International Journal of Fatigue 72 (2015) 42–52

Contents lists available at ScienceDirect

International Journal of Fatigue

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

Fatigue life of laser clad hardfacing alloys on AISI 4130 steel under rotary bending fatigue test

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ARTICLE INFO

Article history:
Received 28 September 2013
Received in revised form 25 October 2014
Accepted 2 November 2014
Available online 13 November 2014

Keywords:
Laser cladding
Hardfacing coatings
Fatigue life
Neutron diffraction
Residual stresses

ABSTRACT

Fatigue life study of structures constructed by laser cladding using two types of hardfacing alloy, Stellite 6 (Co base) and Deloro 40G (Ni base) on AISI 4130 steel substrate was conducted using rotary bending fatigue test at ambient temperature 20 °C. The laser clad specimens showed a reduced fatigue life compared to the specimen without cladding but of the same size due to the presence of residual stresses in substrate and coating regions. The presence of higher compressive residual stresses in substrate region and lower tensile residual stress in coating region of specimen laser clad with Stellite 6 generated longer fatigue life compared to the specimens laser clad with Deloro 40G, at a similar coating thickness level. With the same final structure size, coating thickness produced an inversely proportional effect on fatigue life where thinner coatings result in less reduction of fatigue life compared to thicker coating. The analytical model employed in this study demonstrated that thinner coatings alters axial residual stress by generating lower tensile residual stress in coating region which enhance fatigue life, compared to thicker coatings. This work has demonstrated the influence of coating type, coating thickness and load level on the fatigue life of the laser clad structures.

1. Introduction

Laser cladding is a laser surfacing technique that can enhance the properties and/or regenerate the surface of a component. In laser cladding, laser radiation is absorbed and melts a small region of the substrate into which the coating material is injected and fuses the coating material to the substrate, thus producing a new layer (Fig. 1). Compared to other thermo-mechanical processes, laser cladding is identified to be superior in terms of its capability to produce lower dilution levels [1–3] and finer microstructure in clad layer [2,4], thus this technique has been implemented to enhance surface properties, i.e. increases surface hardness [5,6], wear resistance [3,7,8] and corrosion resistance [9,10]; refurbish deteriorated engineering component across different industries [4,11–16]; and perform rapid prototyping with the aid of numerically controlled equipment (CNC) [17]. Despite the extensive research on laser cladding for re-surfacing or rapid prototyping, little information can be found on fatigue life of structure constructed by laser cladding, a type of loading that many engineering components are exposed in service. Several studies have addressed fatigue life of structure constructed by laser cladding using uniaxial tensile-compression fatigue load [18] and bending fatigue load [19] which represent two of the types of loading applications for fatigue. However, the fatigue life behavior based on rotary bending loading, in particularly simulating a shaft refurbished by laser clad hardfacing alloys on its surface, has not been extensively investigated. The analysis of fatigue life is based on the alteration in residual stresses generated by laser cladding processes.

2. Experimental and numerical simulation

2.1. Laser cladding

The substrate and coating materials used in this experiment were AISI 4130 steel, Stellite 6 and Deloro 40G, respectively, with chemical composition shown in Table 1. Laser cladding was performed with a fiber delivered Nd:YAG Rofin Sinar laser, using a power of 550 W, a spot size 3 mm with a Gaussian beam profile and was shielded by Argon gas, with a scan speed of 500 mm/min. Stellite 6 and Deloro 40G powder was injected using an off-axis nozzle inclined at 60° to the substrate surface with powder

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http://dx.doi.org/10.1016/j.ijfatigue.2014.11.001
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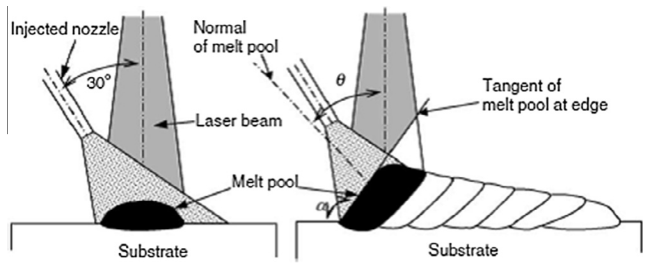

Fig. 1. Schematic illustration of single track and multi tracks laser cladding process [5].

feed rate of 4 g/min. Multiple tracks and multiple layers of Stellite 6 and Deloro 40G, each with powder size of 45–150 µm, were circumferentially deposited onto the surface of the grooved part of round bar AISI 4130 steel (Fig. 2).

2.2. Laser clad and fatigue test specimens manufacturing

The manufacturing of laser clad specimens were initiated by cutting a 12 mm diameter 4130 steel rod into 146 mm sections and followed by created groove at the middle of each section (Fig. 2). The diameter of grooved sections was set to three different size 5.5 mm, 6 mm and 6.5 mm that after laser cladding will create three different thickness of coating layer when cladding of the grooved section reaches the target diameter of minimum 8.3 mm. Smallest grooved section diameter (5.5 mm) is expected to generate the thickest coating layer (1.4 mm) while the largest grooved section diameter (6.5 mm) generate the thinnest coating layer (0.9 mm). Following the manufacturing of grooved section, multiple tracks with 70% overlap between track and multiple layers with 0.25 mm increment between each layer of Stellite 6 hardfacing alloy was laser clad onto the grooved section until the final grooved section diameter reached the minimum 8.3 mm, measured using Vernier caliper. Using the similar specimen geometry and laser processing parameters, sets of specimens were manufactured by deposited Deloro 40G hardfacing alloy on the grooved section of the specimens. This combination of initial groove diameters and laser cladding process parameters generated cladding layers with average thicknesses ranging from 1.06 to 1.82 mm in the machined fatigue samples.

Following the manufacturing of laser clad specimens, one specimen with grooved section diameter of 5.5 mm laser clad with Stellite 6 (specimen code STS) and one specimen laser clad with Deloro 40G (specimen code DS) were separated for residual stress measurement using neutron diffraction while others underwent a machining process to convert laser clad specimens to fatigue test specimens (Fig. 3). Along with laser clad specimens, substrate only (uncoated 4130 steel) also machined in order to manufacture fatigue test specimens (Fig. 3). All laser clad specimens that were machined down to fatigue test specimens geometry showed that coated region fully covered by coating material and no undercut was observed. This implied that the addition of 0.15 mm thick of coating layer that yielded 8.3 mm diameter on grooved section was sufficient to compensate dimensional distortion (e.g. bent) that occur during laser cladding process. Fatigue test specimens manufacturing was finalized by applying surface notch on the surface of substrate only (Fig. 4a) and on the surface coated specimen (Fig. 4b). The surface notch was made using wire cut method with a wire diameter of 0.25 mm, the depth of notch was 0.5 mm.

2.3. Metallography and hardness

The laser clad specimens were cut perpendicular to the laser clad track direction and ground-polished down to 1 µm. The samples were then etched in 2% Nital solution to reveal the microstructure of coating and heat affected zone at the vicinity of interface (location C and H in Fig. 4b). The Stellite 6 and Deloro 40G were electrolytically etched in 2% Nital solution using a circuit voltage of 8–10 mV. Micro-Vickers hardness measurements were performed using Buehler Micro Hardness Tester unit under 100 g load to measure the hardness of the coating and the substrate.

2.4. Residual stress measurement

Considering the fact that bending of a solid cylindrical object generates tension and compression along its axial direction, therefore the main interest of this research is to measure the axial residual stress that affecting the tension and compression stresses in axial direction of the specimen.

Table 1
Chemical composition of AISI 4130 steel, Stellite 6 and Deloro 40G.

	Composition (wt%)										
	Fe	C	Mn	P	S	Si	Cr	Mo	Co	Ni	W
AISI 4130 [47]	Bal	0.28–0.33	0.40–0.60	0.035 max	0.04 max	0.15–0.30	0.80–1.10	0.15–0.25			
Chemical composition Stellite 6											
Stellite 6 [48]	3	1.2	1			1.5	29	1.5	Bal	3	4.5
Deloro 40G[a]	1.5	0.35				3.5	7.5			Bal	1.7

[a] Material Safety Data Sheet (MSDS) of Deloro 40G.

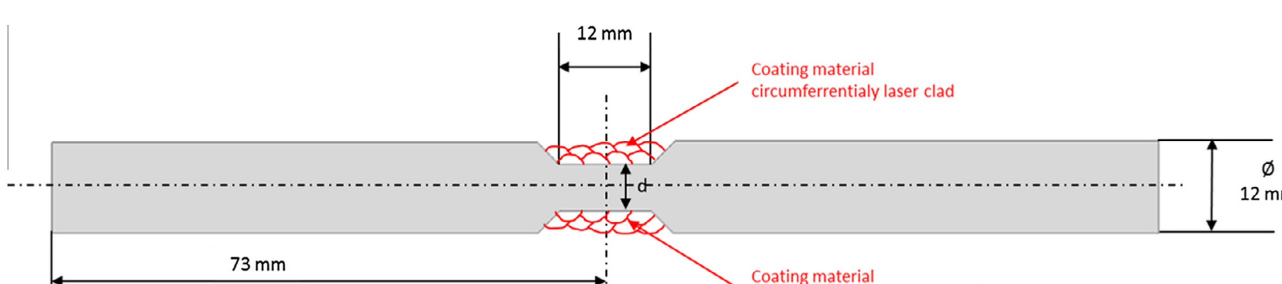

Fig. 2. Laser cladding specimen geometry. Diameter of grooved section (d) are 5.5 mm (S), 6 mm (M) and 6.5 mm (B).