Considerations Regarding the Current State of Research in the Field of the Processing of Titanium Alloys Used in the Aeronautical Industry

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Abstract: *The paper presents some considerations from the analysis of the current state regarding the efficiency of processing some titanium alloy parts used in the aeronautical industry. The basic requirement is to improve the machining processes of titanium alloys components of aerospace structures using modern machining strategies as well as the characteristics of titanium in machining and its limits. With the rapid development of science and technology, it is necessary to make full use of advanced technology in the research and development of titanium alloys, and continue to explore, improve the manufacturing technology of titanium alloys. As an emerging metal material, titanium alloy is used in spacecraft due to its own performance advantages*

Keywords: *aerospace, aircraft, alloy, titanium alloys, aeronautical industry.*

1. INTRODUCTION.

Currently, titanium alloys are widely used in the aerospace industry in space vehicles, as well as in many fields such as: automotive, medical, sports and electrolysis, etc.

In the future as a way of space development, spacecraft must use titanium alloy with higher performance, continue to reduce costs and improve its production efficiency. Titanium alloy has low density, high specific strength (strength / density), good corrosion resistance, high heat resistance, hardness, plasticity and weldability.

With the rapid development of science and technology, it is necessary to make full use of advanced technology in the research and development of titanium alloys, and continue to explore, improve the manufacturing technology of titanium alloys. As an emerging metal material, titanium alloy is widely used in spacecraft due to its own performance advantages.

2. THE USE OF TITANIUM ALLOYS IN THE AIRCRAFT INDUSTRY

2.1. General Aspects

The first uses of titanium date back to 1952, when titanium was used in the construction of Douglas DC-7 aircraft. Since then, titanium and its alloys have been used more and more in this field, benefiting from the advantages of the material, a very diverse range of aircraft.

The unique properties of titanium make it increasingly attractive to designers in many industrial fields. However, titanium technology is still quite expensive compared to that of steel and aluminum, but due to the expansion of its use, it will eventually lead to a reduction in costs, stimulating the spread of the material in the most varied fields.

Applications cover a wide range of structural parts from heavy-duty heavy-duty components, forged wing structures and landing gear components, to small components, critical accessories, springs or hydraulics.

Fig.1.. Machined parts made of titanium alloys

As examples of the variety of applications of titanium we find them in the aerospace industry (Fig. 1), airplanes where the metals used for construction must present high mechanical resistance in correlation with low density, jet engines in the composition of which the metal used must present resistance high, low density and keeping these properties up to approximately 550°C.

In the aeronautical and aerospace construction industry, titanium and its alloys are mainly used in the construction of fuselages and resistance structures, jet engines, turbines, as well as satellites and rockets [2].

For these applications, more performance is constantly demanded, doubled by the economy of resources and new processing technologies. Solutions are needed that allow the processing with maximum precision, quality and efficiency even of the newest materials, as well as new processing tools.

The main structural components where titanium alloys are used are:

- Wing ribs being thin-walled aluminum constructions from raw or forged pieces

- Mounting elements of the propulsion engines for connection to the aircraft structure
- Fuselage panels as titanium structures in parts of the wing or fuselage, from blanks
- Propulsion unit
- Propeller casing, of the cold zone of the propulsion unit (turbine).
- Monobloc rotor made of titanium or superalloys
- The casing of the combustion chamber, of the hot zone of the propulsion unit.
- Titanium or superalloy turbine blade in the cold or hot zone of the propulsion unit
- Landing gear titanium materials, due to stability
- Landing gear master cylinder, preferred material 300M
- Supports for the landing gear, as a support element

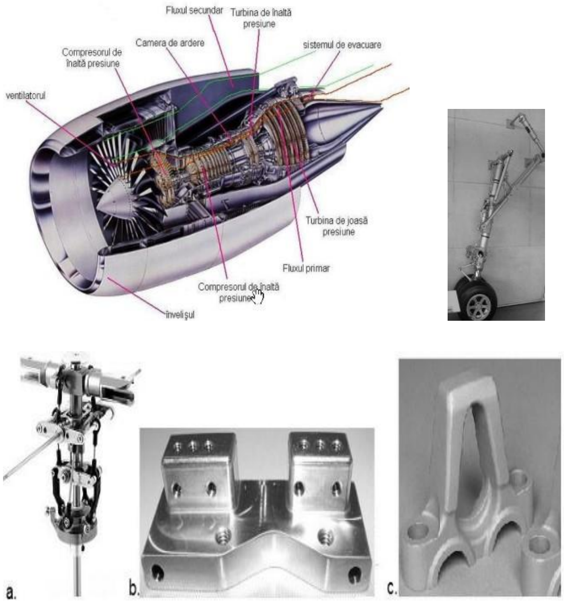

Fig. 2. Structural components [2]

2.2. The main types of titanium alloys used in aerospace vehicles

2.2.1. The physical properties of titanium

The properties of titanium are determined by its degree of purity, which fundamentally depends on the technological conditions of obtaining and processing.

Two of the metal's most useful properties are its resistance to corrosion and the highest hardness-to-weight ratio of all metals.

Titanium is one of the strongest metals on the market today, about twice as strong as aluminum. It was discovered in England by William Gregor in 1791 and is named by Martin Heinrich Klaproth after the Titans of Greek mythology.

Titanium is a chemical element with the symbol Ti and atomic number 22. It has a low density and is a hard, shiny and corrosion-resistant transition metal with a silver color. It is the ninth most abundant element, making up 0.6% of the Earth's crust.

Titanium is a very reactive metal (right after aluminum in the reactivity series of metals). It reacts intensely in contact with gases, especially at high temperatures. For the processing of precision parts, which require an impurity-free surface, such as the case of titanium medical accessories, their elaboration must be carried out only in a vacuum or under a controlled atmosphere of argon [2].

Applications cover a wide range of structural parts from heavy-duty heavy-duty components, forged wing structures and landing gear components, to small components, critical accessories, springs or hydraulics, etc. .. As more and more titanium products are used, and suitable modern processing methods are used, the use of titanium is expanding rapidly in the aeronautical industry.

The physical properties of titanium stand out especially for the favorable ratio between mechanical strength and density, the high melting point, the low thermal conductivity and the high surface tension in the molten state, having major influences in the hot processing of the material. The main physical properties of pure titanium are shown in Table I [2].

Table 1. Physical properties of titanium

Property	Characteristic/ Value
Color in compact state	Gri-argintie
Density at 25°C (α Ti)	4.51g/cm3
Density at 900°C (β Ti)	4.33g/cm3
Melting point 1677°C	Melting point 1677°C
Coefficient of thermal expansion 9.1x10	6/K
Thermal conductivity at 25°C	17-22 W/mK
Tensile strength	450Mpa before casting 850 MPa, after casting
Stretch limit 100	200 N/m2; 15
Hardness 160	190 HB, 80

2.2.2 Classification of titanium titanium alloys and the influence of alloying elements

Titanium alloys are divided into three classes, depending on the structure and alloying elements (Fig. 3):

1. Alpha alloys are alloys with the addition of aluminum, oxygen and/or nitrogen, which generally stabilize the "alpha" phase (C.P.-Ti, Ti5Al2,5Sn) [15, 20]. These generally cannot be heat treated, but can be easily welded. It exhibits medium strength, acceptable ductility, resilience and has good mechanical properties.
2. Mixed α+β alloys are combinations between the two alpha and beta phases (Ti6Al4V, Ti6Al7Nb) [2, 10]. These alloys can be heat treated and

welded, but the creep strength at high temperatures is not as good as that of most alpha alloys.
3. Beta alloys are alloys with the addition of molybdenum, iron, vanadium, chromium and/or manganese, which generally stabilize the "beta" phase (Ti13Nb13Zr, Ti15Mo) [2, 10]. These alloys can be easily heat treated and welded.

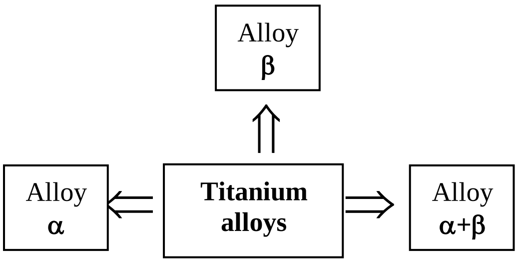

Fig. 3. Classification of titanium alloys

The main advantages of titanium alloy materials
(1) Titanium alloy has high strength and low density (4.4 kg/dm3) and light weight, which provides a solution for reducing the weight of large structural parts.
(2) High heat resistance, can still maintain high resistance and work stably under 400-500 °C.
(3) Compared with steel, the inherent high corrosion resistance of titanium alloy can save the cost of daily operation and maintenance of aircraft.

2.2.3. Analysis of the processing characteristics of titanium alloys [11]

- Low thermal conductivity which means that in the cutting process, the heat dissipation and cooling effect is weak, which shortens the life of the tool.
- The elastic modulus is low, which leads to an increase in the contact area of the machined surface with the tool flank, which reduces the dimensional accuracy and durability of the tool.
- Hardness factor. Titanium alloys with low hardness values will be sticky during processing, which affects the processing effect; titanium alloys with high hardness values are prone to chipping and tool abrasion during machining. The machining time is much longer than that of steel parts of the same size.

(4) Strong chemical affinity. it can chemically react with substances in the air to form hardened TiC and TiN layers on the surface of the alloy, but also react with the tool material reducing the durability.
(5) Poor safety performance during cutting, titanium is flammable.

2.3. Analysis of the technological methods of processing titanium alloy parts

In her doctoral thesis "Innovative titanium deposition processes on the surface of steel parts", Simona-Elena CUTEAN in [2] presents the theoretical research and the experimental tests undertaken that sought to replace parts made of titanium with steel parts coated on the surface with titanium, thus achieving a significant reduction in manufacturing costs and at the same time a decrease in the amount of steel degraded by corrosion. The important uses of titanium and tritan alloys are also presented.

Ivan Radu Alexandru in his doctoral thesis [5] presents the Ti6Al4V alloy and its fields of use: automobiles, power generators, sports equipment, electronics, engines having resistance to very high temperatures. It brings a series of contributions regarding the analysis of dynamic aspects in the particular case of channel milling in the Ti-6Al-4V alloy, briefly presented below.

Processing this type of alloy, the challenge is the use of high speeds in order to increase productivity, but the increase in speed implicitly leads to a rapid increase in wear.

Regarding HSM (High Speed Milling) WANG used liquid nitrogen as a coolant in order to reduce the high temperatures in the cutting area. The experimental results show that the performance is also improved by reducing the temperature, using H13A carbide and CBN50 carbide. At the same time, the use of liquid nitrogen as a cooling liquid leads to an improvement in the roughness of the processed surfaces.

From an economic point of view, Ti6Al4V and other alloys used in the aerospace industry present problems in terms of machining. Different areas of processing depending on the revolutions of the main drive shaft are presented in figure 4.

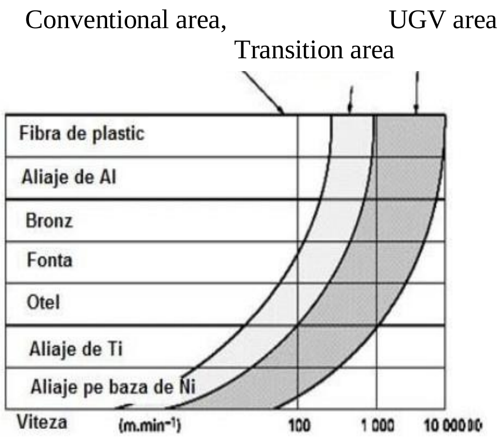

Fig. 4. Processing areas for different materials (conventional area, transition area and UGV high-speed processing area) [5]

It can be observed that the processing speed is inferior to steel, cast iron and non-ferrous alloys. Following the experiments carried out, the diagram in the figure shows the three known areas of processing (conventional, transition and high-speed processing) for certain materials.

Ditu, V., in [3] presents a synthesis of the processes for generating surfaces by chipping as well as the main wear phenomena occurring in the chipping process, such as wear by abrasion, adhesion, diffusion and oxidation, due to the chipping thermal current , through fatigue.

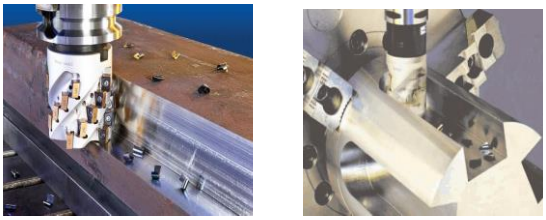

Fig.5. Milling of landmarks from titanium alloys

2.3. Modern processing processes of titanium alloys [9].
2.3.1. Trochoidal milling - modern solution

Andrei Raul Oșan in his doctoral thesis, [7] makes scientific contributions to the processing of complex curved surfaces with toroidal milling cutters on machining centers, regarding the identification of the optimal regimes, where the cutting speed, the advance on the tooth and the inclination of the tool axis angle vary in order to obtain the best surface quality.

Also, the surface roughness in the direction of feed is much less than that associated with the cylindrical face mill. However, the radius of curvature varies with the indices R, r and B as shown in figure 6. [7]

The toroidal end mill is an improvement on the cylindro-front tool with sharp edges, which-frontal and to ensure a variation of the edges, he recommends the use of toroidal cutters. Also, the surface roughness in the direction of feed is much less than that associated with the cylindrical face mill. However, the radius of curvature varies with the indices R, r and B.

He developed an experimental research methodology for the determination of roughness, by machining with a toroidal milling cutter compared to a spherical milling cutter and established new strategies regarding the processing of complex curved surfaces, using toroidal milling cutters [7].

He highlighted the optimal inclination direction by the fact that the inclination angle of the tool axis is the most important influencing factor on the surface roughness.

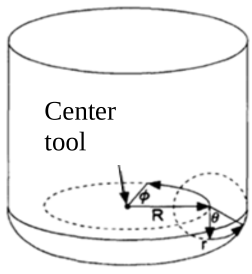

Fig. 6. Toroidal tool [7]

2.3.2. Toroidal milling strategies

A strategy that is gaining more and more ground in titanium processing, with the aim of producing the largest possible chip volumes per unit of time, is trochoidal milling.

Machining the internal surfaces in titanium is difficult, because at the initial moment, a large area of the tool is in contact with the material of the part, so the cutting forces and the released heat are high. The second important element is the uneven load on the cutter teeth.

This is high in the area where the cutter is advancing rapidly through the material and low in other areas. In recent years, the high potential of trochoidal milling has been noted and that is why the development of the line of monobloc cylindrical-frontal carbide milling cutters, as well as corn type milling cutters for increasing productivity, when using removable inserts, has been accelerated.

Thus, the trochoidal milling method can be applied using a wide variety of ISCAR tools [9]. This recommends the use of CHATTERFREE cylinder-front milling cutters, in the case of monobloc construction and HELIDO or HELIMILL solutions, with removable plates to obtain high, constant and safe performances.

The challenge that processing in titanium raises is all the greater when the channels to be made are relatively deep in relation to the width. In this case, the difficulty of chip evacuation increases. Moreover, when the channels are curved, the evacuation is even more difficult, compared to the situation where they are straight [9].

The difficulties described above lead to the need to adapt the cutting regime, in the sense of decreasing the advance and cutting depth when processing channels, in order to prevent the occurrence of vibrations and premature destruction of the tools. The immediate consequence is the decrease in productivity and at small feeds, the durability tends to decrease, when we machine channels, for which a potential solution is trochoidal milling

Toroidal or in other words, the spiral, this milling method represents a potential solution to the problem. The basic idea is to program a sequence of circular trajectories for the milling tool and print them and feed them into the material with each circle traversed.

The key advantage of this method is that only a small area of the cutting tool is in permanent contact with the material to be processed. The advance is constantly constant. In addition, this type of milling allows the use of a cutter with a smaller diameter than the width of the channel to be processed, thus leaving free space necessary for chip evacuation (figures 7 and 8) [9].

Fig. 7. Trochoidal milling [9]

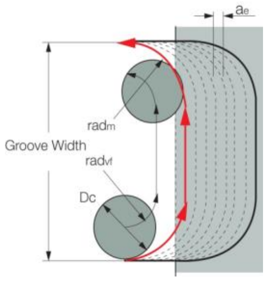

Fig. 8. Processing strategy [9].

ISCAR Chatterfree cylinder-front milling cutters - anti-vibration, with variable pitch - not only eliminate harmonic vibrations during machining, but have proven extremely effective in fully penetrating pockets, managing to produce large volumes of chips in a short time and durability upper edge, also resulting from the reduced level of vibrations.

They can easily process full channels, with cutting depths of up to 2xD, in configurations with 4 or 5 teeth, even when we have at our disposal low power machines, with ISO40 or BT40 clamping systems, without any problems compromises very high productivity.

There are also alternative solutions with removable plates, such as the ISCAR HELIDO or HELIMILL lines, the same plates can also be mounted on corn cutters. When the multi-tooth tool engages in trochoidal machining, each individual cutting edge penetrates the material with minimal heat generation and associated stresses.

The advantage of using milling cutters with many inserts, corn type, is the particularly high advance per tooth, which ultimately translates into exceptional productivity.

One of the benefits is that channels wider than the diameter of the tool used can be machined. This means in fact that several type-dimensions of channels can be made with the same tool, in a very efficient way.

The fact that this milling method is much faster than the conventional method was demonstrated primarily by tests

2.3.3. Radial milling for processing titanium alloy

Radial milling is very suitable for machining titanium alloy. However, a large radial depth of cut will greatly shorten tool life, while a large axial depth of cut has little effect on cutting temperature, so will not affect tool life in the same way .

Therefore, using a long edge milling tool with a dense tooth pitch, using a radial depth of cut of 30% and the maximum axial depth of cut allowed by the specific application is the best method to effectively remove titanium alloy materials .

Therefore, the long edge milling tool is suitable for rough milling and fine milling of the sidewalls of many titanium alloy parts. The long spiral edge of the long edge milling tool is very suitable for a large number of radial milling titanium alloy machining.

At present, indexable blades arranged upwards along the periphery of the lower part of the tool have reached the limit of good machining performance and safety in titanium alloy [10].

3. TITANIUM ALLOY PROCESSING TECHNOLOGY

Guides with instructions are also developed in the field of titanium processing:[13]

(1) Use cemented carbide tools as much as possible. Tungsten-cobalt cemented carbide has the characteristics of high strength and good thermal conductivity, and is not prone to chemical reactions with titanium at high temperatures, so it is suitable for machining titanium alloys.

(2) Reasonably select the tool geometry parameters In order to reduce the cutting temperature and reduce the tool sticking phenomenon, the inclination angle of the tool can be reduced accordingly, and the contact area between the cutting edge and the machined surface can be increased to dissipate heat; at the same time, the tool clearance angle can be increased to reduce the arcs of the machined surface and the tool flank. Frictional surface contact causes tool adhesion and reduced precision of the machined surface; the tip of the tool should adopt a circular spring transition to increase the strength of the tool.

(3) Appropriate cutting parameters. To determine the cutting parameters, there are the following solutions: the lower cutting speed of the high cutting speed will lead to a sudden increase in the cutting temperature; moderate high feed rate means higher cutting temperature, and low feed rate means that the cutting edge In the hardened layer, the cutting time is long and the wear is accelerated; the greater depth of cut of the tool tip over the hardened layer on the surface of the titanium alloy can increase tool life.

(4) When drilling titanium alloys, it is necessary to modify the standard drill bit to reduce the phenomenon of edge burning and drill breakage. Thus the following changes are necessary: increase the angle of the tip accordingly, reduce the angle of inclination of the cutting part, increase the back angle of the cutting part and double the inverted taper of the cylindrical edge.

Also, the number of tool withdrawals should increase during processing. The drill must not remain in the hole, and the chips must be removed in time. Pay attention to observe the condition of the drill and remove the stuck chips in time, and the sufficient amount of emulsion must be cooled.

(5) In the milling of titanium alloys, among the cutting parameters, the cutting speed has a great influence on the tool life, followed by the radial engagement of the tool [12]
(6) In milling the chipping and chipping of the cutting edge produced in the machining of the titanium alloy is much more serious than the damage to the cutting edge caused by milling down

5 CONCLUSION

The existing state of research in this area indicates that there is still room for improvement in titanium alloy machining processes. It is known that advanced machining methods have a high potential to improve the efficiency of machining processes and reduce production costs. It is also known that optimization of processing parameters can lead to improved performance of finished products.

Compared to most other metal materials, the machining of titanium alloy is not only more demanding, but also more restrictive. However, if you use the appropriate tools correctly and optimize the machine tool and configuration to the best condition according to its machining requirements, a satisfactory titanium alloy machining effect is obtained.

The development of scientific knowledge in the field of titanium alloy processing technology is achieved through the new issue addressed regarding the analysis of the technological methods of processing titanium alloy parts, as well as the new processing procedures with the character of technical progress.

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