactured by additive manufacturing methods . In the as-built condition, the largest porosity (about 0.35%) and the largest defects are in the outermost layer 0.4 mm thick and are the site of crack initiation. HIP provides effective reduction of porosity in the whole element (below 0.05%). Beyond the heat treatment, machining is also used to reduce surface roughness, as it affects the mechanical and fatigue strength of structural elements



D. TENSILE TEST

Commercially pure (99.2% pure) grades of titanium have ultimate tensile strength of about 434 MPa (63,000 psi), equal to that of common, low-grade steel alloys, but are less dense. Titanium is 60% denser than aluminium, but more than twice as strong as the most commonly used 6061-T6 aluminium alloy.

The tensile strength of titanium and its alloys at ambient temperature ranges from 240 MPa for the softest grade of commercially pure titanium to more than 1400 MPa for very high strength alloys. Proof strengths vary from around 170 to 1100 MPa according to grade and condition.

The tensile strength of titanium and its alloys at ambient temperature ranges from 240 MPa for the softest grade of commercially pure titanium to more than 1400 MPa for very high strength alloys. Proof strengths vary from around 170 to 1100 MPa according to grade and condition.

At elevated temperatures each grade of titanium exhibits characteristic tensile properties. The alloy grades, particularly the high strength materials, retain both proof and tensile strengths up to much higher temperatures than the commercially pure grades. This is shown clearly in Ductility normally increases with increasing temperature. However, there is a slight irregularity with the commercially pure grades in that ductility increases consistently up to a temperature of between 200°C and 300°C but thereafter decreases until at 400 to 450°C values are very similar to those at room temperature. creep values for the material to 0.1% plastic strain in 100,000 hours are approximately 50% of the tensile strength at temperatures up to 300°C.

VI. RESULT AND CONCLUSION:

During the Ti–6Al–4V machining process, multi wall carbon nano-tubes (MWCNT) nano-fluid was used to research their effect on cutting temperature and surface roughness reduction. The conclusions of the study were as follows:

1. The percentage of added multi wall carbon nano-tubes (MWCNT) nano-fluid has been shown to be a significant variable in design influencing both cutting temperature and surface roughness reduction using ANOVA.
2. Multi wall carbon nano-tubes (MWCNT) nano-fluid has been reported to give better results in terms of cutting temperature and surface roughness related to experiments conducted without nano-additives.
3. The capability of lubrication of the coolant, which is used with MWCNT machining, compared to without diffusion of MWCNT and lower cutting temperature and surface roughness value was measured in 2% of MWCNT diffused cutting fluids.
4. Based on the range of design variables studied, two mathematical models were established to describe the researched cutting responses, and reasonable average accuracy was achieved for each proposed system.

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