Available online at www.sciencedirect.com
ScienceDirect
Scripta Materialia 56 (2007) 641–644
Scripta MATERIALIA
www.actamat-journals.com

Laser surface hardening of titanium–titanium boride (Ti–TiB) metal matrix composite

P. Chandrasekar,[a,1] V. Balusamy,[a] K.S. Ravi Chandran[b,*] and Harish Kumar[c]

[a]Department of Metallurgical Engineering, PSG College of Technology, Coimbatore 641004, India
[b]Department of Metallurgical Engineering, University of Utah, 135 South 1460 East Rm. 412, Salt Lake City, UT 84112, USA
[c]Raja Ramanna Center for Advanced Technology, Indore 452013, India

Received 20 November 2006; revised 28 November 2006; accepted 29 November 2006
Available online 11 January 2007

A study of modification of titanium boride (TiB) whisker distribution on the surfaces of titanium–titanium boride (Ti–TiB) composites was performed using laser surface treatment. A surprising finding is that a substantial increase in surface hardness to 1055 VHN, relative to 513 VHN for the untreated material occurred with a laser energy input of above 70 kJ m^{-1}. This corresponded to a substantial increase in surface volume fraction of TiB whiskers to about 67%, at such high energies.

Keywords: Laser treatment; Titanium alloys; Metal matrix composites; X-ray diffraction; Hardness test

High-strength titanium alloys are being used increasingly in aerospace applications because of their better strength to weight ratio compared with high-strength steels. Discontinuously reinforced titanium–titanium boride (Ti–TiB) composites [1] have the further advantage of high stiffness, approaching that of steels, and hence are considered more viable for applications compared with the fiber-reinforced titanium composites [2]. However, titanium in general shows poor surface performance in dry friction conditions of sliding or rolling contact motion, due to extensive surface deformation and galling, regardless of its form as a monolithic material or matrix in composite. Laser surface treatment can be an effective surface modification processes for improving the tribological behavior of titanium composites.

There have been a number of studies on laser surface treatment of titanium alloys. They include studies of laser treatment in the presence of carbon or nitrogen or boron [3–6], surface melting with pre-placed boron nitride [7], formation of Ti–TiC cermet surface layer [8] and feeding of titanium and TiB_2 particles into a laser melted pool [9,10]. These are effective in modifying the subsurface microstructure to a depth of 0.5–0.9 mm and hardening the surface to about 800 VHN. This is advantageous over other surface hardening process such as plasma boriding [11] or nitriding [12], where the depth of hardening is limited to tens of microns. A difficulty in these techniques is the requirement of "atmosphere" or "pre-placement" or "feeding" of hardening additive on the surface, making the process more difficult to implement in practice, if not impossible. This study was designed to explore whether it is possible achieve equally deep surface hardening simply by the direct laser re-melting of titanium composite surfaces with the hardening species (titanium boride) present as an internal reinforcement; if successful, the pre-placement difficulties can be eliminated and the process can be easily implemented for any component shape. The objective of this study was to evaluate this possibility using a Ti–TiB composite containing about 34 vol.% of TiB whiskers as the reinforcement. The laser treatment conditions that lead to refinement of TiB whiskers and the substantial increases in surface hardness variations obtained have been determined.

The starting material was a Ti–TiB composite made by reaction sintering (1350 °C for 1 h) of the mixture of titanium powder, β stabilizing elements (Fe and Mo) and TiB_2 powder, in a hot press. The relevant reaction that leads to formation of in situ Ti–TiB composite is: $Ti + TiB_2 \rightarrow 2TiB$. The composite elemental composition, as determined by X-ray fluorescence in wt.%, is:

* Corresponding author. E-mail: ravi@mines.utah.edu
[1] Present address: Department of Mechanical Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi 642003, India.

1359-6462/$ - see front matter
doi:10.1016/j.scriptamat.2006.11.035

Ti, 69.89; B, 15.77; Mo, 8.51; Fe, 5.09; Si, 0.50; and Al, 0.21. The composite is made of $\alpha + \beta$ titanium matrix with 34 vol.% of TiB whiskers. Additional microstructural details can be found elsewhere [13].

Laser surface treatment was performed using a 10 kW CO_2 laser system (Fig. 1) integrated with a three-axis workstation. Specimens of size 10 mm × 10 mm × 10 mm were metallographically prepared. The laser was focused using a ZnSe lens of 127 mm focal length housed in a water-cooled nozzle. The focal plane was adjusted to obtain a defocused laser spot size of 3 mm on the specimen surface. Single pass, multiple tracks were made to laser treat the entire surface. Argon at a pressure of 1.5 kg f cm^{-2} was supplied through a nozzle to protect the melt pool from oxidation. In addition, there was a side argon flow through a nozzle at an angle of 45° to the work-piece surface. The argon was purged until the laser treated specimen had cooled to room temperature. The conditions of laser treatment are listed in Table 1. X-ray diffraction analysis of treated surfaces was performed in a Shimadzu XRD-6000 X-ray diffractometer, operated at 40 kV and 30 mA and using Cu Kα radiation. Secondary electron imaging of laser treated surfaces, after deep etching the treated surfaces with Kroll's reagent, was performed using a JEOL JSM 6360 scanning electron microscope (SEM) at 25 kV. Vickers hardness measurements were made using a Mitutoyo microhardness tester at a load of 200 g.

Figure 2a–d shows the SEM micrographs of TiB whisker structure on surface laser treated materials with different heat inputs (Table 1). Generally, the TiB whiskers had a high aspect ratio (>10) in all treatment conditions. Most of the TiB whiskers had diameters in the nano-dimension, apparently due to nucleation and growth of TiB whiskers in the laser melted pool. The microstructures resemble the eutectic structures produced in laser treatments with Ti–TiB_2 powder feeds [9,10]. Figure 3a and b presents the SEM micrographs of transverse sections for surfaces treated at laser incident energy of 62.5 and 87.5 kJ m^{-1}, respectively. At a heat input of 87.5 kJ m^{-1}, the TiB whiskers appear to be more refined compared with at 62.5 kJ m^{-1}. Figure 4 illustrates the X-ray diffraction patterns of the untreated Ti–TiB composite and that of the laser treated surfaces. The strong peaks in the treated surfaces correspond to β-Ti phase and the TiB whiskers. For the untreated surface, the dominant β-Ti peak present is $(110)_{\beta\text{-Ti}}$ and those of TiB are $(102)_{TiB}$, $(112)_{TiB}$ and $(200)_{TiB}$. The laser treated specimens showed very pronounced $(102)_{TiB}$ peaks at $2\theta = 42.5°$. This peak is relatively less pronounced at lower incident energies (<70 kJ m^{-1}). A surprising aspect is that there appears to be a critical incident energy, somewhere between 62.5 and 70 kJ m^{-1}, above which the enrichment of TiB phase occurs at the laser treated surface, as indicated by the strength of the $(102)_{TiB}$ peak at energies of 70 kJ m^{-1} and above. The ratio of the integrated intensity of $(102)_{TiB}$ peak to the $(110)_{\beta\text{-Ti}}$ peak is a measure of the relative volume fraction of TiB and β-Ti phases, as shown in a separate study [14] of Ti–TiB functionally graded materials of varying TiB volume fractions. This ratio for the surfaces laser treated at energies $\geqslant$70 kJ m^{-1} is significantly large compared with either the untreated composite or the surface treated at energies <70 kJ m^{-1}, suggesting that the amount

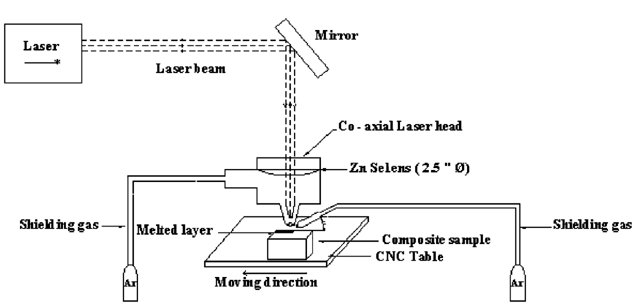

Figure 1. Schematic of the laser surface treatment process.

Table 1. Laser surface treatment conditions

Power (kW)	Traverse speed ($m\ s^{-1}$)	Incident energy (power/traverse speed) (kJ m^{-1})
3.5	0.04	87.5
3.5	0.05	70.0
2.5	0.04	62.5
2.5	0.05	50.0
1.5	0.04	37.5
1.5	0.05	30.0

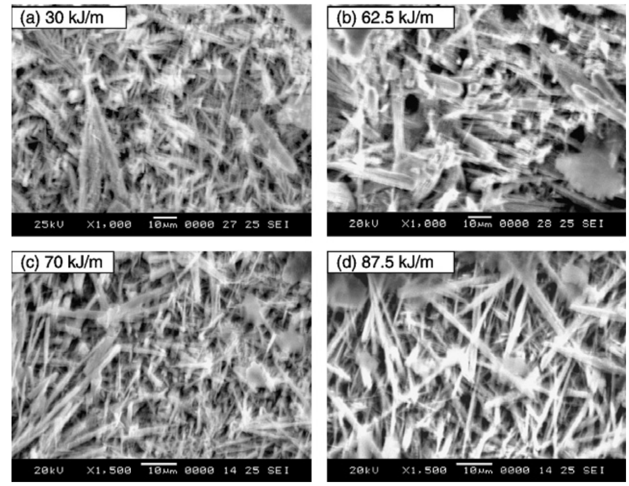

Figure 2. SEM micrographs of microstructures of Ti–34TiB composite laser treated at power input levels indicated in the figures.

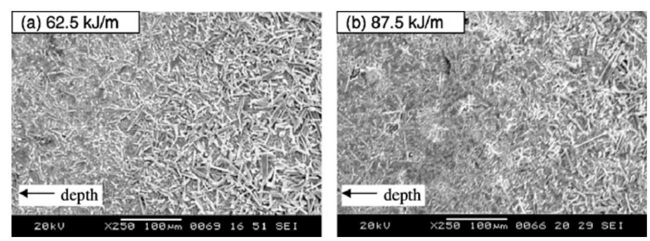

Figure 3. SEM micrographs of transverse sections of laser treated subsurface regions.