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Research on the Influence of Vibratory Machining on Titanium Alloys Properties

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Abstract

This article proposes these of vibratory machining to Ti-6Al-4V titanium alloy as finishing treatment. Titanium alloy was used in the aerospace industry, military, metallurgical, automotive and medical processes, extreme sports and other. The three-level three-factor Box-Behnken experiment examined the influence of machining time of vibratory machining, the type of mass finishing media used and the initial state of the surface layer on the mass loss, geometric structure of the surface, micro hardness and the optimal process parameters were determined. Considerations were given the surfaces after milling, after cutting with a band saw and after the sanding process. The experiment used three types of mass finishing media: polyester, porcelain and metal. Duration of vibratory machining treatment was assumed to be 20, 40, 60 minutes. The form profiles before and after vibratory machining were determined with the Talysurf CCI Lite - Taylor Hobson optical profiler. Future tests should concern research to carry out tests using abrasive pastes with a larger granulation of abrasive grains, to carry out tests for longer processing times and to determine the time after which the parameters of geometrical structure of the surface change is unnoticeable.

Keywords: Titanium alloy, Vibratory machining, Mass finishing, Surface roughness, Micro-hardness

1. Introduction

Titanium is a light metal, much lighter than iron- density 4507 kg/m³. Application can be found in the aerospace (jet engines), military, metallurgical, automotive, medical (prosthesis), extreme sports and other industries [1]. The most common form of failure is mechanical damage as a result of high cyclic loads caused by vibrations [2]. Titanium alloy has low hardness, low wear resistance and poor fatigue properties [3]. It should be emphasized that titanium is difficult to machine [4]. In order to improve the operational properties of titanium alloys in the application of various industries it must be subjected to surface and finishing treatment. Effective surface treatment is required, consisting in smoothing the surface while obtaining a relatively high surface hardness. Research was conducted to improve the fatigue properties of the titanium alloy through reinforcing treatment. Zhecheva investigated the modification of titanium by nitriding [5, 6]. Finishing as the last step in the machining of machine parts can improve the surface integrity of mechanical parts, improve fatigue properties and increase service life. The subject of study, titanium alloy Ti-6Al-4V is commonly used in aerospace, construction of blades for aircraft engines.

The authors proposed a finishing treatment in the form of vibratory machining [7-9] with three types of machining media (polyester, porcelain and steel media). The level of media content in the tumbler was 50%. The impact of vibratory machining on surfaces roughness and micro hardness after sandblasting, cutting and milling was assessed. The duration time of vibratory machining was also analyzed.

2. Vibratory Machining

Finishing of responsible and cooperating machine parts requires high dimensional accuracy of machined parts. In order to achieve the requirements, low surface roughness and relatively high hardness should be strived to ensure a long, maintenance-free period of operation [10-13]. If machining is necessary, adequate allowances for machining should be provided [14]. In order to reduce manufacturing costs, the smallest mass losses should be sought. Vibratory machining with loose abrasive media is the solution for finishing of complex geometry objects.

Devices for vibratory machining were introduced for common use in the 1850s, and thanks to improvements they became the basic construction of the industry [15]. The devices usually consist of a drive unit forcing the vibrating motion connected to the working container [16]. The tank is mounted using spring susceptible to the fixed base [17]. The movement of machining media is usually controlled by adjusting the engine speed.

Vibratory machining is one of the varieties of container machining, involving the use of energy of a vibrating working bowl by setting the working charge in motion [18]. The working charge is usually abrasive media in different size, shapes and various abrasivity, support fluids, abrasive pastes and the workpieces themselves. Usually abrasive media consist of abrasive grins embedded in a ceramic or plastic base. The workpieces can be either held in a stationery position inside the machine or freely floating with the media [18]. The trajectories of the working charge components are the result of the imposition of a rotational movement around the drive axis of the device and an upward movement and falling colloquially called the spiral movement [19, 20]. The interaction between the elements of the charge causes micro-cutting of the surface of the processed elements, and as a result the surface abrasion [21, 22]. Vibratory machining is mainly used for surface finishing, deburring and is designed to reduce its roughness, remove paint coatings, etc., signs of corrosion, heat effects or edge rounding [11]. The choice of process parameters such as:

- type of media (grinding or polishing),
- support chemical fluids and processing pastes,
- machining time,
- frequency of vibration,
- the proper ratio of media and workpieces.

The machining time ranges from several minutes (silver jewellery in the inertia tank) to several weeks (precious stones in drum or vibratory smoothing machines) and depends on the type of the used machine, media and the workpieces materials.

3. Conditions and methodology of research

The aim of the research was to show quantitative relations between vibratory machining parameters and effects. The tests included determining the effect of conditions on the speed of machining and surface roughness. The tests were carried out using a Rollwach SMD-R25 container smoothing machine using different machining media, at 50% tumbler filling of media.

Polyester media used for the research is PB 14 KT with a cone shape with a diameter of 14 mm and a height of 14 mm with a density of approx. 1.7 - 1.9 kg/dm^3. Porcelain media are rollers with a diameter of 4 mm and a length of about 10 mm, density about 3.0 kg/dm^3. The used steel media are SB 3.1 lotto balls with a diameter of 3.1 mm. A finishing fluid FE-L120-B32/R was used for treating chemistry. The vibration frequency of the container was set at 2500 Hz. The experiment consisted of using cuboid samples of 15 x 17 x 9 mm made of Ti-6Al-4V titanium alloy. On the sample, the selected surfaces were machined with a given technique in order to obtain different output areas. The selection of input factors was based on the analysis of the preliminary results of the research and the criterion of their easy selection. The input factors and ranges of their variability are presented in Table 1.

Table 1.
Conditions of research

Input quantity	Variable range		
Machining time, min	20	40	60
Material of media	polyester	porcelain	steel
Surface	after milling	after cutting	after sanding

The design of the orthogonal test is shown in Table 2. Using the three-level and three-factor orthogonal test, the effect of the study on the arithmetic mean surface roughness value and the effect of micro hardness change was analyzed. In addition, changes in mass loss were considered.

Table 2.
Design for orthogonal experiment of three factors and three levels

No	Process parameters		
1	Surface	Machining time, min	Finishing media
1	after milling	20	porcelain
2	after sandblasting	20	porcelain
3	after milling	60	porcelain
4	after sandblasting	60	porcelain
5	after milling	40	polyester
6	after sandblasting	40	polyester
7	after milling	40	steel
8	after sandblasting	40	steel
9	after cutting	20	polyester
10	after cutting	60	polyester
11	after cutting	20	steel

4. Results and discussion

Using the orthogonal test - the three-level three-factor Box-Behnken experiment, the impact of vibratory machining on surface roughness, surface micro hardness of Ti-6Al-4V titanium alloy was analyzed. Samples of titanium with different starting surfaces were finishing on 20, 40, 60 minutes using steel, polyester and ceramics media. The samples were marked and weighed in order to determine the mass loss. Collected data made it possible to construct the Figure 1 and 2- variation of mass loss after vibratory machining.

Based on Figure 1, we can conclude that as the machining time increases, they cause larger mass losses. The smallest mass losses occur for surfaces after milling and the largest for surfaces after sandblasting. This is inevitably associated with the initial surface roughness - the greater the surface roughness (the variation in surface topography), the greater the weight loss The type of used media is of great importance for the value of mass loss. Polyester fittings cause intense mass losses, while metal fittings have negligible mass losses, accompanied by the effect of micro-burnishing.

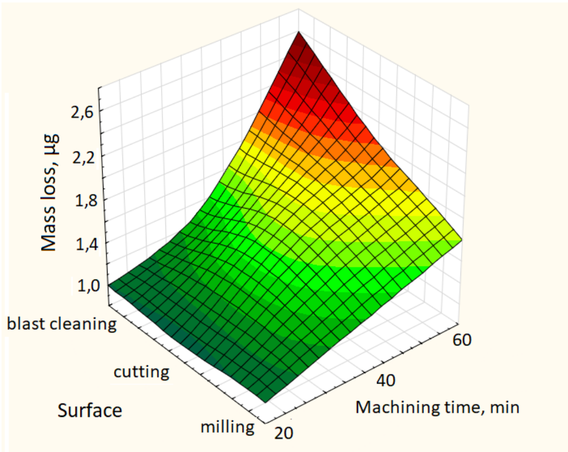

Fig. 1. Graph of mass loss dependence of surface output state and machining time.

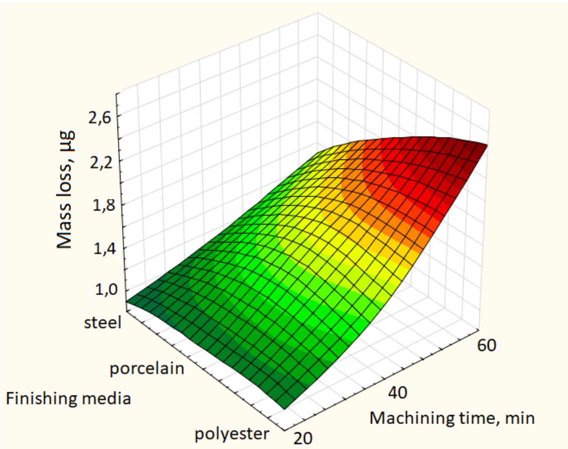

Fig. 2. Graph of mass loss dependence of finishing media and machining time.

The surface roughness was measured using a device Talysurf CCI Lite - Taylor Hobson optical profiler optical profilometer. The measurement resolution was set on 1024x1024 points. 3D surface topography analysis was performed for all samples. One of the most frequently assessed parameters of the geometric surface structure is Sa - arithmetic average surface height [23-25]. Collected data made it possible to construct the Figure 3 and 4- variation of average surface height roughness after vibratory machining.

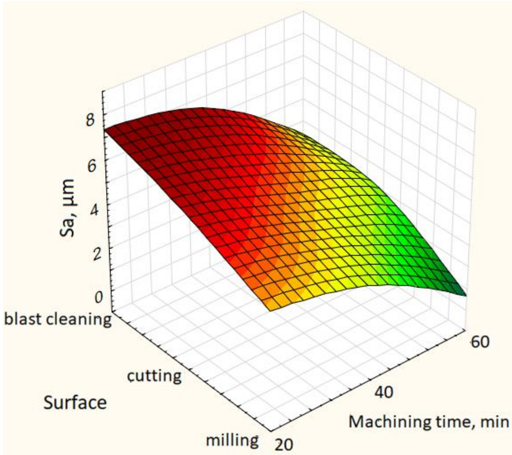

Fig. 3. Graph of surface roughness - Sa, µm dependence of surface output state and machining time

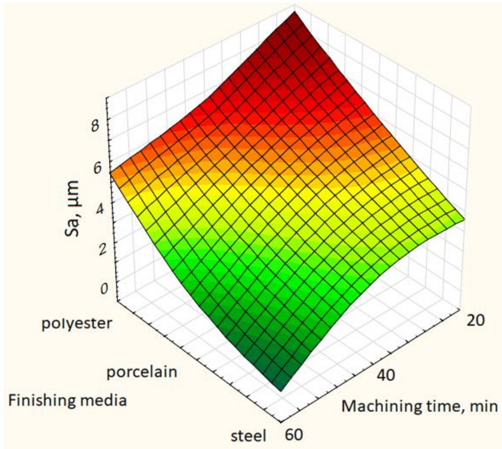

Fig. 4. Graph of surface roughness - Sa, µm dependence of finishing media and machining time

The arithmetic average roughness decreases with the duration of the vibratory machining. The final surface roughness is decisively influenced by the type of media used and the original surface being analyzed. The use of more aggressive media results in greater surface roughness. Polyester media resulted in the formation of surfaces with the largest average arithmetic surface roughness. while the steel media of very smooth surfaces - with the lowest values of the Sa parameter. Similarly, the rougher the initial surface, the greater the final surface roughness, regardless of the duration of the vibratory machining.

The lowest value of the parameter Sa = 0.37 µm was obtained for surfaces after milling with the use of metal media processed for 60 minutes.

Data obtained from Vickers micro hardness measurements using a 10 kG load allowed for drawing graphs in the Statistica program presented in Figures 5 and 6.

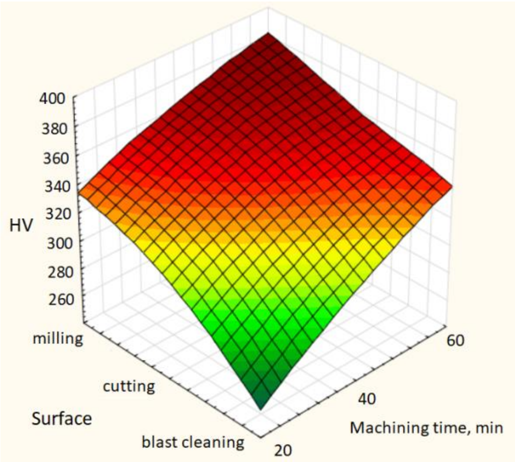

Fig. 5. Graph of micro hardness HV dependence of surface output state and machining time

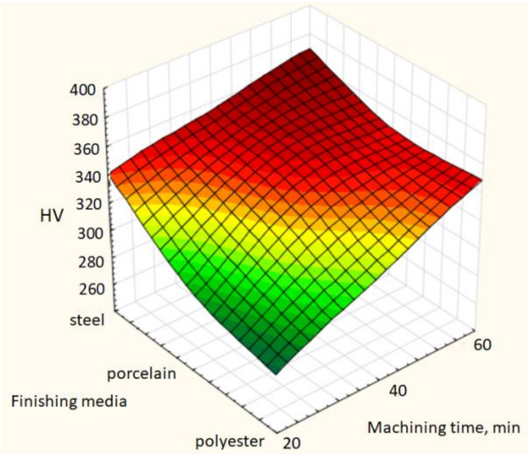

Fig. 6. Graph of micro hardness HV dependence of finishing media and machining time

Based on Figures 5 and 6, it can be concluded that along with the duration of the vibratory machining, the micro hardness of the tested surfaces increases. The highest micro hardness can be obtained using metal media and surfaces after milling. The lowest micro hardness values were obtained with the use of polyester media and surfaces after sandblasting. The highest micro hardness of 378.7 HV was obtained for surfaces after milling treated with metal fittings. It increased by approximately 13% from 334 HV.

Figures 7 and 8 show optical microscopy image of the surface before and after vibratory machining. On the example of comparing surfaces after milling (example c), we can conclude that it is possible to obtain isotropic surfaces for titanium alloys for 40 minutes vibratory machining with polyester media used. In the case of surfaces after cutting, longer processing times should be used to obtain isotropic surfaces.

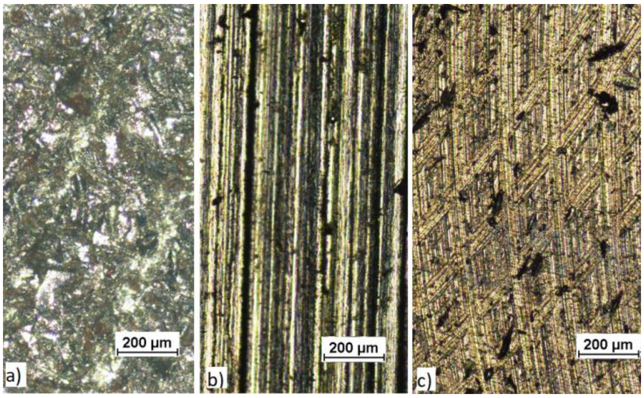

Fig. 7. Optical microscopy image of the surface before vibratory machining: a) after blasting, b) after cutting, c) after milling; (magnification x10);

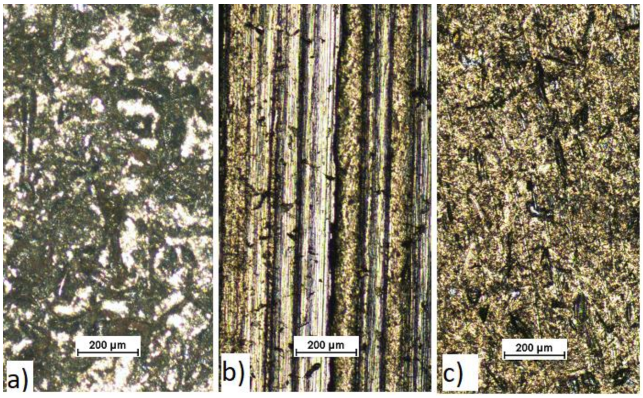

Fig. 8. Optical microscopy image of the surface after 40 min vibratory machining with polyester media: a) after blasting, b) after cutting, c) after milling (magnification x10)

5. Conclusions

Test study shows that as a result of the processes it was possible to reduce the arithmetic mean of surface roughness and increase the micro hardness. Interaction of machining media causes surface hardening and thus improvement of fatigue properties of tested samples.

The studies of container machining of titanium alloy show that the efficiency of material removal rate increases with increasing machining time, intensity of abrasive media used and higher roughness of the initial surface.

The vibratory machining allows effective smoothing of the surface from titanium alloys. Observations of the directivity of the geometric structure of the surface allow to state that after vibratory machining the surface has the anisotropic structure. There are no traces of the previous drawings and redrawing processes.

We observe the largest mass losses at the longest processing time of 60 min and the use of polyester media.

The largest micro hardness are observed with the use of metal media for surface after milling and 60 minutes of processing time, even to 370 HV - it increased by approximately 13%.
The smallest surface roughness can be observed when using typical polishing media, i.e. steel and porcelain media. Media dedicated to polishing processes allow to reduce the roughness of the surface along with the duration of the machining. The use of stell media increases the micro hardness through local burnishing.
The condition of the initial surface is of great importance for the micro hardness and arithmetic average surface roughness after vibratory machining.
The best of the tested combinations of process parameters to obtain the lowest surface roughness, the highest micro hardness with the lowest weight loss of machined parts are: surface after milling, use of steel media and machining time of 60 min.

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