Effect of laser scanning speed on nitrided layers fabricated on titanium alloy

Y. S. Tian*, Q. Y. Zhang, C. P. Qin and D. Y. Wang

Laser nitriding of Ti–6Al–4V alloy was performed at different laser scanning speed. The results show that higher nitride concentration and microhardness are formed in the coatings laser nitrided with lower scanning speed. Nevertheless, higher nitride concentration results in higher residual stress which induces cracks occurring in the coatings.

Keywords: Laser nitriding, Cracks, Titanium alloy, Microhardness, Scanning speed

Introduction

Laser nitriding of Ti alloys is one of the effective methods for improving their surface properties such as wear and corrosion resistance and the work has been performed by some researchers.[1–4] By melting the surface of the Ti alloys using a focused laser beam in a nitrogen gas environment, laser nitriding provides a potential for an excellent metallurgical bond between nitrided layer and substrate, and by adjusting the processing parameters such as laser output power, scanning speed, beam size and nitrogen pressure, a nitrided layer with suitable smooth surface and microhardness can be obtained. But one of the main problems in laser nitriding of Ti alloys is the surface cracking which reduces the strength and the toughness of the nitrided layer. Yilbas *et al.*[5] reported that porous and cracks are observed in the nitrided layer produced with high power irradiation and nitrogen concentration. Santos *et al.*[6] also reported that the laser output power affects the formation of the cracks in laser nitrided layers. Mridha and Kloosterman *et al.*[7,8] found that laser nitrided Ti alloy in a diluted nitrogen environment can reduce the formation of the cracks. But Pérez *et al.*[9] reported that neither a diluted nitrogen environment nor a change in laser processing parameters was successful in crack elimination. Nevertheless, it is found in the authors' previous experiment that the amount of cracks does have something to do with the laser processing parameters. And we knew that the amount of heat absorbed by the laser melt was significantly affected by the laser processing parameters such as the laser power, the size of the beam and the scanning speed. In the present study, the work of laser nitriding of Ti–6Al–4V was carried out in an open environment at different scanning speed, in order to evaluate the effect of scanning speed on the microstructures and the cracks formed in the nitrided layers.

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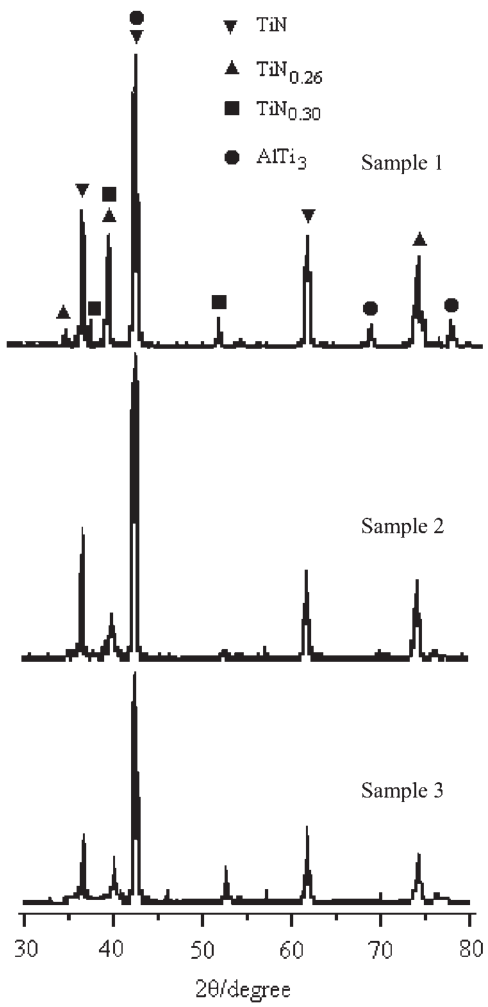
Experimental procedure

The samples of Ti alloy Ti–6Al–4V, $10 \times 10 \times 12$ mm in size, were abraded with SiC grit paper before the nitriding operation. A 1500 W continuous wave CO_2 laser, output power of 1200 W, beam size of 2 mm was employed to melt the surface of the samples and the



1 X-ray diffraction patterns of laser nitrided samples 1–3

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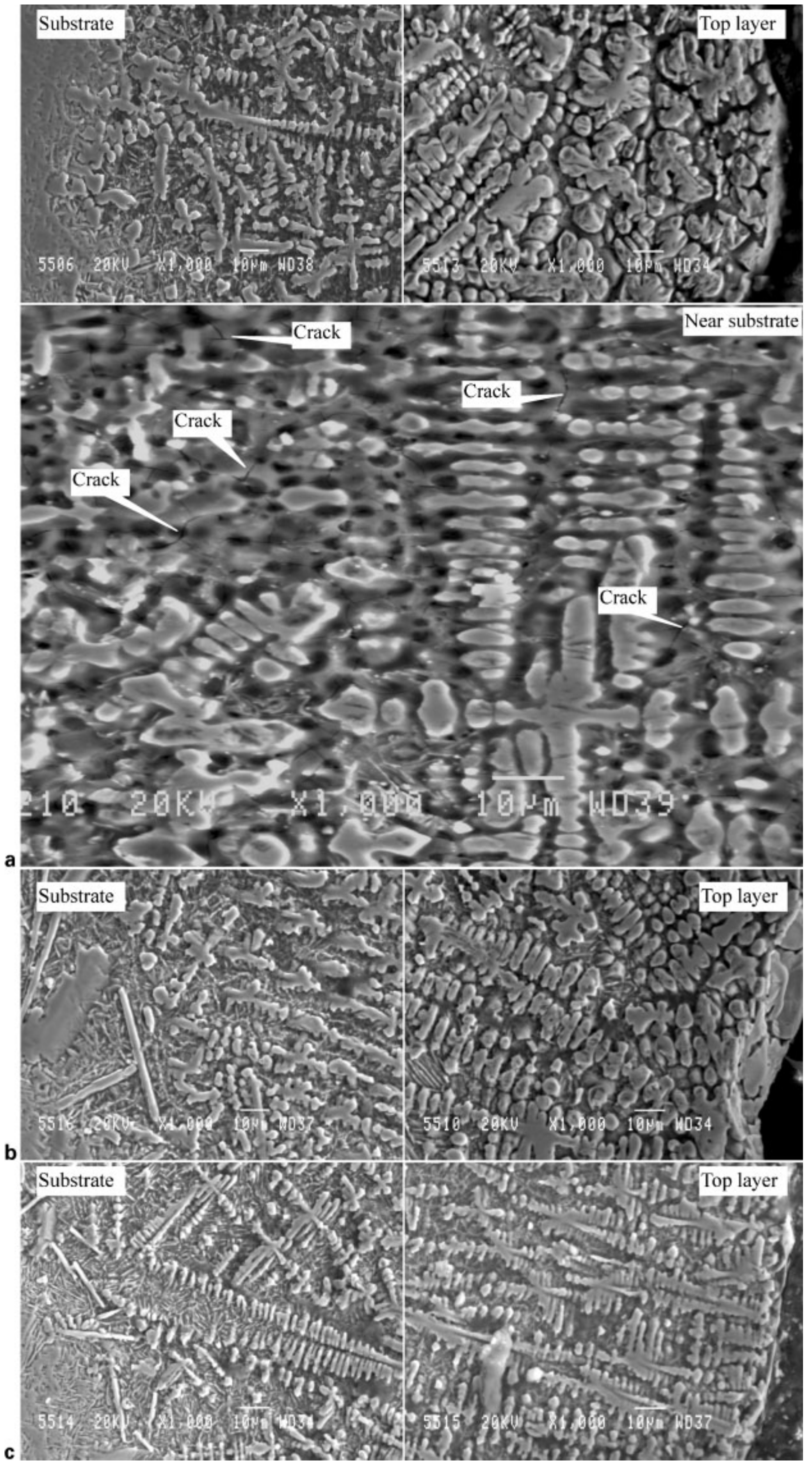
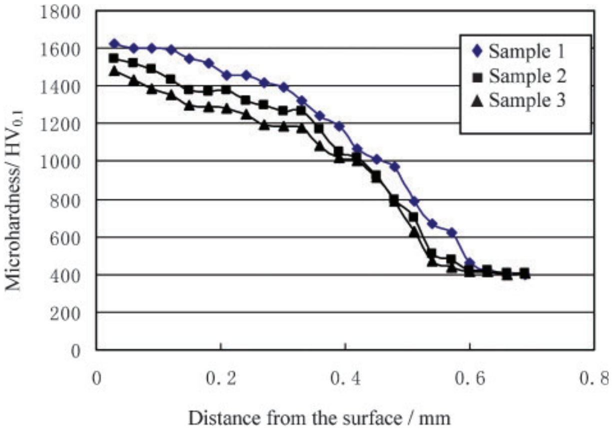


2 Microstructures of coatings laser nitrided at different scanning speed: *a* sample 1, scanning speed 3 mm s^{-1}; *b* sample 2, scanning speed 5 mm s^{-1}; *c* sample 3, scanning speed 7 mm s^{-1}

tracks were 50% overlapped. Nitrogen gas at a pressure of 0·4 MPa was fed through a nozzle which was coaxial with the laser beam acting as both nitriding and protecting the melt pool from oxidation during laser processing. Metallographic samples were prepared using standard mechanical polishing procedures and then etched in a mixed solution of HF, HNO_3 and H_2O in volume ratio of 2 : 1 : 47 for about 1 min. Phase composition and microstructure of the coatings were characterised using D/max-rC XRD, H-800 TEM and JXA-840 SEM. The laser scanning speeds of samples 1–3 are 3, 5 and 7 mm s^{-1} respectively.

Results and discussion

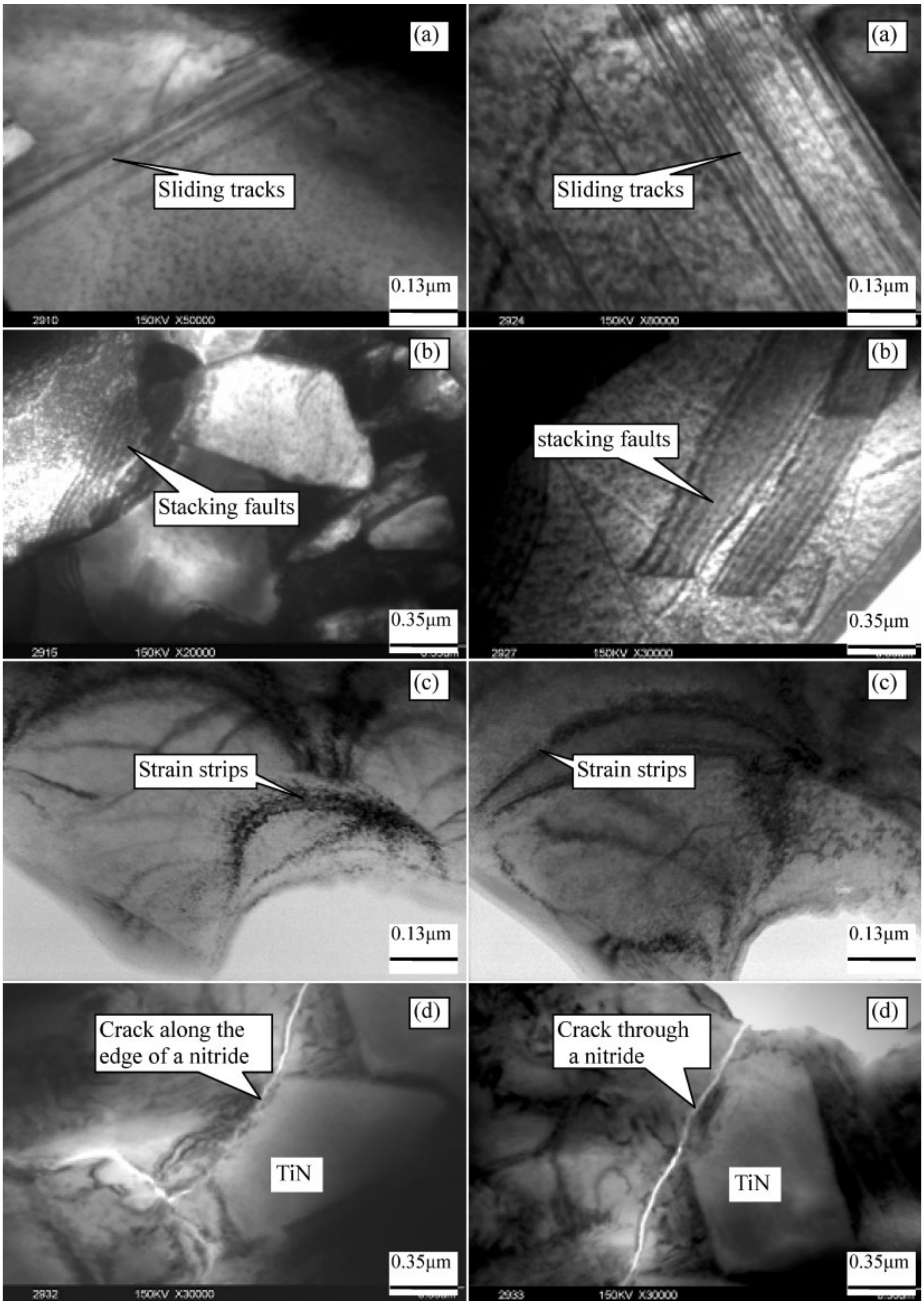
X-ray diffraction patterns (Fig. 1) show that the compounds formed in the coatings are mainly Ti nitrides, but the peaks of the nitrides decrease with increasing the scanning speed. This means that increasing scanning speed will result in decrease in the content of the nirides.



3 Microhardness profiles of laser nitrided samples

That is, increasing scanning speed results in the formation of shallower melted pool and solified more quickly than that scanning at lower speed, which restrains the dissolution and diffusion of the nitrogen and thus less nitrides are formed in the coatings. In addition, less Ti–Al intermetallics are produced when scanning speed is low, which may be attributed to the relatively sufficient diffusion time for the elements in the melt pool.

From Fig. 2, it can be seen that nitrides with different morphologies are formed when laser nitriding at different scanning speed. At a low scanning speed (3 mm s^{-1}) coarse nitrides of higher concentration with a developed dendritic morphology are produced and cracks occur throughout the coatings (see sample1). At a scanning speed of 5 mm s^{-1}, the size of nitrides becomes



4 Images (TEM) of laser nitrided sample 1

smaller and cracks disappear. When scanning speed increases up to 7 mm s^{-1}, fine nitrides dendrite of lower concentration with short second arms are produced, which indicates that scanning speed affects not only the concentration but also the size and morphology of the nitrides in the coatings. In addition, it can be seen that the morphology of the nitrides are more developed in the top layer compared with that next to the substrate, which demonstrates that the nitrogen dissolved in the melt pool is not uniform from top to bottom because of the fast solidification.

The microhardness profiles along the depth direction of the nitrided layer are shown in Fig. 3. It is seen that the coating laser nitrided at a lower scanning speed having a higher surface microhardness is easy to crack and this is in agreement with the result obtained by Abboud.[10] Yang[11] also found that with decreasing the scanning speed from 500 to 100 mm min^{-1}, the surface microhardness increased from 300 to 800 HV. All the above experiment results indicate that the scanning speed is one of the principal factors associated with the microhardness and the cracking of the nitrided layers and which can be explained as follows.

The decrease of laser scanning speed results in the increase of irradiation time which increases nitrogen concentration in the melt pool and thus promotes the formation and growth of nitrides. The increase of the hard and brittle nitrides enhances not only the microhardness, but also the elastic modulus of the coatings (elastic modulus of TiN and Ti are 616 and 110 GPa respectively). The increase of the elastic modulus also results in the increase of tensile stress in the coatings.[12] Appel *et al.*[13] found in their experiment of Ti aluminide alloy under a tensile stress that stacking faults are produced by the propagation of interfacial dislocations. Nevertheless, Liu *et al.*[14] reported that the glide of dislocations is restricted due to their interaction with nitrides as well as the strain fields around them in Ti alloy strengthened by nitriding. Figure 4 also shows that under lower scanning speed, lots of dislocations, stacking faults and cracks are formed in the coatings containing more nitrides. This indicates that dislocations glide and jam under stress and thus induce stackimg faults which in turn aggravate the levels of stress. On the other hand, the dislocations inside the coatings strengthened by the nitrides are difficult to move and therefore the accumulated high stress is difficult to release by plastic deformation. Thus, cracks occur when the accumulated stress goes up to tensile strength. So, laser nitrided at low scanning speed, coatings containing nitrides of higher concentration having higher elastic modulus and tensile stress will be easier to crack than that having lower elastic modulus and tensile stress. That is, the laser scanning speed significantly affects the properties of the nitrided layer.

Conclusion

During laser nitriding of Ti alloy, the variation of the laser scanning speed affects the qualities of the coatings. With decreasing laser scanning speed, the concentration of nitrogen in the melt increases and thus results in the increase of both the nitrides concentration and the microhardness of the coatings. The morphology of the nitrides also changes from fine dendrite to coarse dendrite. Nevertheless, higher nitride concentration not only enhances the microhardness but also facilitates the formation of cracks in the coatings.

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