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Pitting corrosion resistance and bond strength of stainless steel overlay by friction surfacing on high strength low alloy steel

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Abstract

Surface modification is essential for improving the service properties of components. Cladding is one of the most widely employed methods of surface modification. Friction surfacing is a candidate process for depositing the corrosion resistant coatings. Being a solid state process, it offers several advantages over conventional fusion based surfacing process. The aim of this work is to identify the relationship between the input variables and the process response and develop the predictive models that can be used in the design of new friction surfacing applications. In the current work, austenitic stainless steel AISI 304 was friction surfaced on high strength low alloy steel substrate. Friction surfacing parameters, such as mechtrode rotational speed, feed rate of substrate and axial force on mechtrode, play a major role in determining the pitting corrosion resistance and bond strength of friction surfaced coatings. Friction surfaced coating and base metal were tested for pitting corrosion by potentio-dynamic polarization technique. Coating microstructure was characterized using optical microscopy, scanning electron microscopy and X-ray diffraction. Coatings in the as deposited condition exhibited strain-induced martensite in austenitic matrix. Pitting resistance of surfaced coatings was found to be much lower than that of mechtrode material and superior to that of substrate. A central composite design with three factors (mechtrode rotational speed, substrate traverse speed, axial load on mechtrode) and five levels was chosen to minimize the number of experimental conditions. Response surface methodology was used to develop the model. In the present work, an attempt has been made to develop a mathematical model to predict the pitting corrosion resistance and bond strength by incorporating the friction surfacing process parameters.

Keywords: Friction surfacing; Coating; Pitting corrosion resistance; Response surface methodolgy

1. Introduction

The surfaces of engineering materials are given the specific treatments that are different from those of the core. These treatments can alter the composition of the case by incorporating the specific species on the surface of the substrate material or it can be subjected to heat treatment which do not alter the composition of the substrates or the deposited layer can have a different material than the substrate. The surface treatments can be physical, physico–chemical, fusion, as well as non-fusion based. Solid state process that does not involve melting and solidification is versatile as it gives rise to the deposits which are free from solidification related defects it is an amenable process for many incompatible dissimilar metals owing to the short interaction time available for the extensive formation of deleterious intermetallics. Friction surfacing is one such solid state process currently being pursued extensively for various surfacing applications requiring wear and corrosion resistance properties. A schematic diagram of the surfacing process is shown in Fig. 1. The friction surfacing process involves a rotating coating rod called mechtrode that is brought in contact with the substrate under axial load. Intense friction heat is produced on the rubbing surface between the

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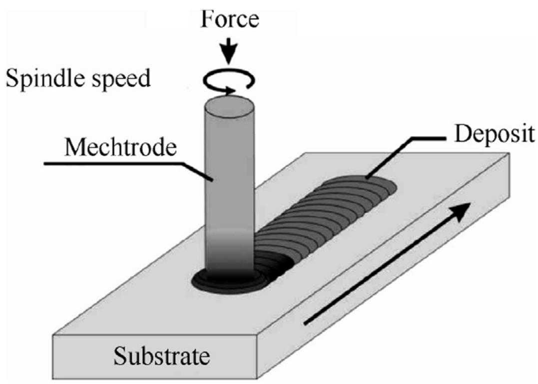

Fig. 1. Friction surfacing process.

substrate and the coating rod. Generated heat is sufficient to plastically deform the end of the mechtrode. A layer of mechtrode material is deposited by moving the substrate across the face of the rotating rod. Metal coatings are made possible by the generation of high contact stress and intimate contact between the coating material and substrate which initiates solid-state adhesion between the coating and the substrate [1]. Being a solid state process, the friction surfacing offers several advantages over conventional fusion welding processes. Friction surfaced coatings exhibit zero dilution and wrought microstructures with very fine grain size. Since melting and solidification are not involved, the problems, such as solidification cracking, brittle intermetallic formation and porosity, do not arise. The critical areas of application include the deposition of hard facing materials on cutting edges of knives of various categories, punch, die, tools and blades required for food processing, chemical, agriculture and medical industries. It opens up a new area of repair and reclamation of worn and damaged components [2,3].

However, the use of friction surfacing process for many applications has been limited due to the difficulty of monitoring and control of the process outputs, such as bond quality and coating dimensions [4]. Proper selection of process parameters is vital for obtaining the quality coatings using friction surfacing. Selection of process parameters and torque-time characteristic are important for the quantum of heat generated at the contact surface and to maintain consumable at quasi steady status in entire process, which affect the quality of deposit [5].The three main friction surfacing parameters are rotational speed of mechtrode, substrate traverse speed and axial force on mechtrode by means of which the desired quality of the coating layer with improved bond strength and corrosion resistance can be achieved [6,7]. Empirical investigations are normally required to determine the optimum parameters that produce the required process response.

High strength low alloy steel is widely used due to easy availability and good weldability. Corrosion resistance of low alloy steel can be improved by surface coating with stainless steel, high speed steel, tool steel and metal matrix composites [6–8]. A number of successful research studies on friction surfacing of similar and dissimilar combinations have been done especially in the areas of microstructural analysis of coating and mechanism during process [9,10]. However very few systematic studies have been performed on relationship between the various process parameters and resulting properties, especially bond strength and corrosion resistance. In the present study, AISI 304 was chosen considering its widespread industrial use as corrosion resistant clad material for high strength low alloy steels. This investigation is aimed at studying the microstructure, pitting corrosion resistance and bond integrity of friction surfaced austenitic stainless steel 304 coatings produced on high strength low alloy steel substrate in detail.

Table 1
Chemical composition of materials.

Materials	Elements/wt. %							
	C	Si	Mn	Ni	Cr	P	S	Fe
High strength low alloy steel(substrate)	0.08	0.3	1.5	0.8	0.3	0.015	0.012	Rest
AISI304(mechtrode)	0.05	1.0	1.0	8.0	18	0.045	0.03	Rest

2. Materials and experiment

The stainless steel AISI 304 (15 mm diameter and 250 mm length) and the low alloy steel plate (10 mm × 100 mm × 250 mm) are used as mechtrode and substrate, respectively. The chemical compositions of materials are shown in Table 1. The experiments are carried out using friction surfacing machine (50 kN capacity), specially designed and developed by Defence Metallurgical Research Laboratory, Hyderabad, India.

Trial experiments are conducted to determine the working range of the factors, such as rotational speed of mechtrode (A), substrate traverse speed (B) and axial force on mechtrode (C). Feasible limits of the parameters are chosen in such a way that the coating should be free from any visible defects.

In the present study, the temperature measurements were carried out close to the rubbing end of the rotating mechtrode using a caliberated infrared camera capable of measuring the temperatures up to 1500 °C. The setup is shown in Fig. 2. The camera was focused at the rotating mechtrode/substrate interface.

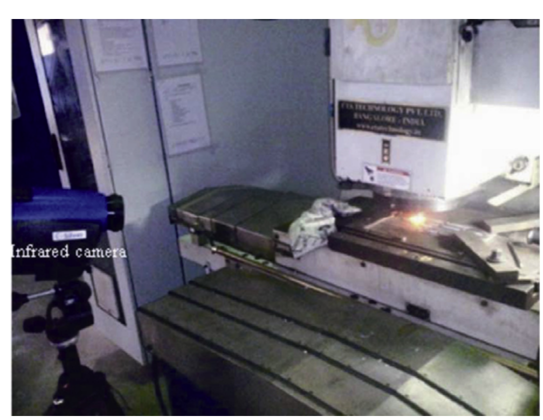

Fig. 2. Experimental setup for temperature measurements during friction surfacing.