Titanium – the finicky superalloy

Machining titanium cost-effectively requires special attention to the distinctive features of this material – particularly for choosing the right tools.

Text & Images by Arno Werkzeuge

Anyone who has ever machined the superalloy titanium knows that it can be a real diva, requiring special care and attention. Chips that won't break, heat that won't dissipate, and built-up edges are some of the common ways in which titanium puts up a fight during machining. However, titanium's remarkable properties make it a favourite in aviation, motorsport, and medical technology, so it is worth learning how to machine it properly. You never know when a renowned sports car manufacturer will need to place an order for titanium screws. Whether or not the chemist Martin Heinrich Klapproth named the titanium element after the deities from Greek mythology because of its god-like properties is unclear. But the fact is that its properties make it a superalloy. Extremely tension-proof, very light, and outstandingly resistant to corrosion, titanium offers something other materials and alloys don't. In addition, titanium is antimagnetic, biocompatible, and resistant to even the most aggressive media. As a result, this expensive material is becoming popular in more fields and applications. It's no secret to the engineers at Bugatti, who use many titanium parts in their work.

Titanium is expensive – avoid waste

Machining titanium is an investment, as it costs about three to five times more than tool steel. So logically, you want to avoid waste. The careful selection of a suitable cutting tool is only the first step. Manufacturing precision turned parts made of titanium, which are frequently needed in aviation and spaceflight, the chemical industry, vehicle construction, and medical technology, require tools that are suited to machining this particular material, allowing for the most stubborn titanium alloys to be machined as needed.

But this diva of the materials world can do a number on your cutting tools due to:

- High heat resistance (see diagram)
- Chips not breaking
- Titanium's distinct tendency to stick to cutting tools
- A low elastic modulus ($Ti6Al4V$ = 110 kN/mm^2, steel Ck45 = 210 kN/mm^2)

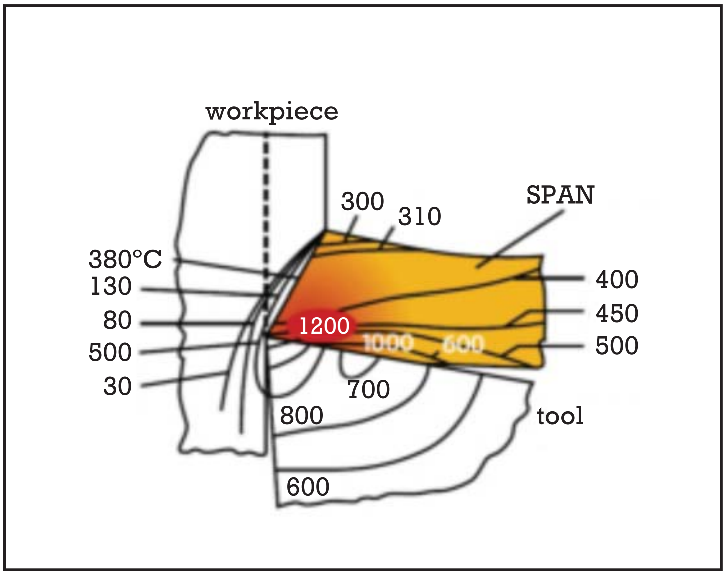

Figure 1. Titanium is a poor thermal conductor so the heat cannot be evacuated from the cutting zone via the chips. And at temperatures of 1200°C and higher in this area, the cutting tool can quickly sustain heat-related damage.

An endless chip could wind itself around the workpiece, tool, or machine chuck and can pose a hazard to the machine or your safety. It can help to change the direction of rotation and the approach angle of cut. © Image source: ARNO

Since only a privileged few manufacture titanium screws for the 1500-HP Bugatti Chiron super sports car, let's instead take a look at the manufacture of a threaded and grooved shaft made of the standard titanium alloy Ti6Al4V Grade 5/23, as is frequently used in medical technology. With a tensile strength of Rm = 990 N/mm², yield strength of Re = 880 N/mm², a hardness of between 330 and 380 on the Vickers hardness scale, and elongation at fracture A5d of approximately 18%, this titanium alloy is typically used for medical implants as well as aviation applications (3.7164) and industrial applications (3.7165). With six percent aluminium and four percent vanadium, and extra-low interstitial elements (ELIs), this alloy is highly biocompatible, inducing virtually no known allergic reactions.

Evacuate heat from the cutting zone

This requires a high-quality surface finish, reliable process safety, and controlled chip removal, all while keeping process times short despite potentially high rates of chip removal. You might assume that most of the heat generated in the turning process is evacuated via the chips, but this isn't so. Since titanium is a poor thermal conductor, the heat cannot be alleviated from the cutting zone via the chips. And at temperatures of 1200°C and higher in the cutting zone, the cutting tool can quickly sustain heat-related damage. The easiest things you can do to prevent too much heat from building up are to feed coolant directly to the cutting zone, reduce the cutting force by using a sharp cutting edge, and adjust the cutting speed to suit the process at hand.

Choose the right tools to increase service life

Real improvements are made by selecting the correct cutting tool. Since the heat must be evacuated via the cutting edge and the coolant, not via the chips, as is the case with steel, a small portion of the cutting edge must withstand extremely high thermal and mechanical stress. The cutting pressure is reduced by using ground, high-positive indexable inserts with polished flutes, if necessary, with the appropriate coating, minimizing friction in the chip removal process. These three parameters help prevent heat from being produced in machining. If only a little bit of the heat is reduced further through optimal coolant flow, the cutting edge will have a longer service life. Or the cutting speed (Vc) can be increased again to improve productivity.

So far, so good. But since this diva's chips don't like to break, you may face other difficulties. An endless chip could wind itself around the workpiece, your tool, or the machine chuck and pose a hazard to the machine or your safety. It could help to change the direction of rotation and turn the cutting edge around if the machine's design allows it. If the cutting edge is pointing downward, chips will fall freely to the ground and no longer pose a danger. However, when working with demanding roughing applications and less-than-stable machinery, you will have to check whether the cutting action allows the chips to be directed towards the machine bed. Once the chips have left the work zone, they can no longer disrupt the process.

Find the right tool manufacturer

If you want to make sure that you choose the right tool for titanium machining, turn to a manufacturer. Some go above and beyond, offering advice based on specific application experience in addition to supplying the cutting tool itself. For instance, ARNO Werkzeuge is a tool manufacturer that has been around since 1941. In addition to manufacturing one of the largest selections of high-positive indexable inserts, it employs many experienced application consultants who share their knowledge to ensure that customers' manufacturing processes run smoothly. Its high-positive indexable inserts are sharp enough to keep cutting force to a minimum, and their optional rounded edges ensure excellent stability. Expedient high-tech coatings make them well-equipped against the poor thermal conductivity of this tricky material. Negative indexable inserts with EX, NFT, NMT, and NMT1 geometries provide an affordable, reliable solution for more basic machining and roughing. Arno's positive indexable inserts with geometries PSF and PMT1 are ideal for machining superalloys. After all, you never know when you're going to get that call from a Bugatti engineer.