Materials used to manufacture pipes and their machinability

In an industrial setting, a material is never selected by chance. During the design phase, the characteristics of the materials must be carefully studied and determined in order to avoid subsequent complications when in use, and to avoiding incurring unnecessary costs.

This is especially the case when choosing a material to be used in a pipe. This is because some pipes are subjected to considerable mechanical, thermal or chemical stresses, depending on the type of fluid they convey, with pressure and temperature playing a determining role.

The material used to manufacture the pipe has an influence on all the manufacturing operations, including machining. The machinability of the pipe depends directly on the material used to manufacture the pipe, and for each given material, specific precautions must be taken in order to ensure high quality machining.

Machining is a common operation when preparing a piece for welding. The pipe end has to be machined at specific angles so that the weld can penetrate the entire thickness of the pipe material.

1. Machining a thick pipe prior to welding with a PROTEM US 150HSB beveling machine

Standard steel

Standard steel pipes are the most commonly used types of pipes owing to their low cost and mechanical properties which make them suitable for a wide range of applications. Steel pipes are resistant to mechanical stresses, durable and formable. This means that they can be used for applications with significant temperature or pressure variations. Standard steel pipes are also very commonly used in situations where impacts or vibrations can affect the pipeline (underneath roads, for example). In addition, steel pipes are fairly easy to manufacture, bend and cut.

Steel pipes are, however, very prone to corrosion if no preventive treatment is applied. Galvanization is a common corrosion-control treatment; this consists of applying a zinc coat to the steel pipe. This coating then oxidizes in the place of the steel which it protects, with the all-important difference, however, being that the zinc oxidizes very slowly.

Low-alloy steel (i.e., with a low carbon level between 0.008% and 2.14%) can be easily machined. When the carbon rate increases, the material properties (such as hardness or mechanical resistance) tend to improve significantly. However, machining steels with a high carbon level is more difficult.

2. Machining a pipe at an angle of 30° with a PROTEM US 25 beveling machine

P91 Steel

P91 steel is an alloy steel with a high chromium (9%) and molybdenum (1%) content. Adding chromium increases the mechanical resistance at high temperatures as well as corrosion resistance, and adding molybdenum improves creep resistance. Small amounts of nickel and manganese are added to enhance the overall hardness of the material. P91 steel is very sensitive to changes in its microstructure that can occur during excessive heating. These microstructure variations tend to weaken the material. This is why cold machining is often preferred for cutting this material.

P91 was initially developed for the manufacturing of pipelines in conventional or nuclear thermal power plants, where the steam leaves the superheater of a boiler in a modern conventional/thermal plant at a temperature of between 570°C to 600°C and a pressure of 170 bars to 230 bars. This means that the final stages of the superheater and the pipelines delivering the turbine steam must be able to withstand these extreme conditions. In such a case, the high mechanical resistance of P91 and its fatigue strength makes it the right choice.

By using P91 in such circumstances, the engineers were able to reduce the thickness of the pipelines while simultaneously increasing the operating temperature, all of which enhances the overall thermodynamic efficiency of a power plant.

The high mechanical resistance of P91 steel means, however, that machining is difficult. Thus, the tool bits should be changed regularly to ensure their sharpness, and the cutting speeds should be kept slow. The feed rate can also be adjusted to increase the machining speed.

3. Machining the inside of a P91 pipe with a PROTEM TT series beveling machine

Duplex steel

A Duplex stainless steel consists of stainless chromium steel with nickel added. The matrix contains both ferrite and austenite, hence the name Duplex. This alloy was designed to provide corrosion resistance and tensile strength. Duplex steel pipes are very commonly used in gas and petroleum offshore platforms where the pipelines are subjected to intense pressures and corrosive elements (salt water). Duplex steel tubes can also be found in industries with chlorinated products and acids, such as in the chemical or pharmaceutical industries. In recent years, more strongly alloyed Duplex steels have emerged under the name of Super-Duplex or Hyper-Duplex.

Duplex steel pipes are relatively difficult to machine due to their tensile strength and high yield strength. This can lead to very high cutting temperatures and to plastic deformation of the pipe. In any case, the tooling and clamping must be sufficiently rigid and stable in order to machine a Duplex steel pipe.

4. Machining a Duplex pipe at an angle of 30° with a PROTEM US 150 beveling machine

Stainless steels

Just like standard steels, stainless steels are comprised of iron and carbon, to which chromium has been added. Upon exceeding a certain proportion of chromium (10.5%), a chromium oxide layer is formed on the steel surface. This so-called “passive layer” is chemically inert, corrosion resistant and stable.

Other elements can be added to improve the mechanical strength (nickel) or high-temperature performance (molybdenum, titanium, vanadium, tungsten).

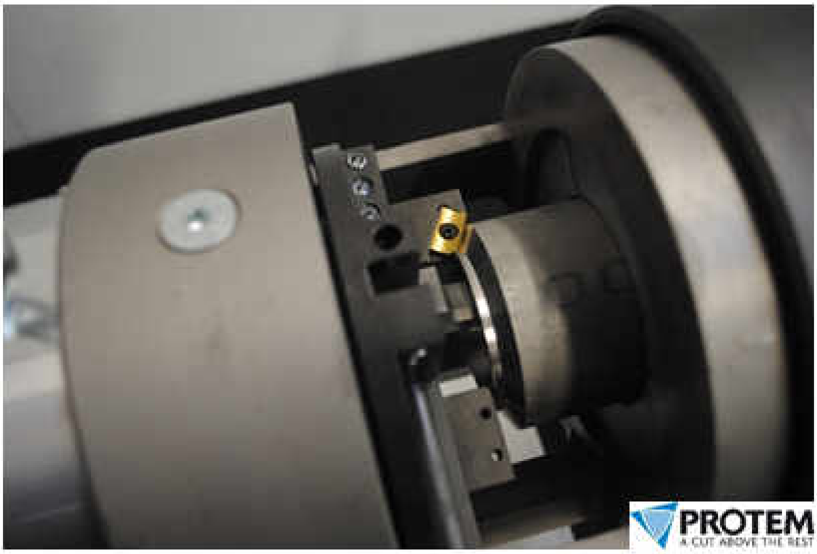
Although more expensive than standard steel pipes, stainless steel pipes are widely used in many industries (chemical, petroleum, pharmaceutical, food, aerospace, shipbuilding, etc.).

Their popularity stems from their corrosion resistance and chemical stability which make stainless steel piping suitable for fluids that must not be contaminated (pharmaceutical industry, food industry, etc.) and for corrosive fluids (the chemical industry, in particular).

The machinability of stainless steel is highly dependent on the proportion of alloying elements. Specifically, a high proportion of chromium, nickel or titanium makes machining more difficult, whereas adding carbon or sulfur facilitates machining.

The cutting edge must be sharp to facilitate chip detachment from the material and reduce the cutting forces.

The cutting tool must be sufficiently well assembled and the machine itself must be sufficiently rigid to support the forces caused by machining; as a rule of thumb, the forces deployed when cutting stainless steel can be more than 50% higher than with standard carbon steel.



5. Machining a stainless steel pipe before welding with a PROTEM SE60 beveling machine

Superalloys

Most of the superalloys used to manufacture pipes belong to the range of nickel-based superalloys. This range includes Inconel and Austenite, named after the alloy manufacturer.

Therefore, the alloy base is nickel which can be alloyed with chromium, iron, titanium or aluminum. These alloys have the same advantages as stainless steels, but to a greater extent. Specifically, their heat resistance is higher (about 900°C) as is their corrosion resistance (corrosion in chlorine ion solutions, ultrapure water and caustic mediums). They are also much more expensive than standard alloys, but this is justified for applications where operator safety is an essential criterion.

Pipes made from nickel-based superalloys are used in aerospace (in combustion chambers, for example), the chemical industry (due to their corrosion resistance), nuclear engineering, and, to a lesser extent, in the food industry.

Superalloys are considered very difficult to machine. This can be attributed to several factors. First, one must bear in mind that 70% of the heat is returned directly to the cutting tool (as opposed to 15% for standard steel, for example). Therefore, it is essential to keep the cutting-edge cooled during machining. The second complication is the hardness of the material; in fact, the lifetime of a cutting tool used to machine a superalloy can be reduced to just a few minutes if the tool does not have the necessary power, or if the cutting speeds and tools are not suitable.

6. Machining with superalloys, PROTEM TTNG 1016 Orbital Tube Cutting & Beveling machine

Titanium

Titanium is an extremely interesting metal for the industry. Titanium can be used to manufacture pipes which are light and yet highly resistant to corrosion and able to withstand very high temperatures (600°C). Its mechanical properties (resistance, fatigue and ductility) are also appreciated. Titanium is, however, expensive and this limits its use to specific applications. In general, one finds titanium in the aerospace sector where its low density combined with its attractive mechanical properties make it an essential material.

Since the thermal conductivity of titanium is very low (about ten times lower than steel), the heat dissipation during machining is relatively poor. Therefore, the cutting edge needs to be properly cooled to avoid machining defects.

Sharp tools should be used to facilitate chip detachment from the material, and thus reduce the cutting force.

Machining is even more difficult in the case of treated titanium (e.g., treatment by precipitation hardening, presence of chromium coating or alloying).

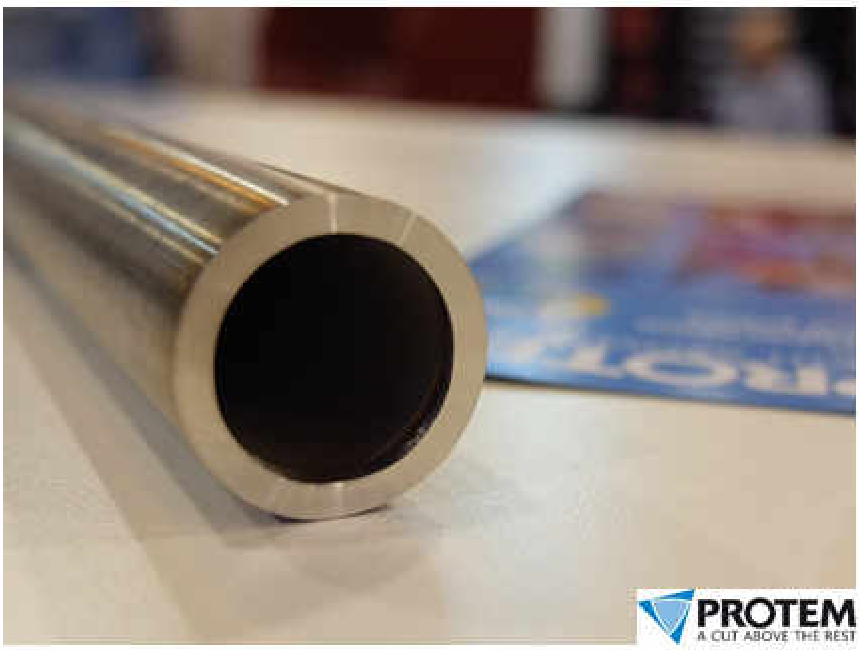
7. Titanium-elbow machining for the Aeronautics sector, PROTEM SE 2T pipe-squaring machine

Aluminum

Aluminum is very widely used in the industry. Aluminum pipes are inexpensive, easy to form and assemble. They are also light and corrosion-resistant, making them a natural choice in the aeronautics, transport and construction sectors. Aluminum pipes are also used to build compressed-air pipelines.

Aluminum pipes have a very low level of hardness, and are therefore relatively easy to machine. However, the malleability of aluminum can cause problems (shavings can lead to machine jamming, for example). In this case, the best response is to increase the cutting speed, the depth of the pass and the feeding speed. There is also a risk of aluminum pipes being deformed during machining if the machine tool, and in particular, the clamping jaws, are not correctly chosen.

The high thermal conductivity of aluminum allows for good heat dissipation. Thus, the cutting speed can be increased without reducing the lifetime of the tools.



8. Drawn aluminum pipe with PROTEM SE 90 pipe-squaring machine

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