ATLANTIS PRESS
Advances in Engineering Research, volume 188
International Conference on Aviamechanical Engineering and Transport (AviaENT 2019)

Study of Phase Transformations in Parts Made From Titanium Alloy VT22 During Pendulum Grinding

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Abstract— **Titanium alloys can change their phase composition after abrasive processing. Grinding by CBN wheels affects quantitatively the variation in intermetallic compounds into VT22 that can be experimentally confirmed. These changes are positive or negative, depending on the purpose of the titanium part. X-ray diffraction analysis revealed the presence of a phase not previously detected.**

Keywords— titanium alloy, grinding, intermetallic, X-ray spectrum

I. Introduction

Currently, grinding becomes the most important process of the final stage of machining of responsible parts. This is due to the fact that as a result of developing methods for more accurate forging and casting, the dimensions of which are close to the final geometry. In this case, grinding has become a more priority process of single machining directly from the workpiece to the final dimensions with cutback turning or milling [1, 2, 3].

It is known that titanium alloys are widely used in various branches of machine-building production for responsible products: aviation and space technology, gas-pumping equipment, chemical equipment and shipbuilding. However, titanium alloys have a low thermal conductivity. Therefore, during grinding there is a high cutting temperature in their contact area with the abrasive wheel, which can lead to the appearance of burns and ground cracks. As shown in [4], the grinding temperature of α-titanium alloys should be below 500° C to prevent hydrogen embrittlement and below the recrystallization temperature, which will avoid embrittlement and softening of the surface layer of the part. When grinding titanium alloys of (α + β) –group with heating to a temperature above the eutectoid transformation and with rapid cooling, an intermetallic compound of titanium with alloying constituents (ω-phases) is formed. This increases their fragility and reduces the resistance to fatigue fracture during their work on bending. On the other hand, the content of the ω-phase makes it possible to increase the microhardness of the surface layer and contributes to the growth of the elastic modulus with an increase in strength in the interaction of the ω phase with the (α + β) -group. The foregoing is a favorable phenomenon for parts that works as body, etc., which supports significant contact loads. In determining the grinding temperature, the authors of [5] constructed a finite-element model to predict it. It is established that when grinding VT6 parts by grinding wheels made from silicon carbide with the use of coolant, the cutting temperature can exceed 700° C when the cutting depth increases to 0.02 mm. When dry grinding the temperature in contact area with the abrasive wheel is further increased by 150° C as for as [6]. Grinding titanium alloys by wheels made from cubic boron nitride (for example, CBN) due to its excellent wear resistance can provide a lower temperature in the contact area of parts with the grinding tool (up to 423° C). This reduces or localizes thermal damage and undesirable residual stresses [7]. When grinding parts made from VT22, CBN wheels increase the fatigue failure resistance by 1.5 times in comparison with the wheels from the monocorundum and by 20% with the wheels from silicon carbide [8].

In connection with the foregoing, this work is devoted to the study of the phase transformation of intermetallic, α- and β-titanium phases of parts made from titanium alloys VT22 when pendulum grinding by high porous CBN wheels.

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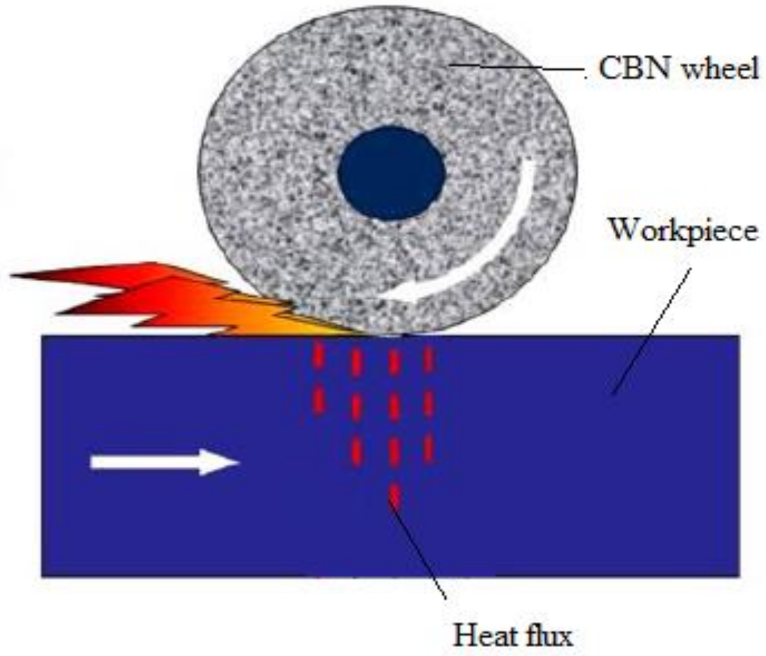
II. METHODS

This section included two consecutive stages: carrying out a full-scale experiment and determining the phase composition.



Grinding was carried out under the following conditions (fig. 1): surface grinder 3E711B; CBN high-porosity wheels 1A1 200×20×76×5 mm CBN30 B107 100 OV K27 KF40; cutting speed v_w = 28m/s; coolant lubricant – "Akvol – 6", 5% solution supplied to the processed part at 7 to 10 l/min; object of study made from titanium alloy VT22 (5.5Al–5.0Mo–5.0V–1.0Cr–1.0Fe) with mechanical properties: $\sigma_{strength\ limit}$ = 1400 MPa, relative extension δ = 8 % with sizes B×L×H=40×40×40 mm. The grinding was carried out over B×L spark-out surface. The variation of parameters of the grinding mode is shown in Table 1.

TABLE I. CONDITION VARIABLES OF THE STUDY

Test *j*	Grinding parameter			
	Creep feed s_l, (m/min)	***Cross feed s_{cr}, (mm/double stroke)***	***Cutting depth t, (mm)***	***Operating allowance z, (mm)***
1	5	2	0.0200	0.3
2	18	2	0.0050	0.2
3	18	2	0.0125	0.2
4	18	2	0.0200	0.2
5	18	10	0.0200	0.3

Shooting X-ray spectra from the ground parts was carried out on a Shimadzu XRD-7000 X-ray diffractometer using Cu-Ka radiation with a wavelength 1.541874 A^0 in the range of angles 2θ from 10.0° to 80.0°. In order to improve the accuracy of measurements and to reduce the effect of random errors in determining qualitative and quantitative composition of phases, two parts obtained with the same grinding condition were analyzed. Shooting X-ray spectra was conducted on the ground surface and the initial surface, which was previously milled. An analysis of shootings X-ray spectra was performed using a program Match 1.11. Qualitative and quantitative phase analysis was carried out by the method [9]. The quantity of phases in the alloy is determined by reference intensity ratio method (RIR). In the sequel, in this paper, all the values of quantitative X-ray phase analysis are average and calculated for each experiment.

III. RESULTS AND DISCUSSIONS

It is known that in titanium alloys the main transformation is polymorphic Tiα↔Tiβ. The low-temperature α-phase has a hexagonal close-packed lattice but a high-temperature β phase is a body centered cubic lattice. Like other industrial titanium alloys, VT22 is alloyed with aluminum (5.5 %), vanadium (5.0 %), chromium (1.0 %), which makes it possible to form intermetallic based on systems Ti-Al, Ti-Cr and Al-Ti-V [10]. As showed in Table 2, in this work phases Ti_3Al (α_2-phase), $TiCr_4$, $Al_5Ti_3V_2$ was detected in the X-ray diffraction analysis of the initial surface. The phase $Al_5Ti_3V_2$ is formed by TiAl and V_5Al_8.

Fig. 2, 3 shows the X-ray diffraction spectrum with the mark of titanium and intermetallic phases determined from the experiment *j* = 4 on the initial surface (fiq. 2) and the grinding surface (fig. 3) by wheel CBN30 B107 100 OV K27. When analyzing the shootings X-ray spectra of the initial surfaces (fig. 2), the same content α- and β-phases is very rarely observed. In most cases, a quantity of α-phase was more β-phase than 1.13 times. After heat exposure caused by grinding the quantity of β-phase has greatly decreased to 1.8% and the quantity of α-phase has ambiguously increased to 39.2% (Fig. 3).

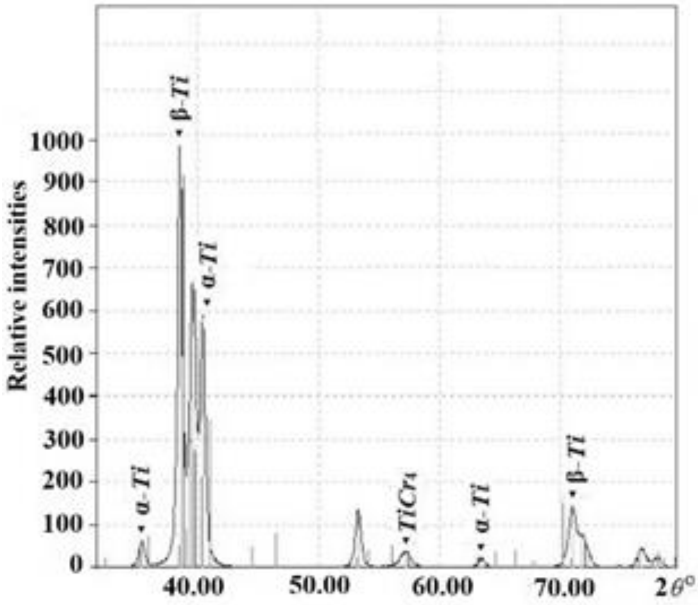


Fig. 2. X-ray diffraction spectrum of surfaces of the ground parts at the condition j = 4 for the initial surface

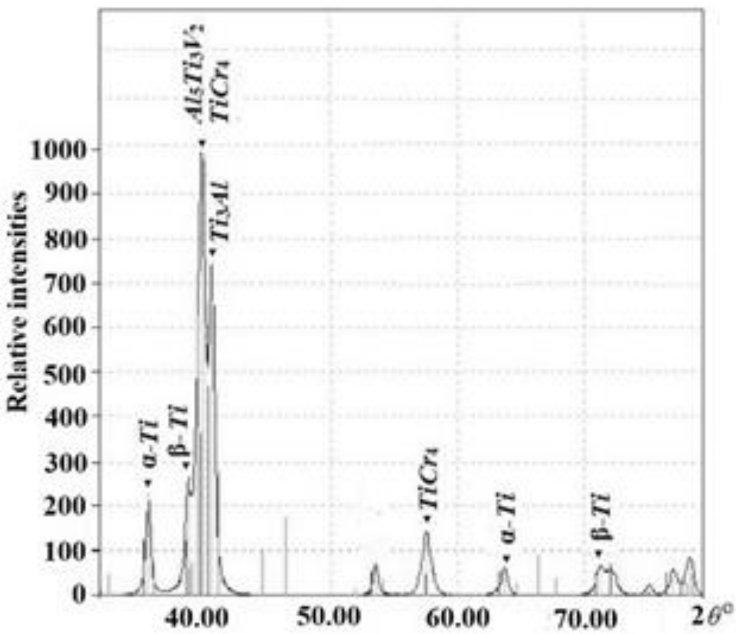


Fig. 3. X-ray diffraction spectrum of surfaces of the ground parts at the condition j = 4 for the grinding surface

It is known that titanium alloys have a low thermal conductivity (15 times less than aluminum and 5 times less than iron and steels). There is a large amount of heat in the cutting zone when grinding such alloys with increasing the cross feed from 2 to 10 mm/double stroke and the cutting depth from 0.005 to 0.020 mm. When grinding with a minimum feed sl = 5 m/min (j = 1), the heat source moves slowly over the ground surface of the part that leads to an increase in heat removal into the part. It is likely that there is a high metastable β-phase in the initial state of the VT22 alloy (after milling). At a high grinding temperature, the β-phase decays with the formation of the ω phase [11]. In addition, during the grinding process the surface layer of the parts undergoes severe plastic deformation, which probably leads to an increase in the volume fraction of the α-phase precipitates in the high-temperature region [12]. As a result, the crystal lattice changes and its deformation leads to a shift in the angle θ.

As shown in Table 2 at relatively hard grinding modes with a high intensity of heat formation, especially when test j = 5, the quantity of intermetallic phase $TiCr_4$ and $Al_5Ti_3V_2$ was more than in other experiments.

TABLE II. THE RELATIVE CONTENT OF THE INVESTIGATED PHASES IN THE ALLOY VT22

Phase	**The relative content of phases, [%]**					
	Initial surface	***Test j***				
		1	2	3	4	5
α-Ti	24.0	39.2	38.3	24.6	32.4	33.6
β-Ti	21.3	6.8	6.4	3.0	1.8	5.0
$CrTi_4$	9.9	17.9	20.8	16.8	14.3	18.6
Ti_3Al	19.1	0.0	8.1	15.8	13.9	0.0
$Al_5Ti_3V_2$	25.8	36.2	26.6	39.9	37.7	42.9

The quantity of these phases reaches a minimum when grinding at minimum cross feed scr and cutting depth t (j = 2). The ambiguous change of the Ti_3Al phase depending on the grinding modes is possible due to its instability and transition to other intermetallic phases.

IV. CONCLUSIONS

As a result of quantitative phase analysis of X-ray diffraction spectra, a significant effect of the grinding process on the relative content of intermetallic phases in the alloy VT22 was revealed. In addition, the quantity of such phases depends on the parameters of the grinding process by a hardly predictable regularity.

Acknowledgment

This work was supported by grant №9.6484.2017/8.9.

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