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A parametric study of Inconel 625 wire laser deposition☆

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ABSTRACT

Laser deposition with wire offers saving potentials over powder based systems. These include a cleaner processing environment, reduced economic and environmental cost of producing the wire, better surface finish and higher material deposition rates. This technique is rapidly finding applications for the manufacture and repair of high value components. For the first time, the deposition of Inconel 625 wire for single tracks at varying processing parameters using a 2-kW Ytterbium doped fibre laser has been investigated. A process map predicting the process characteristics in terms of wire dripping, smooth wire transfer and wire stubbing at different cladding conditions has been developed. Track geometrical characteristics including aspect ratio and contact angle were evaluated using surface profilometry and optical microscopy. Scanning electron microscopy equipped with energy dispersive X-ray spectroscopy was used to determine the dilution ratio (%) of the tracks. Wire deposition volume per unit length of track and energy per unit length of track were found to be key parameters influencing both the process and track geometrical characteristics. Aspect ratio and dilution ratio showed positive dependency whereas contact angle showed negative dependency on energy per unit length of track. Conversely, material deposition volume per unit length of track varied directly with contact angle but inversely with aspect ratio and dilution ratio (ranging from 0% to 24%). Processing conditions at which a combination of favourable single track properties including low contact angle (<80°), minimal dilution ratio (5–13%) and high surface quality were achieved are presented. These properties are required for depositing overlapped tracks of good surface finish, minimal dilution and free of inter-run porosity.

1. Introduction

Laser cladding had been shown to be an effective metal surface coating technique capable of increasing component lifetime. The technique has several advantages over competing coating techniques such as plasma cladding, arc welding and thermal spraying. These include strong metallurgical bond at the clad–substrate interface (Chen et al., 1996), minimal distortion of the substrate (Desale et al., 2009), low dilution (Huang, 2011), minimal porosity (Sexton et al., 2002) and controllable heat input often producing a small heat affected zone (HAZ) (Huang et al., 2004).

Laser cladding involves the use of a high-precision heat source to create a melt pool by simultaneously melting the additive material and a thin layer of a substrate. The relative movement of the laser beam and the substrate forms a track. The track is most often referred to as a clad bead. Additive material which is either in powder or wire form can be delivered using three methods. Preplacing powder in the form of slurry on the substrate prior to heat application is less flexible compared with other methods. The coaxial and side feeding of powder currently has wide applications over side feeding of wire due to high availability of additive materials in powder form.

Extensive research in laser cladding using metal powder has been undertaken for enhanced surface performance. Consequently, a range of high corrosion and wear resistant materials had been processed in this way. Desale et al. (2009) researched on the erosion wear behaviour of Colmonoy-6 and Inconel 625 powders. Baldridge et al. (2013) have reported the analysis of laser cladding of Inconel 690 powder on Inconel 600 for corrosion protection in nuclear applications. Cobalt-based alloys have also been the subject of some investigation by Lusquiños et al. (2009). Quantitative characterisation of porosity in stainless steels LENS powders and deposits have also been reported by Susan et al. (2006). Common observations amongst these processes are high surface roughness, low powder deposition rate and susceptibility of the clad to porosity usually caused by the entrapment of gas in the powder. As a result, cladding with powder material is less economical for coating large areas, especially, where high dimensional accuracy

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Table 1
Chemical compositions of Inconel 625 wire and 304 stainless steel in wt.%.

Element	Ni	Cr	Mn	Si	Al	Ti	Fe	C	Mo	Nb	P	S
Inconel 625	Bal	22.46			0.26	0.26	0.14	0.02	8.84	3.46		
304 stainless steel	7.86	18.58	1.78	0.42			Bal	0.08			0.10	0.03

is of paramount importance. Also, presence of porosity is disadvantageous to the corrosion behaviour of the clad (Zareie Rajani et al., 2013).

Due to its combination of favourable properties such as high temperature strength, excellent corrosion resistance, high ductility and good stress corrosion cracking resistance, Inconel 625 (a nickel based superalloy) has been the material choice for a diverse range of applications. These include gas turbine ducting, furnace hardware and components exposed to seawater (Paul et al., 2007). More importantly, the low dilution of the laser cladding technique coupled with the excellent corrosion properties of the alloy had extended the applications of Inconel 625 laser coating to oil and gas industry. Down-hole drilling equipment are manufactured from stainless steels because of their high impact strength, reasonable corrosion resistance and low cost (Sue et al., 2010). The resistance offered by the steels against corrosion is limited because steels suffer localised corrosion in specific environments, particularly in chloride ion rich solutions (Mahmood et al., 2012). Following this fact, the lifetime performance of off-shore equipment in harsh corrosive environment is currently being increased by laser coating the surface of the steels with Inconel 625 alloy. To date, a number of studies have been reported on laser deposition of Inconel 625 powder, for example, the microstructural evolution (Dinda et al., 2009), optimising processing parameters (Paul et al., 2007), thin wall manufacture (Gao et al., 2011) and corrosion properties of coatings (Tuominen et al., 2003). However, laser deposition using Inconel 625 wire as a feedstock material rather than powder has not been undertaken.

Laser cladding with lateral wire feeding system, compared with powder based feeding systems, offers better rewards such as increased material usage efficiency (Syed et al., 2005), improved surface quality of the deposit (Heralic, 2009), lower cost of preparing the wire materials (Kim and Peng, 2000) and higher material deposition rates (Syed et al., 2005). However, wire based systems are highly sensitive to changes in processing condition. As a result, it is important to establish a balance of several impacting processing parameters such as wire tip position in the meltpool, feed angle, feed direction, laser spot size, laser power (P), wire feed rate (WFR) and traverse speed (V) before a stable wire deposition process can be achieved.

Three wire tip positions, i.e. the centre, leading and trailing edges, in the meltpool have been identified by Syed and Li (2005). When the wire tip was positioned at the trailing edge, Syed and Li (2005) discovered that the deposition process was mainly characterised by droplet transfer of wire (dripping) forming irregular beads whereas smooth wire transfer was only found possible at the centre and leading edge of the meltpool. Mok et al. (2008) established that wire feed angle around 45° gives the highest track deposition efficiency during diode laser cladding of Ti–6Al–4V wire with front feeding orientation. In the past, optimisation of the processing parameters for Nd–YAG laser deposition with wire of ZE41A-T5, a magnesium alloy, using Taguchi method for parameter design had been undertaken (Cao et al., 2008). The results include the variation of dilution ratio with the main processing parameters. However, a study of the laser deposition with wire process characteristics at varying processing parameters is absent from the literature. Also, significantly few authors have reported on the investigation of the wetting angle usually referred to as contact angle of laser deposited wire tracks at varying cladding conditions.

In this study, single tracks of Inconel 625 wire were deposited at varying processing parameters via laser cladding. The primary objectives are of two folds. Firstly, a process map which predicts Inconel 625 wire fibre laser deposition process characteristics at varying processing parameters will be developed. Secondly, processing parameters at which a combination of favourable single track properties including low contact angle (<80°), minimal dilution ratio (5–13%) and high surface quality can be achieved will be determined. These properties are quality criteria for depositing overlapped tracks of good surface finish, minimal dilution and free of inter-run porosity.

2. Experimental

2.1. Materials

Plates of dimension 100 mm × 180 mm × 6 mm were machined from austenitic stainless steel AISI 304 and used as substrate material. These were grit blasted and cleaned with acetone before the deposition runs so as to improve substrate surface laser absorptivity and remove contaminants, respectively. The additive material is Inconel 625 wire of 1.2 mm diameter supplied by VBC group, Loughborough, UK. Table 1 gives the chemical compositions of Inconel 625 wire and AISI 304 stainless steel, as quoted by the manufacturers.

2.2. Laser processing

A diagram of the laser deposition system used in this study is shown in Fig. 1. Deposition was performed using a 2 kW Ytterbium doped fibre laser (IPG Photonics) operating at 1070 nm wavelength. The beam was focused to a small round spot of approximately 3.1 mm at 20 mm away from focus giving a 212 mm working distance with a Gaussian energy distribution. Inconel 625 wire was "front fed" at an angle of 42 ± 1° to the horizontal so as to aim the wire tip at the centre of the meltpool. A WF200DC wire feeder (Redman Controls and Electronic Ltd.) was used.

Single tracks were deposited, at varying processing parameters, on the steel plates inside a transparent enclosure (bag) which was evacuated and back-filled with high purity argon gas supplied at 0.42 l s^{-1}. The utilised processing parameters were selected following preliminary trials so as to reduce the number

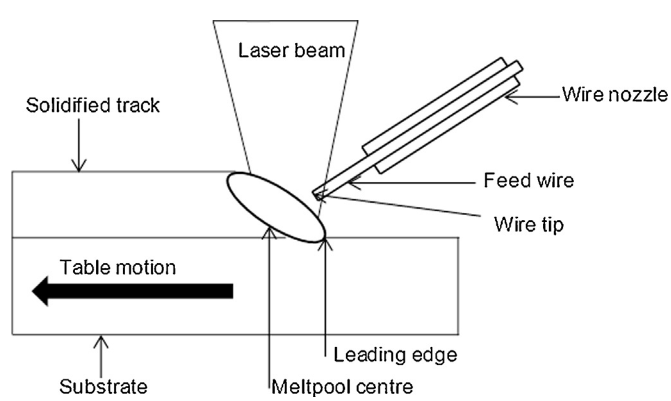

Fig. 1. Schematic representation of the laser deposition system.