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Increasing Cutting Tool Life when Machining Inconel 718

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Abstract

Machining of Inconel 718 is still very problematic. During the machining the cutting edge is stressed by high temperature and pressure in a small area. So it is important to use fluids with high pressure and a very accurate and high quality cutting wedge. When cutting inserts are used we can do this by special internal cooling systems and special inserts. When a monolithic cutter is used the options for it are not broad when standard machines are used. Main aim for the increasing of the cutting tool life is in the cutting edge microgeometry which is designed by special processes after grinding or after deposition of the thin layer. When the special edge modification is used the cutting edge has high quality, an identifiable edge radius and better roughness on the back and rake area and identifiable K factor. For the good deposition of the thin layer and longer tool life of a monolithic cutting tool it is important to have an optimal value of the radius. When all parameters have optimal values, this can prolong cutting tool life.

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1. Introduction

Heat resistant super alloys are most widely used in industries such as aerospace, automotive, gas turbine and others. Their advantages are strength and hardness at high temperatures and corrosion resistance. These main properties influence their machinability, which is still very bad. During machining the cutting edge is stressed by very high heat treatment and high pressure which depend on the hardness of the material. This causes the most problems during the machining and influences the type and style of the tool wear. In our case Inconel 718 was tested which belongs to the group of nickel based alloys. For example, this group of materials is used in the aircraft industry. They currently constitute over 50% of the weight of advanced aircraft engines. The trend is that this will increase in new engines in the future." [1]

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Nomenclature

ρ_r	edge radius between rake face and flank face
K	K factor - description of the cutting edge symmetry
T	cutting tool life
R_t	roughness - maximum height of the profile
R_z	roughness - average distance between the highest peak and lowest valley in each sampling length
V_c	cutting speed
V_f	feed rate

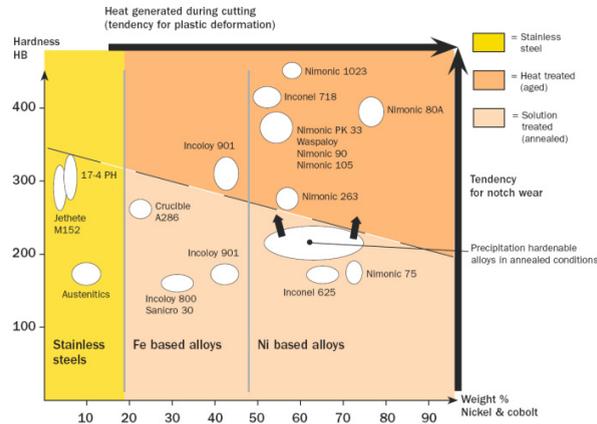


Fig. 1. Types of superalloys and their effect on tool wear [1].

Cutting tools with positive geometry are used for machining Inconel 718 and it is recommended to use cutting inserts and high coolant pressure. If it is not possible to use a cutting insert the manufacturer must use solid cutting tools. In our case we will focus on milling with solid carbide mills. Very important parameters are cutting tool geometry in the critical area of the cutting tool, the tip of the wedge, design of the cutting edge and quality of thin layer and cutting edge [2, 3, 4, 7]. So it is very important to monitor these parameters and investigate their influences on the cutting process when machining Inconel 718.

2. Cutting edge monitoring

Different solid cutting tools with different edge radius and geometry were used for the tests. Drag finishing (DF) was used for the edge rectification in different steps during the manufacturing process. It means that the DF was applied after grinding or after deposition of the thin layer and in the next case polishing by DF was used. The main aim is how the cutting edge quality will influence the cutting process during machining. In the first step the edge radius ρ_r , K factor and edge roughness were monitored.

For measuring these parameters the Infinite Focus System G4 from the Alicona Company was used. The measuring principle of this device and measuring methods are described in the article 'Evaluation of the cutting tool when Inconel 718 is machined' [9] by my colleague. A very important fact is that based on the recorded deviances it is possible to measure the roughness in the area where the tool wear will be increased [5,6,8], see Fig. 2.

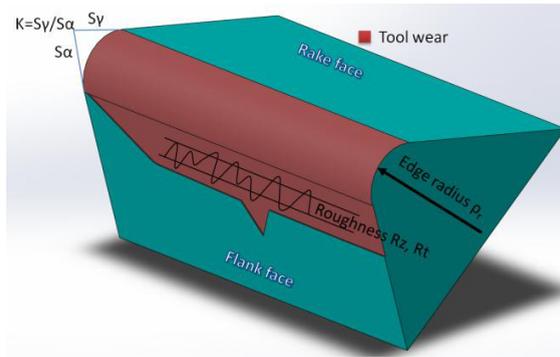


Fig. 2. Monitored parameters on the cutting edge.

For the test these values of edge radius ρ_r and tool geometry were used, see Table 1.

Table 1. Value of the edge rectification.

No. of cutting tool	1	2	3	5	10	15	20	25
ρ_r [μm]	2	2	5	5	10	15	20	25
Tool geometry	V1	V2	V3	V4	V4	V4	V4	V4

During the manufacturing process from grinding to deposition of thin layer the parameters on the cutting edge were monitored. The first case, see Fig. 3a, shows how the edge radius increases during the time of the rectification process.

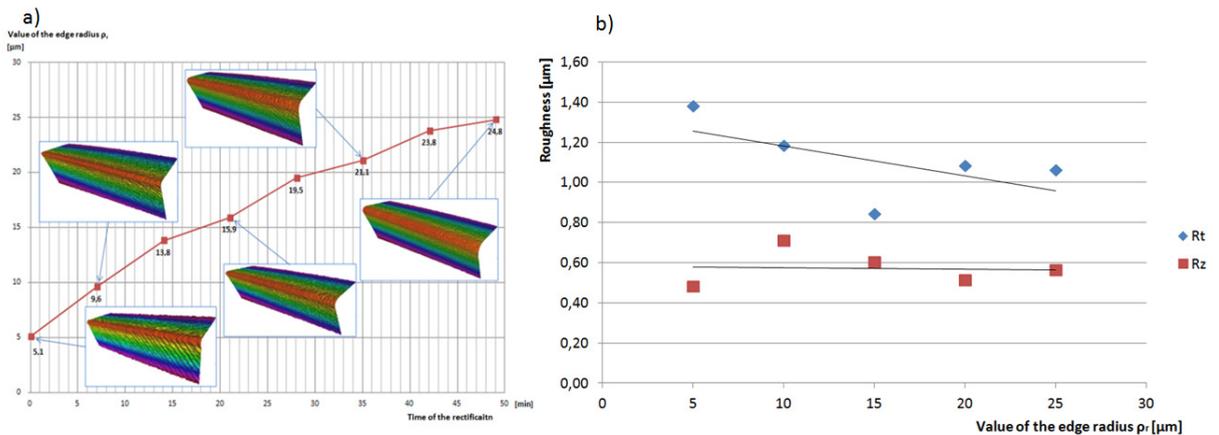
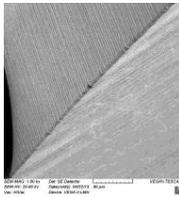
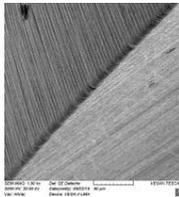
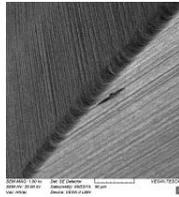
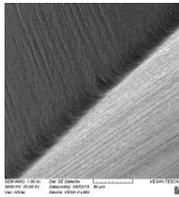
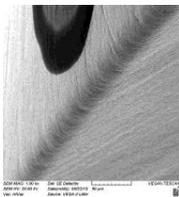
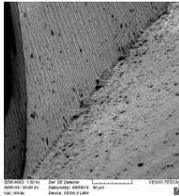
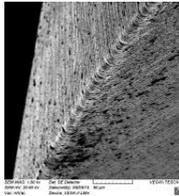
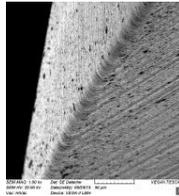
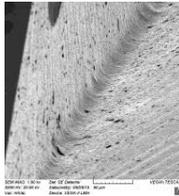
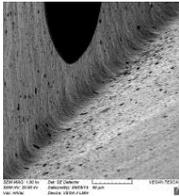


Fig. 3. a) Influence of the rectification time on the value of the cutting edge radius, b) Influence of the edge radius (rectification time) on the roughness.

From Fig. 3b it is evident that with the increasing of the rectification time, the value of the cutting edge increases and the quality of the faces is better, which means that the value of the roughness decreases, see Fig. 3 - right.

These same parameters were measured after the deposition of the thin layer and the value is very similar because the same thin layer was used. It is very important to control the quality of the thin layer on the cutting edge where tool wear and all parameters are monitored and of course the cutting edge where the edge radius is. SEM analysis was used for this.

Table 2. SEM analysis of the cutting edge with geometry V4 after grinding and after deposition.

ρ_r [μm]	5	10	15	20	25
Edge after rectification					
Edge after deposition					

It is evident that the value of the edge radius influences edge quality, thin layer adhesion and quantity of the droplets. Table 2. shows that when the edge radius is smaller the droplets are more concentrated on the blade. This can have a positive or negative effect and it depends on the workpiece material and on the cutting conditions. Table 2. shows some defects on the edge radius. When the edge radius is smaller there are more defects. This causes stress in the thin layer after the deposition and in many cases the thin layer is broken. In these cases it is better to use DF after deposition. This results in the cracks being polished and in many cases the droplets are removed from the face.

3. Experiments

The experiment was focused on measuring the tool wear on the flank face VB, on monitoring the cutting forces and workpiece quality (mainly on the burr). Two tooth mills from sintered carbide were used for the tests. For the evaluation of the tool wear the Multicheck PC500 optical microscope was used and a Kistler dynamometer was used to measure the cutting forces. The tool wear was monitored at a distance of 2 mm from the mill tip as were all the results from IFM and SEM.

Table 3. Cutting conditions .

Cutting speed vc [m/min]	Feed speed vf [mm/min]	Axial depth of cut ap [mm]	Radial depth of cut ae [mm]	Cutting environment	Cutting tool dia. ød [mm]
35	111	3	0,5	External cooling	8

The workpiece was clamped on the dynamometer clamping area by the clamps, and the Tribos system by the Schunk company was used for the cutting tool.

3.1. Evaluation of tool wear

This part is focused on the influences of the edge rectification on the cutting tool life. The cutting tool with edge radius $\rho_r = 15 \mu\text{m}$ was used as an etalon (cutting tool No. 15). The maximum tool wear was $VB_{\text{max}} = 150 \mu\text{m}$. A standard VB-t diagram was made for this tool.

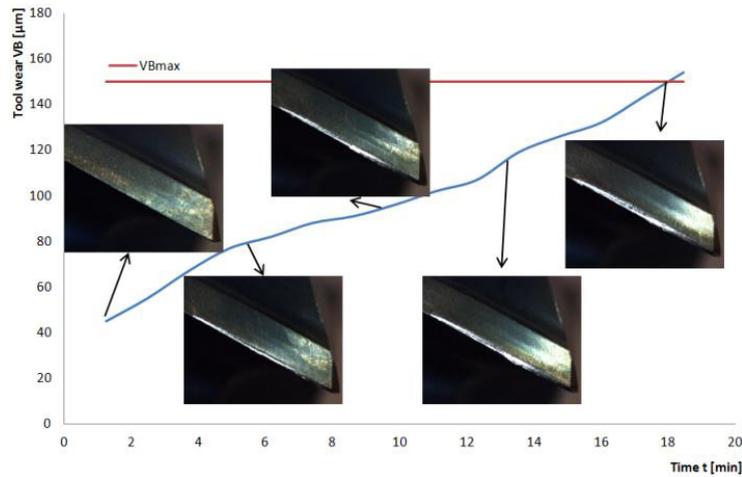


Fig. 4. The course of the cutting tool wear VB-t.

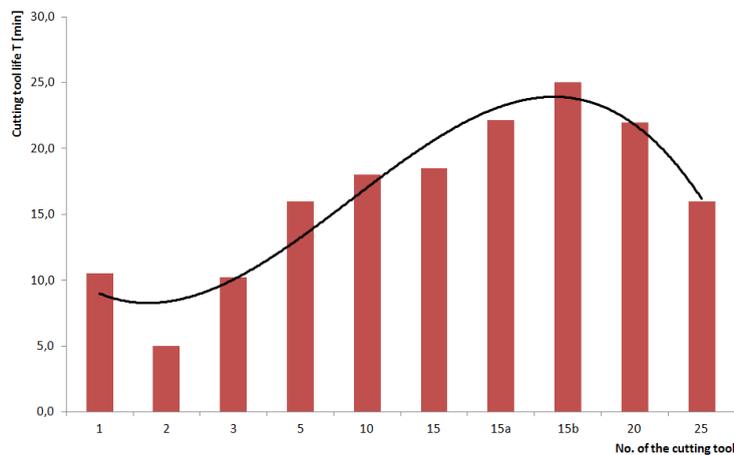


Fig. 5. Influence of the edge radius on tool life.

Fig. 5 shows the influence of the edge radius on the cutting tool life. It is evident that cutting tools with higher radius have better tool life. As described in section 2 on the problems with defects on the cutting edge after deposition of the thin layer, it was recommended to use polishing after deposition (cutting tool No. 15b) or before deposition (cutting tool No. 15a). If the rectification is used before deposition the tool life increases compared to the etalon because the edge roughness is smaller and the adhesion to the tool substrate is better. But on the face of the thin layer there are still cracks which can decrease thin layer adhesion and of course there are droplets. If we use polishing after the deposition the sharp areas around cracks are polished. It causes smaller pressure on it and the droplets are removed from the surface of the thin layer. It causes an increase of the tool life by more than 20%. Fig. 7 shows the differences between the cutting tools with different geometry and microgeometry. These cutting tools have a protected corner and facet on the blade. This causes different stabilization time of the cutting process and different process of the cutting forces. The tool life of these cutting tools is about 5 or 10 min, and that is less than 50% of the etalon.

3.2. Evaluation of cutting force

The main aim was to describe the influences of the different edge radiuses and rectification methods on the cutting forces. If we want to describe the edge radius influence correctly it is necessary to monitor the cutting forces at the beginning of the machining, for example from time 0s to 60s. At this time the edge microgeometry changes from the static value which we measured to kinematic values which are influenced by the vector of the cutting speed. So the dominant values are at times where the cutting processes are going towards stabilization.

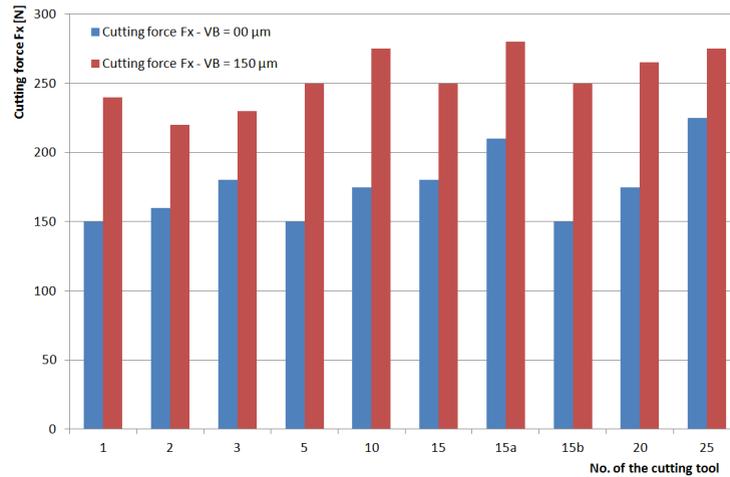


Fig. 6. Cutting force Fx at the beginning of the machining and at the end of the machining.

From this time the values in Fig. 6 are the blue column. It is evident that the smallest edge radius indicates smaller cutting forces and the bigger radius indicates higher forces. The next is if we compare edge radius $\rho_r = 15 \mu\text{m}$ where polishing is used (cutting tool No. 15 a,b); it is evident that polishing after deposition influences the cutting forces, which are smaller. This is caused by removal of droplets from the edge surface and cutting edge shape is influenced by the polishing process. This means that there is a very small area which is influenced by the vector of the cutting speed. This thesis is confirmed in Fig. 7.

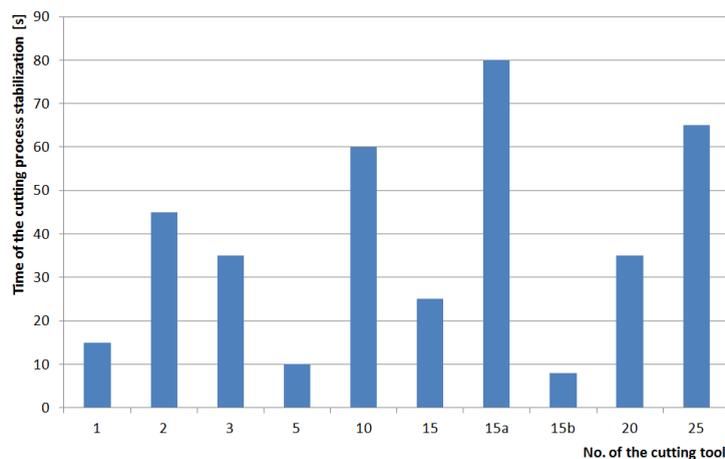


Fig. 7. Influence of the edge radius on the time of the cutting process stabilization.

Fig. 7. shows how much time cutting tools need to reach stabilization during the process with different edge radiuses. Cutting tools polished after deposition need the shortest time for stabilization. It is evident that the sharpest edge needs a shorter time to stabilization but on the other hand this variant has worse adhesion, which is caused by the higher stress in the layer. So the main factors which influence the time of the stabilization are edge geometry, microgeometry and surface quality. These are shown in Fig. 8 and Fig. 9.

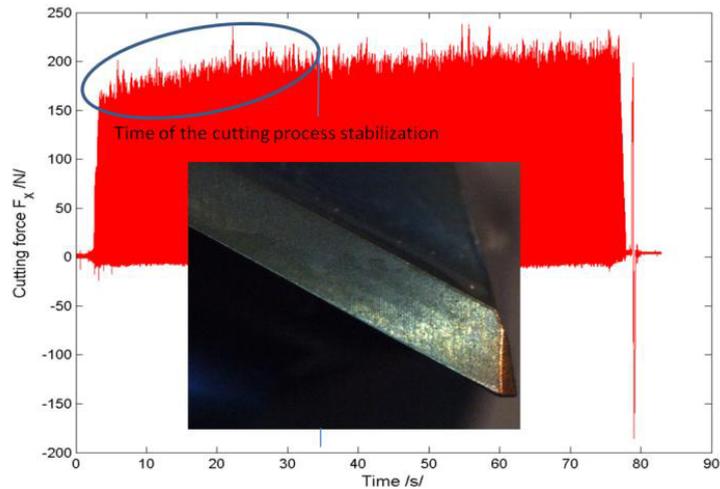


Fig. 8. Stabilization process of cutting tool No. 20.

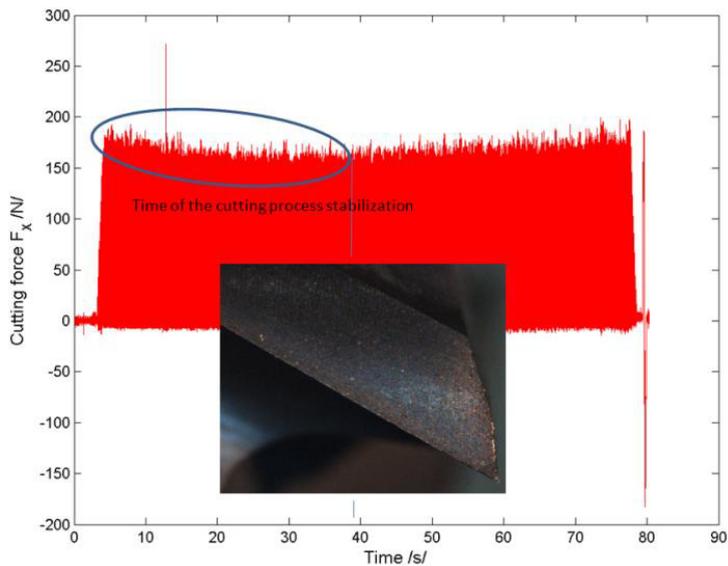


Fig. 9. Stabilization process of cutting tool No. 3.

The figures show the influence of the geometry and edge radius value on the principle of the cutting process stabilization. The cutting forces of the tool with edge radius from $\rho_r = 10 \mu\text{m}$ after the first contact increase to the point of stabilization and then the increase of the cutting forces depends on the tool wear. The cutting tools with

smaller edge radius than $\rho_r = 10 \mu\text{m}$ without blade protection have a different process of stabilization. At the beginning cutting force decreases to the point of stabilization and then it increases with increasing tool wear.

3.3. Evaluation of other parameters

Before machining, the workpiece was milled with face milling with tangential cutting inserts because the surface must be clean. New inserts were used for the milling and at the end of machining the cutting inserts had tool wear of about $VB = 350 \mu\text{m}$ (cutting time was 4 min).

Formation of burr on the workpiece was monitored during the machining. In many cases the main factor was tool wear. With a higher value of tool wear the burr was bigger along the whole line of machining and there was a direct link with tool wear. But for cutting tools with greater edge radius and cutting tools with polished edge after deposition the burr started to increase only at the end of machining and its value was smaller.

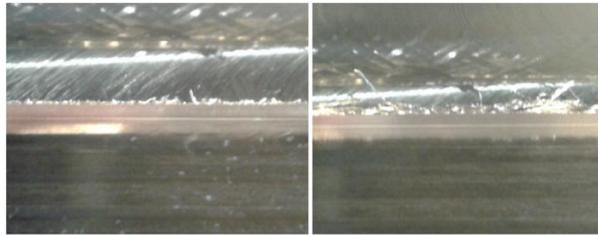


Fig. 10. Increasing of the burr during machining - left - tool wear was $90 \mu\text{m}$; right - tool wear was $150 \mu\text{m}$.

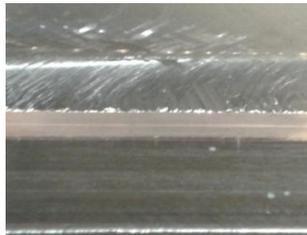


Fig. 11. The burr after machining (tool wear $VB = 150 \mu\text{m}$) with cutting tool with polished surface after deposition.

The last parameter which is connected with the burr is the formation of the notch between the air and the corner of the workpiece. This phenomenon was monitored on cutting tools with smaller edge radiuses and edges with bigger values. Very often the notch is formatted in the middle of the cutting tool life for a few minutes and then it merges with the linear area of the tool wear.



Fig. 12. Formation of the notch.

4. Conclusion

This article aims to show what it is important to monitor during the optimization process. The main focus was on different cutting edge radiuses where polishing methods and standard finishing surface processes were used. If we want a complex view of the cutting tool and cutting process it is necessary to use suitable devices and correct measuring methods. Because, as is shown in Fig. 7, a minimal difference between the edge radius causes a big difference in tool life.

Other results show how it is very important when machining Inconel 718 to choose a correct tool substrate and apply the correct tool geometry. In experiments were used a cutting tool with sharp tip and blade with protected radius or facet. These parameters influence the type of tool wear formation. In terms of reliability it is desirable to have linear tool wear without maxim tool wear and notches or other defects. This will increase the overall safety, reliability and cutting tool efficiency, and this is desirable when machining superalloys. These conditions are met by cutting tool with the protect facet and optimal rectification process. In our case, when different cutting tools were used, problems started and the tool wear was not linear (Fig. 13).

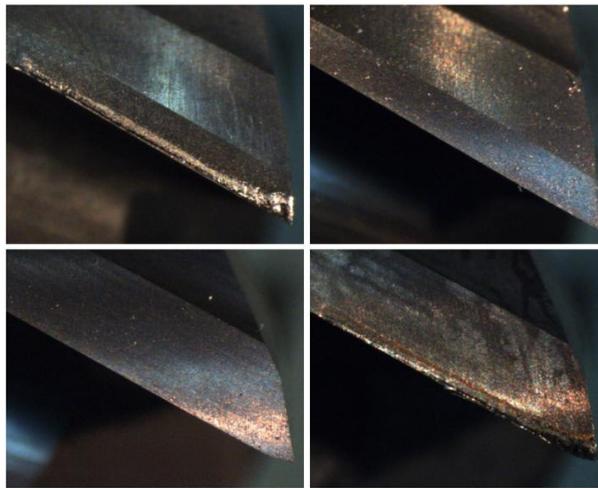


Fig. 13. Problems if the cutting tool without protected facet is not used, excessive wear on the cutting tool tip and notches.

From all the results of these first tests it is evident that there is a relation between the edge radius and cutting tool life. This has been known for a long time, and a lot of producers or users prefer an edge radius of about 15 μm and use it as a standard. But all parameters must be in an optimal setup. If other applications are used, such as polishing, and if this is combined with standard methods for modification of the cutting edge it can cause further increases to the cutting tool life and we can machine super alloy very productively with monolith cutting tools. A big potential is in the substrate which is used for the DF and of course in different methods such as stream finishing (SF). The value of these variables will be investigated in the next step of our research. Other cutting tools are being prepared for this. Different rectification substrates were used, different methods were used (SF and DF), different process times during rectification, combinations with the polishing process and different cutting tools substrate from the sintered carbide. All the cutting tools will be tested with the same conditions when machining Inconel 718.

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