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Laser nitriding of an intermetallic TiAl alloy with a diode laser

M.G. Pérez [a,b,*], N.R. Harlan [a], F. Zapirain [a], F. Zubiri [a]

[a] Centros Tecnológicos de Navarra (Cetenasa), Polígono Elorz s/n, Noain 31110, Spain
[b] Universidad Publica de Navarra, Campus de Arrosadia, Pamplona 31006, Spain

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Abstract

Laser nitriding of a Ti–Al–Nb–B intermetallic alloy with a diode laser was investigated. Different processing parameters were used to obtain a crack free, smooth and wear resistant TiN layer. A superficial roughness (Ra) of less than 0.4 μm without postnitriding finishing operations was achieved using a laser energy density of 0.25 kJ/cm^2. Hardness measurements and microstructural analysis were done on the laser nitrided samples. Reciprocating wear tests comparing a PVD nitrided sample, an untreated sample and different laser nitrided samples indicated that the laser nitrided sample with the lowest surface roughness exhibited the least amount of wear and had the lowest friction coefficient.

Keywords: Laser nitriding; Diode laser; Pin-on-disc; Intermetallic alloy

1. Introduction

In recent years, light-weight metals that possess the required material properties to replace conventional alloys like steel have generated increased interest. The potential weight savings offer an appealing advantage in the automotive industry where the demand for increased engine efficiency, due to more stringent CO_2 emission requirements, has become a top priority. For high temperature, high strength applications, titanium based alloys are an attractive light-weight alternative to steel [1], due to their high strength-to-weight ratio [2] and corrosion resistance [3].

In applications that require good wear resistance, titanium alloys pose a problem due to their typically poor tribological behavior. A common technique used to improve the wear response of titanium alloys is to nitride the surface, using chemical or physical vapor deposition, ion implantation, or surface remelting in a nitrogen atmosphere [4,5]. In this work, laser nitriding was explored as a quick, efficient method to create a wear resistant surface on a titanium–aluminium intermetallic alloy.

The objectives of this work were clearly defined in order to comply with the requirements for specific automotive engine components. A titanium–aluminium intermetallic alloy was selected as a substitute for steel because of its excellent high temperature properties, high strength and ductility [6–10]. A laser-nitrided surface was chosen with the aim of improving the total wear response of the metal couple in which it functions [11]. One of the most important characteristics required of the nitrided surface, in order to ensure low wear, was a low surface roughness (Ra), ideally less than 0.4 μm. Post-nitriding finishing operations are costly and were intentionally eliminated as an option. Other requirements included lack of surface cracking, homogeneity, repeatability and a short laser processing time.

In order to create the optimum laser-nitrided surface, several strategies were used, based on a literature search of other successful laser-nitriding of titanium alloys. In order to decrease surface roughness, researchers have used techniques such as track over-lapping, a diluted processing atmosphere, and beam defocusing [12]. To avoid micro-cracking, substrate pre-heating [13–17], reduced cooling rates, a dilute processing atmosphere [12,15] and laser

* Corresponding author. Universidad Publica de Navarra, Campus de Arrosadia, Pamplona 31006, Spain. Tel.: +34 948 151277; fax: +34 948 152472.
E-mail address: gurutze.perez@unavarra.es (M.G. Pérez).

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Table 1
Abbreviated table of laser nitriding parameters tested

ID	Processing gas	Gas nozzle	Preheat temperature (°C)	Scan speed (mm/min)	Laser power (W)	Track overlapping (%)	Slow cool-down
T1	N2	Coaxial	None	1000	500	Single track	No
T10	N2	Coaxial	300	1000	500	Single track	No
T31	N2	Coaxial	500	1000	500	Single track	Yes
T32	N2–Ar	Coaxial	500	1000	500	Single track	Yes
T35	N2–Ar	Lateral	500	1000	500	Single track	Yes
T37	N2	Lateral	500	1000	500	Single track	Yes
T33	N2	Coaxial	500	1000	500	30	Yes
T34	N2–Ar	Coaxial	500	1000	500	30	Yes
T43	N2	Coaxial	500	1000	300	30	Yes
T45	N2–Ar	Coaxial	500	1000	300	30	Yes
T52	N2	Coaxial	500	3000	500	Single track	Yes
T57	N2	Coaxial	500	3000	500	25	Yes
T59	N2	Coaxial	500	3000	500	50	Yes
T53	N2	Coaxial	500	3000	500	100 (2 tracks superimposed)	Yes
T58	N2	Coaxial	500	2000	333	25	Yes
T60	N2	Coaxial	500	2000	333	50	Yes
T61	N2	Coaxial	500	2000	333	75	Yes
T62 a T71	N2	Coaxial	500	2000	333	75	Yes

scanning parameter optimization [12] have been employed. In this work, all of these techniques were tested, with the exception of beam defocusing, in order to obtain the optimum result for the chosen application. Beam defocusing was not employed due to the limitations of the laser used.

After the optimum nitrided surface was obtained, the laser nitrided titanium–aluminium alloy was tested for its wear response, coupled with a brass pin. The response of the laser-nitrided sample was compared with the response of a non-treated titanium–aluminium substrate and a titanium–aluminium substrate nitrided using physical vapor deposition (PVD).

2. Experimental methods

The substrate material for this work was a cast γ-based titanium aluminium alloy (Ti–44Al–8Nb–1B), provided by the University of Birmingham. The material was provided in the form of rectangular coupons, 20 mm × 20 mm × 2 mm. The coupons were prepared by removing the oxide case, caused by the casting process, with 180-grit SiC paper, followed by grinding with 280, P400 and P600 grit Si–C paper. The ground coupons were washed, degreased in an ultrasonic bath of acetone and stored in a dessicator until processed. Microstructural analysis revealed a fully lamellar ($\gamma + \alpha_2$) microstructure.

A 3-kW high power diode laser, $\lambda = 800$ to 980 nm, was used to laser nitride the titanium–aluminum coupons. The diode laser has the advantage of a rectangular beam profile, in this case a 1 mm × 4 mm spot, that allows quick and efficient scanning of large areas. The focusing distance of the diode laser is fixed; no defocusing is possible due to the large divergence of the beam. The nitriding gas, either pure nitrogen or a nitrogen–argon mixture, was delivered through a coaxial nozzle, specially designed to fit the diode laser and bathe the molten zone in the delivery gas.

The first experiments were done at room temperature, varying the laser scanning parameters and the delivery gas mixture. Because all samples produced at room temperature exhibited microcracks, substrate pre-heating and a reduced cooling rate were tested. Further experiments employing different nozzle configurations, overlapping tracks, gas mixtures and different scanning parameters were conducted

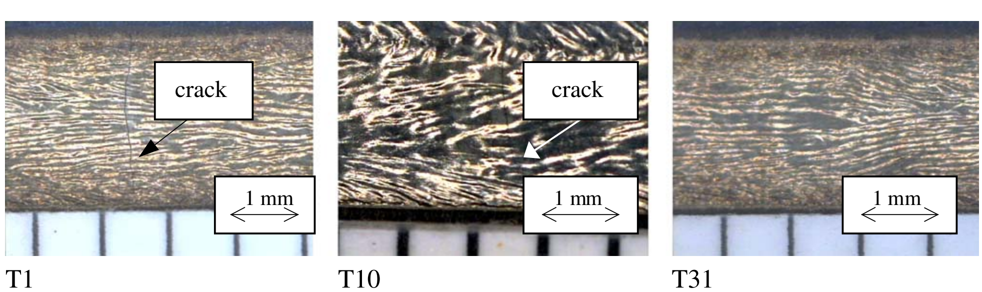

Fig. 1. Superficial photographs of laser nitrided samples. Macro-cracking (T1 and T10) and crack avoidance (T31). Each division: 1 mm.