13. Tsuge Akihiko, K. Nishia, and M. Komatsu, "Effect of a crystallizing grain-boundary glass phase on the high-temperature strength of hot-pressed Si_3N_4 containing Y_2O_3," J. Am. Ceram. Soc., 58, Nos. 7-8, 323-326 (1975).
14. Kamiya Nobuo, Oyama Yoichi, et al., "Silicon nitride solid solution in the ternary system Si_3N_4–AlN–SiO_2," Yogyo Kyokaishi, J. Ceram. Soc. Jpn., 83, No. 963, 553-557 (1975).

ANTIFRICTION PROPERTIES OF A VK15 ALLOY COATING APPLIED BY THE DETONATION METHOD TO VT5 ALLOY*

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Titanium and its alloys constitute an important group of constructional materials. Titanium alloys possess good resistance to corrosion and stress corrosion, show no tendency toward cold brittleness, are nonmagnetic, and have a number of other attractive physicomechanical characteristics, and are thus materials characterized by an unusual combination of properties.

However, the marked propensity of titanium and its alloys toward contact seizure during rubbing restricts the extent to which they can be employed in frictional units of mechanisms and machines. For improving their antifriction properties many methods have been developed, which may be broadly divided into three groups:

1. Diffusional strengthening of rubbing surfaces (accomplished by impregnating the surface layers of parts with oxygen, nitrogen, boron, carbon, silicon, etc.).

2. Application of metal layers to rubbing surfaces by electrolytic and chemical methods, deposition from vapor phases and melts, and the like.

3. Facing with hard alloys and application of coatings by high-temperature spraying processes.

In [1, 2] it is shown that of all the known methods of surface strengthening of titanium and its alloys the most effective and simplest is thermal oxidation (surface impregnation with oxygen), which enables strengthened layers up to 100-μ deep to be obtained. However, such layers operate satisfactorily only in frictional pairs composed of dissimilar materials, when one of the parts is made of an oxidized titanium alloy and the other of an antifriction alloy. The operation of frictional pairs both components of which are made of oxidized titanium is unsatisfactory because of appreciable wear, the maximum path length attainable varying, depending on the load, from some hundreds of meters to a few kilometers. It should be noted that in corrosive environments it is not always possible to employ dissimilar alloys in frictional pairs, because the presence of titanium intensifies the contact corrosion of bearing materials. Apart from this, the relatively small depth of strengthened oxidized layers and the fact that their hardness sharply falls and bearing qualities deteriorate with increasing distance from the surface preclude such finishing operations on oxidized parts as machining or grinding. All these factors limit the useful life of real units and mechanisms made of such materials. In this connection, in the present work a study was made of the frictional service performance of VK15 hard-alloy layers, which are free from the above-mentioned drawbacks of oxidized layers, applied by the detonation process to VT5 alloy.

Coatings were applied using the apparatus and procedure developed at the Detonation Spraying Research Section of the Leninskaya Kuznitsa Central Design Bureau [3, 4]. Coatings of 0.4-mm thickness adhered to the base metal with a strength of 13-20 kgf/mm^2. The coating thickness on specimens after diamond grinding was 0.15-0.25 mm. The surfaces had a Class 8-9 finish. The antifriction properties of the VK15 hard-alloy coatings were investigated in a Model B point friction machine designed at the Leningrad Polytechnic Institute (a modified version of Professor A. K. Zaitsev's design). In this machine rubbing took place between the end face of a

*VK15 is a WC + 15% Co hard alloy and VT5 is a Ti + 4.0-5.5% Al alloy; Br.OF10-1, also referred to in this article, is a Cu + 10% Sn + 1% P bronze – Translator.

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TABLE 1. Results of Friction and Wear Tests at Speed of 0.2 m/sec on Detonation-Deposited VK15 Hard-Alloy Coatings in Various Frictional Pairs

No.	Frictional pair materials		Lubricant	Pressure, kgf/cm^2	Friction path, km	Wear intens. $I_h \cdot 10^9$	Wear, μ	Rel. wear indic. $I_0 \cdot 10^{-10}$, cm^2/kgf	Dynamic coeff. of friction	Notes
	ring	disk								
1	Deton.-depos. VK15 on VT5	Deton.-depos. VK15 on VT5	Water	100	5	4.1	20.6	0.4	0.195-0.227	Undamaged working surfaces
2	The same	The same	The same	200	5	6.2	31.0	0.3	0.211-0.298	The same
3	" "	" "	" "	400	10	6.1	61.0	0.15	0.142-0.284	" "
4	" "	" "	" "	500	20	6.6	131.8	0.13	0.147-0.224	Some plucking after 10 km
5	" "	" "	Spindle oil	100	5	0.7	3.5	0.07	0.043-0.081	Undamaged working surfaces
6	" "	" "	The same	500	5	1.64	8.2	0.03	0.024-0.096	The same
7	" "	Br.OF10-1	" "	100	5	3.92	19.6	0.3	0.043-0.108	Bronze smears on ring surface
8	" "	The same	" "	500	5	7.4	37.1	0.1	0.032-0.109	Barely noticeable bronze smears
9	" "	Deton.-depos. VK15	Dry friction	25	5	0.7	3.4	0.27	0.412-0.78	Undamaged working surfaces
10	VT5 oxid. at 800°C, 1 h	VT5 oxid. at 800°C, 1 h	Water	50	1	110	110	22.0	0.277-0.520	Scuffing and seizure spots
11	The same	Br. OF10-1	The same	400	10	34-44	340-440	0.85-1.1	0.270-0.318	Undamaged working surfaces
12	" "	The same	Spindle oil	50-150	25	51	425-1275	3.4	0.07-0.1	Bronze smears on working surfaces
13	" "	" "	Dry friction	50-200	1	95-600	95-600	19.5-30	0.38	Scuffing and seizure spots
14	VT5 oxid. at 850°C, 5 h	VT5 oxid. at 800°C, 1 h	Spindle oil	20-400	1	2-16	2-16	0.4-1.0	0.08-0.16	The same

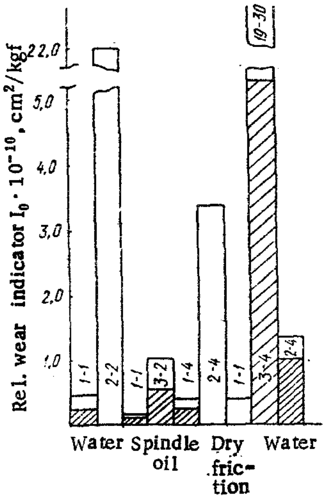

Fig. 1. Comparative wear resistance data for various frictional pairs (crosshatched areas represent minimum values): 1) detonation-deposited VK15 coating; 2) VT5 oxidized at 800°C for 1 h; 3) VT5 oxidized at 850°C for 5 h; 4) Br.OF10-1.

52-mm o.d. × 32-mm-i.d. × 8-mm-high ring and three 5-mm diameter × 14-mm-high pegs mounted in a special disk. In the rubbing experiments, carried out at a speed of 0.2 m/sec, pressures of up to 500 kgf/cm^2 were employed. As lubricants, mains water and spindle oil were used; some dry tests, in which no lubricant was supplied were also conducted. Before testing, the rubbing surfaces were run-in under pressures rising stepwise to the level at which testing was to be performed. Running-in was stopped after contact was established on 80-90% of the area of the rubbing surface.

Specimen wear was measured, using an IZV-2 vertical comparator, with an accuracy of $\pm 0.1\ \mu$ after running-in and after each kilometer of rubbing path. Wear was assessed by measuring its intensity I_h and determining the wear indicator proposed in [5],

$$I_0 = \frac{V}{N \cdot L} \quad \text{or} \quad I_0 = \frac{\Delta h}{qL},$$

where V is the volume of material worn away (cm^3), N the normal load (kgf), L the length of frictional path (cm), q the pressure (kgf/cm^2), and Δh the linear wear (cm).

As part of the test program determinations were made also of the dynamic coefficients of friction of rubbing pairs. The results obtained, which are given in Table 1 and Fig. 1, were compared with data yielded by earlier tests on pairs both elements of which were of oxidized VT5 alloy and pairs of elements made of dissimilar materials – oxidized VT5 alloy and a high-tin bronze, Br.OF10-1.

As can be seen from the test results, the wear resistance of a sprayed VK15 alloy coating in a similar-metal frictional pair operating with water lubrication is 50-150 times higher than that of a similar-metal oxidized titanium pair, and its dynamic coefficient of friction is 33-50% lower. Characteristically, such a pair has also a greater performance capacity during the whole period of operation to the total wear or disintegration of the reinforcing layer. Assessed as the product of pressure and length of frictional path to disintegration, for a similar-metal pair of oxidized titanium operating with water lubrication the performance capacity coefficient is $C = qL = 10\text{-}20$ kgf/cm^2-km, while for a similar-metal pair detonation-coated with VK15 alloy $C = 5000\text{-}10{,}000$ kgf/cm^2-km, which is 250-1000 times higher.

Comparing a similar-metal pair coated with VK15 alloy with a dissimilar-metal pair consisting of oxidized VT5 alloy and bronze, it will be seen that the wear resistance of the former is almost an order higher than that of the latter; the dynamic coefficients of friction of both pairs are similar.

Lubrication with spindle oil appreciably improves rubbing conditions, affecting both the extent of wear and the coefficient of friction (see Table 1 and Fig. 1). In this case the difference in wear between the frictional pairs under consideration diminishes, but here, too, the wear resistance of a VK15 coating in a similar-metal pair and of tin bronze in a dissimilar-metal pair is an order higher than that of oxidized metal pairs, while the coefficients of friction are either similar (in the dissimilar-metal pair) or some 33% lower (in the similar-metal pair).

In dry friction tests, because of the high temperatures generated, the load was restricted to 25 kgf/cm^2, at which the wear resistance of the similar-metal pair coated with VK15 alloy proved to be two orders higher than, and the coefficient of friction twice as high as, those of the pair composed of oxidized VT5 alloy and BrOF10-1 bronze.

Thus, the investigation has shown that the application of a detonation-deposited VK15 alloy coating sharply increases the performance capacity of titanium and its alloys in frictional units (by one to two orders) and can therefore be recommended for adoption in actual industrial units.

LITERATURE CITED

1. V. N. Gol'dfain, A. I. Zuev, and A. G. Kablukov, "Effect of hydrogen and oxygen on the friction and wear of titanium alloys," in: Problems of Friction and Wear [in Russian], No. 8, Tekhnika, Kiev (1975), pp. 49-52.
2. Titanium and Its Alloys [in Russian], Vol. 1, Sudpromgiz, Leningrad (1960).
3. A. I. Zverev, Yu. F. Ocheret'ko, E. A. Astakhov, et al., "New methods of detonation deposition of coatings," Abstracts of Papers to an All-Union Scientific-Technical Conference [in Russian], Voroshilovgrad (1976).
4. A. I. Zverev and E. A. Astakhov, "Detonation deposition processes and plants," Sudostroenie, No. 4, 69-75 (1978).
5. B. B. Chechulin, S. S. Ushkov, et al., Titanium Alloys in Machine Construction [in Russian], Mashinostroenie, Leningrad (1977).