Technical note

EFFECTS OF LASER HARDENING ON FRETTING WEAR BEHAVIOUR OF Ti ALLOY

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Fretting wear is a serious problem with titanium alloys. Surface treatments may be good methods for improving the fretting wear resistance of titanium alloys. This paper investigates the effects of the slip amplitudes and normal loads on the fretting wear of titanium alloys before and after laser surface hardening. The results of the fretting wear experiments show that laser hardening can increase the fretting wear resistance of titanium alloys significantly. This improvement is a result of the reduction in grain size induced by laser hardening.

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INTRODUCTION

Titanium alloys are widely used in aerospace, electrical, chemical, and petrochemical engineering owing to their attractive properties such as a high strength to weight ratio, high temperature strength, and good corrosion resistance. However, titanium alloys are very sensitive to fretting conditions and may undergo severe damage,[1] therefore surface treatments should be considered.[2]

Laser treatments are new methods for the surface treatment of metals, which can be divided into laser hardening, laser glazing, laser alloying, laser cladding, and laser shocking.[3] Research has shown that laser hardening can improve the fretting wear resistance of steels and aluminium alloys.[4–7] However, studies of the influence of laser hardening on the fretting wear resistance of titanium alloys have been limited.[8]

The aim of the present paper is to investigate the effects of laser hardening on the fretting wear of titanium alloys.

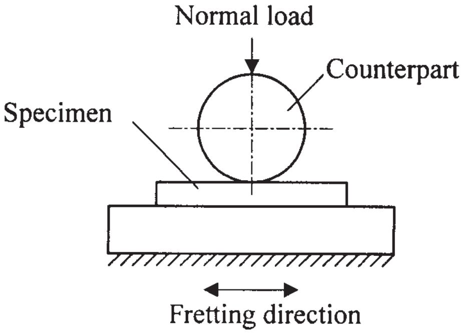
EXPERIMENTAL DETAILS

Materials

The material studied was TC11 titanium alloy. Its heat treatment consists of 950°C for 1 h, then air cooled, and followed by 530°C for 6 h, then air cool, which results in an annealed two phase $\alpha + \beta$ structure. The chemical composition and the mechanical properties of the TC11 alloy are given in Tables 1 and 2, respectively.

Laser hardening

The specimens with dimensions $15 \times 4{\cdot}5 \times 2{\cdot}5$ mm were laser treated with a five-axis CNC 5 kW CO_2 laser processing system. In order to enhance the beam absorption, the specimens were painted with black paint. The laser processing parameters were as follows: laser power 1 kW, beam scanning speed 100 mm min^{-1}, and spot size 6 mm in diameter.



1 *Schematic illustration of specimen contact in fretting test*

Fretting wear test

The fretting wear experiments were performed on an SRV fretting tester at room temperature and under dry friction conditions. A schematic illustration of the contact arrangement is shown in Fig. 1. The friction counterpart was a cylinder (8 mm in diameter and 10 mm in length), which was also made of titanium alloy TC11.

Before the fretting test, all specimens were ultrasonically cleaned in acetone for 10 min. The test frequency was fixed at 33 Hz and the test duration was set at 1×10^5 cycles of fretting. The normal load was set at 3, 9, 35, and 70 N, and the slip amplitude was 30, 60, 90, and 150 μm, respectively.

To obtain accurate results, the fretting wear tests were repeated four times and the friction and wear

Table 1 Chemical composition of TC11 titanium alloy, wt-%

Al	Mo	Zr	Si	Ti
5·8–7·0	2·8–3·8	0·8–2·0	0·20–0·35	Bal.

Table 2 Mechanical properties of TC11 titanium alloy

Yield strength $\sigma_{0{\cdot}2}$, MPa	Ultimate tensile strength σ_b, MPa	Elastic modulus E, GPa	Reduction in area ψ, %
1024	1133	115	46

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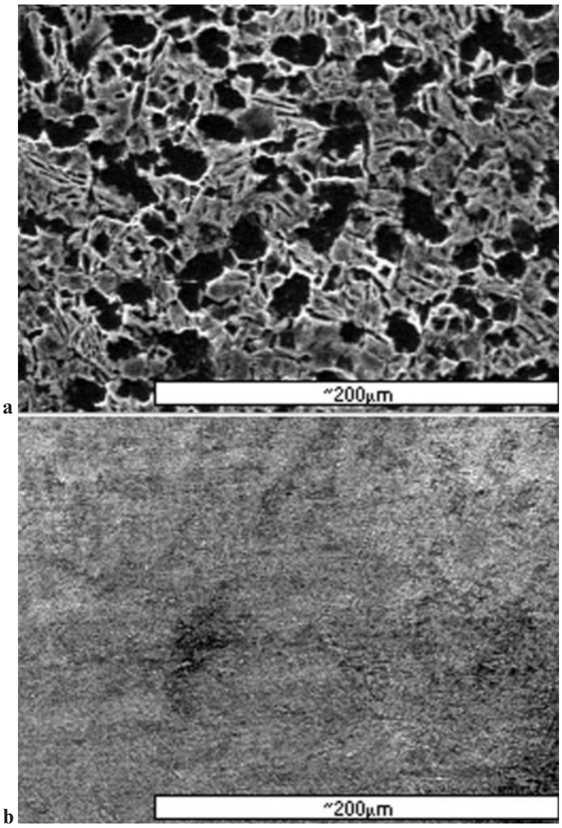


2 *Microstructures of **a** untreated and **b** laser treated Ti alloy*

data reported in this paper are the mean values of the four tests.

Characterisation

A IIMT-3 Vickers hardness tester was used to measure the microhardness with a 100 g load and 15 s hold time. An Amray-1000B scanning electron microscope (SEM) was used to observe the microstructures and wear surfaces. A profilometer was used to measure the profile of the wear scar along and across the fretting direction, through the centre of the wear scars, to calculate the wear volume.

RESULTS AND DISCUSSION

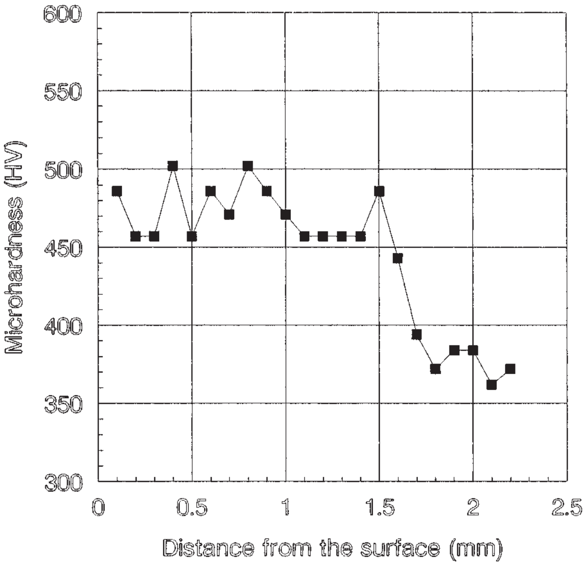
Microstructure and mechanical properties of laser treated Ti alloy

The microstructures of the untreated and laser treated titanium alloys are shown in Fig. 2. It can be seen that the microstructure of the titanium alloy has been changed into a fine structure after laser treatment. The microhardness distribution of laser treated specimens is shown in Fig. 3. The depth of the laser hardened layer is 1·6 mm. Laser hardening leads to a significant hardening effect: the maximum hardness of the treated titanium alloy reached 502 HV, while the hardness of the substrate is only 362 HV. This hardening effect can be explained by the reduction in grain size.

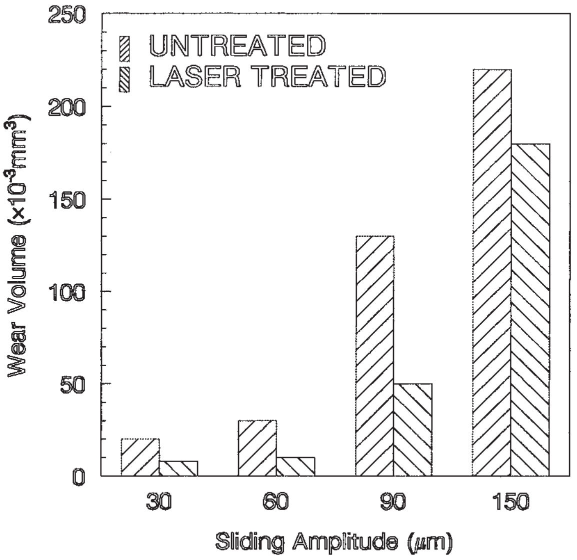
Fretting wear behaviour

Slip amplitude

The relationship between the slip amplitude and the fretting wear volume for both the untreated and laser treated titanium alloys at a load of 9 N is shown in Fig. 4. It can be seen that the fretting wear volume increases slowly with increasing slip amplitudes below 90 µm, but increases rapidly above 90 µm.



3 *Microhardness distribution of laser treated titanium alloy*



4 *Relationship between slip amplitude and wear volume in untreated and laser treated conditions*

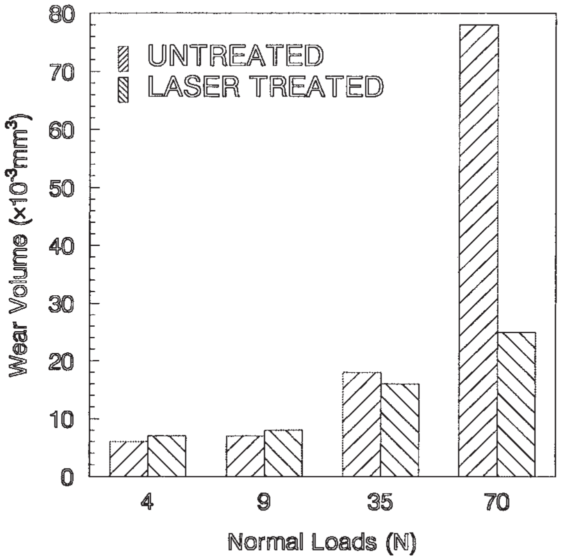
Normal load

Figure 5 shows the effects of normal load on the fretting wear volume for both untreated and laser treated titanium alloys at a slip amplitude of 30 µm. It can be seen that the fretting wear volume increases slowly with increasing normal load. When the normal load is higher than 35 N, the wear volume increases rapidly.

From Figs. 4 and 5 it can be seen that laser hardening causes the fretting wear resistance of the titanium alloy to increase significantly. Laser hardening can decrease the fretting wear volume of TC11 titanium alloy by a factor of three.

Fretting wear mechanism

The wear scars of the untreated and laser treated titanium alloy were examined using SEM after



5 *Relationship between normal loads and wear volume in untreated and laser treated conditions*

fretting tests. It was found that the fretting wear mechanisms of untreated and laser treated titanium alloys are almost the same (i.e., abrasion, adhesion, oxidation, and delimitation wear), as shown in Fig. 6.

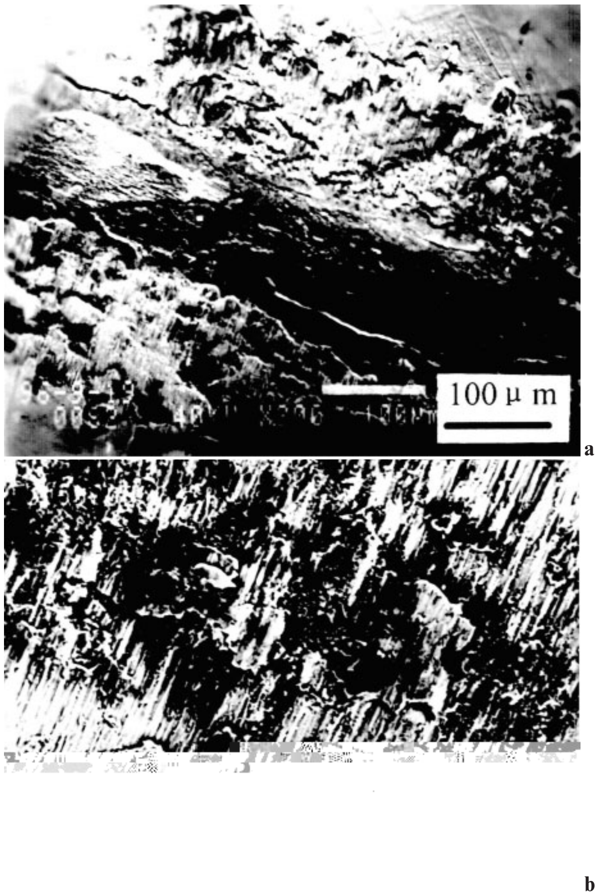
For the untreated titanium alloy, ploughing and scratching of the fretting surface were very severe. The laser treated specimens had a higher hardness compared with the untreated specimens. Therefore, their ability to resist abrasion, adhesion, oxidation, and plastic deformation were increased significantly. It can be seen that the ploughing and scratching of the laser treated surface is not as severe as that of the untreated one in Fig. 6.

CONCLUSIONS

1. Laser hardening can reduce the fretting wear volume of the TC11 titanium alloy by a factor of three.

2. The fretting wear volume of the TC11 titanium alloy increases with increasing normal load and slip amplitude.

3. The improvement of the fretting wear resistance of the TC11 titanium alloy is a result of the reduction in grain size produced by laser hardening.



6 *SEM of fretting surface of* ***a*** *untreated and* ***b*** *laser treated specimens*

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