The use of titanium alloys for details of downhole hammers

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Abstract. The influence of cementation technology of titanium alloy Ti-Al-Mn on its wear resistance is studied. It is established that after lubrication a friction pair with mineral oil the wear resistance of the cemented titanium alloy is comparable to wear resistance of the tempered steel 12HN3A, and in water medium surpasses it by 1.5 times. Decrease in the tendency to seizure with steel is the main reason for increase of wear resistance of titanium alloy. Industrial tests of the ASH43 hammer have shown that the use of titanium alloys for the manufacture of hammer strikers allows to increase impact capacity by 1.5 times and to increase drilling rate by 30 % compared to hammers with steel strikers.

1. Introduction

At present the most efficient, cost-effective and productive drilling methods are based on the use of downhole hammers. The hole hammers must be as compact as possible to accommodate the limited space, and herewith to effectively fracture the rock, they must have a considerable impact capacity. One of the most promising materials for vital parts of impact mechanisms are high-strength titanium alloys [1, 2]. The cost of titanium strikers is higher than of the steel strikers, however, they have lower specific gravity and high corrosion resistance [3]. This allows to increase the speed and the frequency of impact loading, as well as to use water as an energy resource medium. Titanium alloys have a high attenuation of acoustic waves and effectively extinguish reflected impact pulses [4].

The major disadvantage of titanium alloys is low wear resistance in the friction pair with steel. It is possible to increase the wear resistance of titanium alloys by rational choice of the conjugated component material, for example to produce it from brass, or by modifying the surface of a titanium alloy. The most rational method of modifying the surface of the impact machine parts is a thermochemical treatment. Unlike coating processes it ensures high adhesive strength and reliability of components under dynamic load. Nitriding, cementation and oxidation are the most rational technologies of titanium alloy surface modification used in industry [5]. The main disadvantages of nitriding and oxidation of titanium alloys are small thickness of the hardened layer (10…30 μm) and a significant reduction in the resistance to fatigue failure. A hardened diffusion layer with the thickness of 80…100 μm can be obtained by cementation, so this process is best suited to improve the wear resistance of titanium parts, working with the steel in friction pair. The purpose of the work was to evaluate the effectiveness of the cementation process to improve wear resistance of parts made of titanium alloys and to identify the possibility of using titanium alloys for the production of impact mechanism strikers.

2. Materials Methods and Results of Research

A high-strength titanium alloy OT4-1, which is the most manufacturable deformable titanium alloy, was used as a material for studies. It has high fracture toughness (K_{1C} = 106 MPa · √ m) and exceeds the majority of high-strength titanium alloys by this measure [6]. The alloy's chemical composition is shown in the Table 1. For increase of wear resistance indicators the surface of a titanium alloy was subjected to cementations by the following modes: heating of samples in hard carburizer up to the temperature of 900 °C with soaking at this temperature for 3 hours and the subsequent cooling together with the furnace. Charcoal with addition of 20…25 % $BaCO_3$ and $CaCO_3$ was used as carburizer. Samples of steel 12XN3A were used for comparison of mechanical and tribotechnical properties of the modified titanium alloy; such steel is widely applied for production of details of impact mechanisms. Samples of steel 12XN3A were subjected to cementation and hardened with tempering to HRC 40 hardness.

Static tension tests were carried out on flat proportional samples with use of Instron 3369 complex. Impact strength was defined on impact pendulum-type testing machine MetroCom on samples of 10x10x55 mm in size with the concentrator of U-type at the maximum energy of impact of 300 J. The wear resistance assessment of friction couples was carried out by the method of crashing indenter in conditions of sliding friction according to the 'disk – plane' scheme. The essence of the method is to wear a sample of the material by rotating disk (indenter) with subsequent determination of the volume of worn-out material. The friction distance was 706 m. Rectangular samples of 35×10×4 mm were studied. 3 samples were tested in each series. Relative wear resistance was calculated as the ratio of mean value of wear volume from reference sample to mean value of wear volume amount on the surface of test sample. Discs with a diameter of 50 mm and a width of 10 mm made of hardened steel 45 (HRC 50) or brass L63 were used as indentors. Rotating speed was 300 revolutions per minute. The load on the friction pair was equal to 100 N. Tests were carried out in water and mineral oil M8B. For metallographic research light microscope Carl Zeiss Axio Observer A1m operating in the magnification range from 25 to 1000 was used.

Table 1 – Chemical composition of used materials [wt. %]

Material	Al	C	Cr	Cu	Fe	Mn	Mo	Ni	Si	Zn	Ti
OT-4	1.822	0.007	0.015	0.003	0.079	1.981	0.003	0.014	0.011	0.0007	Rest
Steel 12XN3A	0.02	0.13	0.78	0.07	Rest	0.42	0.03	3.06	0.27	-	-
Steel 45	0.02	0.45	0.01	0.03	Rest	0.44	0.01	0.03	0.21	-	-
Brass L63	-	-	-	Rest	0.13	-	-	-	-	28.38	-

Metallographic studies showed that after cementation a hardened layer with the depth of 350...400 μm is formed on the surface of the alloy OT4-1 (Figure 1). Near the surface it consists of equiaxed grains with sizes 50…70 μm. In the bulk of a sample the structure is of lamellar type representing the plates of alpha phase of titan separated by thin layers of beta phase. The maximum value of microhardness of the cemented layer near the surface reaches 700…720 HV, and decreases to 325 ….350 HV with moving away from the surface of titanium alloy. Mechanical testing of OT4-1 alloy showed that its strength is 2 times lower in comparison with steel 12XN3A (Table 2). However, titanium alloy has higher ductility and impact toughness.

Table 2 – Mechanical properties of steel 12XN3A (HRC 40) and alloy OT4-1

№	Property	Steel 12XN3A	Alloy OT4-1
1	Ultimate tensile strength, MPa	1180	543
2	Yield stress, MPa	1062	508
3	Relative elongation, %	14	17
4	Impact toughness, J/sm^2	59	81

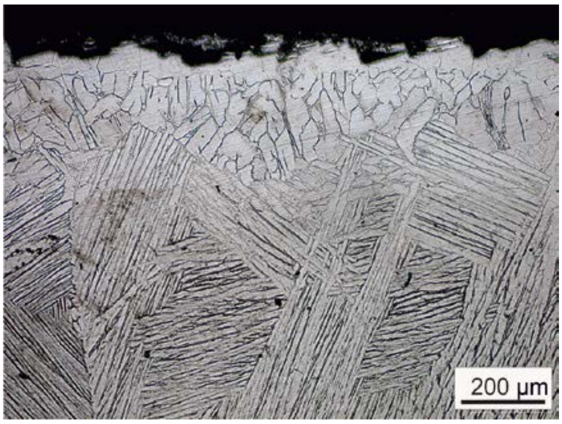


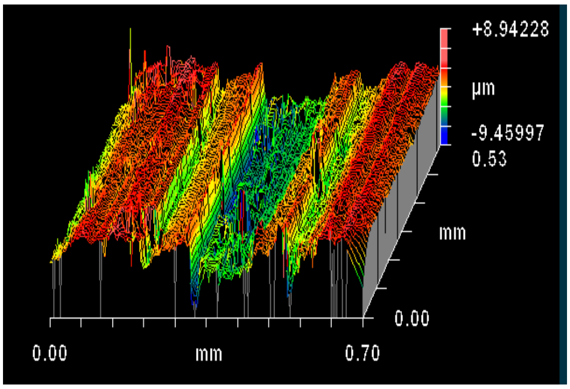
Figure 1. Structure of surface layer after cementation.

Wear resistance is one of the most important indicators of the structural strength of impact machine parts. Surface wear of friction pair “striker – body” leads to pressure reduction in the working chamber of impact machine, reduction of the speed and frequency of loading and, consequently, to decrease of impact capacity and efficiency of impact mechanism. Tribological testing showed that friction pair of ‘titan – steel’ has low properties, both in the conditions of friction in water, and when using mineral oil as the lubricating environment. In a friction pair with steel 45 the wear resistance of alloy OT4-1 is 50…100 times lower comparing to steel 12HN3A. Cementation of titanium alloy surface can significantly increase the resistance to wear caused by friction with steel. Being lubricated with mineral oil the wear resistance of cemented titanium alloy is comparable with the wear resistance of hardened steel 12HN3A, and it is 1.5 times higher in water medium. A friction pair of ‘cemented titanium alloy – brass’ has the highest thibological properties. In this case, the wear resistance of titanium alloy is 4 times higher than the wear resistance of steel 12HN3A operating in the friction pair with steel 45.

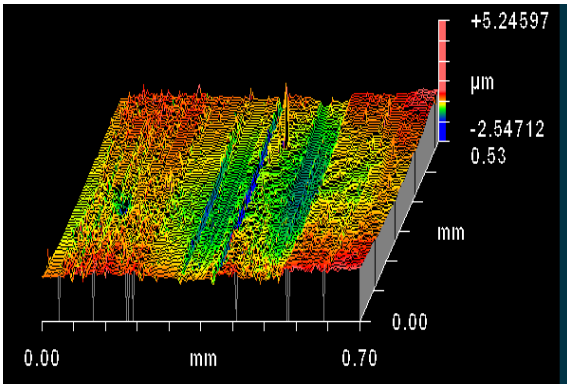
Table 3 – Tribological properties of different friction pairs

Sample material	Counterbody material	Medium	Friction ratio	Volume of wear crater, mm^3	Relative wear resistance
Steel 12XN3A	Steel 45	Water	0.39	0.119	1.00
Titanium alloy OT4-1	Steel 45	Water	0.37	6.197	0.02
Titanium alloy OT4 (cemented)	Steel 45	Water	0.15	0.074	1.61
Titanium alloy OT4	Brass L63	Water	0.17	0.080	1.50
Titanium alloy OT4 (cemented)	Brass L63	Water	0.12	0.068	1.75
Steel 12XN3A	Steel 45	Oil	0.16	0.044	1.00
Titanium alloy OT4-1	Steel 45	Oil	0.20	7.600	0.01
Titanium alloy OT4 (cemented)	Steel 45	Oil	0.13	0.040	1.10
Titanium alloy OT4-1	Brass L63	Oil	0.13	0.018	2.41
Titanium alloy OT4 (cemented)	Brass L63	Oil	0.14	0.011	4.02

Research of wear crater topography of titanium alloy OT4-1 without cementation showed that a developed relief with scratches of 7 μm in depth and local regions of seizure with counterbody material (Figure 2a) is formed on the surface. The average value of the surface roughness of wear craters calculated by measuring ten points is Ra 2.2 μm. On the surface of counterbody material (steel disk) a significant surface damage associated with the contact sticking and adhesion of weld-in particles of titanium alloy is found. Wear crater surface of titanium alloy after cementation has smoothed form with average roughness Ra 0.26 μm (Figure 2b). There were no significant traces of adhesive wear on the steel disk surface. Thus, the reducing of tendency to seizure is assumed to be the main reason for increasing of titanium alloy wear resistance.



a



b

Figure 2. 3D-image of wear crater surface of titanium alloy OT4-1 Without cementation (a); after cementation (b).

Two samples of small-sized hammer ASH43 were manufactured to evaluate the effectiveness of application the cementation process for details made of titanium alloys and the possibility of their usage for the production of the strikers of impact machines (Figure 3). It allows drilling holes with diameter of 46 mm. In one hammer the striker was made from steel 12XN3A and had the weight of 365 g. The striker of another hammer was made of titanium alloy OT4-1 with subsequent cementation. Its weight was 205 grams. Industrial tests showed that at equal energy of a single impact the power of hammer with steel striker was 299 W. In this case the speed of drilling of granite was 70 mm/min. The power of hammer with striker made from titanium alloy was 444 W, and drilling speed was 90 mm/min. The conducted researches showed efficiency of power increase of pneumatic impact hammers due to decrease of striker weight.

a

b

Figure 3. Pneumatic impact hammer ASH43 (a) and striker made of OT4-1 alloy (b).

4. Conclusions

1. As a result of cementation a hardened layer having thickness of 350...400 μm with the highest microhardness near the surface 700...720 HV is formed at the surface of the titanium alloy.
2. Cementation of the titanium alloy OT4-1 is an effective way of improving the wear resistance in the friction pair with steel. Being lubricated with mineral oil the wear resistance of cemented titanium alloy is comparable with the wear resistance of hardened steel 12HN3A, and it is 1.5 times higher in water medium. The reducing of tendency to seizure is assumed to be the main reason for increasing of titanium alloy wear resistance in the friction pair with steel.
3. Results of industrial tests of the hammer ASH43 have shown that the use of titanium alloys for the manufacture of hammer strikers allows increasing impact capacity for 1.5 times and increasing of drilling rate for 30 % in comparison to hammers with steel strikers.

References

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