IOP Conf. Series: Materials Science and Engineering **392** (2018) 032023 doi:10.1088/1757-899X/392/3/032023

Tribological Behavior of Surface-Modified Titanium and Polytetrafluoroethylene-based Composites in Seawater

Liu Yong*, Lin Yuansheng, Wu Jun, Liu Zhouyang, Zhao Zhenxing

Lab. on Steam Power System, Wuhan Second Ship Des. & Res. Ins., Wuhan, China

seasmile2004@126.com

Abstract. In order to improve the wear resistance of Ti6Al4V titanium alloy contacted with polytetrafluoroethylene-based composites in seawater, plasma nitriding (PN), micro arc oxidation (MAO) and plasma spray tungsten carbide (PSTC) were used to modify the surface of Ti6Al4V alloy. The tribological properties of Ti6Al4V alloy matrix and its modified layers sliding with polytetrafluoroethylene-based (PTFE) composites in seawater were comparatively investigated. The PTFE composites were made with glass fiber, graphite and bronze separately by compression molding. The results indicate that low friction coefficients were shown in modified layers of the titanium alloy sliding with PTFE composites in the seawater environment. The Ti6Al4V alloy exhibits poor wear resistance and leads to the serious wear of PTFE composites. The above three kinds of surface treatments improve effectively the wear resistance of Ti6Al4V alloy. The PN treatment with reducing the wear of PTFE composites shows better wear resistance than the MAO treatment with accelerating the wear of PTFE composites. The glass fiber reinforced PTFE shows better wear resistance than the bronze reinforced PTFE in the same experimental condition. It has obvious advantages that the titanium alloy with PN treatment contacted with glass fiber reinforced PTFE were chosen as the materials of the tribological components used in hydraulic transmission in the marine environment application.

1. Introduction

Driving and sealing are two of the key techniques in military materials, especially in the ocean environment. In sea water, choosing of seal pair materials needs to consider various factors, including leakproofness, corrosion-resistibility, water-absorbability, wear-resistibility and etc.[1~3].Titanium alloy is widely used for the sealing surface of ball-valve in sea water, as its excellent corrosion-resistibility and high intensity[4]. And polytetrafluoroethylene (PTFE) is a popular material to form sealing configuration against ball surface of valve, as its outstanding performance in corrosion-resistibility, leakproofness and self-lubrication and etc. [5]. However, wear- resistibility of PTFE against titanium alloy is not gratifying. Such, modifying Titanium surface and enhancing PTFE integration by adding other material elements were developed to restrain PTFE's weariness [6, 7]. In this article, plasma nitriding (PN), micro arc oxidation (MAO) and plasma spray tungsten carbide (PSTC) were used to modify the surface of Ti6Al4V alloy, and glass fiber, graphite and bronze were added to the PTFE composites by compression molding. The tribological properties of Ti6Al4V alloy matrix and its modified layers sliding with those polytetrafluoroethylene-based (PTFE) composites in seawater were comparatively investigated. The results would be as the reference for seal surface hardening process and PTFE enhancing method choosing of titanium alloys ball valve.

IOP Conf. Series: Materials Science and Engineering **392** (2018) 032023 doi:10.1088/1757-899X/392/3/032023

2. Experiment method

Ti6Al4V is α+β crystalloid alloy, annealed in 820℃. Its chemical components are showed in table 1. All Ti6Al4V samples were made into columns in 30mm diameter and 10mm thickness. The rigidity of the Ti6Al4V matrix was $409HK_{0.98}$. After treated with plasma nitriding, micro arc oxidation and plasma spray tungsten carbide, the surface of Ti6Al4V samples were polished by machine, to make the roughness not beyond 0.8μm.

Table 1. Chemical Components of Ti6Al4V (Mass Fractions, %)

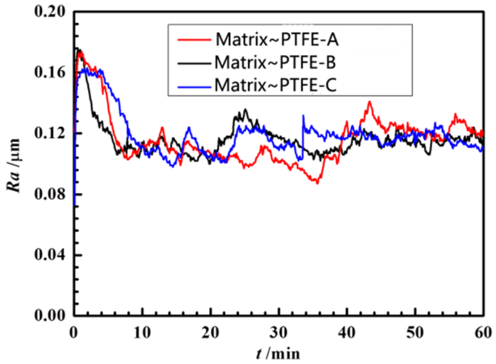
Al	V	Fe	O	Si	C	N	H	Ti
6.70	4.21	0.10	0.14	0.07	0.03	0.015	0.003	The rest

Sealing counterparts were PTFE filled with 25% glass fiber (PTFE-A), 15% glass fiber + 5% graphite (PTFE-B) and 60% bronze (PTFE-C), which were made into pins in 2mm diameter and 10mm height. Experiments were performed on HV-1000 friction machine with samples in 3.5% sodium chloride liquor. Before experiments, Ti6Al4V samples were washed with ethanol and acetone using ultrasonic, and PTFE samples were washed with ethanol using ultrasonic. In experiments, the press between Ti6Al4V and PTFE was 6.3MPa, diameter of friction contrail was 8mm, and friction time was 1 hour. Each pair of Ti6Al4V and PTFE samples was performed 3 times to reduce error.

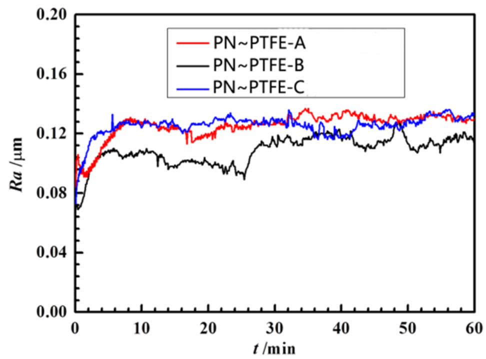
3. Results and discussion

3.1. Friction coefficient

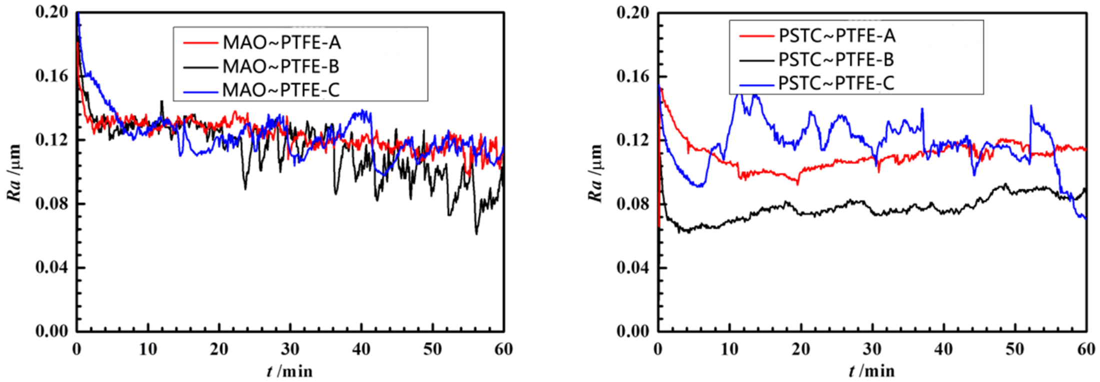
Fig.1 shows the friction coefficients of sealing pairs of enhanced PTFE and Ti6Al4V with surface modified and un-modified. As showed in Fig.1 (a), the friction coefficients of Ti6Al4V matrix against the three enhanced PTFE are very close, all no more than 0.12. However, in Fig.1 (b), friction coefficients of Ti6Al4V by PN against the three enhanced PTFE express dissimilarities, the smallest with PTFE-B, and the biggest with PTFE-C. Fig.1 (c) shows the friction coefficients of Ti6Al4V by MAO against the three enhanced PTFE are most the same, between 0.1 and 0.12. In Fig.1 (d), the friction coefficients Ti6Al4V by PSTC against PTFE-A and PTFE-C are near 0.1, but the friction coefficients against PTFE-B is smaller, with an average value of 0.083.



(a) Ti6Al4V matrix against enhanced PTFE



(b) Ti6Al4V by PN against enhanced PTFE



(c) Ti6Al4V by MAO against enhanced PTFE (d) Ti6Al4V by PSTC against enhanced PTFE

Figure 1. Friction Coefficient Curve

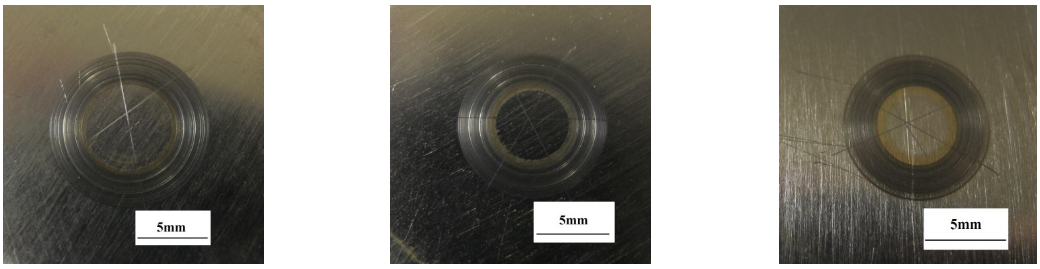
Table 2 gathered all friction coefficients of the four Ti6Al4V surfaces and the three kinds of enhanced PTFE. It indicates that friction coefficient reduce after Ti6Al4V surface modification of any kind. Against the same Ti6Al4V surface, PTFE –B has the smallest friction coefficient, and PTFE –C has the biggest. Against the same enhanced PTFE, PN and PSTC surfaces have smaller friction coefficient than MAO surface.

Table 2. Average Friction Coefficient

	PTFE-A	PTFE-B	PTFE-C
Ti6Al4V matrix	0.103	0.108	0.117
PN surface	0.076	0.094	0.101
MAO surface	0.109	0.107	0.117
PSTC surface	0.083	0.1	0.105

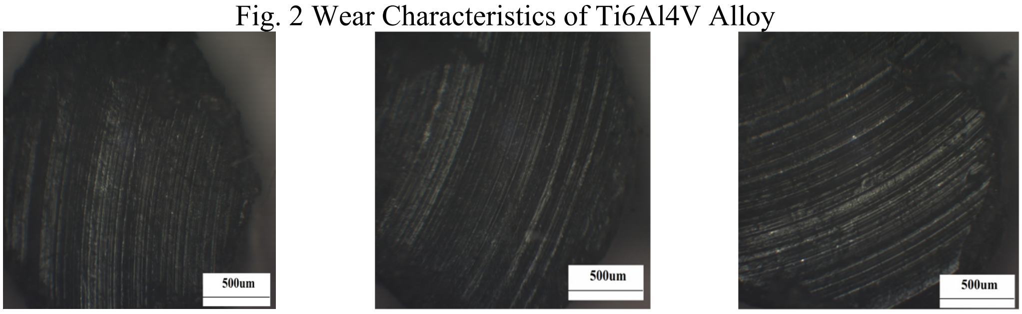
3.2. Wear characteristics

Fig. 2 shows the wear characteristics of Ti6Al4V matrix by different enhanced PTFE. According to the visible, Ti6Al4V matrix exhibits poor wear resistance because of its low rigidity (about 315 $HV_{0.2}$). Fig. 3 shows the wear scars of the three enhanced PTFE against Ti6Al4V matrix. All the three enhanced PTFE have obvious scars, among which PTFE-C Wear away more seriously than the other two.



(a) With PTFE-A (b) With PTFE-B (c) With PTFE-C

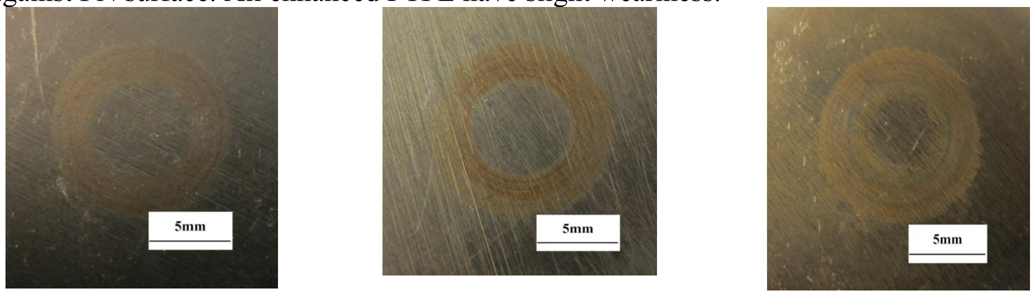
Fig. 2 Wear Characteristics of Ti6Al4V Alloy



(a) PTFE-A (b) PTFE-B (c) PTFE-C

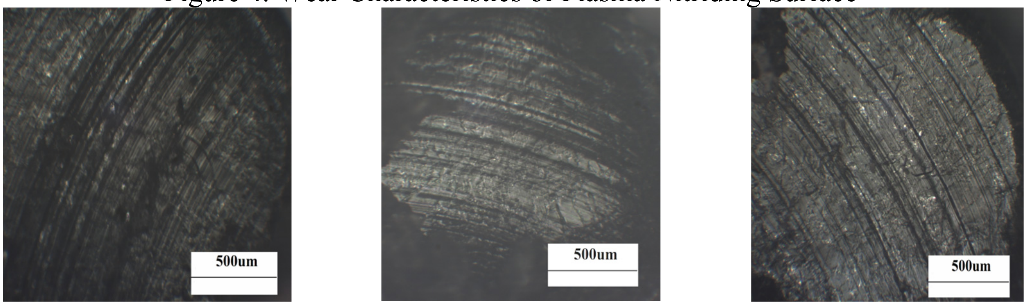
Figure 3. Wear Characteristics of PTFE against Ti6Al4V Alloy

Fig. 4 shows the wear characteristics of Ti6Al4V PN surface by different enhanced PTFE. It can be seen that the wear scars are superficial as to Ti6Al4V matrix, the rigidity of the PN surface is about 550 $HV_{0.2}$, almost two times of Ti6Al4V matrix. Fig. 5 shows the wear scars of the three enhanced PTFE against PN surface. All enhanced PTFE have slight weariness.



(a) With PTFE-A (b) With PTFE-B (c) With PTFE-C

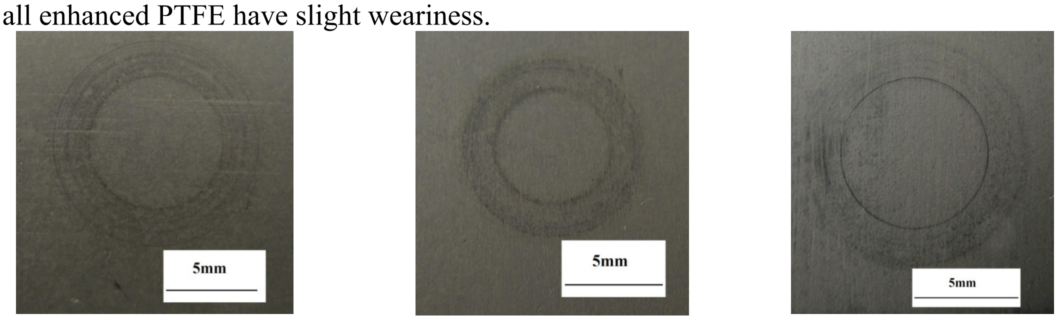
Figure 4. Wear Characteristics of Plasma Nitriding Surface



(a) PTFE-A (b) PTFE-B (c) PTFE-C

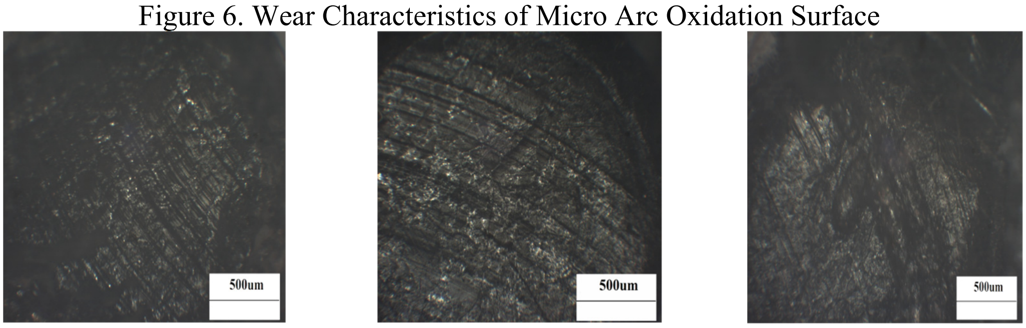
Figure 5. Wear Characteristics of PTFE against Plasma Nitriding Surface

Fig. 6 shows the wear characteristics of Ti6Al4V MAO surface by different enhanced PTFE. The wear scars are superficial as the surface rigidity ascended to 560 $HV_{0.2}$ by MAO process. As showed in Fig. 7, all enhanced PTFE have slight weariness.



(a) With PTFE-A (b) With PTFE-B (c) With PTFE-C

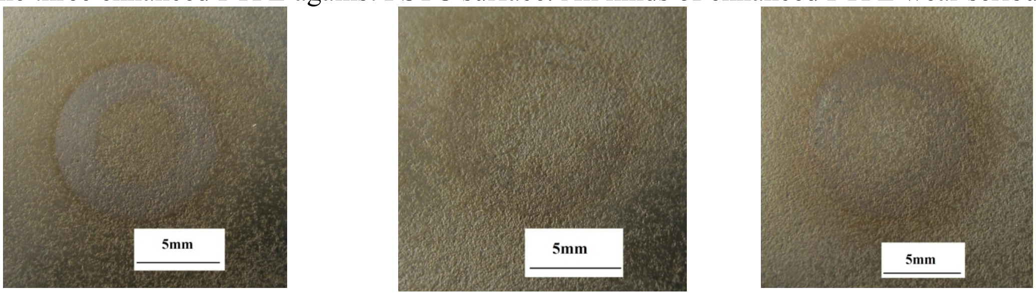
Figure 6. Wear Characteristics of Micro Arc Oxidation Surface



(a) PTFE-A (b) PTFE-B (c) PTFE-C

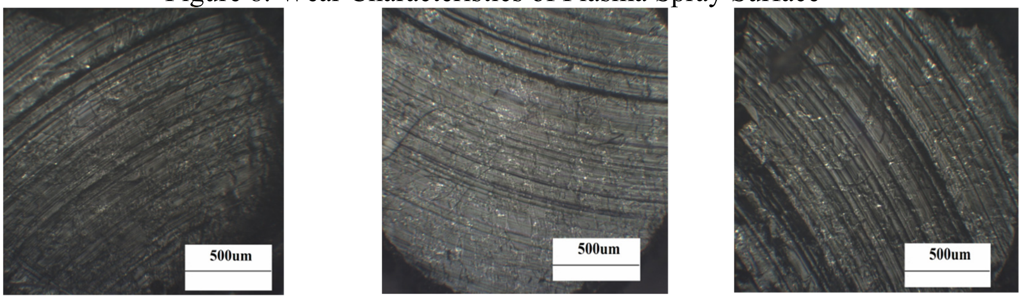
Figure 7. Wear Characteristics of PTFE against Micro Arc Oxidation Surface

Fig. 8 shows the wear characteristics of Ti6Al4V PSTC surface by different enhanced PTFE. The wear scars are almost invisible as the surface rigidity ascended to 957 $HV_{0.2}$. Fig. 9 shows the wear scars of the three enhanced PTFE against PSTC surface. All kinds of enhanced PTFE wear seriously.



(a) With PTFE-A (b) With PTFE-B (c) With PTFE-C

Figure 8. Wear Characteristics of Plasma Spray Surface



(a) PTFE-A (b) PTFE-B (c) PTFE-C

Figure 9. Wear Characteristics of PTFE against Plasma Spray Surface

Table 3 shows the decrements of PTFE samples after experiments. It can be seen that all kinds of PTFE have a great decrement with MAO surface. And PTFE-C shows badly wear- resistibility, as its decrements are much more than PTFE-B and PTFE-C either with Ti6Al4V matrix, PN surface, MAO surface or PSTC surface.

Table 3. Decrement of PTFE (mm)

	PTFE-A	PTFE-B	PTFE-C
Ti6Al4V matrix	1.061	1.098	1.273
PN surface	1.119	1.013	1.263
MAO surface	1.592	2.144	2.134
PSTC surface	1.088	0.875	1.344

3.3. Discussion

All sealing pairs of enhanced PTFE and Ti6Al4V surfaces modified or un-modified has inferior friction coefficient. It's because PTFE has a liner configuration with no branch, which makes its single molecule force low. Such, PTFE exhibits low friction coefficient macroscopically, as molecule is likely to slip while rubbing. Comparatively, PN surface has the smallest friction coefficient with PTFE, due to its high rigidity. PTFE A and B have better wear-resistibility than PTFE-A, as glass fiber can retard PTFE stratum falling off. Wear characteristics of Ti6Al4V improves by any of the three surface treatment methods, as its rigidity raise after surface modified. And PN surface is well-proportioned, which leads light weariness of PTFE.

In all, it presents the most excellent tribological characteristics choosing Ti6Al4V surface treated by plasma nitriding against PTFE filled with 25% glass fiber.

4. Conclusions

In seawater environment， friction coefficients of any kind of pair with Ti6Al4V surfaces against enhanced PTFE are near about 0.1. The wear mechanism is mainly particles monitor. The Ti6Al4V alloy exhibits poor wear resistance and leads to the serious wear of PTFE composites. The above three kinds of surface treatments improve effectively the wear resistance of Ti6Al4V alloy. The PN treatment which reduces the wear of PTFE composites shows better wear resistance than the MAO treatment which accelerates the wear of PTFE composites. The glass fiber reinforced PTFE shows better wear resistance than the bronze reinforced PTFE in the same experimental condition. It has obvious advantages that the titanium alloy with PN treatment contacted with glass fiber reinforced PTFE were chosen as the materials of the tribological components used in hydraulic transmission in the marine environment application.

References

[1] Shan Kunlun, Xiang Dinghan. Investigation on the Friction and Wear Behavior of Short Glass Fiber and Graphite Filled Polytetrafluoroethylene[J].Lubrication Engineering, 2006(5) : 88~90(in Chinese)
[2] Wang Qiang, Jiang Jihai. Development and Applicative Prospect of Water Hydraulic Components[J]. Machine Tool & Hydraulics, 2004(10) : 1~3 (in Chinese)
[3] Wu Zhangyong, Zhao Engang, Luo Jing, Li Jianfeng. Application Research of Modified PTFE Material in Water Hydraulic Components[J]. Machine Tool & Hydraulics, 2008(3): 117~118(in Chinese)
[4] Yang Shudong, Li Anyuan, Tao Aihua. Development of a High Pressure Seawater Hydraulic Pump Lubricated with Seawater[J]. Chinese Hydraulics & Pneumatics, 2007(10) : 15~17(in Chinese)
[5] Finn Conrad, Bjarne Hilbrecht, Hardy Jepsen. Design of Low-pressure and High-pressure Tap WaterHydraulic Systems for Various Industrial Applications[J]. SEA 2000 Transact ions: Journal of Commercial Vehicles, 2000, 109(2) : 316~ 330
[6] Xu Z, Liu X, Zhang P, Zhang Y, Zhang G, He Z. Double glow plasma surface alloying and plasma nitriding. Surface Coatings Technology, 2007, 201: 4822~4825
[7] Tang Jingang, Liu Daoxin, Tang Changbin, Yu Shouming, Zhang Xiaohua. Tribology Behavior of Zr-N Alloying Layer on Ti6Al4V Alloy Surface at Elevated Temperature[J]. Rare Metal Materials and Engineering，2013(2): 331~334 (in Chinese)