Optics and Laser Technology 106 (2018) 182–190

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Direct laser cladding of the silicide dispersed titanium aluminide (Ti45Al5Nb0.5Si) composites

Jyotsna Dutta Majumdar [a,*], Silja Katharina Rittinghaus [b], Konrad Wissenbach [c], Daniel Höche [d], Carsten Blawert [d], Andreas Weisheit [c]

[a] Department of Metallurgical and Materials Engineering, Indian Institute of Technology Kharagpur, India
[b] Lehrstuhl fürLasertechnik LLT RWTH Aachen University, Steinbachstraße 15, D-52074 Aachen, Germany
[c] Fraunhofer-Institut fürLasertechnik ILT, Steinbachstraße 15, D-52074 Aachen, Germany
[d] Institut fürWerkstoffforschung, Helmholtz-ZentrumGeesthacht, Max-Planck-Straße 1, D-21502 Geesthacht, Germany

ARTICLE INFO

Article history:
Received 26 August 2017
Received in revised form 29 January 2018
Accepted 16 March 2018

Keywords:
Titanium aluminide
Titanium silicide
Microstructure
XRD
Microhardness

ABSTRACT

The present study concerns development of titanium silicide dispersed titanium aluminide composite with addition of 5 wt.% and 10 wt.% Si in Ti45Al5Nb0.5Si base alloy by direct laser cladding under varied process parameters. Direct laser cladding has been conducted using a high power (3 kW) fiber optic delivered Nd:YAG laser (with a beam diameter of 2 mm) using a 3-axis handling system in a layer by layer fashion to develop a coupon with a dimension of 10 mm × 10 mm × 4 mm. The effect of process parameters (applied power, scan speed and powder feed rate) on the depth and integrity of the clad zone, microstructures and microhardness have been studied in details to optimize process parameters. Addition of Si leads to formation of micro-cracks in the microstructures under varied parameters. There are formations of different silicides (Ti_5Si_3, $Ti_7Al_5Si_{12}$, $TiSi_2$ and TiSi phases) in the microstructure of the base alloy with the presence $\alpha_2 + \gamma$ phase. The microhardness of the clad layer increases with addition of Si. However, optimization of process parameters needs to be undertaken for the formation of defect free microstructure with improved hardness.

1. Introduction

Titanium aluminide based intermetallics have received a considerable attention as aerospace and automotive components due to its high specific strength, low density and considerably better elevated temperature corrosion resistance property than pure titanium [1–4]. However, a relatively poor high temperature strength and oxidation resistance and sensitivity to high temperature embrittlement due to the dissolution of oxygen are the main troubles for the wide range applicability of this material [4]. In the past, attempts were made to improve the high temperature oxidation resistance of TiAl based alloy by coating with MCrAlY based alloy to form alumina as protective oxide scale [5–7]. However, this coating did not serve well due to their poor chemical and physical compatibility with the substrate aluminide [5–7]. Thin film deposition of aluminium by physical and chemical vapour deposition was also reported to improve high temperature oxidation resistance, but not with a reduced durability because of the formation of brittle phase in the coating [8]. It has been reported that suitable addition of Ag and Cr promotes the formation of a thin and protective aluminium oxide scale on the surface when heated at high temperature and can be successfully applied as coating too [9–12]. However, the minimum Cr content required for a protective alumina formation is 10 at.%, which causes formation of substantial amount of Laves phase, resulting in poor ductility of the material [9,10]. On the other hand, addition of Ag suppresses the formation α_2-Ti_3Al and consists of single phase γ-TiAl phase, causing a poor strength at room and elevated temperature. Among other ternary elements, Si was reported to be most effective in improving high temperature properties of TiAl based alloy, which improves the creep resistance of the alloy due to the formation of Ti_5Si_3 as the strengthening phase [13].

Laser, as a source of heat has been proven to be a precision additive layer manufacturing route, possessing several advantages like manufacturing of parts with a faster processing speed, ability of attainment of non-equilibrium microstructures and repairing of tools [14–16]. Direct laser cladding (DLC) is a process of development of near net shape component directly from the pre-

* Corresponding author.
E-mail addresses: duttamajumdarjyotsna@gmail.com (J.D. Majumdar), silja-katharina.rittinghaus@ilt.fraunhofer.de (S.K. Rittinghaus), konrad.wissenbach@ilt.fraunhofer.de (K. Wissenbach), Daniel.Hoeche@hzg.de (D. Höche), Carsten.Blawert@gkss.de (C. Blawert), andreas.weisheit@ilt.fraunhofer.de (A. Weisheit).

https://doi.org/10.1016/j.optlastec.2018.03.012
0030-3992/

cursor material by melting it in the form of wire or powder and subsequently, depositing the molten material to develop the predetermined shape of the component [14–16]. In the past, DLC was successfully applied for the development of metals/alloys, and repairing of turbine blades [16]. DLC was also reported to be applied for the development of TiAl based alloys [17,18]. Ocylok et al. [19] reported the effect if addition of Si and TiB_2 additions on improving the abrasive wear resistance and high temperature oxidation resistance of TiAl alloy.

In the present study, titanium silicide dispersed titanium aluminide matrix composite has been developed by addition of 5 wt.% and 10 wt.% Si in Ti45Al5Nb0.5Si based titanium aluminide under varied process parameters. The effect of process parameters (applied power, scan speed and powder feed rate) on the depth and integrity of the clad zone, microstructures and microhardness has been studied in details.

2. Experimental

In the present study, commercially available Ti45Al5Nb0.2Si alloy powder (particle size ranging from 20 to 90 μm, manufacturer: Alpha Aeser) and Si powder (manufacturer: Alpha Aeser) of particle size +40 μm −100 μm in the weight ratio of 95:5 and 90:10 have been mixed in a mechanical mixer for 2 h at 25 rpm and used as precursor powder for direct laser cladding (DLC). Fig. 1 shows the scanning electron micrograph of Ti45Al5Nb0.2Si alloy powder used in the present study. From Fig. 1 it may be noted that the powders are irregular in shape. Direct laser cladding was conducted by melting the precursor powder mixtures using a high power (3 kW) fiber optic delivered Nd:YAG laser (continuous wave with a wavelength of 1064 nm and with a beam diameter of 2 mm) using a 3-axis handling system in a layer by layer fashion on Ti-6Al-4V substrate to develop a coupon with a dimension of 10 m m × 10 mm 8 4 mm. Fiber optics delivered Nd: YAG laser clad head was used. Powder was supplied through a side nozzle using a pneumatic powder delivery system with argon as carrier gas at a powder feed rate ranging from 1.5 to 2.6 mg/s. During direct laser cladding, pre-heating was applied by using a hot plate capable of heating the samples up to 780 °C. It is noted that after finishing the DLC process the samples are cooled down slowly (with approx. 8 K/min) to avoid cracking due to thermal stresses. Table 1 shows the detailed process parameters employed in the present study. The process parameters chosen under the present investigation are under the regime of no melting and surface evaporation derived out of a large numbers of parameters chosen for direct laser cladding of the given alloy. To prevent oxygen pick-up from the surrounding, a global shielding atmosphere is provided by use of a gas-purged chamber (glovebox) in which the whole direct laser cladding set-up is mounted. The main process variables in the present study were applied powder (300–500 W), scan speed (200–400 mm/min) and powder feed rate (1.8–2.6 mg/s). The powder was delivered using a co-axial nozzle with Ar as carrier gas. Followed by DLC, the microstructures of the as-processed samples (both the top surface and cross section) were characterized by optical microscope (model no.: AXIO-Imager-Azm, Zeiss SMT AG, Germany) and a scanning electron microscopy (LEO 1455 EP, Zeiss SMT AG, Germany) coupled with energy dispersive X-ray (EDX) micro-analyzer. Compositional analysis was carried out using energy dispersive spectroscopic analysis (EDX) (OXFORD-X-mer). The phases present in the microstructure of the DLC coupon are analyzed by X-ray diffraction (XRD) (X'Pert PRO Diffractometer, PANalytical, Almelo, The Netherlands) technique in Bragg-Brentano (ϴ-2ϴ) geometry operated at an accelerating voltage of 40 kV using Cu-K_α radiation (2ϴ from 15° to 100°). The microhardness of the top surface and cross section of DLC was carried out using Vicker's microhardness tester (Model No.: Leco M-400-G) at an applied load of 300 g with 15 s indentation duration.

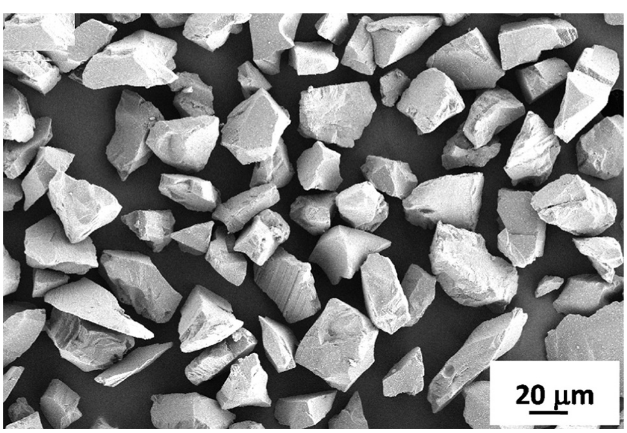

Fig. 1. Scanning electron micrograph of the Ti45Al5Nb0.2Si powder used in the present study for cladding.

3. Results and discussions

3.1. Microstructural evolution

Fig. 2(a)–(c) shows the optical micrographs of the cross section of of direct laser clad (a) Ti45Al5Nb0.2Si, (b) Ti45Al5Nb5Si and (c) Ti45Al5Nb10Si lased with an applied power of 400 W, scan speed of 300 mm/min and powder feed rate of 2.2 mg/s. From Fig. 2 it may be noted that there is formation of a continuous clad layer with the absence of any sharp interface between the two successive clad zones. The laser clad zone is semi-circular in shape, 10% overlapping was employed and dilution in the first layer was 10%, however, was ignored and the middle layer was taken into consideration for the stated investigation. The different layers are labeled as 1, 2 and 3. From Fig. 2 it may further be noted that addition of Si leads to presence of a large numbers of globular agglomerated droplets in the clad zone. The area fraction of the solidified isolated droplets was found to increase with increased Si content of

Table 1
Summary of process parameters employed and the integrity of the clad zone.

Process parameters	300 mm/min, 2.2 g/s			500 W, 2.2 g/s		500 W, 300 mm/min	
	400 W	500 W,	600 W	200 mm/min	400 mm/min	1.8 mg/s	2.6 mg/s
Defects/microstructure							
Systems							
Ti45Al5Nb0.5Si	Defect free	Defect free	Defect free	Defect free	Defect free	Defect free	Defect free
Ti45Al5Nb5Si	Defect free	Cracks	Defect free	Defect free	Cracks	Defect free	Cracks
Ti45Al5Nb10Si	Defect free	Cracks	Defect free	Cracks	Cracks	Cracks	Cracks