Review Of Literature On Investigate The Effect Of Titanium (Ti) Alloys On Machining

*Vineeta Ahirvar And ** Dr. Deepak Kumar Verma

*Research Scholar, Department of Chemistry, SunRise University, Alwar, Rajasthan (India)
**Professor, Department of Chemistry, SunRise University, Alwar, Rajasthan (India)
Email: vinisavi90@gmail.com

Abstract: Titanium (Ti) alloys are produced with the combination of titanium and alloying elements. Titanium and titanium alloys are lightweight materials with high toughness, corrosion resistance and tensile strength at high temperatures. Titanium and its alloys have been widely used in several industrial applications, such as marine, biomedicine, chemical, energy and other industries. However, machining of Ti alloys is extremely difficult due to the high cutting temperature, high tool wear, and built-up edge formation. Therefore, this research aimed to extensively review the impact of machining inputs on the machining force, chip formation, cutting temperature, tool wear, mechanical properties (residual stress, fatigue and hardness) and surface integrity (surface roughness, surface defect and microstructure) during turning and milling of Ti alloys. Moreover, laser-assisted machining, ultrasonically assisted machining and different cooling systems were reviewed and discussed. It was found that these techniques can significantly improve Ti alloys' machinability. They can improve the surface integrity, tool life and mechanical properties as well as reducing the machining force and cutting temperature. The findings of this research can help manufacturers and researchers who work on machining processes, specially machining of Ti alloys.
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Introduction

Titanium and its alloys are highly used structural materials in aerospace sector [1], shipbuilding and chemical industries [2], turbomachinery [3] in machine and instrument making, and medicine [4]. In terms of machinability, titanium alloys are close to corrosion and heat-resistant steels and alloys [5]. High strength and extremely low values of thermal conductivity and thermal diffusivity [6] (about 4–5 times lower than that of low-carbon steels) often become the causes of intense heat in the cutting zone, and consequently, structural-phase transformations in the surface layer of the material [7]. The low thermal conductivity of titanium alloys contributes to the occurrence of temperatures in the cutting zone – an average of 2.2 times higher than when machining AISI 1045 steel [8].

Machining of titanium alloys and its alloys are accompanied by oxidation of the chips and the machined surface [9]. Therefore, cutting fluids used in the processing of such materials should protect the chips and the treated surfaces from oxidation [10]. The machinability of titanium alloys by cutting is worse than that of steels [11], and titanium chips at high cutting speeds can ignite titanium dust explosive [12]. From the above classification, it can be seen that titanium alloys by machinability occupy an intermediate position between stainless and heat-resistant steels and alloys [13]. Their processing is hindered mainly by low thermal conductivity [14]. Compounds of titanium with iron, manganese, chromium, molybdenum, vanadium, tin and other alloying components form titanium alloys with improved strength properties [15] and better machinability by cutting compared to titanium [16]. In practice, the titanium machining is recommended to be carried out at low cutting speeds and with high feed [17].

A reliable condition for the possibility of increasing machinability and, in turn, improved cutting conditions is the use of cooling techniques [18]. For example, Klocke et al. [10] studied tool wear, cutting forces, chip morphology, and surface roughness during high-speed longitudinal turning of workpieces (heat resistant gamma titanium aluminides γ-TiAl). They have studied the effects of conventional flood cooling and the supply of high-pressure coolant (HPC), cryogenic liquid nitrogen cooling, and the minimum amount of lubricant (MQL). It is shown that HPC reduces flank wear, but the tool load increases. Conventional flood cooling provides better roughness than dry machining, but inferior to MQL. Cryogenic cooling also reduces tool wear and improves surface quality and defective layer [19].

Few reviews have been reported of different cooling lubrication methods, or on any specific cooling lubrication method by considering titanium alloys. Krolczyk et al. [11] presented a detailed and comprehensive report about by reviewing the advanced cooling lubrication technologies for machining, however, the main focus was on the ecological aspects than the productivity. Pervaiz et al. [20] in their review article showed the benefits of using minimum quantity of lubricant (MQL), and minimum quantity cooling lubrication (MQCL) using biodegradable vegetable oils for cleaner production. Sen et al. [21] reported the sustainability perception with the minimum quantity lubricants in machining. For mist assisted cooling lubrication in machining, a comprehensive review has been reported by Singh et al. [22] conventional machining processes like turning, milling, drilling, grinding were listed for mist assisted cooling system (MQL group).

However, a comprehensive review is needed that bridges the gap between the state-of-art cooling-lubrication and machining of Ti-alloys. This can give a guidance to researchers who are searching the knowledge about latest updates, and to industrial practitioners to have valuable information about cooling lubrication on the machining of Ti and its alloys. The scope of the current review is shown in Fig. 1. This review is divided as follows: firstly, described titanium and its alloys and their composition, classification, and properties - for following groups of Ti alloys: high-strength structural and high-temperature Ti alloys, intermetallic compounds, pure titanium, as well as composites carbon fiber reinforced polymers (CFRPs)/Ti alloys; secondly, a general methodology is described that covers the main methods of cooling techniques: Conventional Cooling System (CCS), Minimum Quantity Lubricant (MQL), Minimum Quantity Cooling Lubrication (MQCL), Cryogenic Lubrication (CL), High-Pressure Cooling (HPC). Then these methods are examined in the corresponding sections in more detail. The influence of various cooling methods on the parameters of surface roughness, temperature, tool wear, tool life, and productivity are considered. The application of these methods to the processes like turning, milling, drilling, and grinding, etc. in the literature and their advantages, disadvantages and prospects are considered. Finally, the last section discusses cooling techniques and their advantages and disadvantages with respect to facilitating their selection in accordance with the manufacturer's goals. The aim of this review is to analyze the trends in the application of cooling methods in machining of Ti and its alloys in terms of machinability, temperature, cutting force, surface integrity, tool life, environmental aspects, productivity and accuracy to meet the requirements of modern manufacturing.

Review of Literature:

Machining of materials is an integral part of the components in the manufacturing process, where desired final shape, size, and surface requirements are achieved. Traditional or conventional machining of metals and alloys cuts materials by the generation of shear force that plastically deforms the materials, for instance, formation of chip (turning milling, etc.), micro-chipping (blasting, etc.), and abrasion (grinding, lapping, etc.). Nevertheless, conventional machining techniques are expensive to apply for hard-to-machine materials, for example, metal matrix composites, and alloys of titanium and nickel in particular [**1**]. This is because of extended machining time, higher tool wear, and difficulties in shaping parts with complex geometry. Usually, titanium and its alloys possess higher strength-to-weight proportion, better protection from corrosion, greater fatigue performance, and endure moderately higher temperatures without creeping [**2**], which are categorised as hard-to-machine materials. Furthermore, small elastic modulus, lower heat conductivity, and greater chemical acuteness at higher temperatures increase the machining cost of titanium alloy. Metallurgical uniqueness of these materials make it more difficult and expensive for machining, compared to that of steel with comparable hardness range [**3**]. The biphasic α/β Ti-6Al-4V alloy exhibits boosted mechanical and metallurgical behaviours, which are added advantages to numerous fields amongst other Ti-alloys, due to its greater strength at higher temperature, toughness, and resistance against abrasion and corrosion [**4**,**5**]. **Table 1** shows a comparison of the conventional machinability of several Ti-alloys compared to other metals. The rating of machinability of a material is the ease of machining to obtain the expected finish. The American Iron and Steel Institute (AISI) proposed the machinability rating depending on the weighted average of cutting speed, surface finish, and tool life for turning of respective material. It is based on turning tests at speed 180 rpm where 160 Brinell B-1112 steel is assigned as 100% machinability rating [**6**]. Despite reduced machinability, Ti-alloys are employed broadly in medicinal, space engineering, maritime, chemical treating, and automobile industries [**7**].

The rising demand of Ti-alloys in high-tech fields inevitably requires non-conventional machining techniques for shaping parts of these materials. There is much research on many technologies for improving machinability of difficult-to-machine materials [**9**,**10**,**11**]. Among different non-conventional machining of Ti-alloys, electro discharge machining (EDM) is widely employed which is, in principle, a heat-assisted process [**12**,**13**,**14**]. In some instances, laser beam machining of Ti-alloys was also reported, however, to a much lesser extent.

Thus, the aim of the present review is to obtain a comprehensive understanding of the machinability of Ti-alloy via laser beam machining. This review will provide an understanding about the beam–material interaction, the effect of beam characteristics on the surface generated by the laser beam, the recast layer formation, and the material removal mechanism. Together with the critical analysis of the information available in the literature, several recommendations for future work were also reported to fill the present knowledge gap. This comprehensive overview will guide the researchers to make future contributions in this field to make it more applicable for different bespoke applications

Machinability of a material is usually determined based on criteria such as tool life, tool wear, cutting force, chip formation, cutting temperature, surface integrity and burr size. Titanium alloys are classified into four main groups as follows: (1) a; (2) near a; (3) ab and (4) b [3]. Interested readers may find more detailed descriptions of titanium alloys and their properties in [1, 3]. In general, machining titanium alloys include milling, turning and drilling operations. How ever, most of the machining studies for titanium and its alloys have been focused on the turning process. The obtained results of turning are not applicable to the milling process, where interrupted cutting takes place, subjecting the tools to a variety of hostile conditions [4]. During milling operation, the cutting tool is imposed to various failure modes due to extensive loading and unloading effects [5]. This phenomenon adversely affect the tool life, cutting forces, surface quality, dimensional accuracy and economic of machining operations. This implies an appropriate selection of cutting tools, machining parameters and lubrication and coolant conditions during machining titanium alloys. To that end, the correct selection of titanium alloys with respect to operation used must be conducted precisely. In the following section, the main properties impairing the machinability of titanium alloys will be introduced using combination of the following performance criteria: cutting tool wear/tool life, cutting forces, chip formation, part quality mainly surface rough ness. Furthermore, the effects of various lubrications/coolant modes on machin ability of titanium alloys will be presented.

LBM is an extensively applied non-contact non-conventional material removal technique that uses thermal energy. As the name suggests, in this method a beam of laser is concentrated on the workpiece where heat is generated and material is detached through vaporising and melting [**1**,**15**]. Therefore, machining forces, tool wear, mechanically induced surface damage, vibration, and electro-related factors (such as voltage, electrodes, spark, electrolyte, etc.) are absent in this case [**16**]. LBM can be employed for drilling and cutting of different workpieces, such as non-metals, metals, and composites which are appropriate to produce shapes and tiny holes in sheet metal with cut opening (kerf width) as low as 0.25 mm [**17**]. Laser drilling could be performed by percussion, trepanning, or single shot drilling methods. High strength laser pulses vaporise and melt the workpiece in the percussion drilling. Conversely, a focused laser beam is applied in trepanning to remove the required region of the workpiece which is more appropriate for creating holes with larger diameter [**18**]. Generally, several pulses might be essential to complete thorough drilling of workpieces which depends on pulse energy, material properties, and workpiece thickness. Improved quality holes are machined efficiently by using multiple laser pulses of low energy rather than one pulse of high energy [**19**].

Laser machining affects the material removal rate and quality of the machined surface. The key factors include laser type, laser beam property, substrate material, debris removal system, and laser procedure variables.

The most commonly used lasers are Nd: YAG and CO_2 types in the LBM process [**1**]. The gas laser CO_2 releases light in the infrared region which has pulse and is continuous in forms. This laser has a wavelength of 10 µm in the infrared area, good quality beam, large beam power (average), and decent efficacy that are appropriate for satisfactory machining of sheet metal efficiently [**14**]. The solid-state Nd: YAG laser delivers light through a fiber-optic cable. This laser has lower mean power, but during its use in pulsed mode offers great peak power, improved focusing features, thin width of kerf, and reduced heat-affected region. However, the beam of CO_2 laser is generally applied for machining metal sheets in productions whereas Nd: YAG is applied for high-accuracy machining [**1**]. Due to the shorter wavelength (1.064 µm) of Nd:YAG laser, it reflects from a smaller area of the workpiece surfaces which empowers machining of reflective materials. Materials with higher thermal conductivity provide holes of worse characteristics while drilling by CO_2 laser. Because of a briefer thermal interface period, Nd: YAG laser provides improved outcomes. In pulsed form, large instance peak power enables drilling of a thicker workpiece [20]. There are only a few reports available in literature on the laser beam machining of titanium alloy. The machinability in this method primarily relies on the thermal and optical characteristics instead of the tensile behaviour of workpieces [**15**]. Thermal conductivity, reflectiveness, specific and latent heats are significant properties of the workpiece that affect the efficiency of the LBM process. Therefore, brittle and hard materials could be machined by LBM [**7**]. However, this process becomes complex due to the poor heat conduction and excessive chemical acuteness of titanium alloys at elevated temperatures [**7**, 9].

The performance of a cutting tool is normally assessed in terms of its life on the basis of certain wear criterion, mostly flank wear that largely affects the stability of the cutting edge and consequently the dimensional tolerance of the machined work surfaces [6]. The main tool materials used in machining titanium alloys include: (1) uncoated and coated cemented carbides (WC/Co) (2) polycrystalline diamond (PCD) and (3) polycrystalline baron nitride (PCBN) and cubic-boron-nitride (CBN). Amongst described tools, the uncoated and coated carbides tools are the most frequently used tool materials. To protect the tools against wear, various coating materials such as TiN, TiCN, TiAlN and many others such as Al2O3 are widely employed [7]. The appropriate selection of coating materials depend on the workpiece material used, whereas the machining of titanium alloys is a thermal dominant process and a critical temperature of 700 C can be considered as a tool life criterion [6]. The tendency of titanium alloys to react with the most of cutting tool materials is the main factor hindering the machinability of titanium alloys. To reduce the chemical reaction between the tools and material, Ezugwu et al. [8] performed cutting operations in inert enriches environment and observed better tool life under conventional machining environment. According to [49], uncoated tools reach their maximum process temperature faster than coated tools. On the other side, according to [1, 8, 5], during machining titanium alloys, the tool coating rapidly fails, mainly due to high temperature generation between tool and chip and also coating delamination. This exhibits that according to cutting conditions used, various tool performances can be observed from coated and uncoated tools during machining of titanium alloys. Furthermore, in addition to tool wear, machining dynamics and the surface finish of the work part can be used as indicators for evaluating the cutting performance. The tool flank side is the main subject of tool wear in most of the cases in both coated and uncoated tools [16]. It is generally proposed to use the sharp, positive edge tools with ample clearance as well as stable cutting conditions with well-clamped work parts, in order to secure high performance cutting with minimized vibrations tendencies during machining titanium alloys [5]. As pointed out in [17], the majority of tool failure mechanisms during turning Ti–Al-2Sn-4Zr-6Mo were due to flank wear and excessive chipping on the tool f lank edge. The severe chipping and flaking of the cutting edge resulted from high thermo-mechanical and cyclic stresses seem to be the main failure mode when milling titanium alloys with carbide tools [4]. Whereas, to reduce the tool wear in milling operations, it is suggested to use low cutting speed [5]. As observed in [2], the wear progress of the coated tools was slower than that of the cemented carbide tool during high speed milling of titanium alloys. According to [5], cutting speed and depth of cut were identified as the main factors responsible for the failure and fatigue of the coated carbide tools during milling of titanium alloys. This causes by the sudden loading which leads to micro fracture and brittle fracture and consequently propagates until total fracture occurs. Zareena and Veldhuis [3, 18] used single-crystal diamond tools in ultra-precision machining of commercial pure titanium (CP–Ti) and Ti–6Al-4V alloys and then examined the tool wear mechanisms. To reduce the wear mechanism, a protective barrier made of Perfluoropolyether (PFPE) polymer was explored. As concluded in [53], the cutting temperature and high pressure at the tool-chip interface, built up edge (BUE) formation and chemical interaction between the work part and tool are the main reasons of the tool wear. According to [45], better carbide cutting tool properties were obtained when using ultrafine carbide cutting tool grades in conjunction with advanced sintering processes. Although diamond has a high hardness, low friction coefficient and high thermal conductivity, but since it easily reacts with metallic and ferrous work parts, it is not advised to use it as a coating in most of the machining cases. Therefore, more attention has been paid to employ the PCD tools which offer better surface finish and less wear rates compared to PCBN and coated carbide tools [19, 20].

Conclusions

The non-traditional machining of Ti-alloy is still in the developing stage, though good progress has been made in several areas. The greatly appealing characteristics of this procedure introduced additional complications. The methods have varied mechanisms to remove materials and perform nicely to the specific applications. However, there are shortcomings even in these methods to regulate the output factors as necessary. The discussion above provides the latest developments of LBM and guidance for future investigations. After the above analysis, it can be summarised as follows:

1. LBM is a compelling machining approach for producing complicated shapes and holes in various materials. Nevertheless, the major drawbacks are (a) the lower energy efficacy

and (b) diverging/converging profile of the beam.

2. This method is also appropriate for accurate production of miniature parts. The miniature holes of smaller radius (up to 2.5 mm) and higher aspect ratio (above 20) are possible to produce precisely, utilizing tripled lasers of nanosecond frequency.
3. The quality of LBM is controlled by (a) mode of operation, wavelength, and laser power, (b) material thickness and type, and (c) speed, position of focal plane, energy, frequency, pulse interval, aided gas type, and pressure. The output qualities of concern for LBM are hole or kerf taper, HAZ, recast layer, surface finish, dross, and cracks.
4. The investigators optimised the procedure through experimental and statistical optimisation. It is necessary to develop the modelling procedures to identify optimum or close to optimum procedure variables.
5. Substantial investigation is required in the two utmost application fields, for instance, machining of micro-parts and machining thick work pieces.

References

1. Dubey, A.K.; Yadava, V. Laser beam machining—A review. *Int. J. Mach. Tools Manuf.* **2008**, *48*, 609–628.
2. Biffi, C.A.; Lecis, N.; Previtali, B.; Vedani, M.; Vimercati, G.M. Fiber laser microdrilling of titanium and its effect on material microstructure. *Int. J. Adv. Manuf. Technol.* **2011**, *54*, 149–160.
3. Donachie, M.J. *Titanium: A Technical Guide*; ASM International, Materials Park: Novelty, OH, USA, 2000.
4. Arisoy, Y.M.; Özel, T. Machine learning based predictive modeling of machining induced microhardness and grain size in Ti–6Al–4V alloy. *Mater. Manuf. Process.* **2015**, *30*, 425–433.
5. Kalantari, O.; Fallah, M.; Jafarian, F.; Hamzeloo, S. Surface integrity in laser-assisted machining of Ti6Al4V. *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.* **2021**, *235*, 5009–5016.
6. Blog, E. Machinability Rating and Chart. Available online: **https://blog.enerpac.com/machinability-rating-and-chart-download/** (accessed on 10 August 2023).
7. Pandey, A.K.; Dubey, A.K. Simultaneous optimization of multiple quality characteristics in laser cutting of titanium alloy sheet. *Opt. Laser Technol.* **2012**, *44*, 1858–1865.
8. Kumar, J. Investigating the Machining Characteristics of Titanium Using Ultrasonic Machining. Ph.D. Thesis, Thapar Institute of Engineering Technology, Patiala, India, 2009.
9. Kara, F.; Takmaz, A. Optimization of cryogenic treatment effects on the surface roughness of cutting tools. *Mater. Test.* **2019**, *61*, 1101–1104.
10. Plastike, M.O.J.Z.B. Optimization of surface roughness in finish milling of AISI P20+ S plastic-mold steel. *Optimization* **2018**, *195*, 200.
11. Kara, F.; Karabatak, M.; Ayyıldız, M.; Nas, E. Effect of machinability, microstructure and hardness of deep cryogenic treatment in hard turning of AISI D2 steel with ceramic cutting. *J. Mater. Res. Technol.* **2020**, *9*, 969–983.
12. Pramanik, A.; Basak, A.; Prakash, C. Understanding the wire electrical discharge machining of Ti6Al4V alloy. *Heliyon* **2019**, *5*, e01473.
13. Basak, A.; Pramanik, A.; Prakash, C. Surface, kerf width and material removal rate of Ti6Al4V titanium alloy generated by wire electrical discharge machining. *Heliyon* **2019**, *5*, 01473.
14. Basak, A.; Pramanik, A.; Prakash, C.; Kotecha, K. Micro-mechanical characterization of superficial layer synthesized by electric discharge machining process. *Mater. Lett.* **2021**, *305*, 130769.
15. Pramanik, D.; Kuar, A.; Sarkar, S.; Mitra, S. Enhancement of sawing strategy of multiple surface quality characteristics in low power fiber laser micro cutting process on titanium alloy sheet. *Opt. Laser Technol.* **2020**, *122*, 105847.
16. Pramanik, A. Problems and solutions in machining of titanium alloys. *Int. J. Adv. Manuf. Technol.* **2014**, *70*, 919–928.
17. Müller, F.; Monaghan, J. Non-conventional machining of particle reinforced metal matrix composite. *Int. J. Mach. Tools Manuf.* **2000**, *40*, 1351–1366
18. Bandyopadhyay, S.; Gokhale, H.; Sundar, J.S.; Sundararajan, G.; Joshi, S. A statistical approach to determine process parameter impact in Nd: YAG laser drilling of IN718 and Ti-6Al-4V sheets. *Opt. Lasers Eng.* **2005**, *43*, 163–182.
19. Bandyopadhyay, S.; Sundar, J.S.; Sundararajan, G.; Joshi, S. Geometrical features and metallurgical characteristics of

Nd: YAG laser drilled holes in thick IN718 and Ti–6Al–4V sheets. *J. Mater. Process. Technol.* **2002**, *127*, 83–95.

20. Tabata, N.; Yagi, S.; Hishii, M. Present and future of lasers for fine cutting of metal plate. *J. Mater. Process. Technol.* **1996**, *62*, 309–314.

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