CHIP BREAKER OF CUTTING TOOL AND ITS INFLUENCE AT DYNAMIC FORCE OF MACHINING TITANIUM ALLOY TI_6AL_4V.

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Abstract

The article concerns the machining process of the titanium alloy Ti_6Al_4V according to the norm DIN W. Nr 3.7164 and the choice of a suitable cutting tool. For machining the alloy, replaceable cutting inserts indexed in accordance with the standard ISO - CNMG 120408, with varying geometry of the chip breaker, were used in pre-defined cutting conditions. The experimental part was performed to define the influence of the chip breaker geometry at the process and magnitude of the dynamic force at outer longitudinal machining of the titanium alloy Ti_6Al_4V. For measuring the force and setting the magnitude of individual components of the cutting force three-component piezoelectric dynamometer KISTLER 9257B was used during the machining process. Based on the measured and processed values, the lowest and the highest force impact on the surface of the machined material was specified and also the load on the cutting edge at machining the titanium alloy Ti_6Al_4V.

Keywords: Cutting process, inserts, sintered carbide, wear

1. INTRODUCTION

The titanium alloy Ti_6Al_4V is included among difficult-to-cut materials, thanks to its chemical composition, specific mechanical and physical properties. The worse machinability of the alloy makes it more demanding for the machining technology, the applied cutting tools and the cutting conditions. Worse machinability often negatively influences efficiency, economy and ecology of the manufacturing process [1]. Machining the titanium alloy Ti_6Al_4V is very problematic in comparison to the common steels. To reach the required efficiency and productivity of the alloy machining, it is necessary to introduce series of experimental analyzes, including testing of new cutting tools, materials and cutting geometries, choices and optimization of cutting conditions. The above mentioned machinability of the alloy has also a great impact on the tool wear and tool life, the integrity of the machined surface and the effect on the superficial and in-depth layers of the material. Not less important attribute influencing the machined surface is also the chip processing and shaping, especially the chip speed and the motion of chip flow. Consequently, the choice of proper cutting tool geometry and the chip breaker geometry is very important.

The chip breaker geometry should dispose the chips efficiently from the cutting zone, break them and prevent their accumulating in the working space of the machine. Then the mechanical and thermal stress on the cutting edge and also the speed of the tool wear is not that high at machining. At machining the titanium alloy Ti_6Al_4V, the most frequent cutting tool wear is the wear in the form of a dent or a crater on the rake nose. The mechanism of the wear is an intense diffusion and abrasion of the machined material which is caused by hot hardness of the alloy, its low thermal conductivity and by producing short, friable chips which intensively stress the cutting edge on a very small area in vicinity to its very point. As a result of these mechanisms, very fast deformation of the tool nose appears, followed by its destruction [1, 3].

2. MACHINING TITANIUM AND ITS ALLOYS

In machinig of titanium and titanium alloys, higher stress of the whole machining system occurs. Especially the cutting edge of the tool is exposed to very intensive mechanical and thermal stress. The cause of the stress is low thermal conductivity of the material, high strength of the material even at higher temperatures, toughness and low elasticity modulus of titanium. The great forces at chip breaking, combined with rubbing the leaving chip against the tool nose, generate a great amount of heat. The high temperature and pressures in the cutting zone, low thermal conductivity, the cutting tool tendency to react chemically with titanium, and also the production of built-up fragments, result in early tool wear.

A number of experts attempted to prevent the negative influences in the process of machining titanium and its alloys. It was proved that titanium and its alloys cannot be machined in the same cutting conditions as common steels. Like the alloys based on nickel or cobalt, machining titanium and its alloys requires specific approach regarding choice of cutting tool, tool material, cutting geometry and cutting conditions. Generally, it is recommended to ensure high rigidity of both the machine and the tool in titanium machining, to choose positive, acute cutting geometry guaranteeing higher cutting power of the tool, fine grain structure of the tool material, to choose a coating of lower affinity to the machined material which ensures more acute cutting edge. It is also advisable to limit the cutting conditions, i.e. to lower the cutting speed and to ensure sufficient supply of process media directly to the cutting edge of the tool.

In the process of titanium and its alloy machining, intensive strengthening of the surface and surface layers occur, like in nickel alloys. Worse material machinability and strengthening of the machined surface cause fast cutting edge wear and increase of specific cutting resistance and of temperature in the cutting zone. Intensive dent wear occurs on both the rake and flank face of the tools coated with sintered carbide, also craters appear, both of which considerably reduce the cutting tool life. The above mentioned negative phenomena accompanying the titanium and titanium alloy machining considerably influence the surface integrity of the functional areas of workpieces [2, 4, 7, 8].

3. EXPERIMENTAL PART

Experimental machining of the titanium alloy Ti_6Al_4V (material properties see **Table 1 and 2.**) was performed to consider the influence of the geometry of the chip breaker on the magnitude and process of the dynamic force on the machining system. Considering the intensive stress of the system, it is necessary to choose the proper cutting tool, material and cutting geometry of the tool, proper cutting conditions at machining the titanium Ti_6Al_4V alloy [4].

Table 1 Chemical composition (mass %) of titanium alloy Ti_6Al_4V [5]

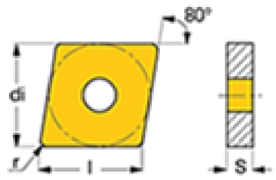
C	Fe	Al	V	Ti
0.10	0.4	5.5 - 6.75	3.5 - 4.5	bal.

Table 2 Mechanical and physical properties of alloy Ti_6Al_4V [5]

Specific Weight [g / cm3]	Melting Temperature [°C]	Modulus of Tensile Elasticity [GPa]	Shear Elasticity Modulus [GPa]	Hardness HRC
8.19	1336	204.9	77.2	36

3.1. Choice of cutting geometry

For longitudinal machining the titanium alloy Ti_6Al_4V, negative cutting geometry indexed CNMG 120408 (see **Figure 1**) was chosen to preserve the cutting tool toughness and tool life. Cutting tool geometries have the cutting edge angle β = 90°, which guarantees the required cutting edge rigidity for machining the high strength materials. The angle of the main cutting edge setting κr = 95° influences the shape of the disposed chip, the structure of the machined surface and above all the distribution and magnitude of the machining force ratios. For machining titanium alloy, four replaceable cutting inserts with different chip breaker geometry were chosen, coated by a thin layer of PVD [6].



	l [mm]	di [mm]	s [mm]	r [mm]
CNMG 120408	19.90	12.70	4.76	0.80

Figure 1 Geometry of inserts CNMG 120408 [6]

3.2. Choice of the cutting conditions

Titanium alloy Ti_6Al_4V machining was performed under predetermined cutting conditions. Their selection was based on recommended values of the cutting tool producers and so that the conditions were comparable for all the used cutting inserts. To reach higher productivity of titanium alloy machining, three different cutting depths were chosen and increasing values of feed. The chosen cutting depth indicates that medium to rough machining was performed, which influenced the choice of chip breaker geometry. Cutting conditions and their values are indicated in **Table 3**.

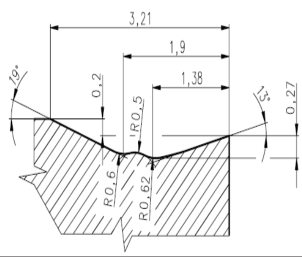
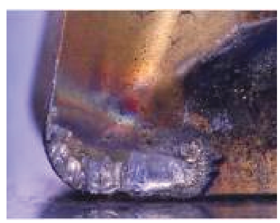
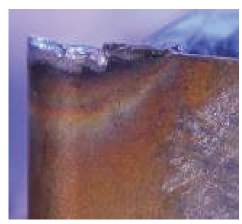
Table 3 Cutting conditions for machining the titanium alloy Ti_6Al_4V

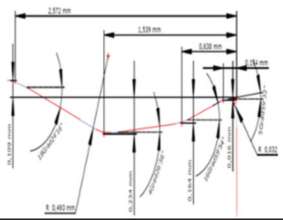
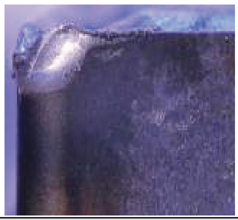
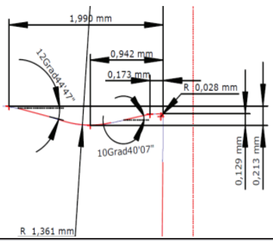
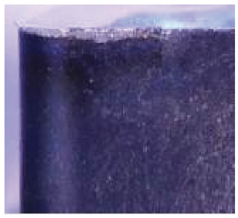
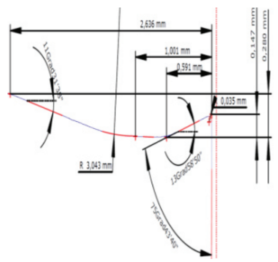
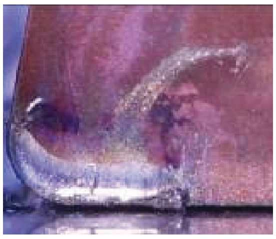
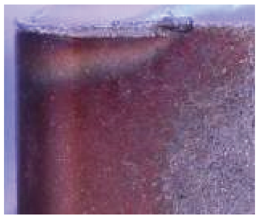
Parametres/ Measurement	Measurement 1	Measurement 2	Measurement 3
Cutting speed - v_c[m·min^{-1}]	44	44	44
Feed - f [mm]	0.20	0.25	0.40
Cutting depth - a_p[mm]	1	2	3

3.3. Used cutting inserts and their breakers

Indexing the used cutting inserts with geometry of the chip breaker for machining the titanium alloy is indicated in the **Table 4**. For illustration, the photos of individual cutting insert wear on the rake and flank face, at predetermined cutting depth a_p = 2 mm and after reaching the pre-set criterion of wear at tool tip VB_C, are also presented in the **Table 4**.

Table 4 Wear of the tool cutting edge

CNMG 120408 - SM	Section A (nose radius) in tip	Rake face	Flank face
			

CNMG 120408 - NRS	Section A (nose radius) in tip	Rake face	Flank face
			
CNMG 120408 - M5	**Section A (nose radius) in tip**	**Rake face**	**Flank face**
			
CNMG120408-SMR	**Section A (nose radius) in tip**	**Rake face**	**Flank face**
			

4. MEASURING THE DYNAMIC FORCE IN MACHINING THE TITANIUM ALLOY TI_6AL_4V

To consider the proper geometry of the tool chip breaker, the values of the dynamic force were measured in the process of titanium alloy machining. Individual components of the cutting force were measured with three-component piezoelectric dynamometer KISTLER 9257B to set the magnitude and process of force.

Generally, the magnitude of the components F_c, F_f, F_p changes dependently on the machined material, chosen tool, cutting geometry and on the cutting conditions. Titanium machining above all requires positive very accurate geometry which has excellent cutting power, ability to dispose chips effectively from the cutting zone, break them and thus prevent developing of a great amount of heat, critical for tool tip life. Proper geometry of the chip breaker results in the change of the machined material cutting resistance, by magnitude of individual components of the cutting force F_c, F_f, F_p and how the cutting tool is exerted.

In **Table 5**, the process of exertion is presented on the values of individual components of cutting force in the process of machining the titanium alloy Ti_6Al_4V. The resulting cutting force (see **Table 6**) is calculated from the measured values which states the magnitude of force of the whole system in machining a material with chosen cutting inserts, under given cutting conditions.

Table 5 Measured values of components F_c, F_f, F_p

CNMG 120408 - SM	Passive component of force F_p [N]				Feed component of force F_f [N]				Cutting component of force F_c [N]			
1. Measurement	149	152	152	151	143	145	145	144	326	328	323	326
2. Measurement	150	150	149	150	361	371	371	368	829	831	824	828
3. Measurement	188	186	181	185	578	571	568	572	1629	1635	1638	1634
CNMG 120408 - NRS	**Passive component of force F_p [N]**				**Feed component of force F_f [N]**				**Cutting component of force F_c [N]**			
1. Measurement	143	144	144	144	134	135	136	135	319	321	323	321
2. Measurement	189	184	184	186	334	330	331	332	779	782	778	780
3. Measurement	294	295	293	294	546	555	559	553	1537	1554	1528	1540
CNMG 120408 - M5	**Passive component of force F_p [N]**				**Feed component of force F_f [N]**				**Cutting component of force F_c [N]**			
1. Measurement	163	162	163	163	170	171	172	171	339	335	336	337
2. Measurement	197	195	197	196	411	404	402	406	829	834	836	833
3. Measurement	304	306	304	305	671	668	664	668	1647	1654	1651	1651
CNMG 120408 - SMR	**Passive component of force F_p [N]**				**Feed component of force F_f [N]**				**Cutting component of force F_c [N]**			
1. Measurement	168	176	176	173	159	163	164	162	333	341	340	338
2. Measurement	204	203	203	203	392	387	394	391	831	829	839	833
3. Measurement	341	351	351	348	770	771	782	774	1785	1792	1808	1795

Table 6 Values of resulting cutting force F [N]

	1.Measurement	2. Measurement	3. Measurement
CNMG 120408-SM	387	918	1741
CNMG 120408-NRS	377	867	1662
CNMG 120408-M5	411	947	1806
CNMG 120408-SMR	413	942	1986

5. CONCLUSION

For experimental machining of the titanium alloy Ti_6Al_4V, four types of replaceable cutting inserts were designed with varying chip breakers. The planned experiment was performed to evaluate the influence of the chip breaker geometry at the process and dynamic force on the system, tool and workpiece. Machining the titanium and its alloys is generally very problematic and increases the requirements not only on the manufacturing technology but also on the choice of the cutting tool and cutting conditions. Experimental machining of the titanium alloy was performed under predetermined conditions to test the ability of the cutting tool and its chip breaker to effectively produce, break and dispose the chips from the cutting zone. With increasing depth of the disposed layer of material and increasing feed speed, also the effectivity of machining such difficult-to-cut material as titanium alloy Ti_6Al_4V increased. The value of the cutting speed was kept constant in the experiment and had to be limited to a certain extent, especially due to prevent development of high temperature in the cutting zone and the possibility of excessive cutting tool wear.

From the experimental process and graphic processing of the measured values results that the highest force was load exerted in the direction of the main cutting motion. The ratio of the individual components of the cutting force changed especially with increasing depth of the disposed layer of material and partially with increasing feed speed. Increasing cutting depth resulted especially in the increase of the cutting component F_c. Intensive force impact in tangential direction affect especially on the rake face of the cutting tool and became the main initiator of the mechanism of a dent shape wear. The feed component of the cutting force F_f was increasing with the increasing cutting depth and feed only gradually. Therefore, it cannot be proved that the force impact in this direction intensively stresses the cutting edge to the extent that it would cause abrasion on the flank face. The passive force component F_p changed minimally during machining of the material and its values were lower in comparison with the cutting force component F_c even many times.

The lowest force load on the whole system was measured in machining the titanium alloy by cutting insert CNMG 120408 - NRS. The chip breaker geometry NRS caused that in the limits of the cutting conditions the lowest values of the force impact were reached in tangential and axial directions and in the direction of the resulting cutting force. Conversely, the least suitable geometry of the chip breaker was the one of the replaceable cutting insert indexed CNMG 1204008 - SMR. The values measured in machining process of the material by this insert exceeded, in the given cutting condition limits, the values of force impact of all other tested cutting inserts. From the experimental process and the measured values it results that machining titanium requires the proper choice of the cutting insert geometry and the chip breaker geometry to attain high effectivity of the cutting process and the cutting tool life.

REFERENCES

[1] NESLUSAN, M., CZAN, A. *Obrábanie titanovych a niklovych zliatin*. 1st ed. Žilina: Technical University of Žilina / EDIS, 2001. 189p.

[2] DORLIN, T., FROMENTIN, G., COSTES, J.-P. General cutting force model including contact radius effect for turning operations on Ti6Al4V titanium alloy. *International Journal of Advanced Manufacturing Technology,* 2016, vol. 13, no. 3, pp, 1-17.

[3] CEP, R., PETRU, J., ZLAMAL, T., VALICEK, J., HARNICAROVA, M., JANASEK, A., CEPOVA, L. Influence of feed speed on machined surface Quality. In *METAL 2013:22nd International Conference on Metallurgy and Material.* Ostrava: TANGER, 2013, pp. 1033-1038.

[4] PETRU, J., SCHIFFNER, J., ZLAMAL, T., SADILEK, M., STANCEKOVA, D. Investigation of Cutting Tool Wear While Machining Inconel 718. *Manufacturing Technology,* 2015, vol. 15, no. 3, pp. 396-403.

[5] Slitiny titanu. Ti_6Al_4V. [online]. [cit. 2016-02-18]. Available: <http://cartech.ides.com/datasheet.aspx?i=101&E=269&FMT=PRINT>.

[6] SANDVIK COROMANT. General Turning. 2014. [online]. [cit. 2016-03-10]. Available: <https://www.sandvik.coromant.com/cs-cz/knowledge>.

[7] MARTIKAN, A., STRUHARNANSKY, J., STANCEKOVA, D., CZAN, A., HATALA, M. Influence of chemical etching on surface micro-geometry of titanium implants. *Manufacturing Technology*, 2015, vol. 15, no. 4, pp. 601 - 604.

[8] HLOCH, S., HLAVÁČEK, J., VASILKO, K., CÁRACH, J., SAMARDŽIĆ, I., KOZAK, D.,HLAVATÝ, I., ŠČUČKA, J., KLICH, J., KLICHOVÁ, D. Abrasive waterjet (AWJ) titanium tangential turning evaluation. *Metalurgija*, 2014, vol. 53, no. 4, pp. 537-540.