Finishing of super alloys and hardened steels

Obróbka wykończeniowa superstopów i stali zahartowanej

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DOI: https://doi.org/10.17814/mechanik.2017.10.127

Presented are challenges of finishing machining of super alloys and hardened steels. The right approach to tool selection for finishing and the effect of coolant delivery on process parameters and optimization options will be described.
KEYWORDS: turning finishing, mechanisms of strengthening, coating CVD and PVD, tool life, high pressure coolant

Finishing is a key operation that determines the consistency of a workpiece with quality expectations. The basic criteria for assessing the correctness of part machining are its dimensions and tolerances, surface quality, roughness or other criteria listed in the specification.

Roughing gives a greater freedom in the choice of methods, tools, or parameters. Typically, most of the material is removed in this process, which implies theoretically much higher temporal share in the machining process, and therefore greater optimization potential. The tolerance requirements are less than for finishing. That is why over the years the finishing work remains second in the process of optimizing or planning new technological processes, where the so-called proven methods.

This article presents the revolutionary, patented Seco Tools TH1000 grade, which allows for a safe increase in the productivity and tool life in the process of finishing hardened steels, in the range of 45÷62 HRC, and super alloys such as Inconel 718.

Another solution to improve tool life and performance in hardened materials and heat resistant alloys machining is use of the Jetstream Tooling®, the high pressure cooling system developed by Seco Tools, whereby the coolant is delivered directly to the cutting zone [1]. An appropriately directed coolant stream enhances chip evacuation, improves surface quality, and significantly lowers the temperature in the cutting zone compared to conventional coolant delivery.

Cutting tool materials and barriers in the finishing of hardened materials and super alloys

In the finish machining of hardened steels and super alloys, the most common are the tools made of coated carbide and polycrystalline boron nitride called PCBN, which may be coated or uncoated.

For finishing operations of hardened materials above 50 HRC, the most optimum tool will be PCBN, allowing use of the highest possible parameters at relatively long tool life. But what if the workpiece is case hardened on the surface and the finishing work must be carried out in a material, where the hardness of falls below 45 HRC under the hard surface? An example of such a situation is grooving in surface hardened steel or removing of a hard layer before welding. At low hardness, the use of PCBN is unprofitable. Short tool life is due to the dynamic progressive diffusion of the cutting material to the workpiece – chemical wear. An additional problem is the long chip due to the general lack of chip breakers on PCBN tools.

The carbide inserts do not allow for high parameters; cutting speed does not exceed 40÷70 m/min depending on material hardness. With hardness over 50 HRC, carbide tools are very difficult to work with, or practically stable work is not possible due to the very fast wear of the edges, and consequently, problems of achieving the desired tolerances and surface quality after finishing. The exception is the TH1000 Seco carbide grade, described later in this article, which allows to uses about 50-100% higher cutting speed, combined with a significant increase in a tool life.

In a super alloy finishing, carbide or PCBN tools are used. Due to the high price of advanced, raw materials used in the production and the components made from them, machining processes must be reliable. Manufacturers can not afford to produce scrap, but at the same time they are looking for an efficient process whereby finishing is crucial for reliability. Selection of suitable tools and processing parameters ensures quality and economically consistent results.

PCBN tools allow machining speeds of up to 300 m/min for super alloys while finishing machining operations, however there are producers that not allow machining of PCBN tools in finish operations, but only carbide tools. The carbide, although offering significantly lower cutting speeds, remains the first choice for super alloys due to its larger operating area and greater resistance to variable conditions that affect process safety.

Deformation of the workpiece in the cutting process. Tooling requirements.

By definition, cutting is a workpiece material deformation until it tears off under the form of chips. Those chips need to be broken in short pieces. By analyzing further the definition and the cutting properties of the workpiece material, we encounter the following features:

- **tensile strength and ductility**, i.e. the ability to withstand deformation without breakage; the greater material's ductility, the greater problem with chip breaking and swarf control (fig. 1);
- **hardness**, i.e. the ability to withstand compression without deformation; the higher hardness, the higher cutting forces;

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- **thermal conductivity**, i.e. the ability of the material to heat transfer; high thermal conductivity means that large amounts of heat generated by the cutting process is removed with chips and machined parts (for comparison, the copper thermal conductivity is 400 W/mK, while titanium is only 17 W/mK);
- **mechanisms of strengthening**: strain hardening, solid solution strengthening, grain boundary strengthening, precipitation hardening, dispersion strengthening.

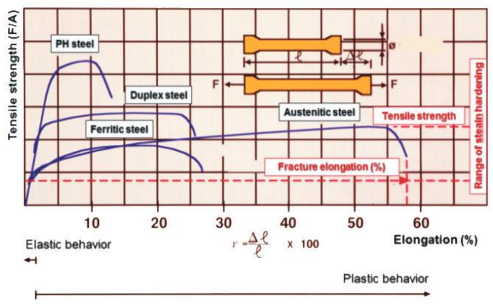


Fig. 1. Comparative graph of tensile strength of different materials

Mechanisms of material strengthening should be considered at every stage of super alloy machining. Although the super alloys do not achieve a high hardness compared to hardened materials, strain hardening mechanism and temperature-activated local precipitation hardening in the cutting zone lead to the so-called micro-hardening. With materials susceptible to strain hardening such as Inconel 718, the deforming zone reaches a minimum of 70÷80 μm and is much harder than the material below the hardened zone, which in turn brings it closer to the working conditions in the hard material [3]. It is considered that the hardened zone can significantly exceed 0.1 mm if the preceding process was run on a worn or overly-protected cutting edge, e.g. when the negative insert for roughing was incorrectly selected.

The low thermal conductivity of super alloys directly affects the tool life of the cutting edge. The decisive role in the process plays a proper determining the cutting speed to the species of the cutting edge material [2]. In tempered materials the cutting speed limit is dictated by high hardness and high heat generation forces. Therefore, with higher hardness, traditional carbide is difficult or even impossible to work with. Then the tools are made of PCBN, which preserves the hardness at high temperatures, called hot-hardness. The workpiece, during machining generates a large amount of heat, locally in the cutting zone. PCBN is ideal for high abrasion hard materials also.

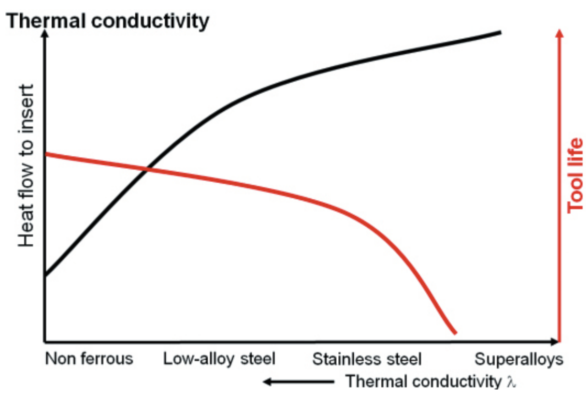


Fig. 2. Influence of thermal conductivity on the tool life of the carbide cutting edge depending on the material to be machined

Low thermal conductivity is responsible for the short tool life of the carbide cutting edge, but not only. It is assumed that the wear of tools in hard-to-machine materials is 5 or even 10 times higher than, for example, in basic structural steels.

Difference between CVD and PVD coating for carbide grades

Carbide grades can be divided according to their ductility in ISO classes, e.g. P05, P15, P25, P35 for steel. Of course, this classification is made by the manufacturers and should correspond to certain applications, workpiece materials. The decisive parameters are grain size and cobalt content, which acts as a binder for carbide grains. They correspond to the toughness of the cutting edge. Current manufacturing technologies allow control of the cobalt content at different areas of the cutting edge – the cobalt gradient – so that the harder grades lose less of their toughness. Of course, the cutting edge toughness depends on appropriate edge preparation as well.

The coating is used to improve the wear resistance and, in general, its layer is within the range of 1÷20 μm. There are 2 types of coatings due to overlaying techniques: CVD chemical coatings, thicknesses of 4÷20 μm, and physical PVD thicknesses of 1÷5 μm.

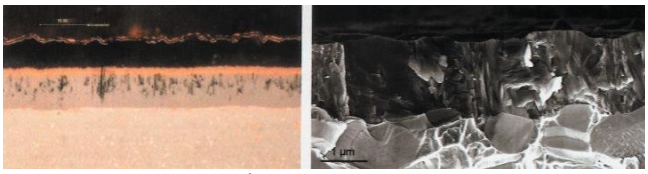


Fig. 3. Cross-section of 15 μm multi-layer CVD coating (left) and cross-section of 1.5 μm PVD coating (right)

Typical CVD coatings in the lower layer include Ti (C,N) and in the upper Al_2O_3. This combination increases wear resistance, thanks to Ti (C,N), and temperature, thanks to Al_2O_3. Layer thicknesses vary depending on the desired coating characteristics (fig. 3). Thick Al_2O_3 layer improves thermal resistance and is primarily intended for roughing, large components or for high cutting speeds.

PVD coating technology makes it possible to use a variety of materials such as Ti, Al, Cr, Si, N, O, and C. PVD coatings are harder than CVD coatings, so for finishing work, where a harder cover provides a longer tool life, most commonly PVD coated tools are applied. Due to the smaller layer of material removed, the effect of the temperature on the cutting edge is smaller than in roughing.

Another important feature of CVD and PVD coatings is the stress generated by the coating process. CVD coating is applied at a temperature of approximately 1000°C. When the coated cutting edge cools, the tensile stress in the coating increases due to the different thermal expansion of the coating and the substrate. In PVD coatings, due to the technique of the coating, there is a lateral compression stress, which results in better coating adhesion to the substrate, which directly improves the edge toughness [4].

Carbide type TH1000 and its properties in finishing operations

TH1000 is a unique, patented Seco Tools carbide coating with PVD (TiSiN-TiAlN) nanoparticle coating of 3 µm thickness. It is a super-fine grain with very hard substrate (2020 HV). This is the first commercial grade with so much hardness (fig 4). For comparison, a maximum hardness of 1850 HV is commonly used. The fine grains and previously described features of the PVD coating ensure excellent edge toughness, even in intermittent workpieces machining.

The combination of high hardness with good thermal insulation from the nano-laminate coating provides excellent wear resistance and allows for much higher cutting speeds compared to other carbide grades. TH1000 carbide grade can be separated from the traditional carbide range, as the work area fills the gap between carbides and advanced materials such as PCBN or ceramics (fig. 5).

TH1000 is the toughest grade of carbide among all available PVD grades.

When choosing high wear resistant tools, it is important to consider that too large depth of cut in a hard-to-handle material at high parameters usually results in uncontrolled wear and sometimes catastrophic edge breakage. TH1000 inserts are excellent for medium and finishing hardened steel in the range of 45÷62 HRC and super alloys such as Inconel 718, Waspaloy and Nimonic [5].

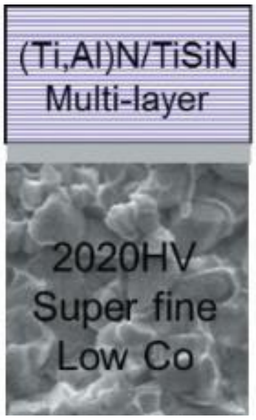


Fig. 4. TH1000 grade, nano-laminate PVD coating of 3 µm thickness – low cobalt content, super-hard substrate

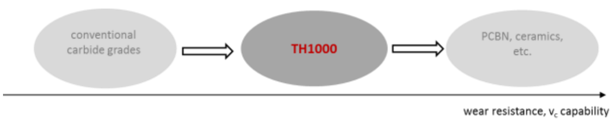


Fig. 5. Positioning of cutting materials in terms of wear resistance

Industry-proven TH1000 demonstrates that even with doubled the cutting speed, these tools have a longer tool life than any other carbide grade. A cutting speed of 100 m/min and an hour tool life in the Inconel 718 material can be assumed.

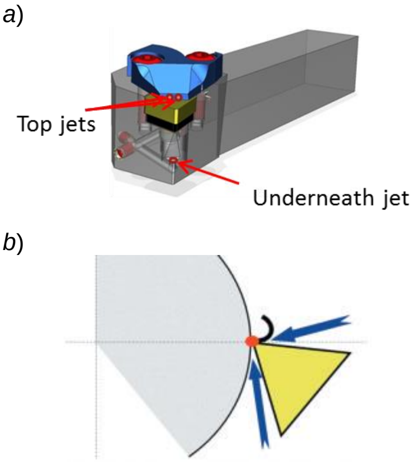
Jetstream Tooling® high-pressure cooling system

The use of the high-pressure coolant delivery system (Jetstream Tooling®) contributes to increased process efficiency. If the cutting speed of the ISO-S material is 50 m/min, the Jetstream system in connection with a properly selected carbide grade allows to accelerate the cutting speed even to 200 m/min and thus a 4-fold increase in productivity. The main advantage of this is the lowering of the temperature in the cutting zone, which is particularly important for high-ductile materials when chips do not break and evacuate in a form of long swarf. Due to the constant, stable coolant delivery, higher cutting speeds can be assumed because it is assured that the coolant is always delivered to the cutting zone and provides longer tool life without risking to thermal shock or plastic deformation of the cutting edge.

Key benefits of using Jetstream Tooling®:

- direct coolant delivery increases tool life and improves surface quality,
- increased pressure significantly improves chip breaking and enables higher cutting speeds,
- Jetstream Tooling® improves process safety, stability and improves productivity.

a)



b)

Fig. 6. Jetstream Tooling® Duo system: *a*) coolant supply flow chart, *b*) Jetstream Tooling® Duo operating principle

Conclusions

Understanding the processes taking place in the workpiece while machining and the right approach to tool and parameter selection allow to design or optimize the process, ensuring both high productivity and safety. Always consider the whole system that yields performance and security. The key parameters are: machined material and its properties, stiffness of the machine and workpiece clamping, possibilities of obtaining machine parameters, machining strategy, stable temperature control in the cutting zone through proper cooling and parameters and many other factors that can directly affect the process. Only this approach provides the highest possible results in terms of economy, productivity and process safety.

REFERENCES

1. *„New tools and strategies take on ISO S materials”*, https://www.secotools.com/#article/21491 (dostęp: 19.05.2017 r.).
2. De Vos P., Stahl J.-E. „Thermal conductivity”. *Metal Cutting Theories in Practice*. Lund–Fagersta, Sweden: Lund University, 2014.
3. Stahl J.-E. „Determining the deformation width”. *Metal Cutting Theories and Models.* Lund, Sweden: Lund University, 2012.
4. De Vos P., Stahl J.-E. „Cutting materials and their deterioration”. *Metal Cutting Theories in Practice*. Lund–Fagersta Sweden: Lund University, 2014.
5. *„Seco introduces new insert geometries and holders for turning challenging materials”*, https://www.secotools.com/#article/20864 (dostęp: 27.06.2017 r.).
6. *„Balancing key factors in stainless steel machining”*, https://www.secotools.com/#article/21497 (dostęp: 19.05.2017 r.).