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INFLUENCE OF THE VARIABLE CUTTING TOOL GEOMETRY ON DURABILITY WHEN MILLING INCONEL 718

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ABSTRACT

The paper is focused on cutting tool testing. The cutting tools have a different helix and rake angle in the groove. The main comparative parameter was the cutting tool durability, which was evaluated by wear on the flank surface of cutting edge. The limit cutting tool wear was 150 μm. Cutting tool diameter was 8 mm. Sintered carbide was the cutting tool material. In addition to variable helix and rake angle, the effect of microgeometry modification was included in the experiment. The main goal of this experiment was to find a suitable cutting tool geometry and microgeometry that significantly increases cutting tool durability. Higher cutting tool durability increases the efficiency of machining DtC (Difficult-to-Cut) materials such as Inconel 718.

KEYWORDS

End mill tool, Cutting edge modification, Helix angle, Durability, Wear

INTRODUCTION

Inconel 718 is very commonly used for components, which are highly stressed during their applications. This alloy is mainly used because of its properties and mechanical advantages over other steel alloys. The main applications are in the energetic industry for turbine components and aerospace and aviation industries for jet and rocket engines. The main reason for its very good mechanical properties is its chemical composition (Table 1). Nickel and chromium are the two main chemical elements. High creep limits (up to 700 °C), corrosivity (up to 1 000°C) and high yield strength (up to 1.4 GPa) are the most important advantages. [1] [9] It means, that products made from this alloy have excellent properties. But on the other hand, a considerable disadvantage is the complicated machining. One of the problems during machining is a workpiece reinforcement due to the high plastic deformation. Also during machining, the wear of the cutting tool increases because of the higher proportion of carbides. [2]

There are many tried and tested methods for increasing the durability of the cutting tool. Modification of the cutting edge is one of these. During cutting edge modification, the cutting edge radius is modified to a predetermined value. [4] [5] At the top of the ground cutting edge there is a high ratio of stress concentration. This stress can cause a sudden cracking and destruction of the cutting edge. The cutting edge radius increases as a result of the modification. The cutting edge became 'blunt', but becomes more durable. A cutting tool with cutting edge modification has a higher resistance, for example against chipping. [6] Also, the surface quality of the flank and rake faces increases as a result of the modification process. Cutting edge modification also increase the adhesion between the cutting tool surface and a resistant thin layer. The deposition of thin layers is the most frequently used technology for increasing cutting tool durability. [7] Almost every type of cutting tool has a thin layer. In many cases, cutting tools with thin layers have a durability of several times higher, than uncoated cutting tools. Currently, there are many types of thin layers with different chemical compositions which can be used for many different applications, for example, milling, drilling and broaching. Multi-layer and gradient layers are often used because they combine more features. Low friction coefficient, resistance to thermal stress, abrasion resistance and diffusion wear are the main advantages of thin layers. When machining Inconel 718, heat is produced and the cutting temperature can be a critical limit for the cutting tool material. [3] To avoid destruction of the cutting tool, process fluid is used. By using a different type of cooling, diffusion wear can be reduced almost to zero. However, a lot of cooling fluid is used during machining. Maintaining, recycling and subsequent disposal of the fluid is, both financially and environmentally, a relatively demanding process. For this reason, there are regulations for using cooling and technological fluids. [8]

PROBLEM SOLVING

The cutting process is very demanding despite considerable research and development into new cutting materials, cutting edge geometry, machining strategies and materials which are still being machined in the industry. These hard to machine alloys are especially used in the energetic and aerospace industries, so it is necessary to machine them. The high surface quality and shape accuracy of machined samples plays a very important role in terms of safety. Therefore, the cutting process of these alloys is investigated in order to improve them. [8] The aim of this research is increasing the durability and stability of cutting tools.

SETUP OF EXPERIMENT

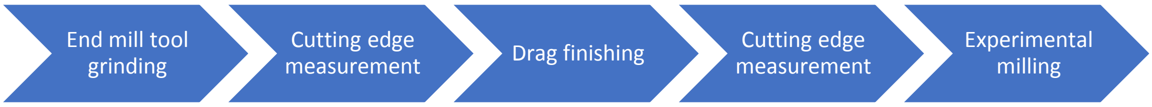

Figure 1: Timeline of experimental research

End mill tool macro and microgeometry

Eighteen end mill tools were used for the experiment. The cutting tool diameter was 8 mm and length 55 mm. Cutting tools were made from sintered carbide with hardness HV_{30}= 1 580. The cutting tools were made on a CNC tool grinding machine. After grinding, the cutting edge was measured using an optical microscope. The measured parameter of the cutting edge was the cutting edge radius. The cutting edge was measured at 2 mm from the tip of the cutting tool. All eighteen tools were measured in this way. The values of the cutting edge radius (r_n) after grinding were in the range 1.98 to 2.51 µm. The quality of the cutting edge was evaluated during measurement, to see whether the cutting edge had any defects after grinding. This control consisted of viewing the cutting edge for the possible occurrence of broken edges, etc. During measurement, the left and right cutting edges were measured. The tools in this experiment were found to have no defects, which may be due to lower cutting tool durability or the resulting bias.

The helix angle (ω_r) of 30°; 37° and 45° was the main variable parameter of this experiment. The aim was to determine the influence of helix angle on cutting tool durability. Also the second variable parameter was the rake angle in the groove (γ_o). This angle was 8°; 12° and 16°. Therefore, for each variant 1 – 3, as shown in the following figure, six cutting tools were ground. The remaining cutting tool angles of end mill tool were constant.

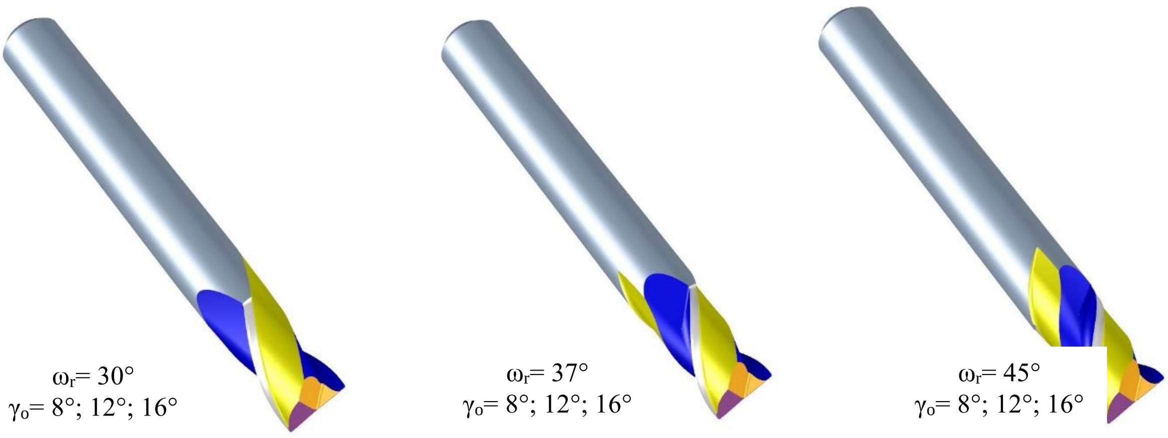

Figure 2: a) Variant 1 – helix angle 30°, b) Variant 2 – helix angle 37°, c) Variant 3 – helix angle 45°

For each geometry variant, the cutting edge was modified. Drag finishing was the technology, used for modification. The cutting edge radii of 15 µm, was the target of the modification. The cutting edge radii were within a tolerance of ± 2 µm. The process parameters were selected using experience from previous research. During drag finishing, the cutting edges were modified in one process. The process media has the biggest influence on the symmetry and the quality of the cutting edge radius. Walnut shells with silicon carbide (HSC 1/300) was used. The cutting tools were without a thin layer.

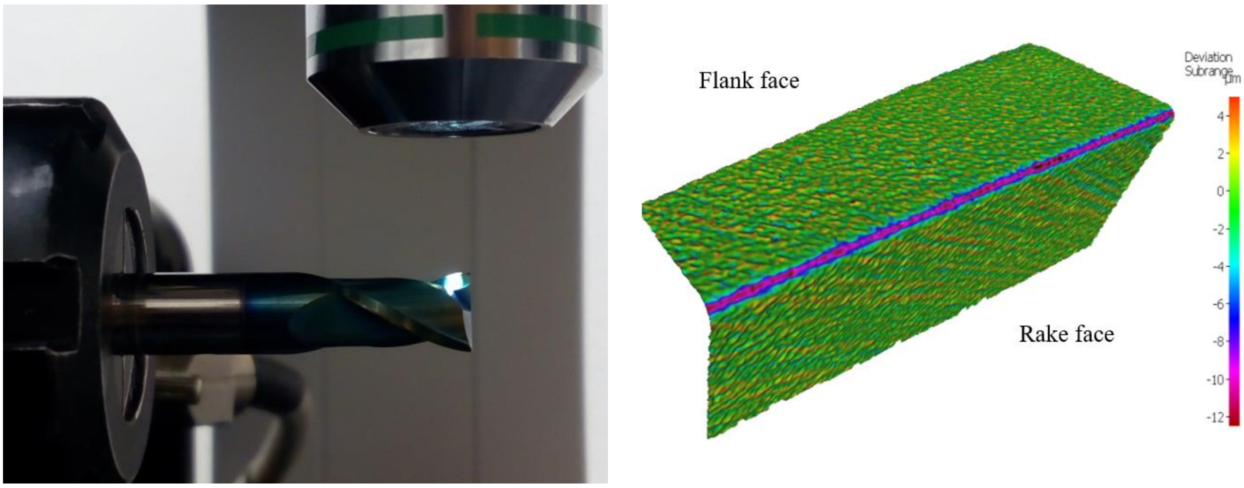

Figure 3: a) Cutting edge measurement by optical microscope IFM, b) Differential analysis of cutting edge after drag finishing

Workpiece material

Nickel alloy Inconel 718 was chosen as the workpiece material for the experiment. For many years it has been known that, this material is hard machined material for its properties. The cutting edge becomes intensely worn during machining due to high abrasion and high cutting temperature. This alloy is composed of many chemical elements in varying proportions. The exact chemical composition is shown in the following table. The mechanical properties of Inconel 718 are: $R_P0.2$= 1040 MPa; R_m= 1275 MPa; A_{min}= 15%; HB= 341. [9]

Ni	Cr	Fe	Mo	Nb	Ti	Al	C
50 – 55	17 – 21	Bal.	2.8 – 3.3	4.75 – 5.5	0.65 – 1.15	0.2 – 0.8	Max. 0.8

Table 1: Chemical composition (%) of nickel alloy INC 718

Cutting process

The following table shows the process parameters. These process parameters were constant throughout the experiment. Constant parameters were necessary to verify the effect of the cutting edge radius when machining nickel alloy. The values of each process parameter were based on previous experiments. These experiments were necessary for obtaining the optimum cutting conditions for machining Inconel 718 with an end mill tool.

v_c [m/min]	rpm [min^{-1}]	v_f [mm/min]	f_z [mm]	a_p [mm]	a_e [mm]
35	1393	111.4	0.04	3	0.5

Table 2: Process parameters for milling

WEAR AND DURABILITY ANALYSIS

The experimental procedure was the same for all the tested cutting tools. It consisted of the following steps:
1. Clamping the cutting tool into a hydraulic holder Tendo Platinum HSK-A 63 ø20 L1=90 with an unloaded length of 25 mm.
2. Measuring the flank face and creating an original mask used for cutting tool wear measurement.
3. Clamping the cutting tool into the milling center. The first linear pass on the workpiece followed. Unclamping cutting tool and measuring the cutting tool wear.

4. Measuring the wear after four linear passes. When VB_B wear approached 145 + 5 µm, the number of passes was adjusted.

The cutting edge wear was measured on an optical microscope Multicheck PC 500. The linear wear of the flank surface was the main parameter used for evaluating the cutting tool wear. The VB_B wear was measured on the flank face according to ISO 3685. Limit wear was 145 + 5 µm. The progressive wear increase was recorded during the first pass in the experiment. The first pass was considered to be the ‘tool cut’. During the first pass, the working cutting tool geometry was created (geometry modified by cutting edge modification was changed). Rapid increase of wear was reduced and during further passes the increase of the wear was linear.

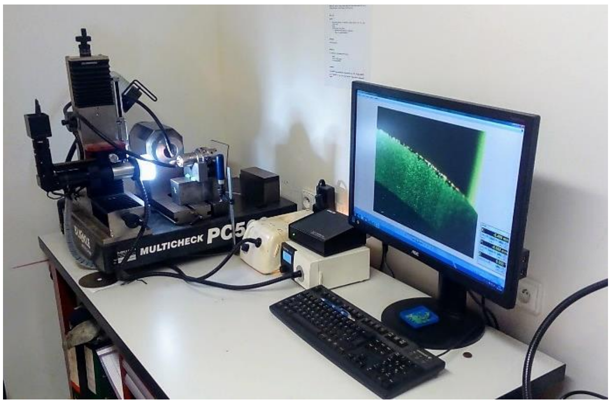

Figure 4: Optical microscope Multicheck PC 500

The following figure describes the wear development on flank face of variant 1. The helix angle 30° and rake angle 8° have been tested several times before. Therefore, this is a reference geometry. This graph shows high wear intensity. After 5.18 minutes of machining, the wear of flank face increased by 28 µm. This wear intensity causes lower values of cutting tool durability. In this case, the effect of the cutting edge modification was demonstrated, because the highest durability 27.2 minutes reached modified cutting tool 30-12 and 30-16. It can be said that the modified edge is more stable and resistant to wear.

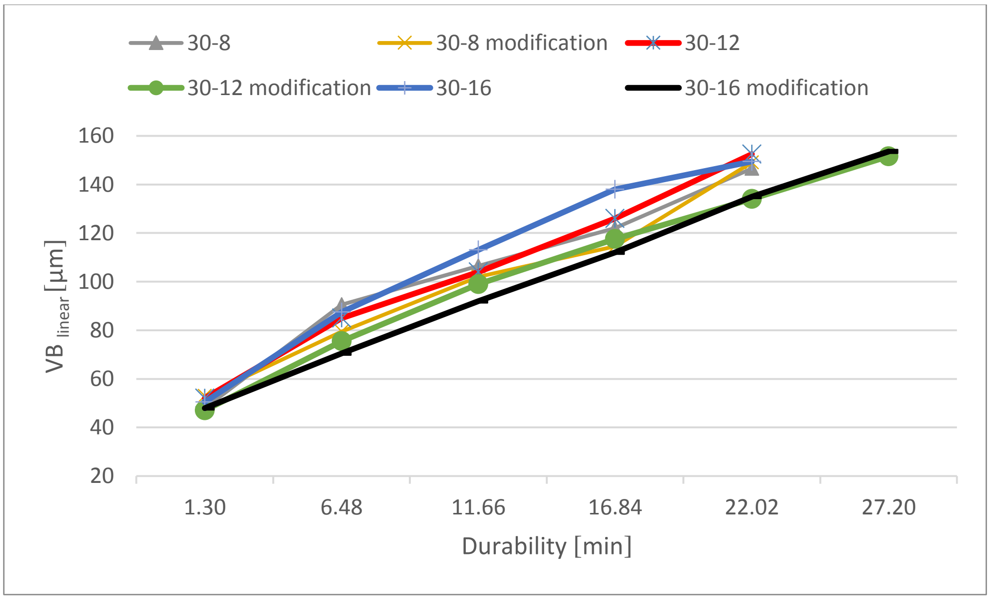

Figure 5: Cutting tool durability – helix angle 30°

Durability of 32.38 minutes was achieved during test of cutting tools with helix angle 37°. Also, in this case, the positive effect of microgeometry was shown, because the modified tool 37-8 achieved the higher durability of 32.38 minutes. A smooth cutting tool behavior was observed during the machining process. At the same time, it was found that there was no effect of different rake angle in a groove. Importantly, the minimum durability of this variant was not lower than in the previous case.

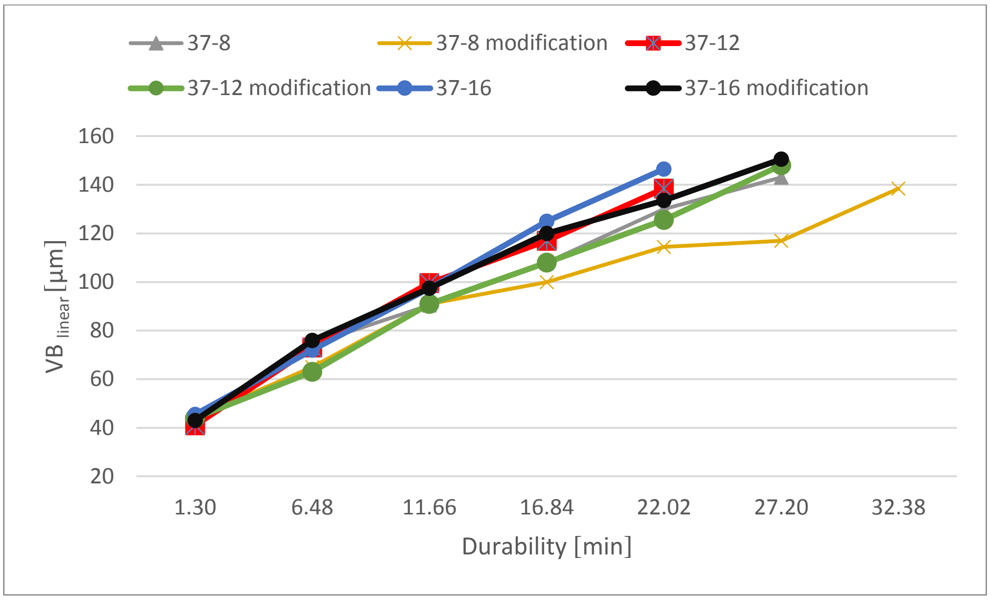

Figure 6: Cutting tool durability – helix angle 37°

The last tested variant was a helix angle= 45°. The durability has increased dramatically, in this case. The positive effect of higher value of helix angle has been verified by this experiment. The maximum durability was 42.75 minutes. Coincidentally, variant 45-16 achieved this durability. It was tools with unmodified and modified microgeometry. However, the unmodified cutting edges showed a local form of wear. So there was also demonstrate the positive effect of cutting edge modification. The wear increase was reduced from 28 to 10 µm. A higher value of helix angle causes a gradual kinematic chip removal. This has a positive effect on energy of chip formation.

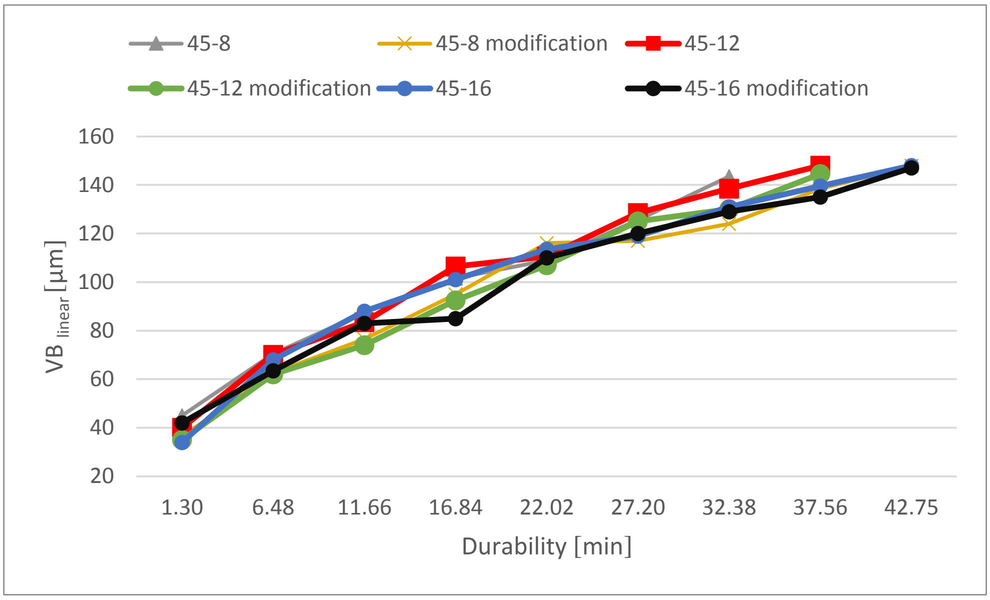

Figure 7: Cutting tool durability – helix angle 45°

Cutting edge wear analysis

An abrasive type of wear was found on the cutting edge of all the tested cutting tools. Abrasive wear is one of the characteristic types of wear when Inconel 718 is machined, because of the high chromium content in the alloy, as can be seen from chemical the composition Table 1. Higher friction between the flank face and the workpiece surface was also a reason for increasing wear. Machining a reinforced layer during the experiment was another reason for increased cutting tool wear. The following figure shows the development of wear in relation to the number of passes.

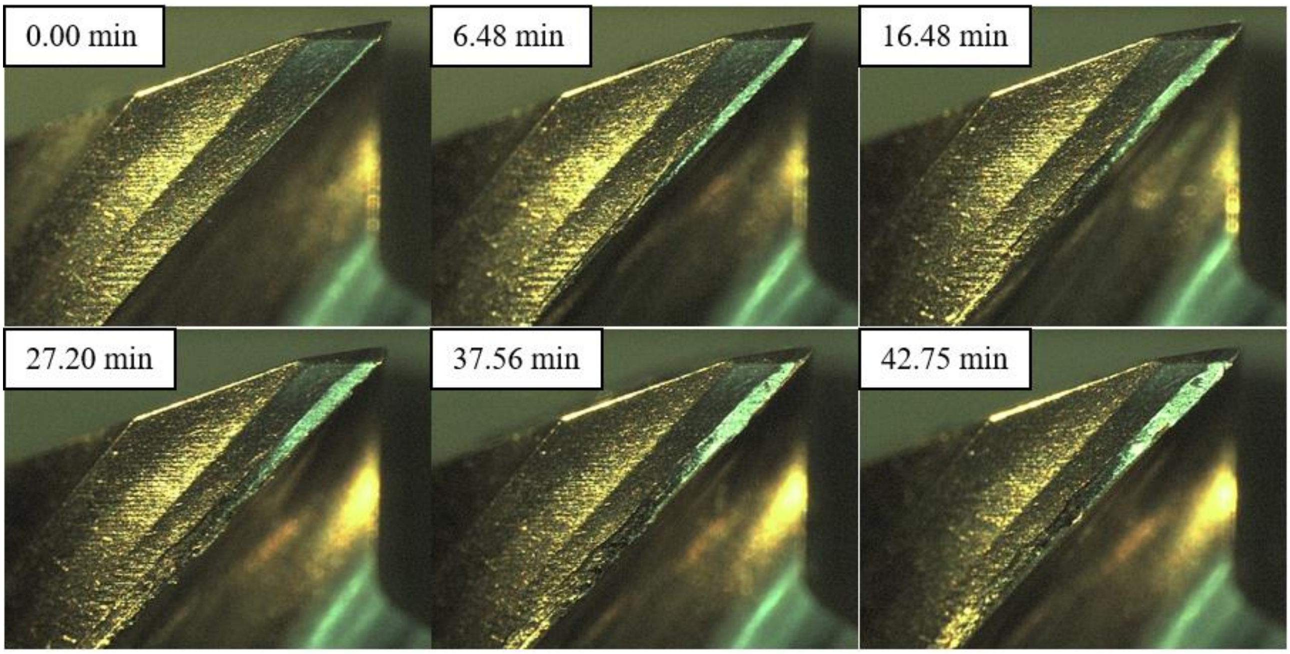

Figure 8: Timeline of flank face wear during experimental test (Tool 45-16 modified)

The wear analysis of the cutting tools by differential analysis was the next step in the experimental evaluation. The main principle during differential analysis is comparing the new and worn cutting edge. These two samples are folded into one another in microscope software. It was necessary to measure the cutting edge at the same distance from the tip of the cutting tool. This resulted in a unified model. The model shows the differences between the new and worn flank surfaces. The following figure shows the differential analysis of the cutting tool with r_n 15 μm. The width of wear was 150 microns. The maximum depth of wear was around 25 microns. A linear type of wear was found on the flank surfaces of the measured samples. The critical depth of wear is around 5 microns, because the thickness of the thin layer is just 5 microns. An area with a depth of more than 5 microns is characterized as the wear of the cutting tool material, not the thin layer. From that wear value, the wear intensity increases to the critical (150 μm) value. Using differential analysis, it is also possible to evaluate, that the chipping face seems to be without any wear. At the same time there is no built-up edge on the chipping face. Built-up edge is also another, common type of wear when machining nickel alloys.

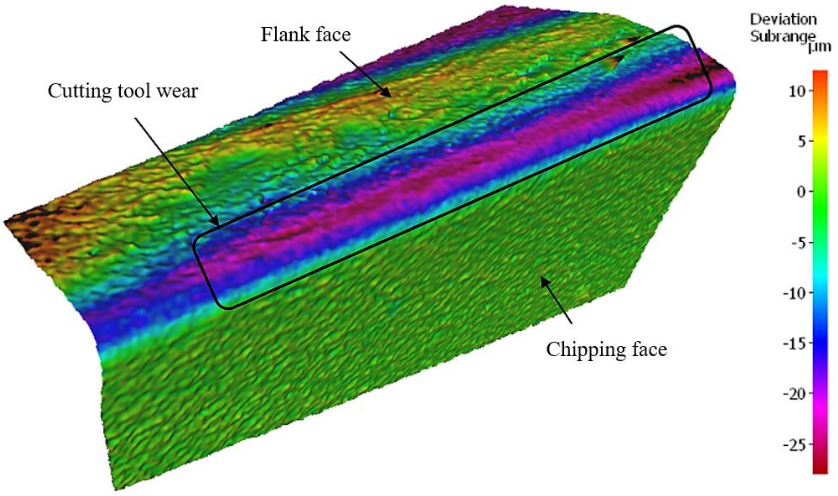

Figure 9: Wear analysis of cutting edge by differential analysis: Tool 30-8 modified

CONCLUSION AND RECOMMENDATIONS

The main focus of this research was on the durability of a milling tool when machining DtC material. Nickel alloy Inconel 718 was machined during the experiment. A double sided end mill tool, made from sintered carbide, was used for the experiment. Eighteen cutting tools with different helix angle, rake angle in groove and cutting edge radii were tested. The helix angle was 30°; 37° and 45°. Rake angle in groove was 8°; 12° and 16°. The cutting edge microgeometry was modified drag finishing. Walnut shells and was used for drag finishing processes. The radii of the cutting edges were 15 μm.

The following conclusions and recommendations can be drawn from the experiment:

1. The highest durability was achieved by end mill tools with a helix angle= 45°.
2. It was researched that the modification of microgeometry (cutting edge radius 15 μm) increases the wear resistance of the cutting edge. This causes durability increasing.
3. This modification not only modified the cutting edge microgeometry to the appropriate radius but also has a positive effect on the quality of flank and rake surface. The roughness of these surfaces is reduced due to the drag finishing process. Higher quality of these surfaces causes a friction reduction between flank face and chips (primary and secondary plastic deformation area).
4. In term of wear shape and form, it was also found that the linear wear was achieved with a modified cutting edge. Cutting edges without modification have a local form of wear (chipping), especially after the first pass.

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