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Surface transformation of Ti–45Al–2Nb–2Mn–1B titanium aluminide by electron beam melting

A.R. Rastkar *, B. Shokri

Plasma Engineering Group, Laser and Plasma Research Institute, Shahid Beheshti University, G.C., Tehran 1983963113, Iran

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ABSTRACT

Microstructure and phase evolution on the surface of Ti–45Al–2Nb–2Mn–1B (at.%) gamma based titanium aluminide was investigated by a series of electron beam melting with different beam energies and scanning speeds. X-Ray Diffraction (XRD), Glow Discharge Spectroscopy (GDS), Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) were performed to characterize the phase modification and morphology after the EBM treatment.

At beam energies of 250 W and scanning speed of 16 mm s^{-1}, the lamellar structure of Ti–45Al–2Nb–2Mn–1B transformed into a dendritic structure composed of initial α_2 (Ti_3Al) dendrites and an interdendritic phase of the γ (TiAl). While at higher energies of 350 W and lower beam speeds of 7 mm s^{-1}, mainly B2 and α_2 (Ti_3Al) phases with higher titanium formed on the surface.

All Phase transformations increased the hardness of the surface to a maximum of 600 HV if compared to 330 HV for untreated material. Lower energies and higher speeds induced cracks in the surface layers, while higher energies and lower speeds produced hard surface layers without cracking.

1. Introduction

Alpha titanium aluminides with the composition range of α_2 or Ti_3Al have shown high strength and low ductility. The mechanical behavior of α_2 or α_2 + B2 titanium aluminides has been considered as less deformable and harder materials than that of two phase α_2 (Ti_3Al) + γ (TiAl) alloys [1]. Structures of α_2 and γ plates or particles balance the properties of these alloys. Lamellar structures of these two phase alloys ($\alpha_2 + \gamma$) can keep their strength up to 750 °C. This group of titanium aluminides is being increasingly demanded for structural applications in high temperatures and load bearing conditions [2,3]. Nevertheless, the surface of the two phase ($\alpha_2 + \gamma$) titanium aluminides with the lamellar or equiaxed structure is considerably deformed or worn under direct contact with hard materials such as AISI/SAE 52100 chromium steels [4].

Many investigations have been carried out to vary the surface of titanium alloys and/or two phase α_2 (Ti_3Al) + γ (TiAl) titanium aluminides by surface engineering processes such as plasma nitriding [5,6], TiN coatings [7], braze coatings, tungsten inert-gas surfacing, thermal oxidation [8] and electron beam surface remelting or alloying [9]. However, the transformation of different titanium aluminides into α_2, and/or B2 structure during various treatments and cooling speeds has also been a wide area of investigation [10–12]. Many investigators have observed that rapid cooling of some titanium alloys with aluminium concentration more than 40% from high temperature phases such as β or α can result in the formation of titanium aluminides with lower aluminium content such as α_2 and B2 structures in addition to the two phases of α_2 and γ [13,14].

During electron beam melting some percentage of volatile elements are evaporated from the surface due to the vacuum exposure (typically 0.1 to 10 Pa) and high temperatures [15]. The evaporation losses of aluminium in Ti–Al systems have been characterized based on the activity of species in the melt [16,17]. The beam scanning speed also affects the evaporation rate of the elements.

Therefore, electron beam surface melting of two phase ($\alpha_2 + \gamma$) titanium aluminides may result in the formation of harder α_2 or B2 structures on the surface due to the evaporation of elements and rapid cooling of the phases on the surface without changing the initial bulk structure of the material. It would be explained in this way that surface treatment processes with high energy beams (electron beam or laser beam) offer a good opportunity to the conventional bulk heat treatment. Due to the focused energy deposition, it is possible to limit the heat treatment to specific areas and to a certain depth where a transformation (hardening) occurs. Therefore, the bulk of the materials is not heated up to critical temperatures and does not transform. Moreover, the thermal load of the whole component is minimized and thus the distortion can also be avoided [18,19].

This work has studied the surface transformation of a two phase ($\alpha_2 + \gamma$) titanium aluminides with the composition of Ti–45Al–2Nb–2Mn–1B under different heat inputs resulting from increasing power

* Corresponding author. Tel.: +98 21 29902696; fax: +98 21 22431775.
E-mail address: a_rastkar@sbu.ac.ir (A.R. Rastkar).

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Table 1
Typical experimental conditions of electron beam surface melted Ti–45Al–2Nb–2Mn–1B alloy.

Sample	Power, W	Traverse speed of electron beam, mm s^{-1}
EBM1	250	16
EBM2	350	16
EBM3	350	7

and decreasing scanning speeds of the electron beam to identify different structural phases appearing on the surface.

2. Experimental work

The surface of the alloy with a nominal composition of Ti–45Al–2Nb–2Mn–1B was electron beam melted (EBM) to evaluate the response of this titanium aluminide to any surface transformation. The samples were cut into rectangular pieces of 20 mm × 20 mm × 5 mm using electrical discharge machining. Then the samples were ground with SiC paper down to 1200 grit to remove any oxide layer and make the surface perfectly smooth. Electron beam surface melting was examined using beam powers from 250 to 350 W and different traverse beam scanning speeds from 5 to 16 mm s^{-1}. A focused beam was oscillated to produce a wider melted track of about 2.5 mm width. Areas of surface treatment were scanned by overlapping 50% of the previous melted track. The treatment conditions of some electron beam surface melted samples are typically shown in Table 1.

The EBM samples were sectioned and prepared using conventional metallographic procedures for titanium alloy. The specimens were etched by a Kroll solution (100 ml H2O, 3 ml HF and 5 ml HNO3). The microstructures were illustrated using optical and scanning electron microscopy (SEM). The phases were identified by X-ray diffraction (XRD) and glow discharge spectroscopy (GDS). The XRD measurements were carried out via detection of two theta reflections of Cu kα line (1.54 Å) from the surfaces of the EBM layers in every 0.02 degree steps. The microhardness depth profiles of the EBM samples were measured using a Leitz hardness tester using a Vickers indenter and a load of 0.50 kg (HV 0.5). The measurement error in microhardness values could be around 5% if compared with those values estimated and/or reported in other works [32].

3. Results and discussion

3.1. Phases and composition

X-ray diffraction patterns of the untreated and EBM samples are shown in Fig. 1. It is clearly seen that the untreated material consists essentially of two phases of α_2 (Ti_3Al) and γ (TiAl). Fig. 1 indicates the relative increase in the intensity of α_2 (20 l) and α_2 (202) peaks to that of γ (111), γ (002) and γ (200) peaks in sample EBM1 if compared to the same peaks in the untreated material. This is related to the cooling rate on the surface of sample EBM1. At a power of 250 W and 16 mm s^{-1} scanning speed, the cooling rate has been fast enough to create a structure with a relatively larger surface area of α_2 phase to that of γ if

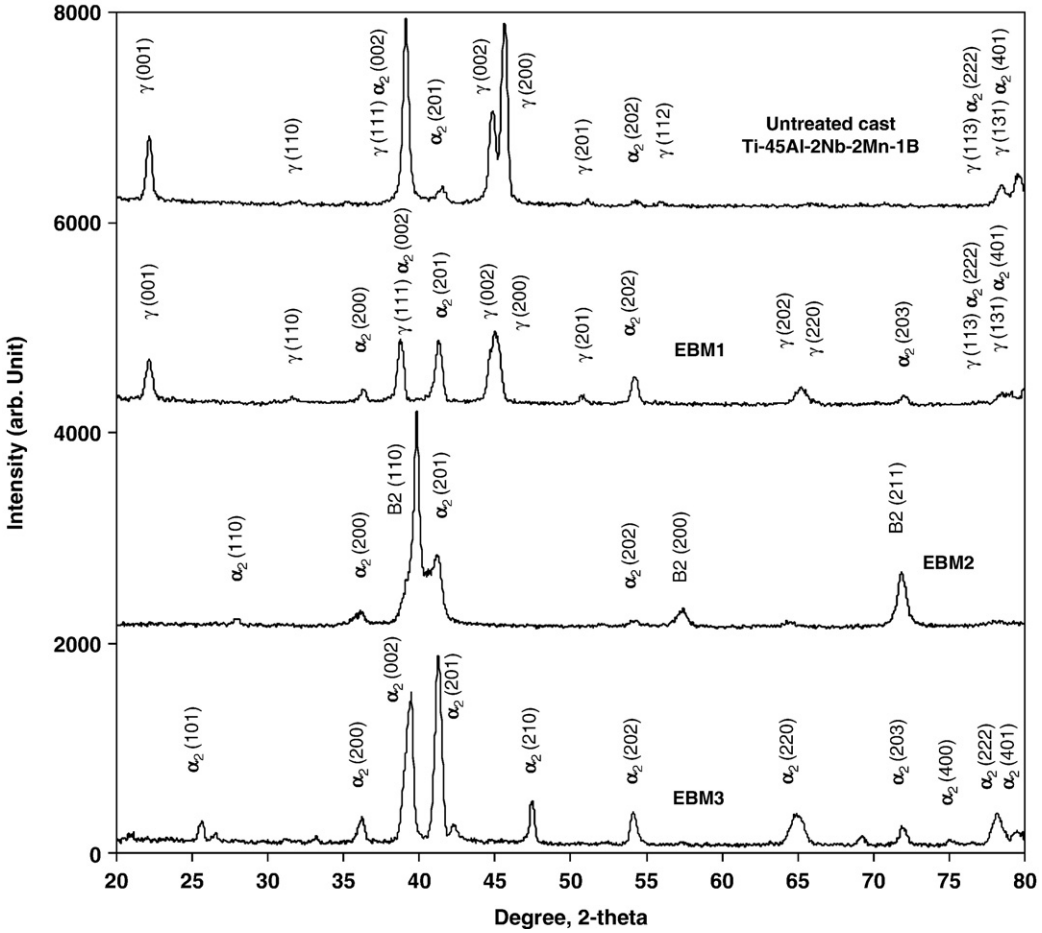

Fig. 1. XRD spectra of untreated Ti–45Al–2Nb–2Mn–1B and electron beam surface melted samples. EBM1 at a power of 250 W and the beam scanning speed of 16 mm s^{-1}, EBM2 at a power of 350 W and the beam scanning speed of 16 mm s^{-1}, EBM3 at a power of 350 W and the beam scanning speed of 7 mm s^{-1}.