CIMCOOL® Technical Report

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Machining Titanium

Background:

With its low mass, high strength, and excellent resistance to corrosion, titanium solves many engineering challenges. [(1)] Titanium is 30% stronger than steel but is nearly 50% lighter. Titanium is 60% heavier than aluminum but twice as strong. [(2)]

The aerospace industry is the single largest market for titanium products. Titanium applications are most significant in jet engine and airframe components that are subject to temperatures up to 1100 °F and for other critical structural parts. Titanium is alloyed with aluminum, manganese, iron, molybdenum and other metals to increase strength, to withstand high temperatures and to lighten the resultant alloy. Titanium's high corrosion resistance is also a valuable characteristic. When exposed to the atmosphere, titanium forms a tight, tenacious oxide film that resists many corrosive materials. [(3)]

In the 1950's the titanium metal industry was established primarily in response to the emerging aerospace industry that used it in the manufacture of airframe structural components and skin, aircraft hydraulic systems, air engine components, rockets, missiles, and spacecraft, where these properties are invaluable. The military also uses titanium in its guided missiles and in artillery. As the 1970's approached, the cost of titanium dropped making it more available for other practical applications such as shipbuilding: primarily in submarines, in ship's propellers, shafts, rigging, and other highly corrosive parts. Titanium is being increasingly used for medical applications due to its lightweight, its strength, and its hypoallergenic properties, as titanium is nickel-free. Titanium products are being utilized in other industries as well, from petrochemical applications to sporting goods. [(2)]

For automotive applications, titanium is used for engine valves, connecting rods, wheel-rim screws, exhaust systems, and suspension springs. Titanium engine components increase horsepower and torque while improving fuel economy and solving problems with noise and vibration. When used in exhaust systems, titanium reduces material weight approximately 50% compared to traditional systems and substantially increases product life. Titanium suspension springs give OEMs greater mass reduction, up to 70%, over conventional springs performing the same function in less space, allowing increased payload and engine or passenger compartment space. [(1)]

While the material once had a reputation for being expensive, advances in production technology and increased consumption in industrial markets have allowed steep cost reductions. [(1)]

General Considerations: [(4)]

Historically, titanium has been perceived as a material that is difficult to machine. Due to titanium's growing acceptance in many industries, along with the experience gained by fabricators, a broad base of titanium knowledge now exists. Given the proper procedures, titanium can now be fabricated using techniques no more difficult than those used to machine 316 stainless steel.

Machining of titanium alloys requires cutting forces only slightly higher than those needed to machine steel, but these alloys have metallurgical characteristics that make them somewhat more difficult to machine than steels of equivalent hardness.

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 low modulus of elasticity, thus it is more "springy" than steel. This means that the work-piece tends to move away from the cutting tool unless heavy cuts are maintained. Slender parts tend to deflect under tool pressure and this can cause chatter, tool rubbing and hence tolerance problems. Rigidity of the entire machining system is consequently very important, as is the use of sharp, properly shaped cutting tools.

- 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 (BUE) 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 loads per unit area. These high forces, coupled with the friction developed by the chip as it passes over the cutting area, result in a great increase in heat on a very localized portion of the cutting tool. All this heat (which the titanium is slow to conduct away), and pressure, means that tool life can be short, especially as titanium has a tendency to gall and weld to the tool surface.

Tool-life Considerations: [4]

When cutting titanium, as cutting speed increases, tool life dramatically decreases, for reasons out-lined above.
Thus, although the basic machining properties of titanium metal cannot be altered, their effects can be greatly minimized by decreasing temperatures generated at the tool face and cutting edge if the following rules are observed:

- Use low cutting speeds. Tool tip temperatures are affected more by cutting speed than by any other single variable. (A change from 20 to 150 sfpm with carbide tools results in a temperature change from about 800°F to 1700°F).

- Maintain high feed rates. Temperature is not affected by feed rate nearly so much as by speed, thus the highest feed rates consistent with good machining practice should be used. Note: a change from 0.002" to 0.02" per revolution (a 10 fold increase) results in a temp increase of only about 300°F. (Compare this to the temperature increase resulting from only a seven and one half fold increase in cutting speed- 900°F).

- Use generous amounts of cutting fluid. Coolant carries away heat, washes away chips, and reduces cutting forces.

- Use sharp tools and replace them at the first sign of wear. However, note that tool wear is not linear when cutting titanium. Complete tool failure occurs rather quickly after a small initial amount of wear takes place.

- Never stop feeding when a tool and work-piece are in moving contact. Permitting a tool to dwell in a moving contact causes work hardening and promotes smearing, galling, seizing and total tool breakdown.

Tooling Considerations:

High-speed steels are widely used for machining titanium because of their flexibility and lower cost than cemented carbides. When it comes to true tool economy, do not equate least expensive tooling with the most economical tooling; often the tooling that costs least to buy ends up being the most expensive on a cost-per-cut basis. For best tool economy, the cutting tool should be matched to the material being machined. [3]

Metalworking fluid Considerations:

Metalworking fluids used in machining titanium alloys require special consideration because chloride ions have, under certain circumstances, caused stress-corrosion cracking in laboratory testing of these alloys. Sodium ions, too, have been implicated in the stress cracking of titanium alloys. Many plants are unwilling to use a metalworking fluid that contains chlorine (used as an extreme pressure lubricant), though few people seem to be aware that sodium might also be a problem.

Water-based fluids are the best choice to provide heat dissipation and good cleanliness for machining titanium. Synthetics offer low-foaming, excellent heat removal, good filterability and cleanliness. Soluble oils offer excellent lubricity. Semisynthetics combine beneficial properties of the synthetics and soluble oils - such as good overall lubricity, cleanliness, sump life, and ease of fluid management.

The final selection of the fluid must include a review of the water quality, filter, fluid delivery and pressure (and foam potential), and other metals involved, tooling, fluid management, and other machine and operator requirements.

Metalworking fluid Recommendations:

CIMTECH® 310, a moderate to heavy-duty synthetic metalworking fluid, has been tested for its effects on stress cracking and found to be safe for use on titanium. This product has been used for machining titanium without problems. It would appear that the most important consideration when using the CIMTECH 310 is to ensure that there is copious flow, and when machining, and that the fluid is applied through the tool. Since CIMTECH 310 is non-foaming, high pressures can be used without fear of foam generation. The main job of the metalworking fluid is to remove heat as quickly as possible to prevent tool damage, thus the more fluid, the better.

CIMTECH 410C and CIMTECH 500 would also be good choices to machine titanium, as moderate to heavy-duty synthetics.

CIMSTAR QUAL STAR XL or CIMSTAR 3890 would be good moderate to heavy-duty semisynthetics for machining titanium. (both chlorine-free)

CIMPERIAL® 1060T is also recommended for titanium machining as a moderate to heavy-duty soluble oil. This product is chlorine and sodium free.

This is a partial list of products that can be used for machining titanium. Contact CIMCOOL Technical Services (1-513-458-8199) for additional information.

References:

(1) AMERICAN MACHINIST 1-1-02 issue
(2) www.Aerospacemetals.com
(3) www.Titanium.com
(4) www.Superalloys.com Titanium: A Technical Guide (1988). ASM International, Materials Park, OH 44073-0002 pgs. 75-83