Machining stainless steel bar – a short guide

Machining stainless steel bar, including the main operations of turning, milling, drilling, threading and sawing is often regarded as demanding. This is because certain grades, but far from all of them, expose the cutting edge to demanding conditions when machining.

Primarily, it is austenitic and duplex stainless steels that may be challenging to machine. Ferritic and martensitic steels are seldom particularly difficult to machine, although ferritic steels can give rise to stickiness and the formation of built-up edges. Martensitic steels can be challenging to machine if they have been hardened to high hardness, although this is not unique to stainless steel.

The reason why machining of austenitic and duplex stainless steels can be demanding is due to a combination of properties of these relatively ductile materials. These properties mean that the hardness can no longer be used as an indication of the material's machinability.

Machinability of a material embraces several factors. Therefore, in addition to tool wear it is also necessary to consider the effect on cutting forces, chip shape and surface quality of the machined surface, see Figure 1.

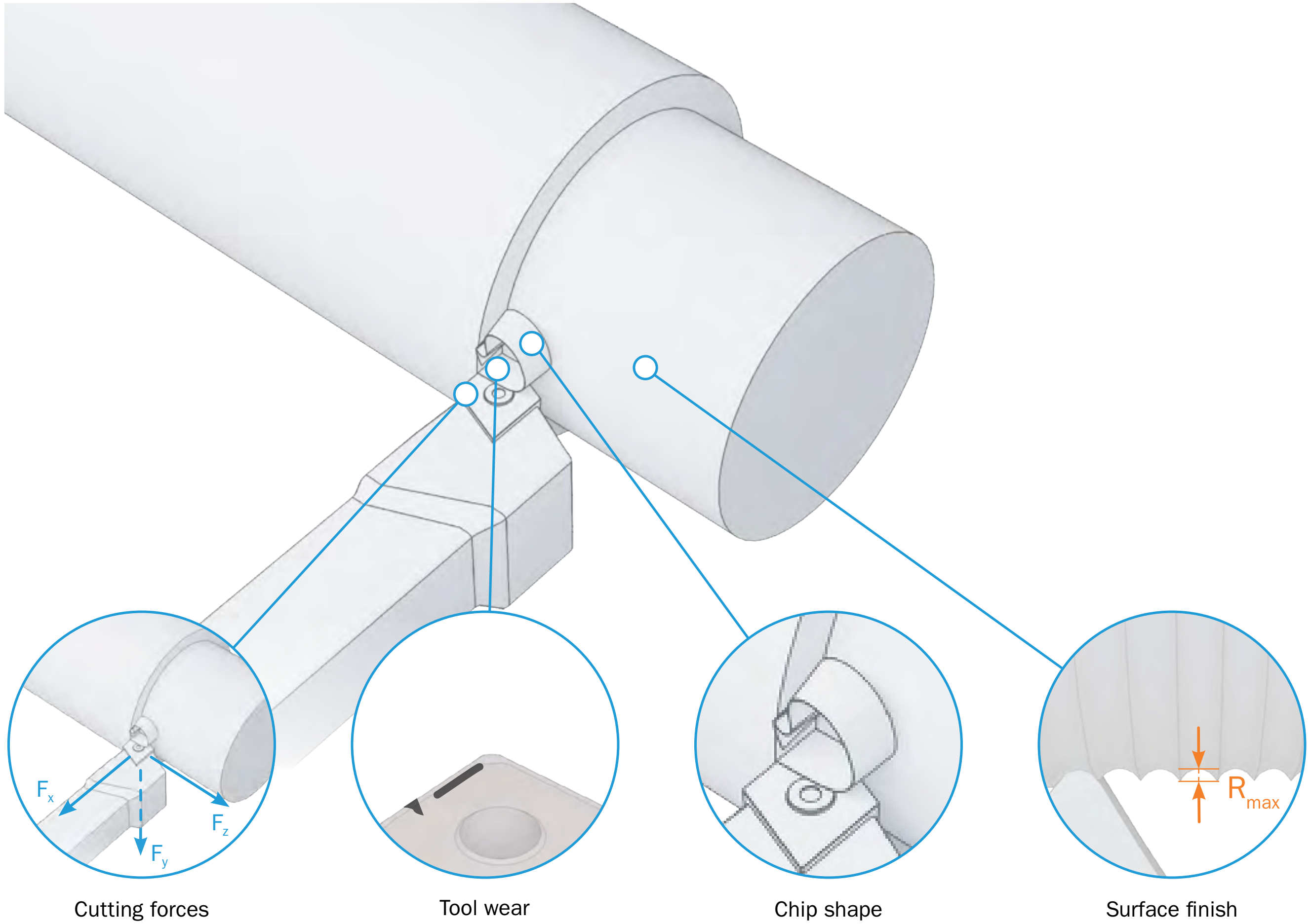

Fig. 1. Four important ‘shop-floor’ machinability factors.

The special material properties of stainless steel affects all four of these machinability factors. In general, the higher the alloy content of a stainless steel, the more demanding it is to machine. The special properties that make stainless steel demanding to machine occur to a greater or lesser extent in all grades of stainless steel. They can be summarized in five points:

1. Stainless steel work hardens

This means that the hardness increases as the material is deformed, such as during chip production. It also means that, after a first pass, the machined surface will have become harder, changing the working conditions for the cutting edge during subsequent passes.

Austenitic stainless steels have the greatest tendency for work hardening, which results in both high cutting forces and a high hardness of the machined surface. This means that the cutting edge must work on a material that is much harder than is indicated by the hardness of the base material. This often results in challenges during finishing, as the depth of cut is so small that the cutting edges work entirely on the work hardened layer.

As well as machining, other types of cold working such as shot and sand blasting or straightening can also produce a hard surface layer that affects machinability. In such cases, the hardness gradient is similar in principle to that resulting from machining, but the increase in hardness can extend to a greater depth into the metal.

2. Stainless steel has low thermal conductivity

Stainless steels are poor conductors of heat, and the thermal conductivity of all types of stainless steel falls off with increasing alloy content. Austenitic stainless steels have the lowest thermal conductivity, while duplex, ferritic and martensitic stainless steels have better conductivity.

Low thermal conductivity means that, for a given machining operation, the cutting edge temperatures are higher in stainless steel than in carbon steel and higher in high-alloyed stainless steel grades than low-alloyed. This imposes requirements on the high-temperature hardness of the cutting edge.

3. Stainless steel has high toughness

Austenitic stainless steels in particular have high toughness, which means that the energy required to form each chip is high. This, in combination with work hardening, results in high power requirements for machining. The high cutting forces, in combination with the low thermal conductivity, impose requirements on the strength of the cutting edge.

4. Stainless steel tends to be sticky

This tendency is most marked in austenitic stainless steels, although both ferritic and duplex stainless steels can give rise to chip sticking and built-up edges on the cutting tool.

Although it is often sufficient to increase the cutting speed to exit the built-up edge range, it can in certain cases be challenging to find a cutting speed range where built-up edge formation is eliminated.

5. Stainless steel tends to have poor chip-breaking characteristics

The high toughness of many stainless steels, and particularly austenitic steels, make it challenging to break chips. By choosing a suitable chip-breaker on the cutting tool this issue can mostly be eliminated.

Comparing machinability

Comparisons of the machinability of different stainless steel grades are based on machinability indices (Vx) derived under standardized test conditions (ISO 3685). Vx is usually expressed as the cutting speed that is needed to give a certain predetermined tool life. This is normally measured either as the time x taken to reach a certain defined wear, or machined length x until the tool fails.

The machinability of different stainless steel grades

The machinability of stainless steel varies from one grade to another. Furthermore, a particular grade of stainless steel does not behave the same way in all machining operations. Instead, a grade that might be easy to machine in the majority of operations can be demanding to machine in some particular cases. This means that it is not possible to estimate either the cutting parameters or the machining cost for a part based on tests with only one machining operation. Instead, it is necessary to allow for all the operations involved in producing the part. However, information on the machinability in a particular operation can still give good guidance for similar machining operations.

Improving the machinability of stainless steel

The ‘classic’ way to improve machinability is to alloy the steel with 0.15–0.35% sulfur, which creates sulfides in the material. These steels are known as free-machining stainless steels, such as Prodec 303/4305. The sulfides

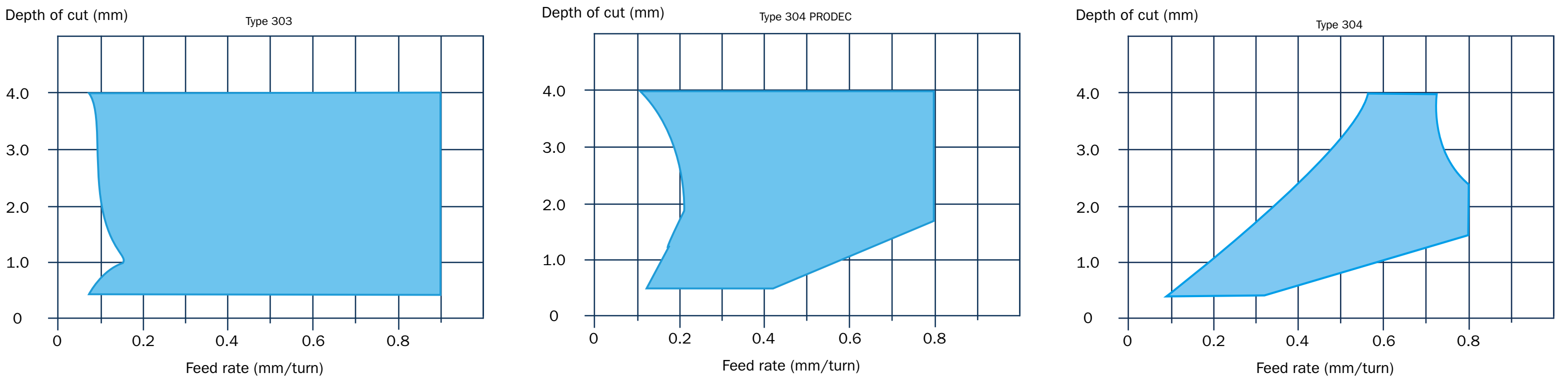

Fig. 2. Chip-breaking charts when turning different metallurgical versions of 304-type stainless steel. The shaded areas indicate acceptable chip characteristics.

improve the machinability, and particularly chip-breaking, but have the drawback of degrading weldability, toughness, corrosion resistance and hot workability.

Through advanced process technology it is possible to control the non-metallic inclusions that are always present in a steel and to give them characteristics that improve the machinability. This is done without having to employ the high sulfur contents used in the free-machining steels. By converting the inclusions from hard, abrasive particles to softer and more lubricating particles, it is possible to produce standard grades such as Type 304 and Type 316 with improved machining characteristics approaching free-machining steels, essentially without sacrificing other characteristics.

The stainless steels in Outokumpu's Prodec range of improved machinability steels are produced by specialized ladle metallurgy that converts the hard abrasive oxides into a group of complex oxides. This substantially reduces tool wear and facilitates the cutting process by improved chip-breaking and through the formation of a lubricating and protective layer between the tool and the chip, which greatly reduces tool wear.

Figure 2 shows the effect of various metallurgical versions of Type 304 on chip-breaking during turning. The charts show that Prodec 304L/4307 has a considerably better chip-breaking performance than the same grade in its standard form, while Prodec 303/4305, the free-cutting version of Core 304L/4307, still has the best chip-breaking properties at low feeds.

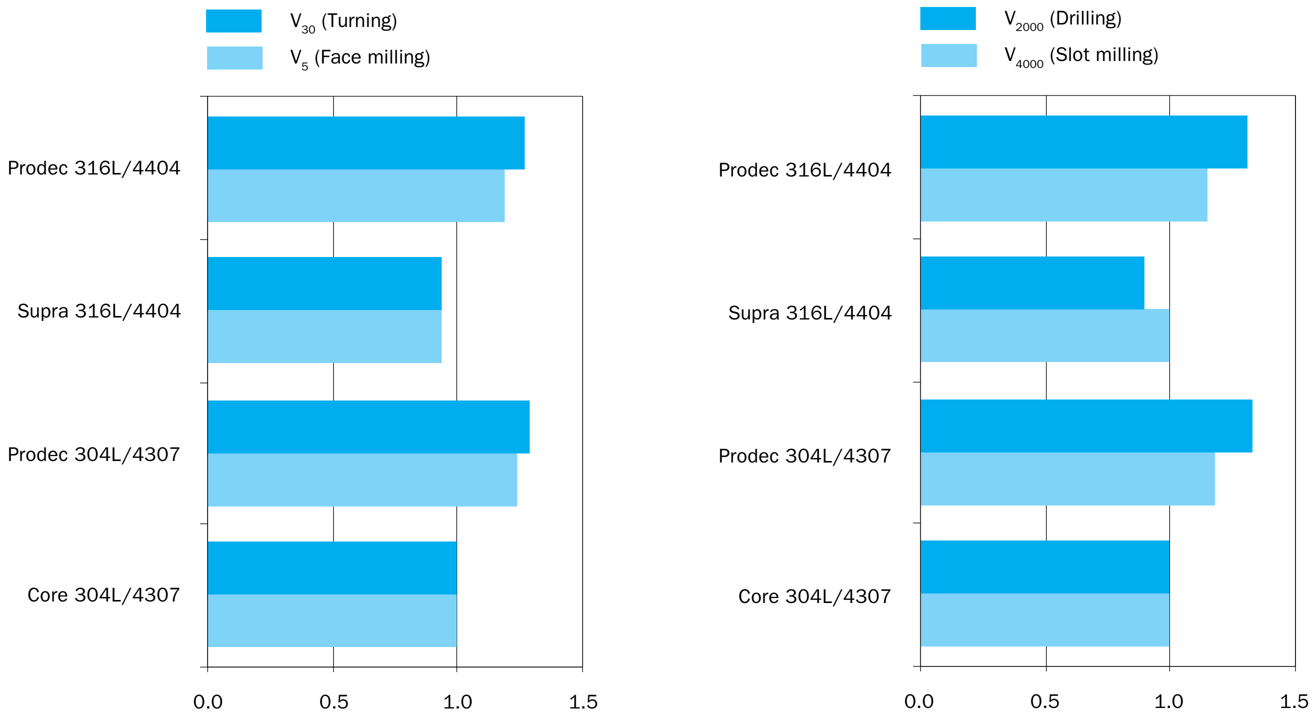

Fig. 3. Comparison of the machinability indices for Type 304 and 316 in standard and improved machinability (Prodec) versions for four different machining operations. All data normalized to Core 304L/4307.

As can be seen from both Figures 2 and 3, the same grade of steel can have different machining characteristics, depending on the metallurgical process by which it was made, which can have a considerable effect on machining costs.

There are some general rules of thumb that can be applied when machining stainless steel to avoid the issues described, or at least to minimize them. They are particularly important when machining austenitic and duplex stainless steel.

- Always use rigid machine tools, as the machining of stainless steel involves high cutting forces.
- Tools and workpieces must be firmly clamped, and the tool overhang must be as small as possible.
- Do not use too large a nose radius, as this can cause vibration.
- Use tools with good edge sharpness and high edge strength.
- Use sufficient cutting depths, so that the cutting edge tip reaches below the work hardened zone from the previous cut.
- Replace the insert more frequently than when machining carbon steel, as a dull edge produces greater work hardening than a sharp edge.
- When using cutting fluid, ensure that it is always applied generously.

Further reading

The information in this article is based on the Machining Handbook, part of a series of stainless steel handbooks published by Outokumpu.

If you would like to obtain a copy of the full 132-page Machining Handbook please contact Outokumpu here:

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