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Machinability of Ni-based Superalloys by Indexable End Mills

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Abstract

The subject of this research is the machining of Ni-based super alloys using indexable end mills. The cutting ability of these materials is known to be difficult, even challenging with modern tools, so our goal is to create an efficient technology recommendation on an experimental basis. To this end, we have developed an experimental design from which results are used to determine the optimal technological parameters. This research took place at John Von Neumann University, Department of Vehicle Technology of GAMF Faculty.

Keywords: *Ni-based super alloy, built-up edge, tool wear.*

1. Introduction

In the automotive industry, especially in aerospace and aerospace industries, the use of Ni-based super alloys is becoming increasingly widespread. Today's modern aircraft are driven by one of our most advanced energy conversion systems; the gas turbine, but these are also used in our power plants. The gas temperature at the turbine inlet can reach 1650 ° C for high-performance jet engines. The turbine blades have to withstand speeds up to 10,000rpm at high temperature. Nowadays, turbine blades, which are exposed to high temperatures in turbines are made of nickel alloys, also called nickel-based super alloys [1]. The advantageous properties of these alloys are high strength, poor thermal conductivity, and paramagnetism. A further advantage is that they retain their strength and resist corrosion at extremely high temperatures. The parts they are made of are often machined, (even though they can be classified as difficult-to-cut materials) and they present a challenge even with modern machining tools. Typically, intensive tool wear and chip breaking are the biggest problems. During the experimental work described, we examined the possibilities of milling the GTD-111 nickel super alloy [2–7].

1.1. Applied materials and tools used in the experiments

Choosing the right tools requires careful attention and expertise in each case. With a good decision, we can increase the safety, raise our productivity and reduce cycle times [8]. Numerous methods are suitable for machining Ni super alloy. It's a fact that we can use EDM [9], but its cycle time is long, so research is being done to explore alternative options [10] but its cycle time is long, so research is being done to explore alternative options [11]. In addition to the tool materials, the machining strategy used for cutting can also be an important factor [12, 13].

1.1.1. The material used in the experiment

The GTD-111 investigated in the research is a special Ni-based super alloy produced by vacuum casting. Table 1. shows the chemical composition of the material. [14]

In terms of its cutting ability, the nickel super alloys are one of the most difficult to cut materials.

Table 1. *The chemical composition of the GTD-111* [14]

Addition (GTD-111)	Percentage (%)
Ni	62.37
C	0.08
Cr	13.7
Co	9
Al	2.8
Ti	4.7
W	3.5
Mo	1.4
Ta	2.4
B	0.05

It is characterized by poor thermal conductivity. This is critical, because ideally the separated material (chips) carries most heat. Furthermore, it requires a very stable and powerful machine tool to manufacture, because of the high cutting force. The mechanical and physical properties that are important for cutting the GTD-111 Ni-based material are shown in Table 2. .

Table 2. *Mechanical and physical properties of GTD-111* [14]

Tensile strength, R_m (MPa)	1310
Strain, A_5 (%)	5
Contraction, Z (%)	5
Hardness	HRC 41,4
Thermal conductivity at 20 °C, λ (W/(m·K))	12,56

1.1.2. Considerations of the tool- and the insert selection

The indexable milling tools consist of three main parts: the tool body, the insert and the insert's coating. First of all, the coating of the insert was selected for the material from TaeguTec® tool manufacturer. For this purpose, a coating selection application is available in which all TaeguTec® coatings are ranked. These are arrange in the table shown in Figure 1., based on their toughness and hardness, from bottom to top. In our case, the GTD-111 is a Ni-based superalloy, which belongs to the group S, which is indicated by the brown color in the table.

Based on this guide, the following coatings are available: TT9080, TT9030, TT8080 and TT8020. All four optional coating qualities are Physical Vault Deposition (PVD) coatings, the difference being the quality of the coating layers, and the field of applications. The manufacturer does not manufacture all insert geometry with every kind of coating. The next step was to select the possible tools and inserts. Our experiment requires Ø20 mm corner mill with Weldon clamping, and we had to choose an insert capable of a 3 mm depth of cut. When selecting the tool, the insert geometry used in practice was taken into account. The 0-degree back rack angle was chosen, since with this property the inserts are much more stable and have a longer cutting edge. Based on this information, the 4NKT 060308R-ML and 6NKU 040308R-M inserts were selected from the catalogue (Figure 2.).

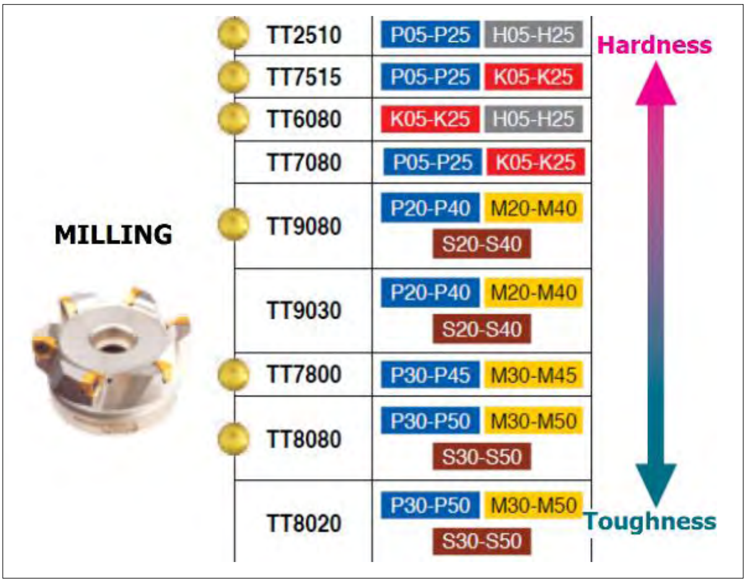

Figure 1. *TaeguTec® coating selection application* [15]

After selecting the inserts, two types of coatings were chosen for them, which differ greatly in their properties. We chose TT9080 and TT8080 quality coatings.

Since our objective was to test the tools while roughing, we chose the TT8080 coating as recommended by the catalogue. Since we planned to use tools with the same number of teeth for each geometry, we chose the 3-toothed cutter. They are marked 4N TE90-320-W20-06, which is a milling tool for the 4NKT 060308R-ML insert, and 6N TE90-320-W20-04, which is for the 6NKU 040308R-M insert (**Figure 3.**).

During the experiments, the tools were named as „A" and „B" tools. The „A" tool had the 4NKT 060308R-ML insert and the associated 6N TE90-320-W20-06 milling tool body, while the „B" tool had the 6NKU 040308RM insert with the 6N TE90-320-W20-04 milling tool body.

2. The experimental design

We used the Taguchi method to perform the experiments, which was designed by the Minitab17 software. This experimental design method helps to find the most defining factors and their possible combinations of experimental results and their effect on the experimental results. It helps to find the right combination of factors for optimal results. Levels for milling factors, including the levels of Cutting speed (v_c) and feed per tooth (f_z), are given based on the TaeguTec® catalog.

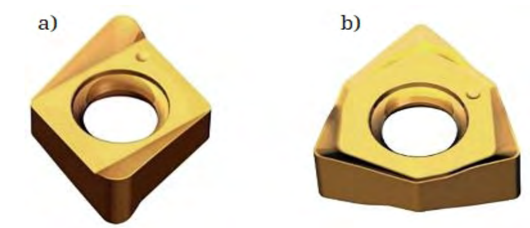

Figure 2. *a) 4NKT 060308R-ML and b) 6NKU 040308R-M inserts* **[16]**

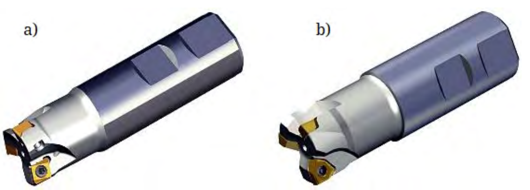

Figure 3. *a) 6N TE90-320-W20-04 and b) 6NKU 040308R-M indexable milling tools* **[16]**

Table 3. *Milling factors and levels for experimental design*

Milling factors		Levels			
		1	2	3	4
A	v_c (m/min)	10	20	30	40
B	f_z (mm/tooth)	0.03	0.07	0.11	0.15
C	Tool	A geometry		B geometry	

2.1. Details of the cutting experiment

The workpiece was fixed in a vice, on the table of the NCT EML850D CNC machining center (**Figure 4.**).

The depth of cut was 3 mm, and repeated eight times with the A and B tools along the 130 mm machining length. Since the maximum depth of 24 mm was too deep for to the geometry of the B tool, and the outlet of the chips would have been more difficult in the 24 mm deep grooves, two grooves were machined with one tool at 12-12 mm depth.

So that the workpiece was clamped enough and the technical parameters were optimally. The parameters of the experiment are summarized in **Table 4.**

Table 4. *The used experimental parameters for GTD-111 material milling by Taguchi-method*

#.	v_c (m/min)	f_z (mm/tooth)	Tool	Mark*
1.	10	0.03	A	AB1
2.	10	0.07	B	BB1
3.	10	0.11	A	AB2
4.	10	0.15	B	BB2
5.	20	0.03	B	BB3
6.	20	0.07	A	AB3
7.	20	0.11	B	BB4
8.	20	0.15	A	AB4
9.	30	0.03	A	AJ1
10.	30	0.07	B	BJ1
11.	30	0.11	A	AJ2
12.	30	0.15	B	BJ2
13.	40	0.03	B	BJ3
14.	40	0.07	A	AJ3
15.	40	0.11	B	BJ4
16.	40	0.15	A	AJ4

*The marking of the grooves:

AB – „A" tool and „B" left-side groove.
BB – „B" tool and „B" left-side groove.
AJ – „A" tool and „J" right-side groove.
BJ – „B" tool and „J" right-side groov

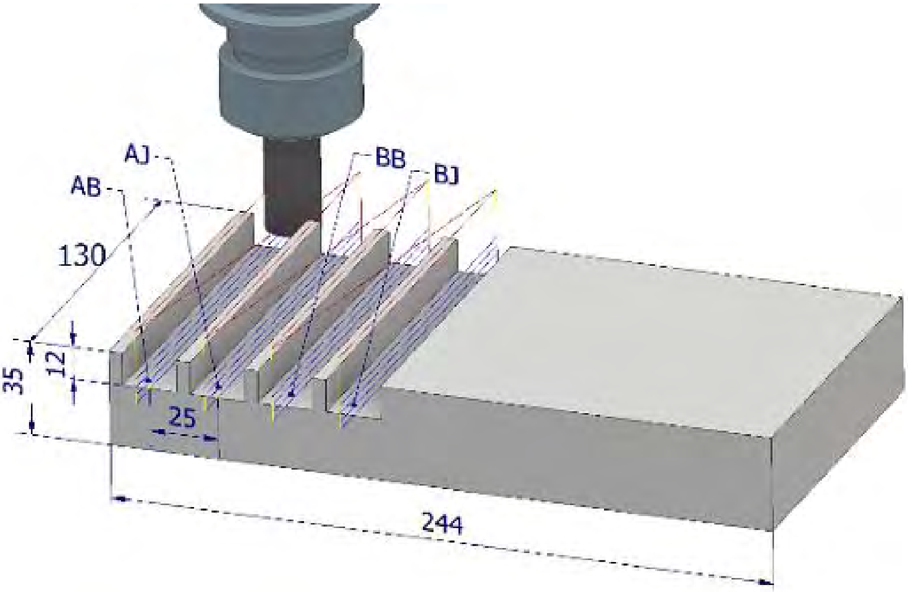

Figure 4. *The experimental method designed in CAD software*

3. Evaluation of results

In order to evaluate the toolware, we have created a list of criteria that we have compiled on the basis of the tests and the expected criteria. The list of criteria is evaluated from 1 to 9. The list is summarized in **Table 5.**, where number 9 is the best, and 1 is the worst result.

The best experimental result is proven by AB1.

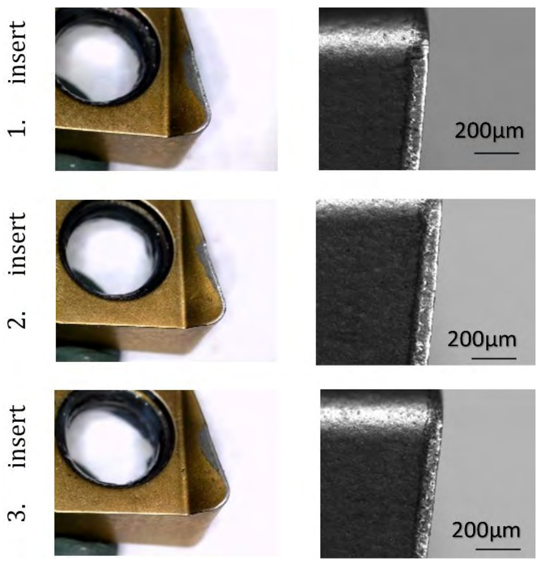

Figure 5. *The inserts of the tool A in the AB1 experiment after cutting with microscopic pictures of edges*

Figure 5. shows the microscope image of the three inserts. The tool wear on front and backside of the inserts surface are uniform. On the cutting edge of the inserts, it is clearly visible that the coating is worn, but there are no other damages.

For the sake of clarity, **Table 6.** summarizes the assessment of the technological parameters of the experiment according to the criteria system of **Table 5.**

4. Summary

The cutting effect (v_c) was the greatest impact on the lifetime of the tool during machining, followed by the feed per tooth (f_z). It is noticeable that the effect of tool geometry had a negligible influence on the life span.

The most effective technological variables with the experimental values are:

- cutting speed v_c=10 m/min,
- feed per tooth f_z=0,03 mm/tooth,
- Tool geometry: „A" tool.

The groove made by these parameters is shown in **Figure 6.**

Acknowledgments

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Table 5. *The used inserts evaluated by the created list of criteria*

Rating (value)	Viewpoints
1	It couldn't go through the machining length.
2	It went through the length, but it critically fractured the edges and the inserts were broken.
3	It went through the machining length, but critically fractured the cutting edges of the inserts.
4	It went through the machining length, but it fractured or broke the inserts.
5	It went through the machining length, but the cutting edge- and the flank of the insert were cracked.
6	It went through the machining length, but the cutting edge of the insert was cracked.
7	It went through the machining length, but the flank of the insert was cracked
8	It went through the machining length but the wear was significant.
9	He went through the machining length and the tool wear was even.

Table 6. *Evaluation of the parameters of the experiment according to the criteria system*

#	v_c (m/min)	f_z (mm/tooth)	Tool	Value
AB1	10	0.03	A	**9**
AB2	10	0.11	A	5
AB3	20	0.07	A	6
AB4	20	0.15	A	2
BB1	10	0.07	B	7
BB2	10	0.15	B	4
BB3	20	0.03	B	**8**
BB4	20	0.11	B	5
AJ1	30	0.03	A	**8**
AJ2	30	0.11	A	1
AJ3	40	0.07	A	1
AJ4	40	0.15	A	1
BJ1	30	0.07	B	3
BJ2	30	0.15	B	1
BJ3	40	0.03	B	1
BJ4	40	0.11	B	1

Figure 6. *The AB1 groove's surface with protruding ragged edge (burr)*

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