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DEVELOPMENT OF A HIGH-PERFORMANCE TOOL FOR SUPERALLOY MACHINING (HRSA)

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Abstract

The main objective of this article is to develop a new specialized cutting tool capable of efficiently machining difficult-to-machine materials, such as martensitic stainless steels (e.g., AISI 440C, AISI 431, AISI 630), Inconel® 718 in AMS 5663 condition, Mionic 80, and Titanium Alloy Grade 5. These materials are commonly used in industries such as aerospace, space, energy, and medical. The article is focused on creating a complete tool assembly, which includes a new cutting insert with modified geometry and a special holder allowing for effective cooling of the cutting insert. The first part concentrates on the development and testing of the cutting insert, while the second part is dedicated to the development and testing of the entire tool assembly.

Keywords: Durability enhancement; turning tools; cutting edge adjustment; additive manufacturing

1. Introduction

This research is focused on the development of a new tool for efficient machining of hard-to-machine materials in industrial sectors such as aviation, aerospace, energy, and the medical industry. The research aims to develop a complete toolset, including a new cutting insert with modified geometry and a special holder that allows for effective cooling of the cutting edge.

The research is a joint initiative of BONAR a.s. and the University of West Bohemia in Pilsen, Faculty of Mechanical Engineering. BONAR a.s. and the University of West Bohemia in Pilsen will collaborate through an "effective cooperation" arrangement, with the University of West Bohemia being the research partner and responsible for part of the research funding. The goal of this research is to provide an innovative solution for efficient machining of hard-to-machine materials [1], which have wide applications in various industrial sectors, including aviation [2,3]. It is expected that the new tool will increase cutting performance by at least 20 % compared to existing tools and extend the lifespan of cutting inserts [4]. This should lead to increased productivity and reduced machining costs for these challenging materials.

The research consists of two phases. The first phase is focused on the development and optimization of the flank geometry of the cutting insert to reduce the contact area and increase the lifespan of the inserts [5,6]. The second phase of the research is focused on the development of a toolset with a cooling system that allows for effective cooling of the cutting insert during machining. It is expected that the new type of cutting insert and toolset will bring significant benefits to customers in progressive industrial sectors [7,8]. Increased cutting performance and extended insert life are anticipated, leading to increased revenues in this market segment. The research also has significant export potential since most customers are located outside the Czech Republic. The research's manufacturing processes will include innovative approaches such as the use of metal 3D printing for producing the tool holder and cooling jets. This will enable the application of design elements that are difficult to achieve with conventional methods.

The aim of the research described in this article is, therefore, to provide an innovative solution for more efficient and high-performance machining of hard-to-machine materials in the aviation and aerospace industries.

2. Stage 1: Development of the cutting insert

Description of the development of the cutting insert in the first phase of the research:

The first phase of the research was focused on the development of a cutting insert for efficient machining of hard-to-machine materials. The primary objective of this phase was to make design modifications to the flank of the cutting insert to reduce the contact area between the flank of the insert and the workpiece surface [9].

These geometry modifications of the insert were achieved through grinding. Reducing the contact area resulted in a reduction in the heat generated due to friction between the insert and the workpiece [10]. It was also intended to increase the lifespan of the cutting insert because less heat was transferred into the tool's cutting edge and was better dissipated from the cutting zone. Another benefit of reducing the contact area was a decrease in friction and its impact on the wear of the insert's coating or base material, depending on the specific design of the insert.

As part of the development of the cutting insert, design modifications were carried out to achieve the desired parameters. Modifications to the geometry of "standard" replaceable inserts were designed to improve performance parameters. For each type of insert intended for specific machining operations (roughing to finishing), suitable cutting conditions were selected, including cutting speed, feed rate, and cutting depth. These conditions were combined with other factors such as cooling, coating, etc., to achieve optimal insert performance.

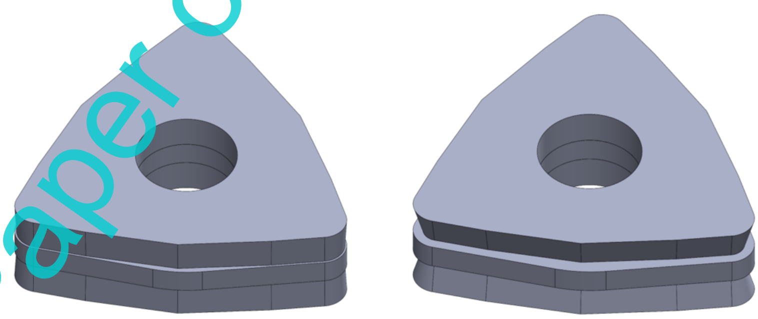

Fig. 1. Models of ground W-Type RCIs

During the testing phase, experiments were conducted with the designed variants of cutting inserts and compared to standardized inserts. The main parameters monitored during these experiments included insert wear and the achieved surface quality, including dimensional accuracy and surface roughness. For some of the tests, a single type of material was used, while for other insert variants, statistical analysis was performed based on the results of physical experiments.

Fig. 2. Replaceable cutting insert with ground flank

Based on the evaluation of the conducted experiments, optimization of the characteristics of the designed inserts was carried out to achieve the desired performance parameters. The goal was to increase cutting performance during machining by approximately 20 % and extend the lifespan of the insert. A special type of negative geometry cutting edge was designed to enhance cutting performance, enable the double-sided use of the insert, and create a groove for focused cooling with a cooling fluid. The development of the tool holder that allows for this cooling was part of the second phase of the research.

3. Stage 2: Development of the Tool Assembly

In this phase of the research, the goal was to develop a special tool assembly with a cooling system for the flank of the replaceable cutting inserts (RCI). Two variants of holders (tools) were developed in this phase. One technical solution was developed by BONAR a.s., and the other, different solution was developed at the Regional Technological Institute within the Faculty of Mechanical Engineering at the University of West Bohemia in Pilsen. Both teams (BONAR and the University of West Bohemia) applied different approaches to the solution and subsequently evaluated which variant was better and achieved better results.

In the initial phase of holder development, the construction of various competing tool holders was examined with the aim of delivering the process fluid as close as possible to the flank part of the RCI.

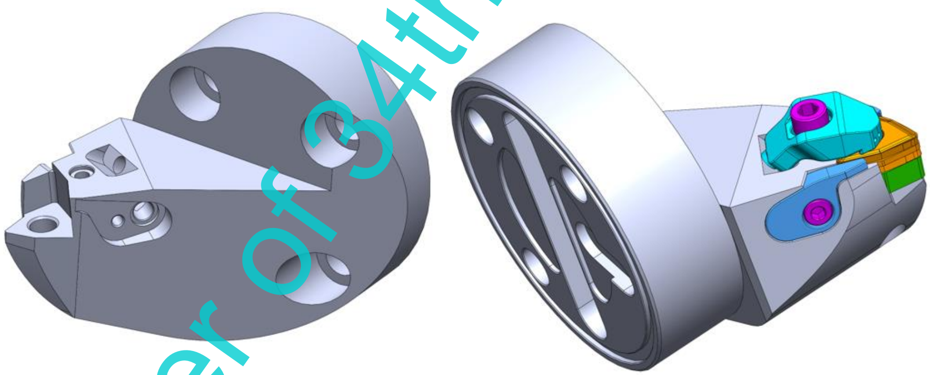

Fig. 3. Model of W-Type RCI holder

Based on the design concept, prototypes of each RCI holder were manufactured and subsequently tested, both statically (i.e., for fluid routing and flow) and later during actual machining operations. Based on these tests, the design solution was optimized for the subsequent full-scale experiment.

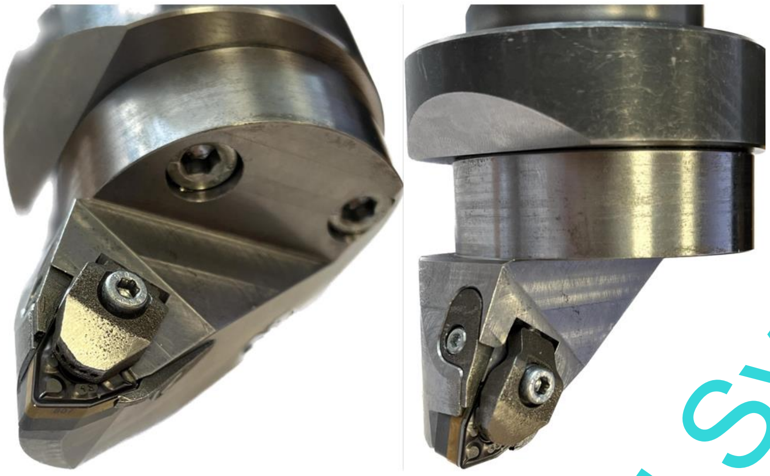

Fig. 4. Prototype holder for W-Type RCI

The next phase of the tool assembly development stage involved testing on selected workpiece materials. Since this innovative cooling tool assembly was being compared to tools tested in the previous stage, this phase was quite dynamic, with a primary focus on fine-tuning the delivery of the process fluid.

The developed holder aims to provide the supply and distribution of cooling fluid pressurized to over 40 bar into the groove on the flank of the RCI, thus ensuring more intensive and even cooling and further enhancing machining performance.

In the final phase of this stage, samples of the tool assembly were deployed in selected industrial enterprises primarily involved in manufacturing of components for the aviation industry. This allowed for the verification of the results obtained during the research phase.

4. Experimental Testing

Experimental testing was conducted simultaneously for both stages, i.e., for the development of the cutting insert and the development of the tool assembly. In the first phase of the experiment, the influence of the ground flank on the lifespan of the RCI was observed. With a focus on ensuring the highest test reliability (for example, to eliminate the influence of changing bar diameter [11]), the experiment was carried out in face turning. Cutting conditions were kept constant, with the only variable being the angle of the ground groove on the flank of each RCI. The experiment was conducted under the parameters mentioned below.

The objective of the durability testing experiment was to compare the innovated holder and RCIs with a ground flank to conventionally supplied holders and conventional RCIs. The same workpiece material as in the previous case of ground flank testing was chosen for this experiment. Machining was performed during face turning to ensure a constant tool path and unaffected results due to diameter changes.

For this experiment, three types of tools were selected:

Tool I: Classic tool holder with an RCI without a ground flank. This tool served as a control group representing the standard configuration commonly used.

Tool II: Classic tool holder with an RCI with a ground flank. This tool had a ground replaceable cutting insert, which had the potential to improve its performance.

Tool III: Innovated W-type tool holder with an RCI with a ground flank. This tool represented the innovated tool assembly with optimized properties and a modified W-type RCI.

Cutting conditions remained constant and were set as follows: cutting speed (Vc) was 35 m/min, feed rate (f) was 0.2 mm/rev, depth of cut (ap) was 1.5 mm, and high-pressure cooling was used. These parameters ensured consistent cutting conditions for all tested tools. The experiment monitored the overall impact of the ground flank and innovated cooling on the lifespan of the RCIs. The volume of material removed was also evaluated for each tool type. This approach allowed assessing the effectiveness and advantages of using ground flank and tool with innovated cooling.

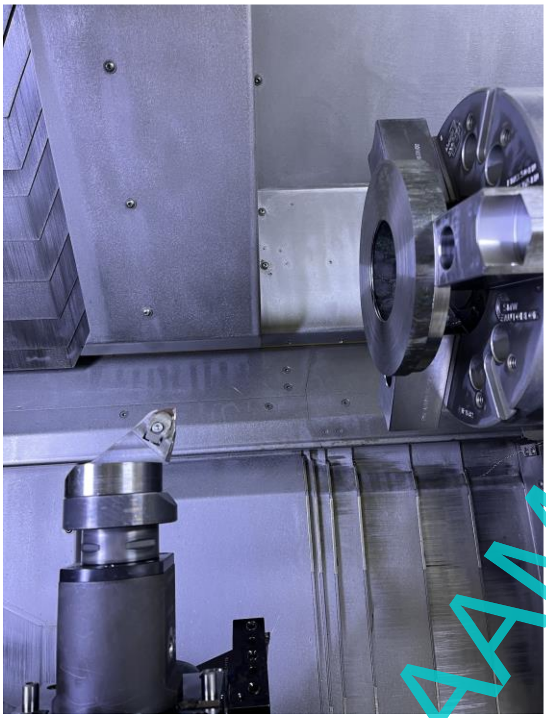

Fig. 5. Innovated tool during experiments

Experiment Parameters:

Workpiece:

- Inconel 718

Tools:

- Tool I: Classic tool holder + RCI without a ground flank
- Tool II: Classic tool holder + RCI with a 7° ground flank
- Tool III: Innovated W-type tool holder + RCI with a 7° ground flank

Cutting Conditions:

- Vc = 35 m/min (cutting speed)
- f = 0.2 mm/rev (feed rate)
- ap = 1.5 mm (depth of cut)

High-pressure cooling

Tool I										
cut	D [mm]	L [mm]	ΔL [mm]	t [min]	Δt [min]	vf [mm/min]	n [ot/min]	ap [mm]	fo [mm/ot]	vc [m/min]
1	165	85	85	6,294	6	13,504	67,520	1,5	0,2	35
2	165	85	170	6,294	13	13,504	67,520	1,5	0,2	35
3	165	85	255	6,294	19	13,504	67,520	1,5	0,2	35
4	165	85	340	6,294	25	13,504	67,520	1,5	0,2	35
5	165	85	425	6,294	31	13,504	67,520	1,5	0,2	35

Tool II										
cut	D [mm]	L [mm]	ΔL [mm]	t [min]	Δt [min]	vf [mm/min]	n [ot/min]	ap [mm]	fo [mm/ot]	vc [m/min]
1	165	85	85	6,294	6	13,504	67,520	1,5	0,2	35
2	165	85	170	6,294	13	13,504	67,520	1,5	0,2	35
3	165	85	255	6,294	19	13,504	67,520	1,5	0,2	35
4	165	85	340	6,294	25	13,504	67,520	1,5	0,2	35
5	165	85	425	6,294	31	13,504	67,520	1,5	0,2	35
6	165	85	510	6,294	38	13,504	67,520	1,5	0,2	35

Tool III										
cut	D [mm]	L [mm]	ΔL [mm]	t [min]	Δt [min]	vf [mm/min]	n [ot/min]	ap [mm]	fo [mm/ot]	vc [m/min]
1	165	85	85	6,294	6	13,504	67,520	1,5	0,2	35
2	165	85	170	6,294	13	13,504	67,520	1,5	0,2	35
3	165	85	255	6,294	19	13,504	67,520	1,5	0,2	35
4	165	85	340	6,294	25	13,504	67,520	1,5	0,2	35
5	165	85	425	6,294	31	13,504	67,520	1,5	0,2	35
6	165	85	510	6,294	38	13,504	67,520	1,5	0,2	35
7	165	85	595	6,294	44	13,504	67,520	1,5	0,2	35
8	165	85	680	6,294	50	13,504	67,520	1,5	0,2	35
9	165	85	765	6,294	57	13,504	67,520	1,5	0,2	35

Table 1. Experiment Progress Table

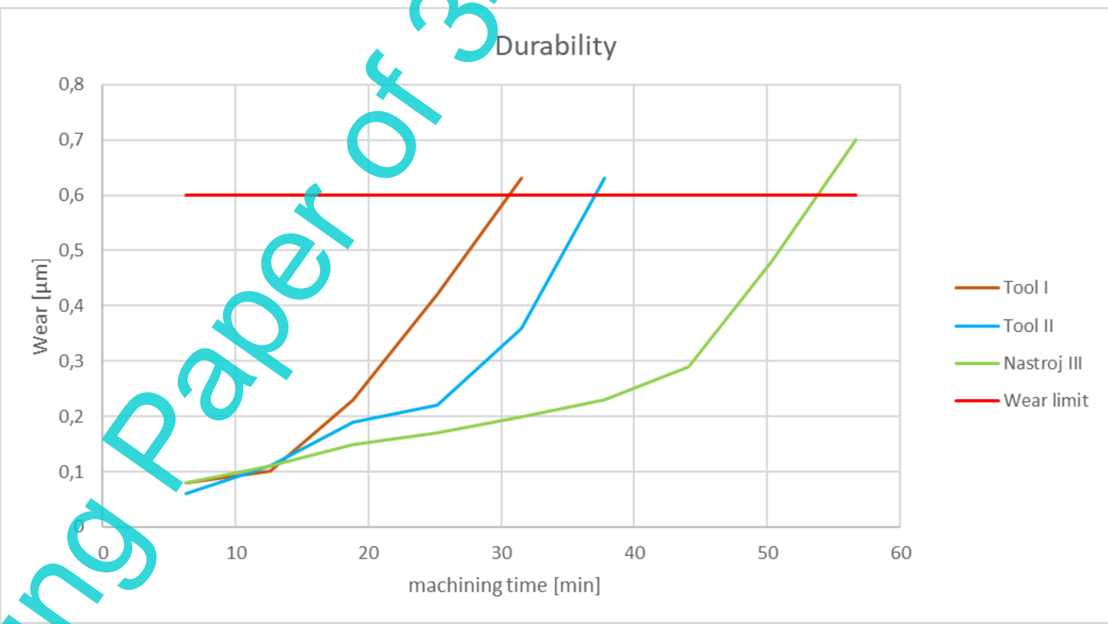

Fig. 6. Durability graph for tested tools

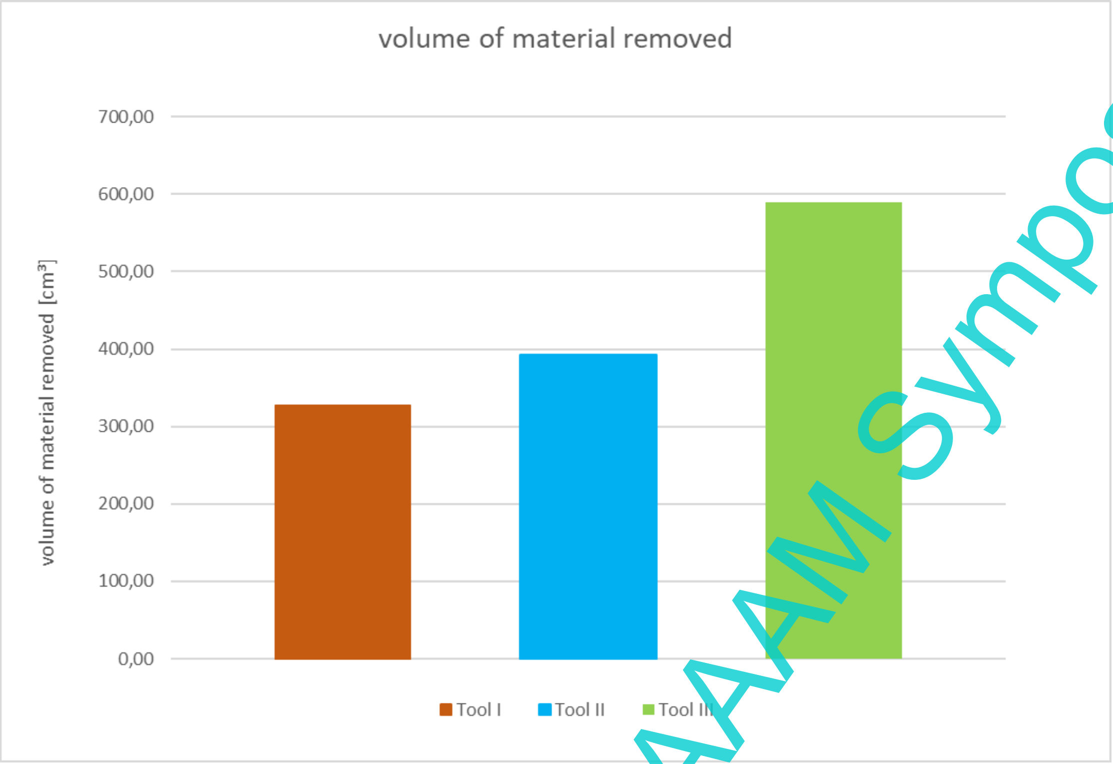

Fig. 7. Volume of removed material graph

The results clearly indicate that the combination of a ground RCI with a conventional tool has a minimal impact on the lifespan but shows a more uniform increase in wear. When using a ground RCI in combination with the innovated tool holder, almost double the lifespan was achieved, and 30 % more material was removed compared to using a conventional tool with a standard RCI. The experiments have thus clearly demonstrated the high potential of using ground RCIs and optimized cooling in machining hard-to-machine materials such as titanium, Inconel, and others.

5. Conclusion

The outcome of this research is an innovative solution for more efficient and high-performance machining of hard-to-machine materials in the aviation and aerospace industries, as well as in other industrial sectors. The research, jointly conducted by BONAR a.s. and the Faculty of Mechanical Engineering at the University of West Bohemia in Pilsen, focused on the development of a new tool assembly comprising a cutting insert with optimized geometry and a special holder enabling effective cooling of the cutting edge.

During the research, the first stage was dedicated to the development and optimization of the geometry of the cutting insert's back to reduce the contact area and extend the lifespan of the inserts. The second stage focused on the development of the tool assembly with a cooling system that allowed effective cooling of the cutting insert during machining. The third step involved the execution of experiments that demonstrated the achievement of the initially set goals and expectations.

It is expected that the new type of cutting insert and tool assembly will bring significant benefits to customers in the aviation and aerospace industries, such as increased cutting performance and extended insert lifespan. This would result in higher productivity and reduced costs associated with machining these challenging materials.

The research outcome also represents significant export potential since most potential customers are located outside the Czech Republic. Innovative manufacturing processes, such as the use of metal 3D printing for tool holder production, allowed for the application of design elements that were challenging to achieve with conventional methods.

In summary, this research has successfully delivered an innovative solution for efficient and high-performance machining of hard-to-machine materials in the aviation, aerospace, and other industrial sectors. The new tool assembly, developed in collaboration between BONAR a.s. and the University of West Bohemia in Pilsen, brings substantial benefits to customers, enhances their productivity, and increases their competitiveness in the market.

In the future this topic of specialized RCI micro-geometry and focused cooling might be extended with other shapes of RCI and geometry specific for other machined materials. This will broughden the applicability of these special turning tools on the industrial market.

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