2001 (2)

Use of a Laser/TIG Combination for Surface Modification of Ti-6Al-4V Alloy

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[Manuscript received June 5, 2000]

The surface modification of materials such as Ti-6Al-4V is necessary to improve their wear resistant properties for use in tribological applications. In this paper it is shown that a laser with low power and tungsten inert gas (TIG) can be combined together for surface modification of Ti-6Al-4V alloy, and when performed in a controlled atmosphere of pure nitrogen or a mixture of nitrogen and argon, can produce a wear-resistant surface alloy. Compared with laser processing, a cheaper surface modification process has been developed involving a shorter processing time, which is free of stringent requirements such as a vacuum system.

1. Introduction

Titanium alloys are extensively used in the aerospace industry where their high strength to weight ratio is of prime consideration. However, they suffer from poor surface wear resistance, which limits further applications in tribological systems[1]. A number of surface modification techniques have been used to improve wear properties of Ti alloys by modifying either the surface composition or microstructure.

Laser processes involving surface melting, nitriding or alloying have been successful in improving surface properties, but they are expensive alternative[2]. Research has also identified cracking in the laser nitrided layers, although crack-free layers were reported to be possible when the volume fraction of the hard phase TiN was kept low and when the hard layer thickness is reduced[2].

Alternative heat sources that can implement melting, such as an arc generation between a non-consumable tungsten electrode and the substrate surface, are being used, for instance, in fusion welding processes to join materials. Since these techniques have not been developed for surface engineering purposes, they remain hitherto untested as methods for surface modification. However, Labudovic and Khan have shown that tungsten metal arc heat source surface melting of Ti-6Al-4V alloy can be performed in a controlled atmosphere of pure nitrogen or in a mixture of argon and nitrogen to produce a wear resistant surface with hardness values greater than 900 VHN[3].

This study reveals a versatile process, which can be used to modify the surface wear characteristics of Ti alloys. Lasers produce highly focused beams but relatively expensive high power, while conventional processing sources produce lower-cost high power but in a rather indiscriminate and unfocused way. In this paper, a low power (1 kW) Nd-YAG laser and tungsten inert gas have been combined together to provide surface melting of Ti-6Al-4V alloy in a shielding atmosphere of pure nitrogen and nitrogen/argon mixture.

2. Experimental

The commercial alloy Ti-6Al-4V was cut into rectangular plates (50 mm×20 mm×10 mm) and the surface prepared to give a flat, polished finish followed by degreasing treatment in acetone before surface melting. The experimental setup is presented in Fig.1.

A 3 mm diameter tungsten electrode was used to create a metal arc between the tip of the electrode and the Ti alloy surface. This was achieved by holding the electrode stationary and at an angle of about 45° to the Ti alloy surface. A metal arc was produced by adjusting the distance between the tip of the electrode and alloy surface, and careful control of parameters such as current and voltage supply to the electrode. Shielding gases were channeled through the electrode gun, and flow regulators used to control the flow rate to give either a pure nitrogen shielding gas or a mixture of argon (80 vol. pct) and nitrogen (20 vol. pct). The laser used was a Nd-YAG laser delivering maximum output power of 1 kW. The laser beam is directed at an angle of about 600 to the Ti alloy surface. The laser processing parameters were: laser power 1 kW, shape wave mode, defocused distance of 5 mm above the focal point, and 35% overlapping fraction. To ensure the accuracy of the 35% overlapping fraction, the specimens were moved under the TIG torch and laser head at constant speed of 10 mm/s by the use of 3 axes positioning system.

3. Results and Discussion

Surface melting to a depth of 2 mm in a shielding atmosphere of pure nitrogen or an argon/nitrogen mixture was possible and resulted in the formation of dendrites in the resolidified surface as shown in Fig.2. The X-ray diffraction analysis taken from the surface

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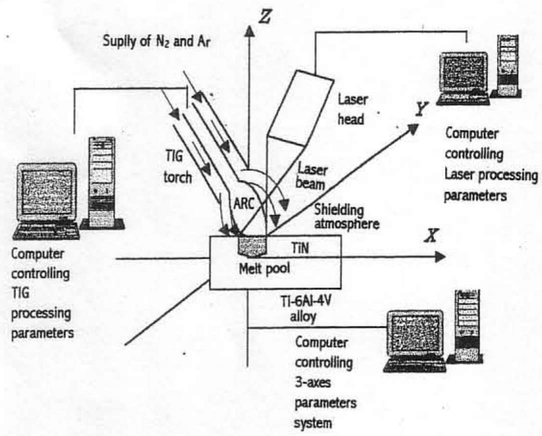

Fig.1 Experimental set-up

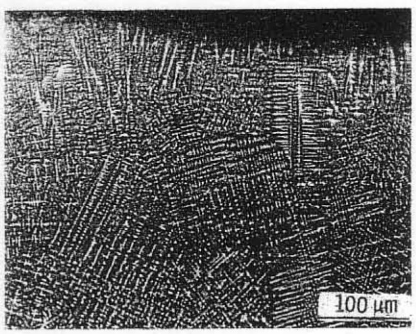

Fig.2 Melted zone produced under a gas shield of nitrogen

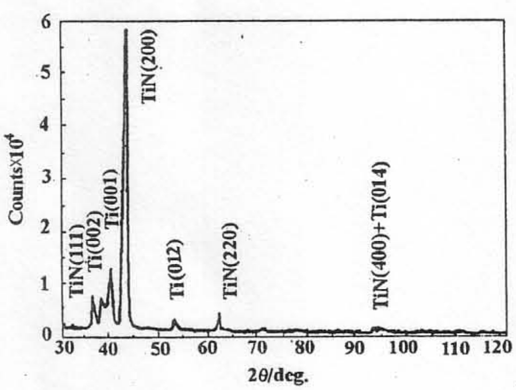

Fig.3 X-ray diffraction spectrum taken from the surface melted under a nitrogen gas shield

is given in Figs.3~4.

The results show that prominent peaks for TiN are present for surfaces treated with pure nitrogen and weaker intensities for surfaces treated by the argon/nitrogen mixture. The shielding gases were also successful in preventing the formation of Ti oxides in the surface melted zone, the presence of which

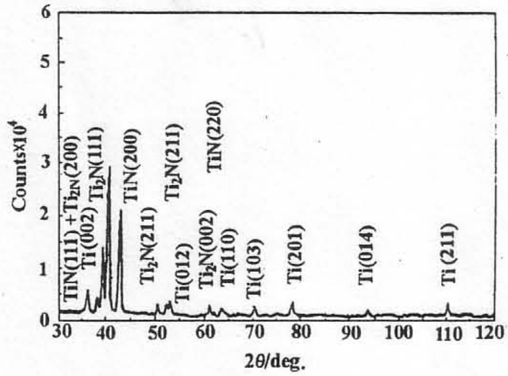

Fig.4 X-ray diffraction spectrum taken from the surface melted under an Ar/N mixture

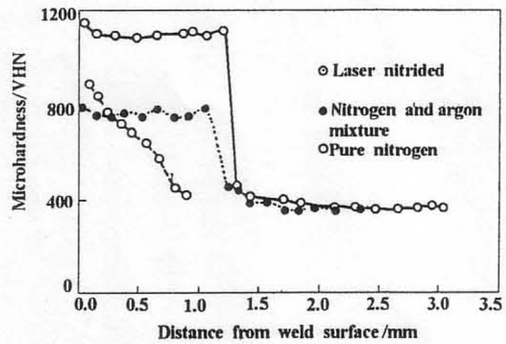

Fig.5 Comparison of microhardness depth profiles for surface treated Ti-6Al-4V alloy

could have been detrimental to surface wear properties. Furthermore, there was no evidence of crack formation or porosity associated with gaseous entrapment in the resolidified region.

The formation of hard nitride phases on the surface was further assessed using microhardness measurements, which are shown in Fig.5.

The surface melted in the presence of nitrogen gave the highest Vickers hardness number (VHN) of about 1100, and a decrease in hardness was recorded outside the heat affected zone at a depth of 1.2 mm from the surface. As expected, the surface treated by a mixture of argon/nitrogen gave lower VHN values of 750~800, which would correspond to a lower concentration of nitride phases in the surface. Some increase in microhardness, particularly in the heat affected zone, has been attributed to the interstitial solid solution strengthening of the α phase of the Ti alloy[4]. For comparison, the results showing variation in microhardness with depth for a laser nitrided surface have been superimposed in Fig.5. For laser nitriding, although high VHN values can be achieved at the surface, the hardness begins to drop rapidly with increasing distance from the surface. In com-

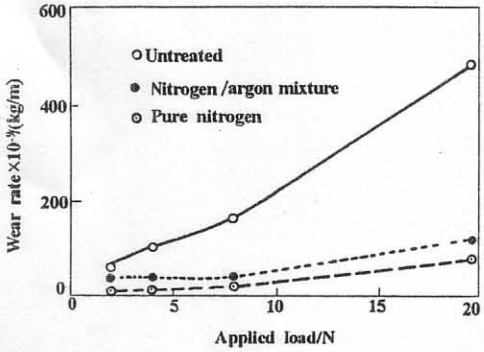

Fig.6 Dry sliding wear graph showing variation in the wear rate with load for surfaces before and after surface treatments

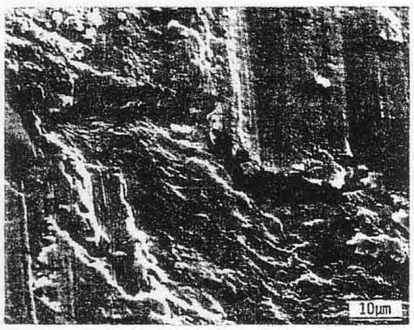

Fig.7 SEM of the untreated Ti-6Al-4V alloy

parison, the laser/TIG combination produces a much wider melted zone (which is determined by the diameter of the electrode used), but also a deeper, more uniform hardened surface region. This has been contributed to the laser beam stabilizing the rooting of the arc providing more effective use of heat. The latter has been due to the ionization in the vapor (localized above the laser-generated molten pool) leading to partial constriction of the arc, raising the local intensity and facilitating enhanced penetration.

The resistance to surface wear was assessed by monitoring variations in the wear rate with increasing applied load, and making a direct comparison with the untreated (reference) Ti alloy. The results show that the untreated surface suffers high wear, which increases in severity as the applied load is increased (Fig.6). The scanning electron micrograph (SEM) in Fig.7 shows adhesive wear dominated by plastic deformation involving the ploughing of materials and surface delamination.

Surfaces treated by melting in either pure nitrogen or argon/nitrogen mixture show better wear resistance than the untreated Ti surface. However, the least change in wear rate was recorded for surfaces shielded by nitrogen. These results are consistent with the microhardness values, showing that the greater concentration of nitrides formed in the surface

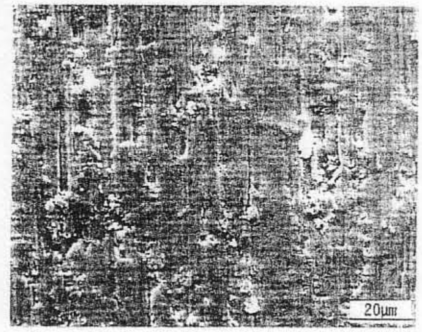

Fig.8 SEM of dry sliding wear surface melted under a shield of nitrogen

improve the surface wear properties of the Ti alloy.

Figure 8 shows a distinct change in surface wear mechanism. In both cases, in which the surfaces were shielded by a nitrogen or argon/nitrogen mixture, severe adhesive wear was absent, and smooth regions were visible within the wear scar. These regions appear to have worn far less than other surface areas. The dry sliding wear test was carried out in air, and these regions could be oxidized zones. However, because Ti oxides were not detected in the wear debris, these hardened regions could be then attributed to the formation of nitride phases.

4. Conclusion

This preliminary study has shown that it is possible to modify the surface of the Ti alloy Ti-6Al-4V by using a laser/TIG combination to provide surface melting under the influence of a shielding gas such as pure nitrogen or a mixture of argon/nitrogen. The use of nitrogen gas for shielding produces a wear-resistant surface with surface hardness values of over 1100 VHN, compared with 360 VHN for the untreated conventional Ti-6Al-4V alloy. This increase in wear-resistant properties is attributed to the formation of Ti nitride phases in the resolidified surface microstructure. In comparison with laser processing, higher and more uniform microhardness values are achieved at the surface. Low-power (1 kW) Nd-YAG laser and tungsten inert gas have been combined together, which resulted in a cost-effective dual-technology torch with performance better than that of a significantly higher-power laser at a fraction of the cost. In addition, laser/TIG combination offers a shorter processing time and is free of stringent requirements such as a vacuum system.

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