Wear behavior of TC4 titanium alloy and 2205 stainless steel friction pair in different media

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Abstract. In order to choose the material of high-pressure pump in seawater desalination, the friction pair of TC4 titanium alloy and 2205 duplex stainless steel was studied in detail. Friction and wear tests were carried out under dry friction, pure water, and seawater media. The friction coefficient and wear extent of friction pair were obtained quantitatively, and the surface topography of friction samples was analyzed. The results showed that the abrasion of 2205 stainless steel and TC4 titanium alloy in seawater was less than in pure water and air/dry friction due to the lubrication effect of seawater medium. The abrasion resistance of 2205 stainless steel was better than that of TC4 titanium alloy. Compared with the rotating speed, the load has little effect on the friction coefficient.

1. Introduction

High-pressure pump of seawater desalination is a key power equipment in reverse osmosis desalination process, and also determines the energy consumption and water production cost of seawater desalination [1]. Material technology restricts the manufacturing level of domestic marine equipment [2]. In the seawater environment, friction pair materials must be selected with good corrosion and abrasion resistance. Metal alloy is the excellent material for high-pressure pump of seawater desalination due to its high specific strength, good abrasion resistance and excellent corrosion resistance in seawater environment [3]. Chen et al. [4] studied the friction and wear behavior of TC4 titanium alloy and 316 stainless steel in pure water and simulated seawater, and found that seawater had an obvious lubrication effect, which reduced the friction coefficient of friction pair. Li et al. [5] investigated the tribological behavior of friction pairs in dry friction, pure water and simulated seawater. The results showed that the wear rate of TC4 titanium alloy in seawater was accelerated due to the interaction between corrosion and wear. In recent years, the study of material tribology in marine environment is of great significance for the development of marine resource equipment. Based on the above review, the tribological and wear properties of TC4 titanium alloy and 2205 duplex stainless steel pair for high pressure pump in seawater environment were studied in this study.
2. Experimental procedure
TC4 titanium alloy and 2205 duplex stainless steel, two commonly used metal materials in seawater environment, were selected as experimental materials. The mechanical properties of materials are shown in table 1. The experiment was carried out on MM-W1B vertical universal friction and wear test machine. The sliding contact form of ring-disk was adopted to simulate the contact form of friction pair. The lower sample was the large ring and the upper sample was the plate. Figure 1 shows the processing diagrams of samples. The upper sample was rotated by the spindle, and the lower one is fixed on the friction pair plate by the pin, with the axial loading force provided through the loading shaft. Figure 2 presents the sample photos after processing.

Table 1. Physical properties of experimental metallic materials.

| Materials            | Density $\rho$ (g/cm$^3$) | Elongation % | Tensile strength $\sigma_b$ (MPa) | Yield strength $\sigma_s$ (MPa) |
|----------------------|-----------------------------|--------------|-----------------------------------|--------------------------------|
| 2205 duplex stainless steel | 7.98                        | $\geq 25$    | $\geq 680$                        | $\geq 450$                      |
| TC4 titanium alloy    | 4.51                        | $\geq 10$    | $\geq 950$                        | $\geq 860$                      |

Figure 1. Sample processing diagrams.

Figure 2. The sample of metal plate and metal ring.

The experiments were carried out under the conditions of dry friction, pure water and seawater respectively. The pure water was tap water that had been left standing for a week, while the seawater was raw seawater. Coefficient of friction in the experimental process was obtained by machine automatic record and output. The wear value was measured using the one-thousandth balance, the precision of 0.1 mg. The surface morphology was observed using the metallographic microscopy.
3. Results and discussions

3.1. Wear extent and friction coefficient
Figure 3 shows the abrasion and friction coefficient curves of different environmental media at 15N and 200r/min. As seen in figure 3a, the abrasion of 2205 duplex stainless steel and TC4 titanium alloy in seawater environment is smaller than that of pure water and dry friction due to the lubrication effect of seawater medium. The new passivation film is generated on the damaged surface in the wear process. Friction damage has an obvious promoting effect on corrosion, and the interaction between corrosion wear and mechanical wear is relatively strong [6]. Moreover, the abrasion of 2205 duplex stainless steel is smaller than that of TC4 in different medium conditions. Material tolerance always has a great relationship with the material hardness, plasticity, toughness, strength [7]. Although the strength of TC4 titanium alloy is higher than 2205 duplex stainless steel (see table 1), its hardness is less than 2205 duplex stainless steel, resulting in the wear resistance has been reduced. The abrasion resistance of 2205 stainless steel in seawater environment is better than that of TC4 obviously.

As can be seen in figure 3b, the friction coefficient is small in seawater environment, and the average friction coefficient after breaking-in is 0.3560, with relatively stable change. The friction coefficient of pure water and dry friction environment fluctuates greatly, with the average friction coefficient being 0.4019 and 0.4215, respectively. The lubrication film formed in seawater has good lubrication effect and reduces the friction coefficient.

![Figure 3. (a) Wear extent and (b) friction coefficient curves under different media at 15N and 200rpm.](image)

3.2. Surface morphology
Figures 4 and 5 show the surface morphologies of 2205 duplex stainless steel and TC4 titanium alloy after being worn under dry friction, pure water and seawater at 15N and 200r/min, respectively. It can be observed that different degrees of grooves appear on the surface of each metal sample surface, and a certain number of abrasion marks exist on the surface parallel to the sliding direction. This is the result of the plough cutting action of abrasive particles on the grinding surface, and the wear mechanism is abrasive wear. There is a large amount of abrasive debris in the dry friction process, and the surface wear of the material is relatively uniform and the abrasion mark is relatively shallow. This is due to the large dry friction contact area, serious wear more, small abrasive particles. The scratch of material surface in pure water is deeper than that in seawater, and the lubrication effect of seawater is stronger than that of pure water. There are flake peeling areas appear in some areas, which is a typical fatigue wear feature. The wear mechanism is the interaction between fatigue wear and abrasive wear [6].
3.3. Influence of speed and load on friction coefficient

Figure 6a shows the friction coefficient of friction pair at 200r/min speed and different loads under the condition of seawater environment. Figure 6b shows the friction coefficient of friction pair at a 15N load and different speeds under the condition of seawater environment. As can be seen in figure 6, the load has little influence on the friction coefficient, while the speed has more influence on the friction coefficient than the load. With an increase in speed, the friction coefficient increases. Although the load will cause different degrees of heating on the surface of the friction pair, leading to the deterioration of the material surface performance. However, the impact on the friction coefficient is not significant in the range of small load [7, 8].

4. Conclusions

In this study, friction and wear experiments were carried out on friction pair material 2205 duplex stainless steel and TC4 titanium alloy of high-pressure pump of seawater desalination in dry friction, pure water and seawater environment, respectively. The main conclusions are as follows:

Figure 4. Surface morphology of 2205 duplex stainless steel in environmental media conditions of (a) dry friction, (b) pure water and (c) seawater.

Figure 5. Surface morphology of TC4 titanium alloy in environmental media conditions of (a) dry friction, (b) pure water and (c) seawater.

Figure 6. Variation curves of friction coefficients at (a) constant speed and variable load, (b) constant load and variable speed in seawater environment.
(1) The abrasion of 2205 stainless steel and TC4 titanium alloy in seawater environment is smaller than that of pure water and dry friction. The abrasion of 2205 stainless steel in seawater environment is smaller than that of TC4 titanium alloy. The abrasion of 2205 stainless steel is better than that of TC4.

(2) The environmental wear mechanism of dry friction is mainly fatigue wear and abrasive wear. The lubrication effect of seawater is stronger than that of pure water.

(3) The influence of load on the friction coefficient is small, while the influence of rotational speed on the friction coefficient is larger than that of the load. The friction coefficient increases with the rotational speed.

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