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Optimisation of the electric wire arc-spraying process for improved wear resistance of sugar mill roller shells

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Abstract

A parametric study using Taguchi's fractional-factorial design L_9 (3^{4-2}) was conducted to optimise the parameters of an electric wire arc spray process to develop coating for improved wear resistance of sugar mill rollers using an iron based material, iron–chromium–boron (FeCrB). Four spray parameters; current, voltage, air pressure and spray distance were evaluated using the Taguchi design. The coatings were characterised by their hardness, micro-structure and abrasive wear. The results of the study indicated that an optimum wear rate could be achieved from the relationships that exist between all parameters evaluated while achieving satisfactory hardness. The present Taguchi analysis employed in this investigation led to the optimised process parameters for the iron–chromium–boron coating with the lowest mass loss over a two-hour period. The coating should be a good candidate for application to sugar mill rollers.

Keywords: Electric wire arc spraying; Abrasive; Wear; Porosity

1. Introduction

Electric arc spraying is a thermal spray process, in which heating and melting occur when two oppositely charged wires, comprising the spray material, are fed together in such a manner that a controlled arc occurs at their intersection. Once struck, the arc continuously melts the wires, and compressed air blown directly behind the point of contact, atomises and projects the molten droplets, which deforms on impact with the work piece and adhere to form a coating. Adhesion on the other hand is heavily dependent on the surface preparation i.e. if the surface is adequately prepared it improves the adhesion between the coating material and the substrate. Solvent cleaning or grit blasting normally achieves adequate surface preparation.

The electric arc-spraying process can be used to effectively deposit surface coatings that have superior hardness, corrosion resistance, and wear resistance [1]. In addition to these advantages, the spray parameters (voltage, current, air pressure and spray distance) of the electric arc spray process can be optimised for specific application, for example, wear and corrosion resistance.

In the Jamaican sugar industry, a great deal of effort is put into preparing and maintaining the surface of roll teeth to ensure good feeding. According to Gomez et al. [2] the crushing process in the sugar industries brings metallic parts in contact with extraneous matters (stones, dirt, iron, etc.), which causes wear and decreases the useful life of the metallic part. Similarly, Oliver and Wilson [3] described the wear of sugar cane rollers as an insidious problem which is desperately in need of a solution. Gomez et al. [2] highlight that as the rollers loose material the extraction efficiency of the plant decreases significantly.

The Taguchi method [4] has been consistently shown to be an effective means of optimising the parameters of thermal spray process. Taguchi's fractional-factorial design is one of the means of determining the effects of process parameters on coating attributes and is highly useful to a wide range of applications [4].

In arc spraying, a wire is fed from a continuous reel to an arc-spraying pistol located within 80 mm and 150 mm from the substrate to be coated. At the nozzle of the pistol the wires are placed at approximately 4 mm apart. Opposite charges are then passed through the wires, which create an arc and melt the

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Table 1
Values of experimental levels

Level	Current (A)	Air pressure (bar)	Voltage (V)	Spray distance (mm)
1_{min}	150	3.5	30	80
2_{std}	175	4.5	35	100
3_{max}	200	5.0	40	120

wires. Compressed air atomises the molten particles and deposits them on the prepared substrate. The pressure of the air being blown through accelerates the molten particles so that the particles leave the pistol at a velocity of approximately 80 m/s and impinge on the substrate and build a thickness of 5–30 μm depending upon the properties of the wire [5].

A deposition rate of up to 40 kg/h at a temperature of approximately 4000 °C at the pistol is obtained [6].

Although arc spraying has been successfully applied to several areas, particularly corrosion [7,5] it has not been utilized on mill roller as a means of enhancing the wear resistance. Hence, the objective of this paper is to optimise the parameters of an electric wire arc spray machine to produce a surface of optimum wear resistance, which can be used to replace the present arcing process in which discrete globules are welded to the surfaces of sugar mill rollers.

2. Experimental procedures

2.1. Parameter design using the Taguchi technique

This study employed a fractional-factorial design [L_9 (3^{4-2})], using an orthogonal array with nine runs. Four process parameters were used with three levels [minimum (level 1), standard (level 2) and maximum (level 3)] to evaluate the effect of each factor. The main process parameters (air pressure, voltage, current, and spray distance) and experimental settings are shown in Table 1. The orthogonal array developed by the Taguchi technique is shown in Table 2, which also reflects the nine experimental runs used in the study.

To select the optimal parameter levels of the process, curves of the average values for each level were plotted to show the influence of each variable on the wear resistance of the coating. These curves allow for the analysis of relationships between different parameters.

Table 2
Taguchi Orthogonal Array

Experiment specimen	Air pressure (bar)	Voltage (V)	Current (A)	Distance (mm)
1	3.5	30	150	80
2	3.5	35	175	100
3	3.5	40	200	120
4	4.5	30	175	120
5	4.5	35	200	80
6	4.5	40	150	100
7	5.0	30	200	100
8	5.0	35	150	120
9	5.0	40	175	80

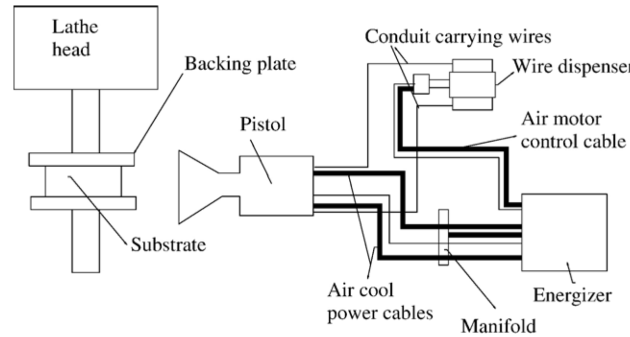

Fig. 1. Schematic of the electric wire arc spray process set-up.

2.2. Materials and equipment

Cast iron substrates (97 mm diameter × 25 mm wide discs) with composition Fe–3.2C–1.73Si–0.5Mn–0.26P–0.11S (wt.%) were employed throughout the experiment for coating deposition. Prior to arc spraying, the surface was roughened by grooving on the lathe to surface roughness of 85 μm ± 5, then cleaned with acetone. The spray material was FeCrB wire of 1.6 mm diameter and of a chemical composition Fe–26Cr–3B–1Mn0.3C (wt.%). The final coating thickness on all discs was maintained within the range of 4 mm ± 0.05 mm. The arc spray was carried out using a 240-metallization electric wire arc spray machine consisting of a power supply, a control unit, and a spray gun, while the cast iron discs were rotated on a lathe at speed of 45 rpm. The experimental set-up is shown in Fig. 1.

2.3. Coating characterisation

The abrasive wear tests were conducted on a Plint multistation block-on-ring tester. The coatings were subjected to a two-hour test during which bagasse blocks of dimension 90 mm × 15 mm × 12 mm were used as the counterface material. A load of 20 N was applied normal to the coating, which was rotated at a speed of 100 rpm. Sugar cane juice was directed between the coated disc and the bagasse board at a rate of 20 ml/min to provide the wet condition.

Each specimen was weighed before and after the test, using a Sartorius electronic scale with an accuracy of 0.01 g. Following the wear tests, a small section of each coating was removed, ground, and polished using standard metallographic procedures and observed under an optical microscope. A Vickers microhardness tester at a load of 200 g was subsequently used to determine the hardness of the cross-section of all coatings produced. The surface roughness and porosity was measured using a Ziess optical microscope.

3. Results and discussion

3.1. Micro-structural examination

Fig. 2 show typical micrographs of the micro-structure of the coatings. The images show that the coatings were moderately dense with relatively dispersed porosity, small cracks were also visible in some coatings as shown in Fig. 2. The samples