ANALIZA OBRADLJIVOSTI LEGURE TITANIJA TA6V

ANALYSIS OF MACHINABILITY OF TITANIUM ALLOY TA6V

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REZIME

Legura titanija TA6V predstavlja izvanredan materijal zbog svojih odličnih svojstava, među kojima možemo izdvojiti odličnu otpornost na koroziju, kao i zadržavanje mehaničkih karakteristika na visokim temperaturama. Mašinska obrada ove legure je veoma zahtjevna. Jedan od problema u procesu obrade je oblik generisane strugotine. Strugotina nastala u procesu obrade je kontinuirana, teško se lomi i odvaja iz zone rezanja, što dodatno može uticati na stabilnost obradnog procesa.Osim nepovoljnog odvođenja strugotine, obrade je dodatno otežana termičkim svojstvima materijala zbog lošeg odvođenja toplote. U okviru ovog rada urađena je analiza rezultata obradljivosti obratka od legure titanija TA6V. Urađena je obrada dijela sa dva različita alata i izmjerene su sile rezanja i površinska hrapavost obratka. Na kraju je uz pomoć 3D mikroskopa prikazano stanje reznih pločica nakon obrade. Rezultati su pokazali da je nakon vrlo kratkog vremena u zahvatu došlo do značajnog trošenja rezne ivice oba alata, što ukazuje na teške uslove obrade.

Professional paper

SUMMARY

The titanium alloy TA6V is an exceptional material due to its excellent properties, among which are its outstanding corrosion resistance and the retention of mechanical characteristics at high temperatures. Machining this alloy is highly demanding. One of the problems in the machining process is the shape of the generated chips. The chips formed during machining are continuous, difficult to break, and hard to remove from the cutting zone, which can further affect the stability of the machining process. In addition to the unfavorable chip removal, machining is further complicated by the material's thermal properties due to poor heat dissipation. In this study, an analysis of the machinability results of a TA6V titanium alloy workpiece was conducted. The machining was performed using two different cutting tools, and the cutting forces and surface roughness of the workpiece were measured. Finally, a 3D microscope was used to examine the condition of the cutting inserts after machining. The results showed that after a very short time during machining, significant wear of the cutting edge of both tools occurred, indicating challenging machining conditions.

1. INTRODUCTION

Titanium (chemical symbol Ti, atomic number 22, and atomic weight 47.9) was discovered more than 200 years ago by William Gregor, but commercial production of titanium did not begin until the 1950s [1]. Titanium alloys have revolutionized modern engineering and manufacturing, with TA6V (Ti-6Al-4V) standing out as one of the most widely used materials due to its exceptional properties. Known for its high strength-to-weight ratio, excellent corrosion resistance, and biocompatibility, TA6V has become a cornerstone in industries such as aerospace, medical implants, and automotive engineering [2]. For instance, in aerospace applications, its ability to withstand extreme temperatures and stresses makes it ideal for critical components like jet engine parts and airframe structures. Similarly, in the medical field, its biocompatibility ensures its use in surgical implants and prosthetics [3]. One of the most important uses of titanium alloys was in the construction of the SR-71 „Blackbird" plane where over 95% of its fuselage was made of titanium alloy [4]. Titanium materials have been used in dentistry and other areas of medicine, such as orthopedic surgery, for decades with great success because titanium is a safe and dependable material. The body accepts titanium very well. It is a biocompatible material, meaning it is not harmful to living tissue. The body does not reject titanium and will not develop an infection when a titanium piece is implanted. The titanium is also resistant to bacteria. Titanium can exist within the body without corroding, decaying or developing other complications [5]. However, despite its remarkable advantages, TA6V presents significant challenges during machining, primarily due to its low thermal conductivity, high chemical reactivity, and tendency to work-harden during cutting processes. These characteristics often result in accelerated tool wear, poor surface finish, and increased production costs, making the machinability of TA6V a critical area of study [6]. Titanium alloys are known for their high strength, excellent corrosion resistance, and low thermal conductivity, making them challenging to machine. Effective CNC machining of these materials requires selecting lower cutting speeds, appropriately large feed rates, reasonable depths of cut, and sufficient finishing amounts to achieve optimal results [7]. A key problem during the machining process of TA6V is chip formation. In the case of TA6V, chip formation is particularly complex due to the alloy's properties [3]. The machining process produces continuos chips that occupy a large volume and are difficult to evacuate from the cutting zone. Also, due to friction between the chip/tool and tool/workpiece interfaces, a significant amount of heat is generated, that together with low thermal conductivity of the material leads to an rapid increase in temperature in the cutting zone, and quick detoriation of cutting edge. A robust machine tool is critical to successful machining of titanium. The ideal titanium milling machine needs to be rigid with spindles that can operate at low spindle speeds and high torque. This helps absorb vibration and reduce chatter during the cut, which is a common problem when machining titanium [8]. In this article, the machining process of a workpiece in the shape of a rod made of TA6V will be analyzed. The workpiece has been machined with two different cutting inserts, but with the same cutting parameters. The cutting forces, as well as the surface roughness of the workpiece and cutting tools, have been analyzed. In the end, the cutting insert will be analyzed using a Marsurf 3D microscope to examine its wear.

2. EXPERIMENTAL SETUP

The machining process of a TA6V titanium bar was analyzed in this experiment using two different tools, with dry machining in both cases. The cutting parameters used in this experiment are presented in Table 1, while the workpiece used in this experiment is shown in Figure 1.

Table 1 Cutting parameters

Parameters	
D (mm)	50
n (o/min)	600
s (mm/o)	0.1
d (mm)	0.5
V (m/s)	94.2

Figure 1. *Titanium TA6V workpiece used in the experiment*

The data on the cutting inserts are given in Table 2. The cutting inserts and tool holders used during this experiment are shown in Figure 2. and Figure 3.

Table 2. Cutting inserts data

Designation	Tool 1	Tool 2
Cutting Insert	CNMG-120408-MP	SNMG-120408-MA
Tool Holder	PCLNR 3232P-12	DSSNL 2525M-12
Material	Carbide	Carbide
Manuf.	Korloy	MITSUBISHI
Inscribed Circle dia.	12.7 mm	12.7 mm
Insert Thickness	4.76 mm	4.76 mm
Corner Radius	0.8 mm	0.8 mm
Main Cutting Angle	95 °	45 °
Rake Angle	-5 °	-5 °

Figure 2. *Cutting inserts*

Figure 3. *Tool holders*

In this experiment, cutting forces were measured using a 3D Kistler dynamometer or force sensor integrated into the machine tool setup. The surface roughness of the workpiece, as well as the tools, was measured using a Mahr Perthometer M1. These parameters were measured after machining with each cutting tool to compare the quality of the surface roughness produced under different conditions. A 3D MahrSurf microscope was used to measure the wear and tear of the cutting inserts.

3. RESULTS

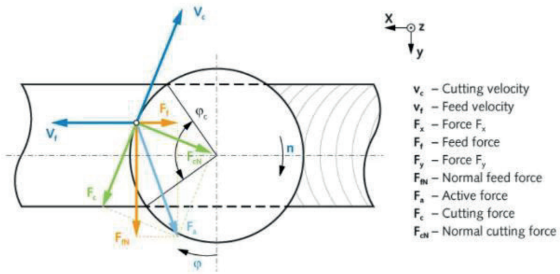
3.1. Cutting forces

In this experiment, cutting forces were measured for both tools to assess their performance during the machining of TA6V titanium alloy. Cutting forces were measured using a dynamometer. The F_x component represents the feed force, which acts in the direction of the tool feed and contributes to material removal. The F_y component represents the thrust force, which acts perpendicular to the cutting direction and pushing the tool away from the workpiece. The F_z component represents the cutting force, which acts in the cutting direction, opposing the tool's advancement into the workpiece. The cutting forces are listed in Table 3.

Table 3. Values of cutting forces

Cutting force [N]	Tool 1	Tool 2
F_x (mean value)	216,1	215,2
F_y (mean value)	195	221,8
F_z (mean value)	175,3	173,8
F_x (max. value)	278	266
F_y (max. value)	242,8	268,1
F_z (max. value)	233	218,7
F_x (integral value)	1,201	1,034
F_y (integral value)	1,804	1,065
F_z (integral value)	974,6	834,6
F_x (RMS value)	216,5	215,6
F_y (RMS value)	195,4	222,2
F_z (RMS value)	175,8	175,2

A schematic representation of these forces during the machining process is shown in Figure 4. Figure 5 and Figure 6 display cutting force diagrams during maching with both cutting inserts.



$$F_x = F_f \text{ and } F_y = F_{fN} \qquad F_a = \sqrt{F_f^2 + F_{fN}^2}$$

$$\begin{bmatrix} F_c \\ F_{cN} \\ F_p \end{bmatrix} = \begin{bmatrix} \cos(\varphi) & \sin(\varphi) & 0 \\ \sin(\varphi) & -\cos(\varphi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} F_f \\ F_{fN} \\ F_z \end{bmatrix}$$

Figure 4. *Schematic representation of cutting forces [9]*

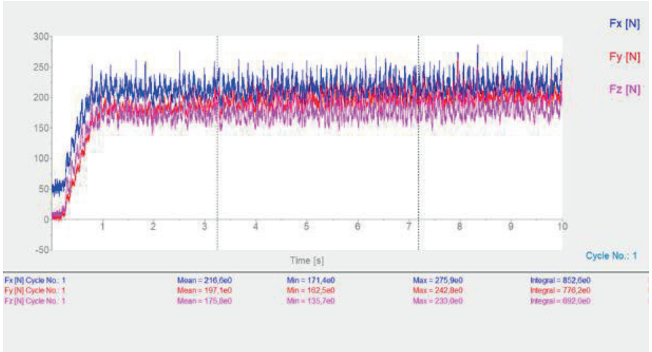


Figure 5. *Cutting force diagram during machining with CNMG-120408-MP*

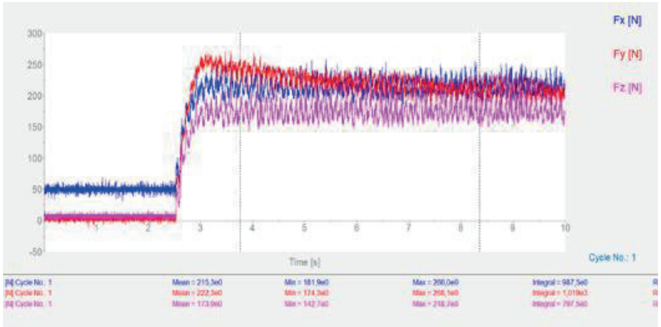


Figure 6. *Cutting force diagram during machining with DSSNL 2525M-12*

3.2. Surface roughness

Surface roughness of the TA6V titanium alloy workpiece was measured using a Perthometer M1 device. The surface roughness measurements are presented in Table 4, showing the results of surface roughness measurements on the TA6V titanium alloy part after machining with cutting inserts CNMG-120408-MP and DSSNL 2525M-12. The surface roughness was measured in 3 positions on the workpiece. In this table, R_a represents the arithmetic mean roughness, R_z represents the average height of the roughness profile, R_{max} represents the distance between the highest and lowest points of the profile within a specified measuring length, and P_C represents the mean height of the profile elements that rise above the mean line. The last column of the table shows the average surface roughness value for all three points.

Table 4. Surface roughness of the workpiece

	Point 1	Point 2	Point 3	Mean value
Tool 1				
R_a (μm)	1.071	1.691	1.147	1.303
R_z (μm)	5.26	8.27	5.53	6.353
R_{max} (μm)	6.65	10.2	6.39	7.746
P_c	30	23	33	28.6
Tool 2				
R_a (μm)	0.956	1.476	1.131	1.1876
R_z (μm)	5.81	7.15	6.25	6.403
R_{max} (μm)	6.83	8.75	7.57	7.716
P_c	48	38	58	48

3.3 Wear and tear

A detailed analysis of the CNMG-120408-MP and DSSNL 2525M-12 cutting inserts was performed after machining using a scanning 3D MarSurf microscope. The microscope is shown in Figure 7. The wear on the cutting edge surface after machining was examined. The wear on the CNMG-120408-MP cutting edge is approximately 0.1 mm. The wear on the DSSNL 2525M-12 cutting edge is approximately 0.2 mm. Even though the machining process lasted less than 30 seconds, it still led to considerable wear and tear on the cutting inserts. Detailed views of the cutting insert after machining are shown in Figures 8.1, 8.2, 9.1, and 9.2.

Figure 7. 3D MarSurf optical microscope

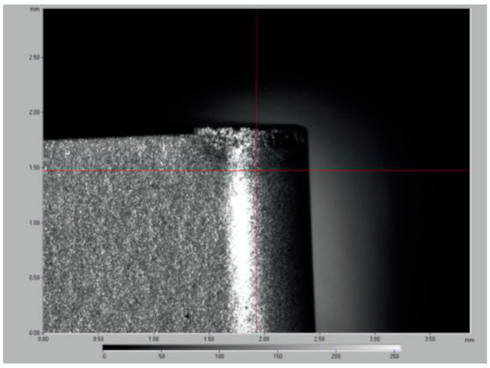


Figure 8.1. Cutting insert CNMG-120408-MP after machining

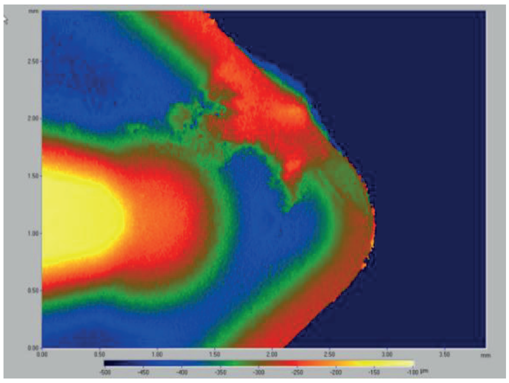


Figure 8.2. Cutting insert CNMG-120408-MP after machining

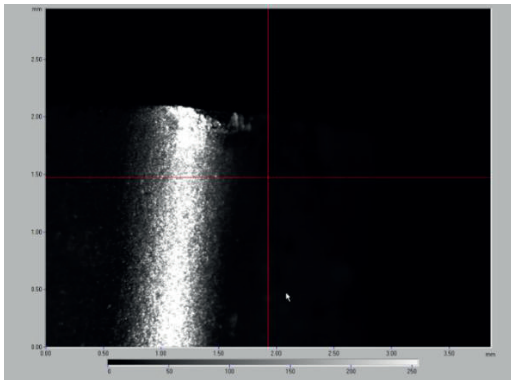


Figure 9.1. Cutting insert DSSNL 2525M-12 after machining

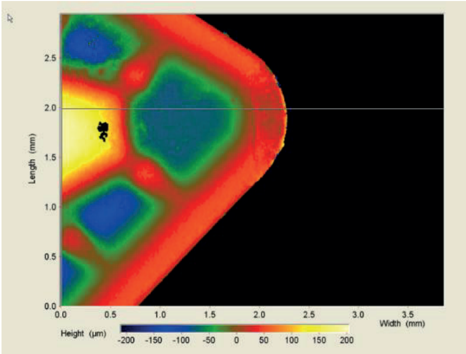


Figure 9.2. *Cutting insert DSSNL 2525M-12 after machining*

3.4 Chip formation

The machining process was accompanied by the formation of a continuous chip that occupied a large volume and was difficult to remove from the cutting zone. One of the most significant challenges encountered during the machining of TA6V is the formation of continuous chips. These chips occupy a large volume and are difficult to remove from the cutting zone, leading to increased temperatures and hindered heat dissipation. This phenomenon not only intensifies tool wear but also affects the overall efficiency of the machining process. The continuous chip formation is a direct result of the alloy's properties, primarly ductility of material. The TA6V chip that was formed after machining is shown in Figure 10.

Figure 10. *TA6V Chip that was formed after 30 seconds*

4. CONCLUSION

The analysis of the machinability of the titanium alloy TA6V has provided valuable insights into the challenges and complexities associated with machining this high-performance material. The experiment conducted with two different cutting inserts, Tool 1 (CNMG-120408-MP) and Tool 2 (DSSNL 2525M-12), under identical cutting parameters, revealed several critical aspects of the machining process. However, the Tool 2 showed marginally lower cutting forces in some components, suggesting a slightly better performance in terms of force distribution during machining. Despite the short duration of the machining process, the high chemical reactivity and low thermal conductivity of TA6V contribute to accelerated tool wear. The wear patterns observed on the cutting edges suggest that the tools were subjected to significant thermal and mechanical stresses, which are typical when machining titanium alloys. The results of this study highlight the importance of selecting appropriate cutting tools and parameters when machining titanium alloys. While both tools performed adequately, the DSSNL 2525M-12 tool inserts demonstrated slightly better performance in terms of surface finish and cutting forces. In conclusion, machining titanium alloy TA6V is a complex and demanding process that requires careful consideration of tool selection, cutting parameters, and chip management strategies. The high strength-to-weight ratio, corrosion resistance, and biocompatibility of TA6V make it an invaluable material in various industries, but its poor machinability poses significant challenges. To improve the machining process, future research should focus on developing advanced cutting tools with improved wear resistance, optimizing cutting parameters to minimize tool wear and surface roughness, and exploring innovative chip control techniques. Additionally, the use of cooling and lubrication systems could be investigated to mitigate the effects of high temperatures in the cutting zone. While dry machining was used in this experiment, the introduction of coolants or lubricants may help reduce tool wear and improve surface finish. Furthermore, the application of coatings on cutting tools, such as titanium nitride (TiN) or diamond-like carbon (DLC), could enhance their performance by reducing friction and improving thermal stability. In summary, while titanium alloy TA6V offers exceptional mechanical and chemical properties, its machinability remains a significant challenge. The results of this experiment provides a foundation for further research and development in the field of titanium machining. By addressing issues such as tool wear, surface finish, and chip control, it is possible to improve the efficiency and cost-effectiveness of machining TA6V, thereby expanding its applications in industries where its unique properties are indispensable.

5. REFERENCES

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