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MACHINING OF NEW BIOMATERIALS FOR IMPLANTS

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Abstract: Article compares cutting conditions and forces generated during milling of advanced biomaterials based on titanium. Since these are hard materials used in the manufacturing of expensive dental implants, the purpose of the article is also to identify and compare the dynamic machinability of said materials. This allows the outputs of this article to serve as an aid in the planning of production processed and calculating of production costs.
Keywords: biomaterial, titanium, dynamic machinability

INTRODUCTION

A constant need for a development of new kinds of medical implants placed into human body, serving as substitutes for dysfunctional or damaged body parts, requires new materials for their production, which must meet difficult and often contradictory requirements. Such materials include for example commercially pure titanium and its alloys, which are used for their excellent biocompatibility and suitable mechanical properties.

In the implant manufacturing are frequently used conventional machining technologies. Since titanium is classified as material with worse machinability, there is need for solutions of complications appearing during conventional machining. The main factors that contribute to poor machinability of titanium are low thermal conductivity a high friction coefficient in contact with other materials, causing thermal degradation of tools. High tensile strength and low modulus of elasticity also contribute to increased mechanical stress in cutting edge of the tool. Reducing of production costs and times while increasing production quality is a fundamental objective of the production process.

Given the geometric and dimensional accuracy and the surface quality of the products made of hard materials, it is necessary to handle problems with machining materials is used for this applications and determine such technological conditions, under which machining will be efficient.

Article is focusing on comparison of machinability of new titanium materials, used in dental implantology, for milling. Mentioned materials are commercially pure titanium TiGr5, commercially pure titanium with volume nanostructure (nTi) and alloy TiNbTa. As reference, material was chosen commonly used commercially pure titanium TiGr2.

Partial goals of article were the force rates in relation with cutting conditions and to determine structural formulas for face milling

STUDIED MATERIALS AND HARD-MILLING CONDITIONS

Unalloyed Commercially Pure (CP) Titanium is available in four different grades, 1, 2, 3 and 4, which are used based on the corrosion resistance, ductility and strength requirements of the specific application. Grade 1 has the highest formability, while Grade 4 has the highest strength and moderate formability. TiGr2 is stronger than Grade 1 and equally corrosion-resistant against most applications. Biocompatibility of Grade 2 Titanium is excellent, especially when direct contact with tissue or bone is required. Mechanical Properties of TiGr2 are Rp0,2 = 275 – 450 MPa, Rm = min. 345 MPa, A5 = 20% and HV10 = 146. [1]

TiGr5 is an alloyed titanium product containing 6% Aluminum and 4% Vanadium, a medium strength product. This titanium grade is predominantly used in airframe and turbine engine parts; and for use in surgical implants. Mechanical properties of TiGr5 are Rp0,2 = min. 828 MPa, Rm = min. 895 MPa, A5 = 10% and HV10 = 314. [2]

Nanostructured titanium (nTi) belongs to the so-called bulk nanostructured metallic materials. For these are considered materials with gran size between 1 – 100 nm. [3]

Production of Nanostructured titanium consists of forming commercially pure titanium (cpTi) by SPD technology – high plastic deformation at which chemical properties remain unchanged, but the mechanical properties are improved significantly in relation to the strength. Mechanical properties of nTi are Rp0,2 = 1200 MPa, Rm = 1240 MPa, A5 = 12% and HV10 = 336. [4]

Milling of hard materials with face mills and milling heads usually does not bring greater difficulties. On the other hand, milling with slab mill is only possible on some materials (high alloyed chrome steels etc.). In hard material milling are preferably used milling tools made of sintered carbides, tougher types particularly. [5]

Rapid durability decrease in very narrow range of cutting speeds is characteristic for milling of hard materials. Therefore cannot be applied higher cutting speeds in milling operations to increase productivity and it is necessary to apply economically acceptable cutting conditions. [5]

EXPERIMENT CONDITIONS

For the purpose of experiment we used vertical CNC 3-axis machining center HURCO WMX 30t (Fig. 1), where we performed measurements of cutting force components during face milling of selected types of titanium biocompatible materials. During machining were not used processing media so influence of third factor is eliminated. Focus was on the interaction of machined material and selected tool, which was monolithic ø4mm end mill, with four cutting edges, made of sintered carbide and coated with TiAlN.

Figure 1. Machining center HURCO WMX 30t

Figure 2. Tool selected for experiment - monolithic ø4mm end mill, TiAlN coating

Tested material samples

Samples made of TiGr2, TiGr5 and nTi were tested in form of cylinders with diameter of 5mm and length of 15 mm. Due to unavailability of TiNbTa rod blanks, samples with diameter of 4mm and length of 15mm were made

Measuring apparatus

For experimental measurement of cutting force components and torque was used piezoelectric dynamometer KISTLER type 9273.

Apparatus consists of:

~ 3 – component charge amplifier KISTLER type 5006
~ Analogue/Digital converter PCL 818 – HG
~ DASY LAB 3,5 software
~ PC

EXPERIMENTAL RESULTS

Example of behavior of measured tangential component of cutting force Fc during milling of selected titanium materials (TiGr2) at v_c= 30 m.min^{-1}, f_z = 0,04 mm, a_p = 0,3 mm is shown in Fig. 3.

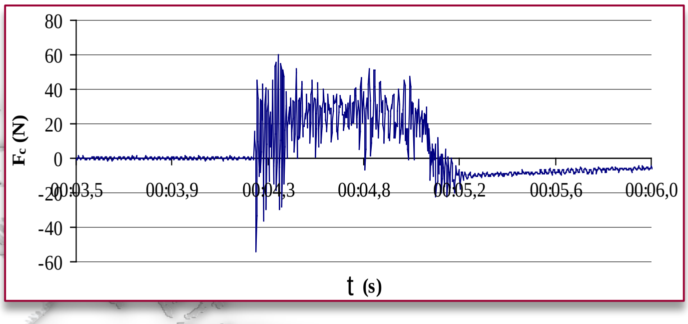


Figure 3. Behavior of measured tangential component of cutting force Fc during milling

Structural formulas of cutting force components for individual materials are shown in Tables 1 and 2.

Table 1. Structural formulas of Fc and Ff determined by measuring

	F_c	F_f
TiGr2	$F_c = 12{,}64.v_c^{1,28}.f^{\,0,9}.a_p^{0,49}$	$F_f = 6{,}97.v_c^{1,4}.f^{\,0,62}.a_p^{1,46}$
R^2	0,89	0,88
nTi	$F_c = 1005{,}63.v_c^{0,18}.f^{\,0,88}.a_p^{1,07}$	$F_f = 1958{,}75.v_c^{-0,28}.f^{\,0,76}.a_p^{1,24}$
R^2	0,96	0,92
TiGr5	$F_c = 795{,}32.v_c^{0,17}.f^{\,0,94}.a_p^{0,84}$	$F_f = 74{,}74.v_c^{0,64}.f^{\,0,88}.a_p^{0,91}$
R^2	0,94	0,92
TiNbTa	$F_c = 127{,}33.v_c^{0,82}.f^{\,1,03}.a_p^{0,95}$	$F_f = 175{,}30.v_c^{0,28}.f^{\,0,57}.a_p^{1,36}$
R^2	0,91	0,9

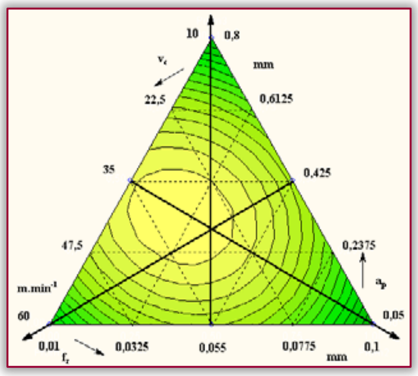
Table 2. Structural formulas of Fp and F determined by measuring

	F_p	F
TiGr2	$F_p = 1{,}05.v_c^{1,95}.f^{\,1,1}.a_p^{0,94}$	$F = 14{,}85.v_c^{1,34}.f^{\,0,84}.a_p^{0,77}$
R^2	0,9	0,87
nTi	$F_p = 178{,}25.v_c^{0,28}.f^{\,0,77}.a_p^{1,46}$	$F = 1498{,}75.v_c^{0,09}.f^{\,0,85}.a_p^{1,1}$
R^2	0,93	0,97
TiGr5	$F_p = 2114{,}31.v_c^{-0,11}.f^{\,1,14}.a_p^{1,41}$	$F = 738{,}09.v_c^{0,28}.f^{\,0,94}.a_p^{0,93}$
R^2	0,92	0,97
TiNbTa	$F_p = 8{,}47.v_c^{1,27}.f^{\,0,93}.a_p^{1,8}$	$F = 191{,}39.v_c^{0,63}.f^{\,0,88}.a_p^{1,04}$
R^2	0,87	0,95

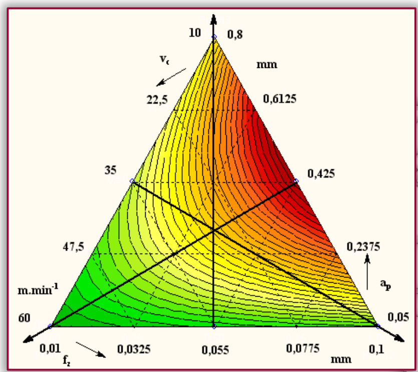
F (N)											
od	0,00	0,09	6,20	12,30	18,41	24,51	30,62	36,72	42,83	48,93	55,04
do	0,08	6,19	12,29	18,40	24,50	30,61	36,71	42,82	48,92	55,03	61,13

Legend for ternary graphs of cutting force components

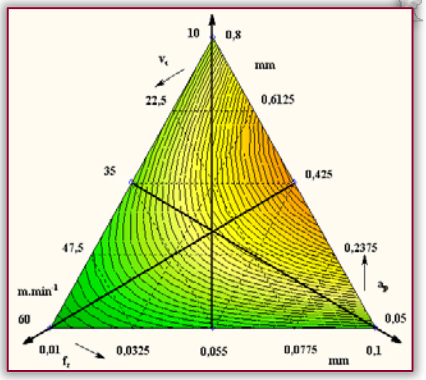
Behavior of the resultant cutting force F during machining of tested materials is shown in ternary graphs in Fig. 4.



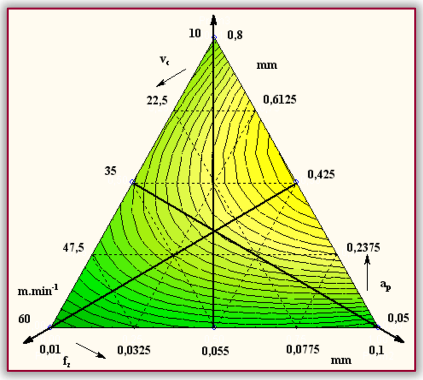
a) TiGr2



b) nTi



c) TiGr5



d) TiNbTa

Figure 4. Resultant ternary graphs for tangential cutting force component F

Dynamic machinability

Dynamic machinability is determined by the ratio of cutting forces measured during machining of reference material Fe and tested material F. According to this criterion, better machinable material is the material that causes lower cutting force at the same cutting conditions. (VASILKO, K. 2007, s. 437)

Dynamic machinability can be described by the following formula:

$$K_d = \frac{F_e}{F} \tag{1}$$

where: Fe – cutting force during reference material machining, F – cutting force during tested material machining

As reference material for evaluation of dynamic machinability was selected commercially pure titanium TiGr2. Based on data from previous experiments we determined coefficients of dynamic machinability during milling. During number of runs the K_{df} values ranged from 0,8277-2,42 (nTi), 0,9717-2,18 (TiGr5) and 1,05-2,69 (TiNbTa). Average K_{df} values are compared in Fig. 5.

DISCUSSION AND CONCLUSION

Due to the longer-term application and greater experience in machining was as a reference material selected commercially pure titanium TiGr2, with which it was posiible to compare behavior of other tested materials during machining process.

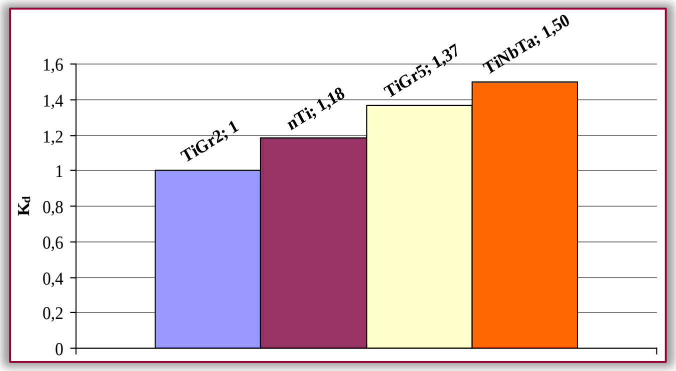


Figure 5. Graphic comparison of the dynamic machinability

The graphic comparison of the dynamic machinability shows, that all tested materials achieved better dynamic machinability than reference material. Thus, said materials are more suitable for production and given purpose. When milling, the best machinability achieved alloy TiNbTA, whose coefficient of dynamic machinability is 1,5, representing a 50% better performance than reference material TiGr2. The worst (but still better than reference material) dynamic machinability of 1,18 achieved material nTi. The cause of better machinability of new materials are significantly different mechanical properties due to present volume structures and alloys.

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Note
This paper is based on the paper presented at The 10th International Conference for Young Researchers and PhD Students – ERIN 2016, organized by University of Zilina, Faculty of Mechanical Engineering, in Liptovský Ján, SLOVAKIA, May 10 – 12, 2016, referred here as [7].

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