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Effect of flux cored arc welding process parameters on bead geometry in super duplex stainless steel claddings

B. Senthilkumar [a,*], T. Kannan [b]

[a] Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore 641 049, Tamil Nadu, India
[b] SVS College of Engineering, Coimbatore 642 109, Tamil Nadu, India

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ABSTRACT

The welding heat input plays a significant role in determining the microstructure and composition of the super duplex stainless steel cladding. The welding process is represented in the form of mathematical models developed using response surface methodology. The models were then used to predict the weld bead characteristics with reasonable accuracy. In this work, the models were developed to relate the identified important process parameters like welding voltage, wire feed rate, welding speed, nozzle to plate distance and welding gun angle with bead geometry. The models found to satisfy the adequacy requirements. It was found that reinforcement form factor was influenced by the factors arc length, torch travel speed, melting rate and resistance heating of the electrode. In the same way penetration form factor is influenced by the arc length, torch travel speed and arc force at the weld puddle. Contact angle influenced by the melting rate and resistance heating of the electrode.

1. Introduction

Corrosion reduces the service life of the components used in the process industries like chemical, petrochemical, paper and pulp industries. Any increase in the service life leads to significant cost and energy savings. The conventional materials like low – carbon steels possess the required strength to meet the needs of the industries. It is preferred because of its low cost and relative ease of fabrication. The major limitation of this low-carbon steel is their poor corrosion resistance. This limitation led to the development of corrosion-resistant materials like stainless steels. The strength and properties of the stainless steels are closely associated with its microstructure. Super duplex stainless steels contain approximately equal proportions of ferrite and austenite grains, which improve strength, resistance against pitting and stress corrosion cracking than their austenitic counterpart [1]. These materials are highly sensitive to the heat and their operating range of temperature is limited between −100 °C and 300 °C to avoid loss of ductility and formation of brittle phases [2]. The fabrication of bulk stainless steel components is limited due to narrow processing limits enforced to prevent the loss of the desirable properties [3–7]. The alternate way to overcome this difficulty is to clad the stainless steel with low alloy steel. Cladding is the process of depositing a relatively thick layer of corrosion-resistant material usually of stainless steel over a low-carbon steel substrate to improve the corrosion resistance [8]. The claddings can be produced by wide range of processes like roll bonding, centric cast, welding, explosive cladding, etc. Welding is a preferred cladding process because of its ability to process prefabricated components and its control on the heat input. The relationship between the bead dimensions and the heat input can be established in the form of mathematical models [9,10]. Simulation of these models

* Corresponding author.
E-mail addresses: bsk_senthilkumar@hotmail.com (B. Senthilkumar), kannan_kct@yahoo.com (T. Kannan).

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helps to understand the complex relationships that exist between the various process parameters and their impact on the properties [11–13]. Automation of the weld cladding process ensures close control of heat input there by producing deposits with uniform composition and microstructure. The FCAW process is found to be versatile because of its smooth bead appearance, all position and automation capabilities [14,15]. The main objective of this experimental investigation is to develop mathematical models in terms of process parameters to predict bead geometry. The data required to develop the models were collected from the experiments based on central composite rotatable design. The developed models can be used to study the direct and interaction effects of the important process parameters on the responses like bead geometry. The experimental investigation was carried out using 1.2 mm diameter super duplex stainless steel flux cored electrode (2507) deposited over a low carbon structural steel plate shielded by the gas mixture of 80% argon and 20% CO_2.

2. Experimental setup

The experimental setup used in this study is shown in Fig. 1. The multi process welding machine Lincoln electric Invertec® V350 PRO coupled with wire feeder LF 74 was used to deposit single bead on the surface of the plates. The electrode is Metrode Supercore FC 2507 (AWS A5.22E2594T0-4) and the base metal is low carbon structural steel. The composition of the base metal and electrode is given in Table. 1. The shielding gas mixture contains 80% argon and 20% CO_2 at a flow rate 25 L/min. The welding torch was held stationary and the manipulator table is moved. The manipulator has the provisions for varying the table speed, and welding torch positioning.

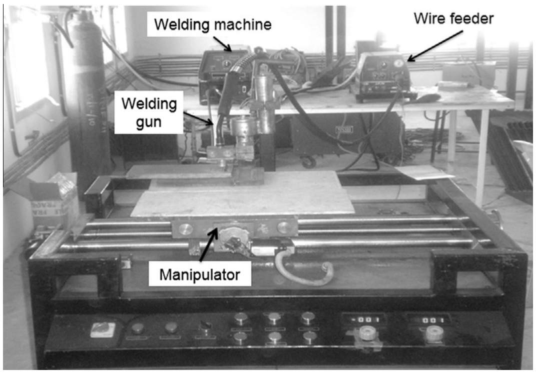

Fig. 1. Experimental setup.

The type of welding process and welding voltage were set at the controller and the wire feed rate was set at the wire feeder and the gas flow rate was measured and controlled by the flow metre attached to the regulator of the cylinder.

3. Experimental investigation

The heat input to the welding process strongly affects the microstructure, composition and properties of the deposited layer. Further super duplex stainless steels are sensitive to the welding heat input and it is limited to the range 0.5–1.5 kJ/mm [16]. The identified process parameters are welding voltage (X_1), wire feed rate (X_2), welding speed (X_3), nozzle to plate distance (X_4) and welding gun angle (X_5). The responses are reinforcement form factor (RFF), penetration form factor (PFF) and contact angle (CA). The working ranges of the process parameters were established by conducting trial runs and observing the bead for any visual defects such as cracking, porosity, and discontinuity, The maximum and minimum values of the parameters were coded as +2 and −2 respectively [17,18]. The intermediate levels were coded using the formula given in Eq. (1). The parameter levels and corresponding values are given in Table 2.

$$X_i = \frac{2[2X - (X_{max} + X_{min})]}{(X_{max} - X_{min})} \tag{1}$$

The parameter combinations in the coded form were presented in Table 3. The design matrix consists of 16 factorial combinations, 10 star points and 6 centre points [19]. The experiments were conducted as per the design matrix at random to reduce bias and before conducting experiments all the parameters were intentionally disturbed to introduce variance in the experimental error. After each pass, the plates were allowed to cool to the room temperature in the open air. A total of 32 deposits were made and each bead sectioned perpendicular to its length and the parallel bead faces were polished.

The polished surfaces were then etched with 5% nital solution to develop the penetration profile. Fig. 2 shows the sectioned weld bead and polished and etched surface. The bead profile was constructed on the transparencies using the reflective type optical profile projector with 10X magnification. Then the bead profiles were imported into the AutoCAD® software for the measurement of responses. The collected responses were presented in Table 3.

4. Mathematical modelling and its validation

The responses are represented as second-order equations of the form given in Eq. (2). The coefficients of the

Table 1
Composition of electrode and base metal.

Material	Elements (% wt.)									
	C	Mn	Si	S	P	Cr	Ni	Mo	N	Fe
Electrode	0.027	0.64	0.47	0.005	0.018	25.8	8.62	4.36	0.28	Balance
Base metal	0.196	1.12	0.293	0.011	0.0044	0.128	0.0336	0.0275	–	