Evaluation of wear corrosion characteristics of Ti-6Al-4V in quasi-human body environment and improvement of wear corrosion characteristics by gas nitriding

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Abstract

Ti-6Al-4V is well known as a material used for artificial joints, however this material has inferior wear corrosion characteristics. For this reason, surface modification was required. At present, wear corrosion characteristics were for improving those characteristics not fully understood comprehensively both from wear and corrosion behaviors. Therefore, in this study, wear corrosion characteristics of Ti-6Al-4V were evaluated comprehensively both from wear and corrosion characters of this material and some trials for improving wear corrosion characteristics by gas nitriding were conducted. As a result, wear corrosion behavior was well understood from the viewpoint of the mutual interaction of wear and corrosion. Also, the improvement in both of wear and corrosion characteristics was recognized when gas nitriding was applied to the surface of the specimen.
1 Introduction

Recently, operating number of the artificial joint has exceeded 500,000 in the world. And also, the number tends to increase gradually. Ti-6Al-4V have been used as the material of the artificial joint. It was used for the reasons of superior corrosion resistance, excellent specific strength and excellent biocompatibility. However the various problems has been occurred in this material, due to its inferior wear resistance. At present, wear corrosion characteristics were not fully understood comprehensively from both of wear and corrosion behaviors. Therefore in this study, wear corrosion characteristic of Ti-6Al-4V were evaluated comprehensively on the basis of both wear and corrosion characters of Ti-6Al-4V and some trials for improving wear corrosion characteristic of this material by gas nitriding were conducted.

2 Experimental procedures

Ti-6Al-4V alloy whose chemical composition was shown in Table1 was used for this study. Figure1 shows the shape and dimension of test specimen. The test surface of specimen was polished using emery paper. Coupling material for wear testing was HDPE (high density polyethylene).

Wear corrosion testing system is illustrated schematically in Figure 2. The experimental apparatus consisted of pin-on-disk wear tester and electrochemical measurements under coupling condition using three electrodes method composed of specimen (working electrode), Pt (counter electrode) and the saturated calomel electrode (SCE) (referential electrode). All the tests were performed at 310K in a lactic Ringer’s solution whose chemical composition was shown in Table 2.

In wear testing, sliding rate was selected as 20mm/s and contact pressure was 2.5MPa. To improve wear corrosion characteristics gas nitriding was
Conducted under conditions of a gas flow rate 1l/min, nitriding temperature 1073°C and holding time 4hr.

After wear corrosion test, wear and wear corrosion surfaces were observed by FE-SEM for examining the changes in surface state during wear and wear corrosion test.

| Table 1 Chemical composition of Ti-6Al-4V alloy [wt.%] |
|---------------------------------|---------|--------|--------|--------|--------|--------|--------|--------|--------|
| H | O | N | C | Fe | Al | V | Y | Ti |
| 0.004 | 0.168 | 0.002 | 0.006 | 0.242 | 6.19 | 4.34 | <0.001 | Re |

| Table 2 Chemical composition of lactic Ringer's solution [mEp/L] |
|---------------------------------|---------|--------|--------|--------|--------|
| Na⁺ | K⁺ | Ca²⁺ | Cl⁻ | Lacate⁻ |
| 130 | 4 | 3 | 109 | 28 |

3 Experimental results and discussions

Polarization curves in the wear corrosion test and corrosion test were obtained and shown in Figure 3. Figure 3 shows the increase of current density obtained under wear condition compared with that obtained in corrosion test. This result indicates that corrosion behavior was accelerated by superposition of wear. This behavior was understood from the standpoint of the acceleration of corrosion by the destruction of passive film by wear process.

Then, change of the friction coefficient during wear corrosion test was measured and shown in Figure 4. As a result, the increase in the friction coefficient was recognized with the increase of corrosion. Therefore it was understood that wear was extremely affected by the progress of corrosion. However, the reason of this behavior was not made clear only from this experimented result.

Therefore, wear corrosion test was conducted under constant potential condition. From these data, the reasons for the increase in wear amount obtained under wear corrosion condition is investigated. Physical meaning of
the increase in wear amount is investigated from the difference between wear corrosion volume and simple summation of wear volume and the volume calculated by using Faraday's law from the total current density detected during wear corrosion test. These results were indicated in Figure 5. Clear difference was recognized between abovementioned two values. Therefore, wear phenomena were accelerated under corrosion condition. And more remarkable acceleration in wear corrosion volume was recognized in case when corroding condition become more severe. From these results, it was made clear that wear phenomena were extremely accelerated under corroding condition.

These results showed that the corrosion behavior was accelerated by wear and also wear volume was increased by corrosion. From these facts, interaction of corrosion and wear is extremely important for considering wear corrosion mechanism (Figure 6). Therefore, to improve the both of corrosion resistance and wear resistance, surface modification method of gas nitriding was employed. For this reason, gas nitrided layer of TiN was formed in the surface of specimen, because gas nitriding method can be applied to artificial joint with complex shape.

As a result of gas nitriding, the color of specimen surface changed into gold. The result of X-ray diffraction analysis of nitrided Ti-6Al-4V is shown in Figure 7. From this figure, it was understood that nitrided layer was made of the mixture of TiN and Ti2N.

Then, polarization curves of Ti-6Al-4V and nitrided Ti-6Al-4V under the wear corrosion condition were obtained in the same solution and shown Figure 8. This figure indicates that the corrosion resistance is improved by gas nitriding because no increase in current density is detected in case of nitrided Ti-6Al-4V specimen compared with Ti-6Al-4V. Then, changes in the friction coefficient of nitrided Ti-6Al-4V were obtained and shown in Figure 9 together with that of Ti-6Al-4V specimen. And wear rate and specific wear amount of Ti-6Al-4V and nitrided Ti-6Al-4V were obtained and shown Table 3. The friction coefficient was indicated to be more stable in case of nitrided Ti-6Al-4V
compared with Ti-6Al-4V. Wear rate and specific wear amount of nitrided Ti-6Al-4V specimen became smaller than that of Ti-6Al-4V. As a result, wear resistance was extremely improved by gas nitriding.

Therefore, it was shown that the gas nitriding was effective to improve the wear corrosion characteristics of Ti-6Al-4V.

4 Conclusions

Various studies were conducted to evaluate of wear corrosion characteristics of Ti-6Al-4V. Then, some trials for improving wear corrosion character by gas nitriding were conducted. The results obtained were summarized as follows.

(1) Wear corrosion behavior is extremely accelerated due to the mutual interaction of wear and corrosion.

(2) The formation of thin TiN layer on the surface of specimen by gas nitriding shows remarkable improvement in both wear and corrosion characteristics.

References


Figure 1  Specimen geometry (mm)

Figure 2  Schematic illustration of wear corrosion tester
Figure 3  Polarization curves of Ti-6Al-4V in lactic Ringer's solution

Figure 4  Change of the friction coefficient and polarization curves of Ti-6Al-4V
Increased amount of wear volume --- Polarization curve of Ti-6Al-4V

Figure 5  Amount of wear increasing by corrosion polarization curves of Ti-6Al-4V

Wear corrosion mechanism

Wear  Corrosion

Figure 6  Mutual interaction in wear corrosion behavior
Figure 7  X-ray diffraction pattern of nitrided Ti-6Al-4V

Figure 8  Polarization curves of Ti-6Al-4V in lactic Ringer's solution
Figure 9  Change of the friction coefficient during were corrosion test under potensiodynamic test

Table 3  Wear rate and specific wear amount of nitried Ti-6Al-4V and Ti-6Al-4V

<table>
<thead>
<tr>
<th>Wear amount [g]</th>
<th>Nitried Ti-6Al-4V</th>
<th>Ti-6Al-4V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear rate [mm²]</td>
<td>$4.26 \times 10^{-7}$</td>
<td>$4.28 \times 10^{-6}$</td>
</tr>
<tr>
<td>Specific wear amount [mm²/N]</td>
<td>$6.04 \times 10^{-9}$</td>
<td>$6.05 \times 10^{-8}$</td>
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