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EXPERIMENTAL RESEARCH ON MACHINING WITH DLC DIAMOND COATED MILLING TOOLS OF ALUMINUM ALLOY PARTS USED IN THE AERONAUTICAL INDUSTRY

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Abstract: *The present work is intended to be a presentation of the results obtained when conducting an physical experiment of milling the parts of the Airbus A350 aircraft structure, using cutting tools with uncoated inserts and DLC diamond coated inserts, using several cutting parameters. The material we chose for the experiment is 2196 T8511, alloy of aluminum with lithium. The paper presents the equipment needed to complete the experiment, a synthesis of the types of materials used is made. The results of the experiment, the roughness of the generated surfaces and the durability of each set of inserts are represented by graphs. The objectives of the experiments are to maintain the roughness within the limits required by the customer through the indications on the technical drawing and to have concrete values of the durability of the inserts used depending on the material and cutting parameters used.*

Keywords: *aerospace, aircraft, aluminum alloys, composite, cutting tools with DLC diamond coated inserts.*

1. INTRODUCTION

This study aims to investigate the effects of DLC diamond-coated milling tools on the machining performance of aluminum alloy parts used in aeronautical applications. By conducting experimental trials under controlled machining conditions, we will analyze parameters such as cutting forces, tool wear, surface finish, and material adhesion. The goal is to determine how DLC coatings influence these variables compared to uncoated tools or alternative coatings. Understanding these effects will contribute to optimizing machining processes for aluminum alloys, enhancing productivity, and meeting the rigorous standards of the aeronautical industry.

The refinement of tools involved improving the geometry and coating with wear-resistant materials such as TiC or TiN, and the use of superhard materials such as cubic boron nitride (NCB) or diamond brought new levels of performance.

Machining technologies continue to evolve, supported by theoretical research and experiments to optimize process parameters. Insert milling and solid milling are two common material processing techniques and are used depending on the specific application requirements and workpiece characteristics. Here is a comparison between the two techniques:

1.1 Milling with monoblock cutting tools:

-The tools (Fig.1): are solid cutting tools, manufactured from a single piece of material, with the geometry of the edge integrated into the body of the tool.

- Rigidity and stability: Monoblock cutting tools offer superior rigidity and stability compared to insert milling, which makes them suitable for machining harder materials or working in difficult machining conditions.
- Performance and efficiency: can provide better performance and efficiency in certain

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applications, such as high-speed milling or deep milling.

- Limitations in flexibility: it does not offer the same flexibility in terms of adjusting the geometry of the cutting edge or replacing individual components as with insert milling.

Fig. 1. Monoblock milling tool [8]

1.2 Milling with inserts:

- The tools use interchangeable inserts mounted on a holder (tool body). The inserts are secured by a clip or screw and can be replaced when worn.
- Flexibility: offers great flexibility in selecting insert geometry, material and grade depending on material and machining conditions.
- Cost savings: maintenance cost can be lower as only worn inserts need to be replaced, while the support remains intact

In conclusion, both techniques have advantages and disadvantages, and the choice between insert milling and solid milling depends on factors such as the material to be machined, the geometry of the part, the requirements for accuracy and productivity, as well as the availability and preferences of the user. [1]

Experimental research on machining with Diamond-Like Carbon (DLC) diamond-coated milling tools on aluminum alloy parts is crucial for advancing knowledge in the aeronautical industry, particularly in materials science and manufacturing engineering. Here are some key points on its significance in the academic field:

- Material performance analysis: aluminum alloys are essential in the aeronautics industry for their high strength-to-weight ratio, corrosion resistance, and durability. Understanding how DLC-coated tools perform when machining these alloys helps researchers improve cutting tool life, surface quality, and production efficiency. This is particularly valuable in academic research where optimizing machining parameters is fundamental to advancements in material science and engineering.
- Tool wear and cost efficiency: DLC coatings provide excellent hardness, wear resistance, and low friction. Research helps in assessing how these coatings perform in terms of tool wear, which is significant for determining the economic feasibility of DLC-coated tools in manufacturing. Academically, studying tool wear and lifespan aids in developing predictive models and innovative solutions that benefit industry applications.
- Surface quality and precision: DLC-coated tools have been shown to produce smoother surfaces due to their low friction and high hardness. This research can advance knowledge on the microstructure and surface properties of machined parts, which is critical for applications requiring high precision, such as aerospace components. Improved surface quality also reduces the need for post-processing, which is a valuable area of study in manufacturing efficiency and sustainability.
- Process optimization and modeling: experimental studies provide data to create models that predict machining outcomes under different parameters. Academically, these models are essential for optimizing tool geometry, cutting speed, and feed rates, leading to more efficient and cost-effective manufacturing processes. This research also opens avenues for machine learning and AI applications in machining, an emerging area of academic interest.

2. THE EQUIPMENT NEEDED FOR TESTING

2.1 Machining center (Fig. 2):

Characteristics:

- Maximum dimensions of the workpiece: 12000x800x575 mm
- Maximum travel of the spindle on the Y axis:

1000-1500 mm, depending on the model

- Maximum axis movement speed:

X = 70 m/min,Y = 40 m/min, Z = 40 m/min

- Spindle technical maximum data:

Power: 80 kW/h, Speed: 30000 rpm, Torque: 36 N/m

Fig. 2. Bavius HD 600 [7]

2.2 The clamping device (Fig. 3):

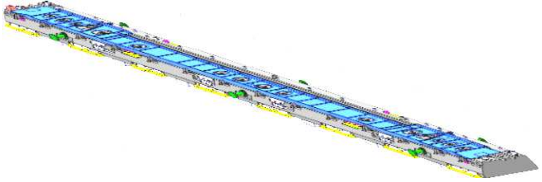

Fig. 3 The clamping device used for machining the parts

The fixture is machined from 5083 series Aluminum and is machined in such a way that it can be used on 238 types of parts. The device is not modular but in one piece with holes for screws to fix the blank and on some parts it has channels for vacuum to provide stability in machining. The clamping device was designed and manufactured taking into account the geometries of all parts.

2.3 Cutting tools (Fig. 4)

Of the 11 tools used for machining the parts, we started the experiment of monitoring for wear, cutting time, load on the spindle and roughness obtained for only one tool:
ICM901-032-086-A063-Z3R-XD-15.

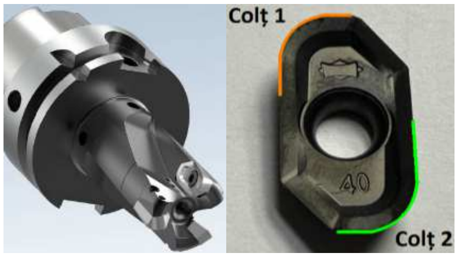

Fig. 4. The milling tool and the inserts used [4]

This type of cutting insert has two cutting corners. After the first corner is found to be wear, the insert is rotated for machining with the second corner.

2.4 Roughness meter (Fig. 5)

The Mitutoyo SJ-210 device provided by the Machining Department will be used to measure the roughness.

Technical specifications:

- works independently of the main supply, allowing measurements to be made on site
- Carry out roughness analyzes according to various international standards (EN ISO, VDA, ANSI, JIS)
- The range of applications can be extended by replacing with different advance units.

Fig. 5. Mitutoyo SJ-210 [5]

2.5 Vibration measuring instrument

To measure the vibrations of the spindle we need the measuring device Hofmann MI 2100 (Fig.6):

The vibration measurement procedure includes the following steps:

- The probe of the device is connected to the center port that measures the rotation of the spindle
- Increase the speed progressively from 1000 to 1000 rpm. The speed is kept for one minute after which the value is read.
- The graph is drawn up with the collected data.

Fig. 6. Hofmann MI 2100 [3]

2.6 Microscope (Fig. 7)

Used to observe the quality of milled surfaces where the inserts damage the surface of the workpieces. The microscope has a magnification up to 1600x.

Fig. 7. LEEXO digital microscope

2.7 Measuring devices

The measuring and control devices used are those listed in the measurement sheets of the parts: calliper, micrometer, radius templates, caliper for measuring thicknesses, GO/NOGO pin.

3. MATERIAL USED IN TESTS, 2196-T8511

Aluminum-lithium (Al-Li) is a type of aluminum alloy that includes lithium as the main alloying element after aluminum. These alloys are frequently used in the aeronautical industry due to their unique combination of properties, which include high strength, light weight and corrosion resistance. Below are some reasons why Al-Li alloys are important in the aerospace industry:

- Light weight: lithium is a light element, which makes Al-Li alloys lighter than conventional aluminum alloys. This is crucial for the aircraft industry, where weight reduction can improve fuel efficiency and overall aircraft performance.
- High strength: Al-Li alloys can have a higher specific strength compared to other aluminum alloys, which means they can support higher loads without significantly increasing the weight of the structure.
- Improved performance: the high strength-to-weight ratio of Al-Li alloys allows for more efficient designs and thinner structures without sacrificing structural strength, which can lead to improvements in aircraft performance and efficiency.
- Corrosion resistance: Al-Li alloys can have higher corrosion resistance compared to other aluminum alloys, making them suitable for use in harsh aerospace environments and applications exposed to adverse weather conditions.
- Advanced manufacturing technology: the production of Al-Li alloys requires advanced manufacturing technologies to ensure a uniform distribution of lithium in the aluminum matrix. This led to the development of innovative casting and machining techniques in the aeronautical industry.
- Critical applications: Al-Li alloys are used in critical aircraft components, such as wing and fuselage structures, where a combination of high strength, stiffness and low weight is required.

In conclusion, Al-Li alloys play a crucial role in the aeronautical industry, offering a unique combination of properties that can improve aircraft performance, efficiency and safety. [2]

Aluminum alloy 2196-T8511 is a low density extruded product developed to provide high mechanical strength, excellent corrosion resistance. 2196 offers improved performance compared to the older 7075 and 2024 models. It is used today as fuselage rails and seat rails and is an excellent choice for other domestic applications balanced between good machinability and strength, such as floor beams and lower beams of the wings. [6]

Table 1

Chemical composition of alloy 2196 T8511

2196 T8511					**DENSITY** 2.63g/cm3							
	Cu	Li	Zn	Mg	Mn	Zr	Ti	Fe	Si	Ag	Others (Each)	Others (Total)
Min	2.5	1.4	-	0.25	-	0.04	-	-	-	0.25	-	-
Max	3.3	2.1	0.35	0.8	0.35	0.18	0.1	0.15	0.12	0.6	-	-

4. THE PHYSICAL EXPERIMENT AND THE INTERPRETATION OF DATAS

The experiment was carried out under normal conditions of serial manufacturing of the parts, respecting the internal procedures regarding the processing of batches of parts. The only thing that was added was that a file was created for the tracked milling to store information related to the designation and durability of each set of inserted inserts and the measured vibration values of the spindle.

Notations used for the experiment:

S – spindle speed expressed in rpm – revolutions per minute

V_f – feed speed expressed in mm/min
f_z – feed per tooth expressed in mm/revolution,
1-20 – numbering of used insert sets
UC – uncoated. It symbolizes the uncoated inserts
DLC – coated. Diamond-Like Carbon coating
F1/F2 – the corners of the milling tool that comes into contact with the blank.

4.1 The testing began with a diagnosis of the vibrations of the spindle.

First step of the experiment was to track any wear that occurred on the spindle during testing:

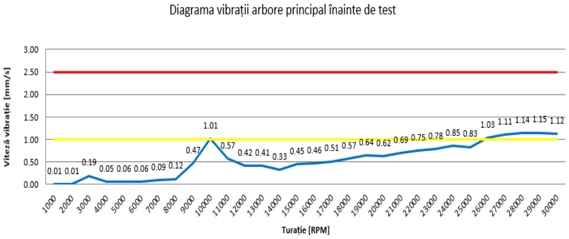

Fig. 8. Spindle vibration diagram before the tests start

1 = value below which the spindle is calibrated over the entire vibration range
2.5 = maximum value allowed for vibrations; if these values are exceeded then the spindle needs to be replaced

4.2 The testing using uncoated inserts.

- Test 1 with cutting parameters:
S=28000 rpm
V_f=14000 mm/min
f_z=0.167 mm/rev

The durability in the chart below was obtained. Average/set=119 minutes (red line).

Fig. 9. Testing uncoated inserts with f_z=0.167 mm/rev

The vibration chart has not undergone any changes since the initial check. The measured roughness was between 0.869-1.327 µm.

- Test 2 with cutting parameters:
S=28000 rpm,
V_f=19000 mm/min,
f_z=0.226 mm/rev.

Since the loads on the spindle reached 70%, the threshold at which the center displays information related to feedrate too high, and 17 stops of the center during machining during the entire testing with fz=0.226 mm/rev, we decided to decrease of the cutting parameters for the third test of uncoated inserts. The durabilities in the chart below were obtained. Average/set=107 minutes (red line).

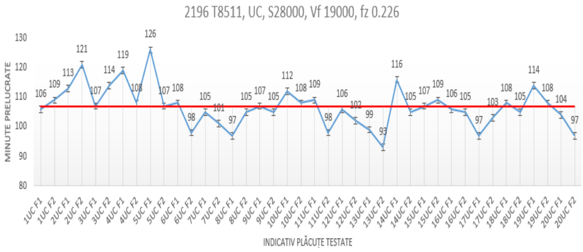

Fig. 10. Testing uncoated inserts with f_z=0.226 mm/rev

The vibration chart has not undergone any changes since the initial check.

The measured roughness was between 0.963-1.981 µm.

- Test 3 with cutting parameters:
S=27000 rpm
V_f=16200 mm/min
f_z=0.2 mm/rev

Durabilities from the chart below were obtained. Average/set=144 minutes (red line).

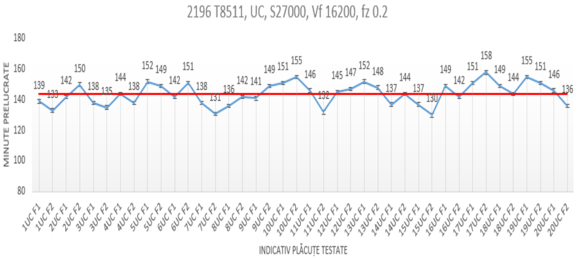

Fig. 11. Testing uncoated in serts with fz=0.2 mm/rev

The vibration chart has not undergone any changes since the initial check. The load on the spindle did not exceed 35%.

The measured roughness was between 0.818-1.367 µm.

4.3. Testing with DLC coated carbide inserts.

- **Test 4** with cutting parameters:

S=28000 rpm
V_f=14000 mm/min
f_z=0.167 mm/rev

Durabilities from the chart below were obtained. Average/set=410 minutes (red line).

Fig. 12. Testing DLC coated inserts with fz=0.167 mm/rev

The vibration chart has not undergone any changes since the initial check. The load on the spindle did not exceed 20%.

The measured roughness was between 0.728-1.219 µm.

- **Test 5** with cutting parameters:

S=28000 rpm
V_f = 19000 mm/min
f_z=0.226 mm/rev

Durabilities from the chart below were obtained. Average/set = 318 minutes.

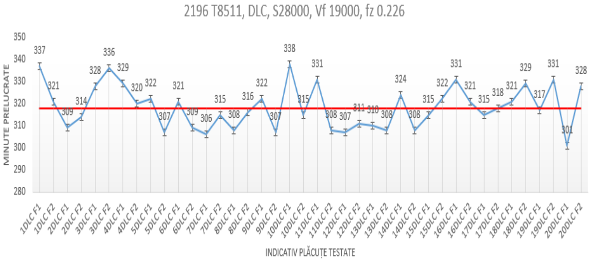

Fig. 13. Testing DLC coated inserts with fz=0.226 mm/rev

The measured roughness was between 1.077-1.690 µm.

During testing it was observed that around 300 minutes machined with a set, the load on the spindle increased to 80% and the center stopped machining.

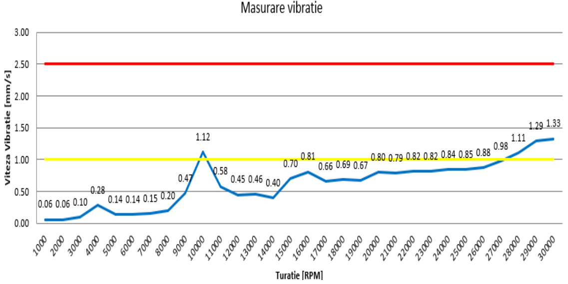

Fig. 14. Spindle vibration diagram using DLC coated inserts with fz=0.226mm/rev.

Increases of vibrations of the spindle are observed from the values at the beginning of the test.

- **Test 6** with cutting parameters:

S=27000 rpm
V_f=16200 mm/min
f_z=0.2mm/rev

Durabilities from the chart below were obtained. Average/set = 497 minutes.

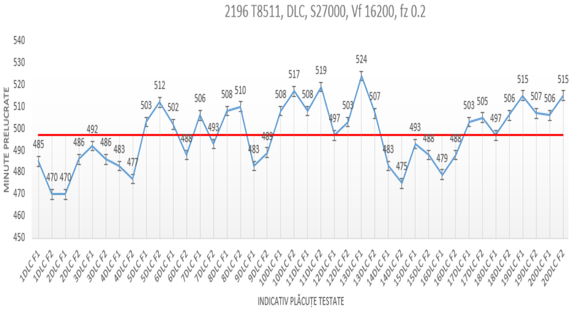

Fig. 15. Testing DLC coated inserts with fz=0.2 mm/rev

The measured roughness was between 0.681-1.448 µm. The load on the spindle did not exceed 27%. The vibration diagram:

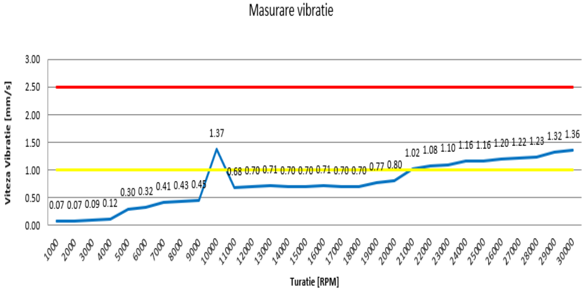

Fig. 16. Spindle vibration diagram when testing DLC coated inserts with fz=0.2 mm/rev

The physical experiment was finished. For every parameter tested we have centralized the data in different graphs depending on the type of inserts used and the parameters used.

Since the vibration diagram showed values that were below the maximum allowed by the manufacturer, we decided that production can continue, checking the vibrations of the main shaft at regular intervals.

5. CONCLUSIONS

The experimental research carried out on the milling of parts from aluminum alloy with lithium 2196 T8511 from the structure of the Airbus A350 aircraft, using DLC coated milling tools, led to the following conclusions:

5.1 Using the parameter f_z=0.167 mm/rev did not involve high loads on the spindle of the machining center compared to f_z=0.226 mm/rev which forced the limits of the spindle. The decision was to increase the parameters.

5.2 Using f_z=0.226 mm/rev parameter involved spindle loads increased up to 80% and the center stopped machining. We re-started the CNC machine and continue the machining. Also, the inserts were very worn – chippimg. Example in Figure 19, worn after 318 minutes machined. After we tested 20 sets of inserts we decided to change the parameters.

Fig. 17. Wear after 318 minutes machined

5.3 The **DLC** coated inserts with the highest wear machined 524 minutes with f_z=0.2 mm/rev.

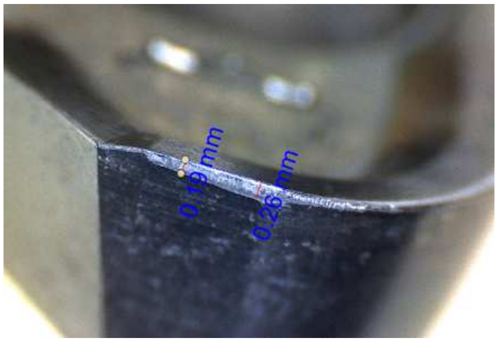

Fig. 18. Wear after 524 minutes machined

5.4 The optimal parameter was f_z=0.2 mm/rev where the best results were obtained both for uncoated and DLC coated inserts.

5.5 The uncoated inserts with the highest wear machined 144 minutes with f_z=0.2 mm/rev.

5.6 The parameter f_z=0.226 mm/rev obtained 338 minutes and due to high feed the DLC coating vanished and the aluminium build up an edge on carbide tip.

Fig. 19. Wear after 338 minutes machined and build up edge

5.7 DLC-coated inserts had up to 3.5x longer durability than uncoated inserts.

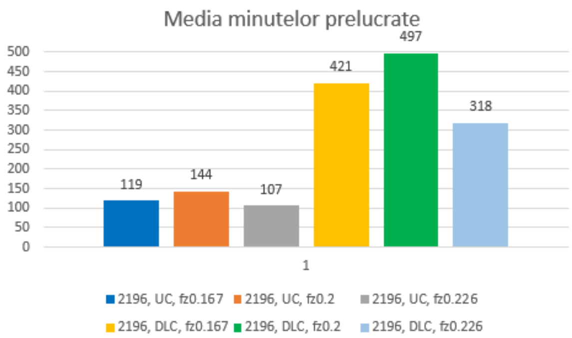

Fig. 20. Medium durability

5.8 The Spindle vibration diagram has suffered changes during the experiment but the maximul value of the vibrations was in tolerance.

5.9 Quantifiable results were obtained that will be taken into account in the following experiments using other types of materials.

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CERCETARE EXPERIMENTALĂ PRIVIND PRELUCRAREA CU SCULE DE FREZARE ACOPERITE CU DIAMANT DLC A PIESELOR DIN ALIAJE DE ALUMINIU FOLOSITE ÎN INDUSTRIA AERONAUTICĂ

Rezumat: Lucrarea de față se dorește a fi o prezentare a rezultatelor obținute la desfășurarea unui experiment fizic de frezare a pieselor structurii aeronavei Airbus A350, folosind scule așchietoare cu inserții neacoperite și inserții diamantate DLC, folosind mai mulți parametri de așchiere. Materialul pe care l-am ales pentru experiment este 2196 T8511, aliaj de aluminiu cu litiu. Lucrarea prezintă echipamentele necesare pentru finalizarea experimentului, se face o sinteză a tipurilor de materiale folosite. Rezultatele experimentului, rugozitatea suprafețelor generate și durabilitatea fiecărui set de inserții sunt reprezentate prin grafice. Obiectivele experimentelor sunt mentinerea rugozitatii in limitele cerute de client prin indicatiile de pe desenul tehnic si sa aiba valori concrete ale durabilitatii inserturilor folosite in functie de materialul si parametrii de așchiere utilizați.

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