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A Review on Machinability Aspects of Titanium Grade-2

Paaka Vidyanand Sai[1], Samatham Madhukar[2] , Malis Krishna Prasad Reddy[3], N V S Ramachandra Rao[4]
[1,2,3]Department of Mechanical Engineering , Vjdya Jyothi Institute of Technology , Hyderabad , India
[4]Deputy manager , Machine Tools-2 , Hindustan Machine Tools Limited (Praga Division) , Hyderabad , India

ABSTRACT

Titanium present in the earth's crust at a level about 0.6% and is therefore the fourth most abundant structural metal after aluminum, iron, and magnesium. High strength, low density, and excellent corrosion resistance are the main properties that make titanium attractive for a variety of applications. The major application of the material is production of airframes, engine components ,steam turbine blades, superconductors, missiles etc. The titanium has good corrosion resistance which makes it excellent use in marine services, chemical, petrochemical, electronics, biomedical industries. Titanium and its alloys are among the most difficult materials to machine, mainly because of the metal reactivity at medium to high temperatures, from which a tendency to weld to the tool while machining leads to chipping and premature tool failure. Additionally, its low heat conductivity increases the temperature at the tool-workpiece interface. Finally, the low elastic modulus of Ti allows relatively large deflections of the workpiece, which affect adversely the tool life. In this paper we study the machinability aspects of titanium grade 2 (commercially pure titanium). It has outstanding corrosion resistance and useful strength (similar to austenitic stainless steels) at low density. It has good weldability and is easily formable. It is the most commonly used grade of titanium.

Keywords: Titanium Grade 2, Corrosion Resistance ,Weldability, Machinability

I. INTRODUCTION

Titanium (Ti) is an element of atomic number 22. It occurs in two allotropic forms: Tiα and Tiβ. Variation α is crystallized at room temperature in a hexagonal configuration and at a temperature of 882.5 °C is converted to a high temperature Tiβ crystallizing in the regular system. Ti is characterized by a very low thermal conductivity of 11.4 W m−1 K−1, which is 3–4 times smaller than for iron and up to 16 times lower than for copper.[1] In soft state, Ti has a tensile strength Rm = 460– 590 MPa. Titanium has a high ductility and excellent corrosion resistance to sea water, chlorides, organic acids, and air atmosphere; no oxidation at 200 °C and has a high creep resistance at high temperature. Pure, unalloyed titanium is used mainly in the construction, which is required to have high corrosion resistance. These include chemical equipment and rigs working in the surrounding seawater as well as elements used in medical technology and watch making. [2]

Figure 1. Titanium in raw material form

Titanium is a metal showing a high strength-weight ratio which is maintained at elevated temperatures and it has exceptional corrosion resistance. These characteristics were the main cause of the rapid growth of the titanium industry over the last 40 years. The [3] major application of the material in the aerospace industry, both in air frames and engine components. Non aerospace applications take advantage mainly of their excellent strength properties, for example steam turbine blades, superconductors, missiles etc ; or corrosion resistance ,for example marine-services ,chemical petro-chemical ,electronics industry ,bio- medical instruments etc.[4] However, despite the increased usage and production of titanium, they are expensive when compared to many other metals, because of the complexity of the extraction process, difficulty of melting and problems during fabrication. On the other hand, the longer service lives and higher property levels counterbalance the high production costs. The poor machinability of titanium has led many large companies (for example Rolls-Royce and general electric) to invest large sums of money in developing techniques to minimize machining costs. Similarly, tool makers are looking for new tool material which could extend tool life in the presence of such a challenge. While improving the machining rates would go a long way towards increasing the usage of the material, it must be noted that this is only one of a number of factors affecting the use of the material. Others which include material cost must also be considered in any specific application. In this review, the machinability of titanium is studied and a conclusion is given for the better machinability of titanium.[5]

II. METHODS AND MATERIAL

1. Machinability of Titanium Grade 2

The term machinability may be taken to imply that there is a property or quality of any given material which can be clearly defined and quantified, thus indicating how easy (or difficult) that mechanical operation can be. In fact, that term is not unambiguous, but the machinability of a material can be assessed by employing criteria such as (i) tool life (ii) cutting forces or power consumption (iii) surface finish and chip morphology[6]

Problems in machining titanium originate from three basic sources: high cutting, temperatures, chemical reactions with tools and a relatively low modulus of elasticity. Unlike steel, titanium does not form a built-up edge on tools, and this behavior accounts for the characteristically good surface finishes obtained even at low cutting speeds. Unfortunately, the lack of a built-up edge also increases the abrading and alloying action of the thin chip which literally races over a small tool-chip contact area under high pressures. This combination of characteristics and the relatively poor thermal conductivity of titanium results in unusually high tool-tip temperatures. Titanium's strong chemical reactivity with tool materials at high cutting temperatures and pressures promotes galling and tool wear. Mechanical problems result from titanium's relatively low modulus of elasticity, half that of steel. The low modulus coupled with high thrust forces required at the cutting edge can cause deflections in slender parts. Distortion of that kind creates additional heat, because of friction between the tool and workpiece, and problems in meeting dimensional tolerances. Because of differences in thermal and mechanical properties, titanium parts may "close in" on steel drills, reamers, and taps.

Machinists commonly assert that titanium machines like austenitic stainless steel. However, comparing titanium directly with stainless steel seems justifiable only to the extent that both materials produce a tough, stringy chip. The situation is different from the viewpoint of feed and cut. Austenitic stainless steel usually requires heavier feeds in order to penetrate the uncut metal below a heavily strain-hardened skin. [7]Conversely, titanium, a material which does not strain harden as severely, does not necessarily require heavy feeds. In fact, tool wear per unit volume of metal removed increases with feed. The relative ease of metal removal for equal tool lives can be expressed in terms of the machinability ratings of metals. In this light, the machinability of unalloyed titanium does resemble that of annealed austenitic stainless steel, while the titanium alloys would be more comparable to 1/4-hard and 1/2-hard stainless steels. The machining characteristics of Titanium Grade 2 are similar to those of austenitic stainless steels. In general, low cutting speeds, heavy feed rates, and copious amounts of cutting fluid are recommended. Sharp tools and rigid setups are also important. Because of the strong tendency of titanium to gall and smear, feeding should never be stopped while the tool and workpiece are in moving contact. [8]Non-chlorinated cutting fluids are generally used to eliminate any possibility of chloride-induced stress-corrosion cracking. It should be noted that titanium chips are highly combustible and appropriate safety precautions are necessary.[9]

- Comparable to austenitic stainless steel
- Low speed, heavy feed rate and abundant cutting fluid
- Employ safety measures because titanium chips are extremely combustible

A. Characteristics Influencing Machinability

The chemical composition of pure titanium Ti99.2 (Grade 2 ASTM) contains a small amount of oxygen and iron (max. 0.5%), which determines the satisfactory properties of the material. It is characterized by a great ratio of density to mechanical properties. It has a tensile strength in the range of 210-1380 MPa, which is equivalent to the properties of alloy steels while density dropped up to 40%.[10] The thermal expansion coefficient is slightly lower than for steel and less by a half of aluminium. Titanium has a low modulus of elasticity.

Titanium grade 2 is readily machinable by conventional methods. It is similar to austenitic stainless steels for machinability. Like stainless steel, titanium has a low thermal conductivity and heat dissipation is poor, so generous use of coolant is recommended. Sharp tools are essential. Cuts should be deep and continuous, with low cutting speeds.[11] In general, low cutting speeds, heavy feed rates, and copious amounts of cutting fluid are recommended. Sharp tools and rigid setups are also important. Because of the strong tendency of titanium to gall and smear, feeding should never be stopped while the tool and workpiece are in moving contact. Non-chlorinated cutting fluids are generally used to eliminate any possibility of chloride-induced stress-corrosion cracking. It should be noted that titanium chips are highly combustible and appropriate safety precautions are necessary.[12]

It can be hot and cold-formed as well as welded. Titanium has a very high melting point ~1660°C and excellent resistance to corrosion. Titanium is biocompatible and non-toxic and does not cause allergies. Those properties determine the range of applications of titanium, as: condensers, steam condensers, heat exchangers in power plants and CHP, process apparatus in the chemical industry, desalination installations in the paper industry, the elements in sewage treatment plants, fuel gas desulphurization installations, the material in the aerospace and automotive industries. [13]

Grade	1	2	3	4
Ti	Remainder	Remainder	Remainder	Remainder
C Max.	0.08%	0.08%	0.08%	0.08%
Fe Max.	0.20%	0.30%	0.30%	0.50%
N Max.	0.03%	0.03%	0.05%	0.05%
H[2,3] Max.	0.015%	0.015%	0.015%	0.015%
O Max.	0.18%	0.25%	0.35%	0.40%

Table 1. Chemical Composition of Titanium Grade 2

Melting Point, approximate	3020°F
Density @ Room Temperature	0.163 lb/in.^{3}
Beta Transus	1675°F +/-25°F
Modulus of Elasticity (Tension)	14.9 X 10^3 ksi
Modulus of Elasticity (Torsion)	6.5 X 10^3 ksi
Specific Heat (RT)	0.124 Btu/lb•°F
Electrical Resistivity (RT)	56 ohm-cir mil/ft
Coefficient of Thermal Expansion	
68°F to 212°F	4.8 x 10^{-6} in./in.•°F
68°F to 572°F	5.3 x 10^{-6} in./in.•°F
68°F to 932°F	5.4 x 10^{-6} in./in.•°F
Thermal Conductivity @ 68°F	9.5 Btu•in./ft^2•h•°F

Table 2. Physical Properties of Titanium Grade 2

Product (Annealed) Form		Tensile Minimum	Yield (0.2% offset)	Elongation Minimum	Other Requirements
Bar	Grade 1	35 ksi	20 ksi Minimum	24%	30% Minimum ROA
	Grade 2	50 ksi	40 ksi Minimum	20%	30% Minimum ROA
	Grade 3	65 ksi	55 ksi Minimum	18%	30% Minimum ROA
	Grade 4	80 ksi	70 ksi Minimum	15%	25% Minimum ROA
Sheet/Plate[2]	Grade 1	35 ksi	20 ksi to 45 ksi	24%	Bend Test: 3T - under 0.070", 4T - 0.070" to 0.187"
	Grade 2	50 ksi	40 ksi to 80 ksi	20%	Bend Test: 4T - under 0.070", 5T - 0.070" to 0.187"
	Grade 3	65 ksi	55 ksi to 95 ksi	18%	
	Grade 4	80 ksi	70 ksi to 65 ksi	15%	Bend Test: 5T - under 0.070", 6T - 0.070" to 0.187"
Welded & Seamless Pipe	Grade 1	35 ksi	20 ksi to 45 ksi	24%	-
	Grade 2	50 ksi	40 ksi to 80 ksi	20%	-
	Grade 3	65 ksi	55 ksi to 95 ksi	18%	-
Welded & Seamless Tube	Grade 1	35 ksi	20 ksi to 45 ksi	24%	-
	Grade 2	50 ksi	40 ksi to 80 ksi	20%	-
	Grade 3	65 ksi	55 ksi to 95 ksi	18%	-

. Minimum requirements per applicable ASTM specifications. **2.** Bend test not applicable if thickness is over 0.187".

Table 3. Mechanical Properties of Titanium

2. Applications

Grade 2 titanium is called the "workhorse" of the commercially pure titanium industry, thanks to its varied usability and wide availability. It shares many of the same qualities as Grade 1 titanium, but it is slightly stronger. Both are equally corrosion resistant.[14]

Titanium Grade 2 may be considered in any application where formability and corrosion resistance are important, and strength requirements are moderate. Some examples of aerospace applications have included airframe skins in "warm" areas, ductwork, brackets, and galley equipment. Ti Grade 2 has also been widely used in marine and chemical applications such as condensers, evaporators, reaction vessels for chemical processing, tubing and tube headers in desalinization plants, and cryogenic vessels. Other uses have included items such as jigs, baskets, cathodes and starter-sheet blanks for the electroplating industry, and a variety of medical applications.[15]

Titanium grade 2 is widely used in heat exchangers, where despite the low thermal conductivity of titanium the efficiency of heat transfer is high due to good strength, high resistance to erosion corrosion and the fouling resistance of the hard, smooth surface. At room temperature grade 2 is an alpha alloy. It transforms to beta phase at 913 ±15°C, and the alpha phase returns on cooling 890 ±15°C. Titanium is reactive, with a very high affinity for oxygen, which forms a skin of very stable and highly adherent oxide. The skin gives excellent corrosion resistance, despite the reactivity of the metal. The oxide layer forms spontaneously and rapidly on exposure to the atmosphere. However, when new parent metal is exposed to anhydrous conditions or in the absence of air, rapid corrosion may occur. Care should also be taken if titanium is to operate in contact with hydrogen, as hydrogen embrittlement from hydride formation can increase strength, with loss of ductility.[16]

Titanium grade 2 has many applications, the most important applications are :

- Architecture
- Power generation
- Medical industry
- Hydro-carbon processing
- Marine industry
- Exhaust pipe shrouds
- Airframe skin
- Desalination
- Chemical processing
- Chlorate manufacturing

3. Machining Difficulties of Titanium

The fact that titanium sometimes is classified as difficult to machine by traditional methods in part can be explained by the physical, chemical, and mechanical properties of the metal. For example:

- Titanium is a poor conductor of heat. Heat, generated by the cutting action, does not dissipate quickly. Therefore, most of the heat is concentrated on the cutting edge and the tool face.
- Titanium has a strong alloying tendency or chemical reactivity with materials in the cutting tools at tool operating temperatures. This causes galling, welding, and smearing along with rapid destruction of the cutting tool.
- Titanium has a relatively low modulus of elasticity, thereby having more "springiness" than steel. Work has a tendency to move away from the cutting tool unless heavy cuts are maintained or proper backup is employed. Slender parts tend to deflect under tool pressures, causing chatter, tool rubbing, and tolerance problems. Rigidity of the entire system is consequently very important, as is the use of sharp, properly shaped cutting tools.
- Titanium's fatigue properties are strongly influenced by a tendency to surface damage if certain machining techniques are used. Care must be exercised to avoid the loss of surface integrity, especially during grinding. (This characteristic is described in greater detail below.)[17]
- Titanium's work-hardening characteristics are such that titanium alloys demonstrate a complete absence of "built-up edge." Because of the lack of a stationary mass of metal (built-up edge) ahead of the cutting tool, a high shearing angle is formed. This causes a thin chip to contact a relatively small area on the cutting tool face and results in high bearing loads per unit area. The high bearing force, combined with the friction developed by the chip as it rushes over the bearing area, results in a great increase in heat on a very localized portion of the cutting tool. Furthermore, the combination of high bearing forces and heat produces cratering action close to the cutting edge, resulting in rapid tool breakdown.

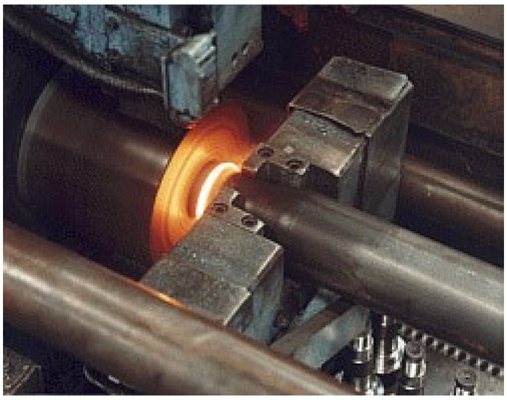

Figure 2. Titanium Machining Process

III. RESULTS AND DISCUSSION

Other Aspects of Titanium Grade 2
Workability of Titanium Grade2

A. Hot working

Ti Grade 2 can be processed by conventional techniques such as hot rolling, forging, and hot pressing. Temperatures for initial roughing may be as high as 30-50ºC (50-100ºF) above the beta transus, and temperatures for finish processing are typically in the alpha/beta phase field, ranging from about 815ºC (1500ºF) to about 900ºC (1650ºF).

Ti Grade 2 can be formed by standard methods such as hot rolling, forging, spin forming, hydroforming, and hot pressing. Typically, more severe forming is done in the temperature range of 480-540ºC (900-1000ºF) and milder forming from 200-315ºC (400-600ºF). Care must be taken to prevent the formation of excessive alpha case, and alpha case must be removed after processing.

B. Cold working

Ti Grade 2 has good ductility and can be formed at room temperature by various standard methods including bending, stretch forming, heading, stamping, and drawing. Ti work hardens fairly rapidly, which is a limitation in some operations, such as cold drawing. The Bauschinger effect results in a drop of up to 25% in compressive yield strength upon stretching at room temperature; this drop can be recovered by stress relieving. Due to the low modulus of titanium, springback allowances are significant. Hot sizing after cold forming is often used to correct for variations in springback.[18]

C. Fabrication

Titanium grade 2 is forged by conventional processes within the narrow temperature range 815 – 900°C. Titanium and its alloys generally are more difficult to forge than both aluminium and alloy steels, due to the narrow temperature range, and high strain rate and temperature dependence of strength. Hot forging leaves a thick, extremely hard layer of titanium oxide on the surface, called "alpha case". It is usually removed by pickling in a mixture of nitric and hydrofluoric acids. As supplied, titanium alloys are usually annealed, and can be readily cold formed in conventional machines using standard methods. When cold formed the alpha case does not form and pickling is not needed, except to remove embedded carbon steel pickup, which can cause pitting corrosion.

D. Weldability

Ti Grade 2 can be welded using Ti filler metal. Inert gas shielding techniques must be employed to prevent oxygen pickup and embrittlement in the weld area. Gas tungsten arc welding is the most common welding process for Ti. Gas metal arc welding is used for thick sections. Plasma arc welding, spot welding, electron beam, laser beam, resistance welding, and diffusion welding have all been used successfully in Ti welding applications.

E. Heat Treatment

Heat treatments used for Ti are annealing and stress relieving. Annealing is used to fully soften the material and remove all residual stresses. Annealing of wrought products at typical temperatures (below the beta transus) results in a fully recrystallized equiaxed alpha structure. Precise control of grain size (and mechanical properties) can be achieved by adjusting the anneal temperature.

Stress relieving is used to remove some or most of the residual stresses from forming, or to recover compressive yield strength after stretching.

Titanium and its alloys have a high affinity for gases including oxygen, nitrogen and hydrogen. When Ti is heated in air, oxygen absorption results in the formation of an extremely hard, brittle, oxygen-stablized alpha phase layer known as alpha case.

Intermediate and final annealing of Ti is often performed in a vacuum or inert gas atmosphere to avoid alpha case formation and the associated material loss. Vacuum annealing can also be used to remove excess hydrogen pickup, a process known as vacuum degassing. Parts to be vacuum heat treated must be thoroughly cleaned (see Cleaning Notes).

IV. CONCLUSION

Despite recent developments and extensive usage of titanium and titanium alloys, machining of titanium still remains as a major industrial concern: short tool life, low metal removal rates, higher cutting force and temperature, and poor surface quality. To improve the machinability of titanium alloys, special attentions must be paid to machining strategies and cutting tools. There are many types of cutting tools employed for machining of titanium alloys. Amongst, carbide tools are still the most commonly used materials. The use of coated tools does not showed a considerable improvement on the machinability of titanium alloys. The cutting temperature and high pressure at the tool-chip interface, built up edge (BUE) formation and the chemical interaction between the titanium and the tool are the main reasons of the tool wear. In fact, the tendency of titanium alloys to react with the most of cutting tool materials is the main factor of tool wear which hinders the machinability of titanium and titanium alloys. Tool wear mostly occur in the tool flank side in both coated and uncoated tools in machining titanium alloys.

The detailed review study of the titanium machinability makes the conclusion by suggesting that the following are the general machining recommendation for titanium alloys : (1) using sharp cutting edge tool (2) providing well-clamped work parts for stable cutting conditions(3) applying appropriate cooling methods (Wet, MQL, Cryogenic, etc.), and (4) minimising the vibration tendencies.

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I. REFERENCES

[1]. Ramesh S, Karunamoorthy L, Palanikumar K. Fuzzy modeling and analysis of machining parameters in machining titanium alloy. Mater Manuf Process. 2008; 23:439–47.

[2]. Ibrahim GA. Tool wear mechanism in continuous cutting of difficult –to- cut material under dry machining. Adv Mater Res. 2010; 126–8:195–201.

[3]. Ozel T. Investigations on the effects of multi layered coated inserts in machining Ti-6Al-4V alloy with experiments and finite element stimulations. CIRP Annuals – Manufacturing Technology. 2010; 59:77–82.

[4]. Aitha Shravan, Samatham Madhukar, Bootla Akhil, Dr. A. A. Sri Rama Krishna , " Experimental and Numerical Analysis of Metal Removal Rate and Surface Finish on Al- Ti Alloy", International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 3 Issue 1, pp.407-411, January-February 2017. URL : http://ijsrset.com/IJSRSET1731104.php

[5]. Arbizu IP, Perez CJL. Surface roughness prediction by factorial design of experiments in turning process. Journal of Materials processing Technology. 2003; 143–4:390–6.

[6]. Ibrahim GA. The effect of dry machining on surface integrity of titanium alloy Ti-6Al-4V ELI. Journal of applied science. 2009; 9(1):121–7.

[7]. Krishna Sastry KV, Seshagiri Rao V, Palanikumar K, Dhanalakshmi R, Kuravi A . Assessment of process parameters influencing delamination factor on the drilling of CFRC composite material with TiN coated carbide tool. Indian journal of science and technology. 2014; 7(2):142–50.

[8]. S. Madhukar, A. Shravan, P. Vidyanand Sai and Dr. V.V. Satyanarayana (2016), A Critical Review on Cryogenic Machining of Titanium Alloy (Ti-6Al-4V). International Journal of Mechanical Engineering and Technology, 7(5), pp. 38-45

[9]. Valarmathi TN, Palanikumar K, Sekar S. Parametric analysis on delamination in drilling of wood composite panels. Indian journal of science and technology. 2013; 6(4):4347–56.

[10]. Dhar N R P S, Chattopadhyay A B 2002 Journal of Materials Processing Technology 118 9-35

[11]. Ezugwu EO. Improvements in the machining of aero-engine alloys using self-propelled rotary tooling technique. J Mater Process Technol 2007; 185(1-3):60–71.

[12]. Semenova IP, Valiev RZ, Yakushina EB, Salimgareeva GH, Lowe TC. Strength and fatigue properties enhancement in ultra ne-grained Ti produced by severe plastic deformation. J Mater Sci 2008; 43(23-24):7354–9.

[13]. Chen W 2000 International journal of machine tools and manufacture 40 455-66

[14]. Thakur D, Ramamoorthy B, Vijayaraghavan L 2009 Materials & Design 30 1718-25

[15]. Samatham Madhukar , Paaka Vidyanand Sai , Sumith Kumar and Dasari Jagath Prakash (2016) , Experimental Investigation on Effect of HeatTreatment on Mechanical Properties of Titanium Alloy (Ti-6Al-4V) , International Journal of Current Engineering and Technology, Vol.7, No.1 (Feb 2017) , pp-238-242

[16]. Ezugwu EO. Improvements in the machining of aero-engine alloys using self-propelled rotary tooling technique. J Mater Process Technol 2007; 185(1-3):60–71.

[17]. Semenova IP, Valiev RZ, Yakushina EB, Salimgareeva GH, Lowe TC. Strength and fatigue properties enhancement in ultra ne-grained Ti produced by severe plastic deformation. J Mater Sci 2008; 43(23-24):7354–9.

[18]. Valiev RZ. Paradoxes of Severe Plastic Deformation. In: Zehetbauer M, Valiev RZ (eds.). Nanomaterials by Severe Plastic Deformation. Weinheim: Wiley; 2004, p. 109–17.

[19]. Stolyarov VV, Zhu YT, Alexandrov IV, Lowe TC, Valiev RZ. Inuenc of ECAP routes on the microstructure and properties of pure Ti. Mater Sci Eng A 2001; 299(1-2):59–67.

[20]. Samatham Madhukar, Birudala Raga Harshith Reddy, Rontala Saketh Reddy And Dr. V.V. Satyanarayana , 2017. Experimental Investigation Of Effect Of Heat Treatment On Nose Radius Of Insert And Temperature At Cutting Area In Turning Of Titanium (Grade 2).International Journal Of Mechanical Engineering & Technology (Ijmet).Volume:8,Issue:3,Pages:34-41