Friction Surfacing of Austenitic Stainless Steel on Low Carbon Steel: Studies on the Effects of Traverse Speed

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H. Khalid Rafi, G. D. Janaki Ram , G. Phanikumar and K. Prasad Rao

Abstract— This work deals with the solid state coatings by friction surfacing process. AISI 310 austenitic stainless steel is coated on low carbon steel substrate. The effects of traverse speed on the geometry, interfacial bond characteristics and mechanical properties of coatings are studied. Traverse speed was varied and rotational speed and axial load were fixed. Metallurgical studies were made using optical microscopy, scanning electron microscopy (SEM), mechanical tests included shear tests, bend tests and microhardness tests. The coatings are free from cracks and have a fully austenitic structure. Traverse speed influenced both bond integrity and coating thickness. Metallurgically sound interface with 100% bond integrity was found for coatings made with higher traverse speeds. Higher the traverse speed thinner the coating and higher the bond strength.

***Index Terms*— Bend test, Friction surfacing, Microstructure, Microhardness, Shear test.**

I. INTRODUCTION

Low carbon steels are widely used for structural applications because of its ease in fabrication and the moderate strength it posses. However, its pure corrosion resistance at normal atmosphere is a matter of serious concern. Hardfacing /coating techniques based on fusion welding [1] and thermal spraying [2] are generally employed to protect steel surface from corrosion. Fusion welding based coating techniques generally suffers from dilution and thermal spraying results in mechanical bonding rather than metallurgical bonding. Friction surfacing is a relatively new technology which is capable of producing coatings with zero dilution and good metallurgical bonding [3]. This is attained because no melting is involved in this process.

Friction surfacing is a solid state deposition process for producing wear and corrosion resistant coatings on metallic surfaces, which involves a rotating rod pushed against a horizontally moving plate. The rotating rod is the coating material and the plate is the substrate. Fig-1 shows a simple schematic diagra of friction surfacing process. The frictional heat generated during the process plasticizes the consumable rod. The plasticized metal gets deposited on to the substrate creating a relatively thick coating with good interfacial metallurgical bonding. The width of the coating depends on the diameter of the consumable rod and is normally in the range of 0.9 times the rod diameter [4]. Most of the earlier works on friction surfacing were focused on feasibility aspects of the process [5]-[7]. Apart from that, parameter optimization models [3], [4], [8], process modeling [9], and the performance of friction surfaced coatings [10] were also attempted. However, a comprehensive evaluation of the effect of different process parameters involved in friction surfacing is limited in the reported works.

In this work, the effect of traverse speed on coating characteristics have been investigated for friction surfacing of stainless steel type 310 on low carbon steel. The results show the significance of traverse speed in producing coatings with good bond integrity/interfacial bond strength.

II. EXPERIMENTAL WORK

AISI 310 grade stainless steel (in wt%: 0.1 C, 24.77 Cr, 19.51 Ni, 1.29 Mn, 0.47 Si, and balance Fe) used as the coating material was taken in rod form with 100 mm length and 18 mm diameter. AISI 1020 grade low carbon steel (in wt%: 0.12 C, 0.42 Mn, 0.02 P, 0.01 S, and balance Fe) which was used as the substrate, had dimensions of 100 mm X 150 mm. Parameters involved in this process are: 1) Rotational speed (RPM) - the speed at which the consumable rod rotates, 2) Traverse speed (mm/s) - the speed at which the substrate traverses horizontally, 3) Axial force (kN) - the external force

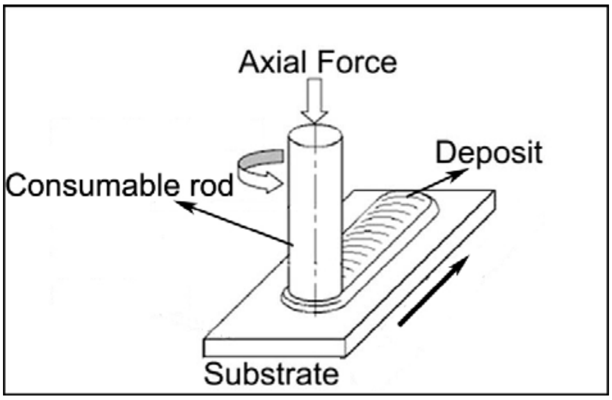

Fig-1: Schematic diagram of friction surfacing

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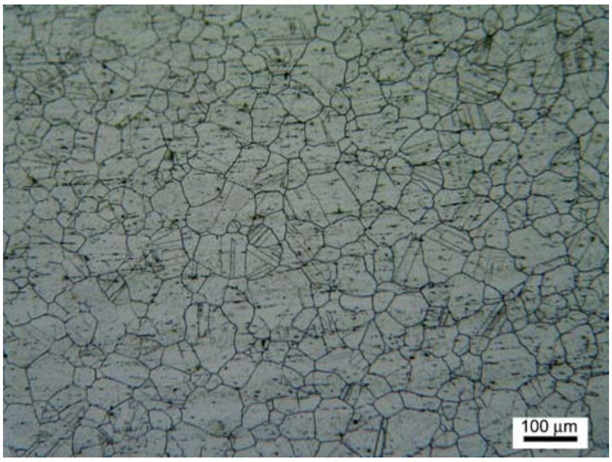


Fig-2: Microstructure of AISI 310 base metal

applied along the axis of the consumable rod. In the current work, the axial force was kept constant at 10kN, which was the upper limit of the equipment, rotational speed was kept constant at 800 RPM and traverse speed was varied between 1.2 mm/s and 5.6 mm/s.

The dimensions of the coating like bead width and bead thickness, produced by friction surfacing, were measured accurately with the help of stereo microscopy. Cross sections were taken from the middle of the coating.

The coating microstructure, substrate microstructure and the bond integrity at the interface were analyzed using optical microscope (Lieca make) and SEM (FEI make, Model: Quanta 200). Standard metallographic methods were used for specimen preparation. Microhardness survey was carried out across the coating/substrate interface. The interfacial bond strength was assessed using shear tests (ASTM A264) and the ductility of the coating was assessed using three point bend tests (ASTM E290).

III. Results and Discussions

A. Coating geometry

The coating material AISI 310 is mainly used for high temperature corrosion applications. Base metal microstructure of the coating material is shown in Fig-2. This material is regarded as difficult to weld as it is prone to solidification cracking [11]. Since no melting is involved in friction surfacing, this could be considered as a suitable process for depositing corrosion protection coatings on plain carbon steels. Fig-3 show a typical friction surfaced coating produced using AISI 310. The coating is characterized with the formation of ripple like features on the surface, which is an inherent characteristic of this process.

A graphical representation of the effect of traverse speed on coating geometry is shown in Fig-4. The observations from the graph show that the thickness of the coating is greatly influenced by change in traverse speed. Highest traverse speed resulted in thinnest coating (1.2mm). However, beyond the traverse speed of 5.6 mm/s, a regular coating was not obtained because of discontinuous distribution of plasticized metal. Similarly, for a lower traverse speed of 1.2 mm/s, the coating thickness obtained was 3mm.

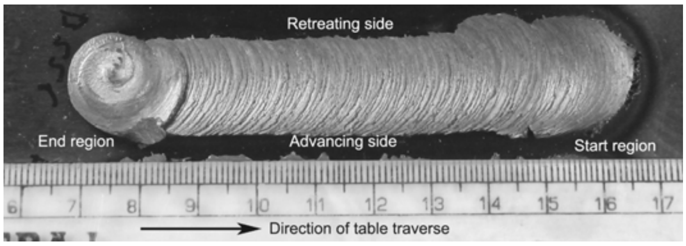
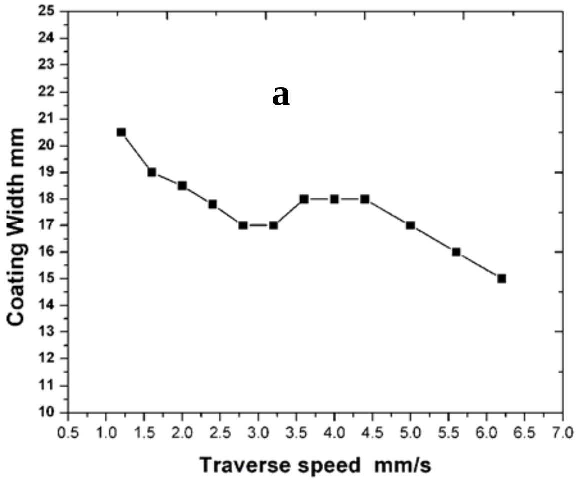


Fig-3: Typical coating produced by friction surfacing



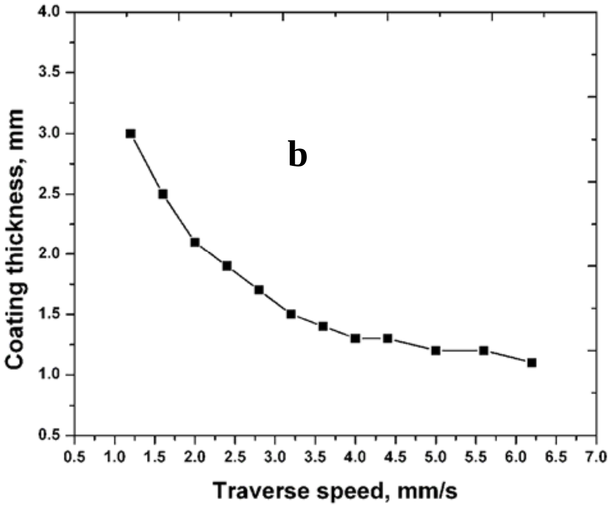


Fig-4: a) Coating width as a function of traverse speed
b) Coating thickness as a function of traverse speed.

The effect of traverse speed on coating width was marginal when compared to coating thickness. Between 3.6 mm/s and 4.4 mm/s, the width of the coating obtained was similar to the diameter of the consumable rod (18 mm). Beyond that, staggered edges were formed on the retreating side of the coating, causing a reduction in effective width of the coating.

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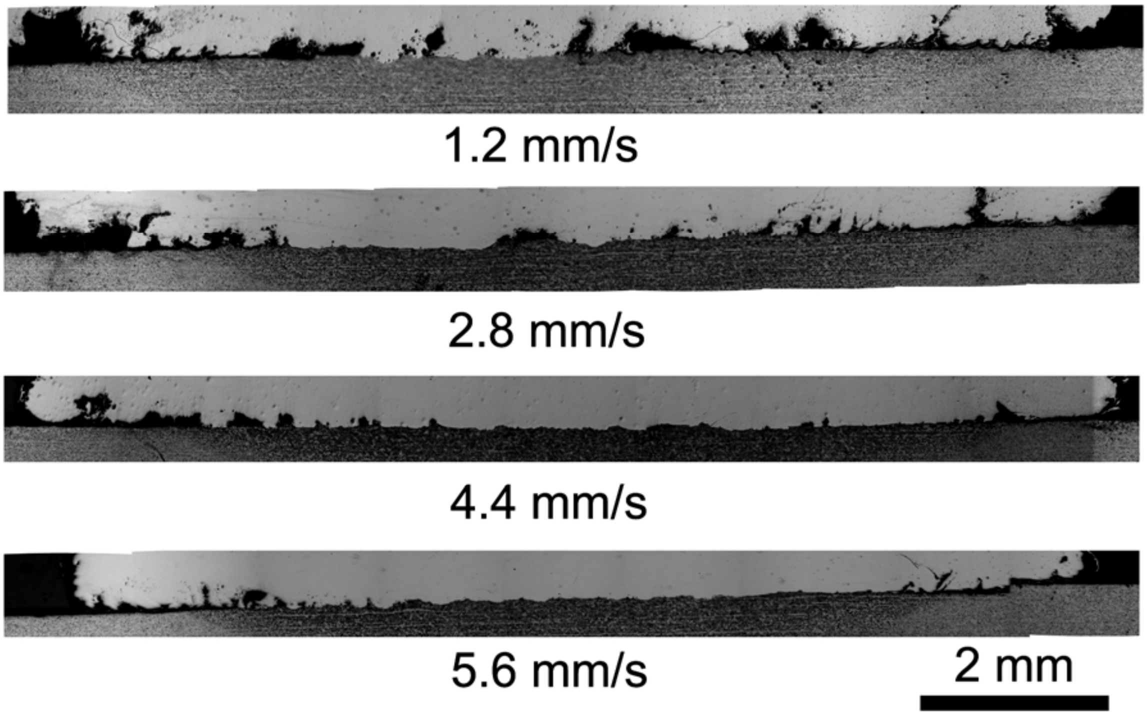

Fig-5: Montage of coating-substrate interface for different traverse speeds.

A. Microstructure characteristics of the interface zone

Montage of interface micrographs corresponding to different traverse speeds are shown in Fig-5. Defect free interface can be observed as the traverse speed increases to higher values. At lower traverse speeds, prolonged plastic deformation time cause the formation of large volumes of plasticized metal. Therefore the forging effect may not be sufficient to consolidate the deposited metal, resulting in lack of bonding at some locations at the interface. The coatings get thinner for higher traverse speeds due to efficient distribution of plasticized metal assisted with application of axial load. This further resulted in clear coating-substrate interface without any unjoined regions. Optical microscopy (Fig-6) and SEM image (Fig-7) taken from the interface corresponding to higher traverse speed shows well bonded coatings with good bond integrity.

The stainless steel coatings produced by friction surfacing process shows fine equi-axed grains. During friction surfacing

process, the regions near to the interface in both consumable rod and substrate experiences very high strain rates and the temperature would reach above A3 temperature. The effect will be more pronounced in the consumable rod than the

substrate, owing to the geometrical differences between them. More heat energy will be concentrated at the rod interface as the propagation of thermal energy will be slower due to size constraints. This leads to rapid softening and plasticization of near interface regions in consumable rod and subsequent deposition of plasticized metal on the substrate. Higher strain rates and higher temperature due to severe plastic deformation causes dynamic recrystalization of austenitic stainless steel and results in highly refined coating microstructure in the order of 2-8 micrometers (Fig-8).

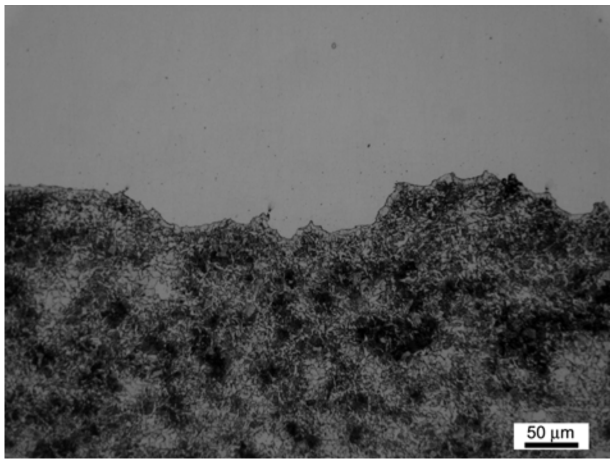

Fig-6: Optical micrograph at the interface.

The formation of fine grained wrought microstructure as opposed to the cast microstructure from fusion based coating technique is one of the major advantages of friction surfacing process.

B. Shear tests and Bend tests.

Interfacial bond strength is a primary requirement of the coating. Results from shear tests carried out as per ASTM A264 shows an increase in interfacial bond strength with increase in traverse speeds (Fig-9). In other words, thinner stainless steel coatings resulted in higher bond strengths as high as 333 MPa. Thicker coatings exhibited very poor interfacial bond strength, which can be attributed to the insufficient consolidation of plasticized metal. This can be

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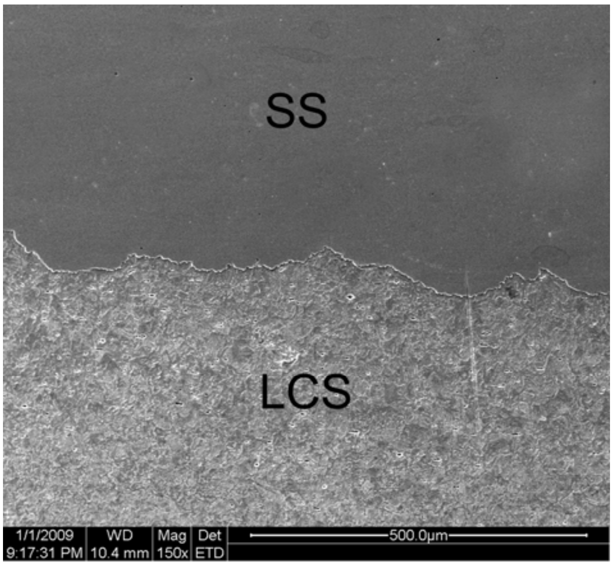


Fig-7: SEM- secondary electron image at the interface (SS-stainless steel, LCS-low carbon steel)

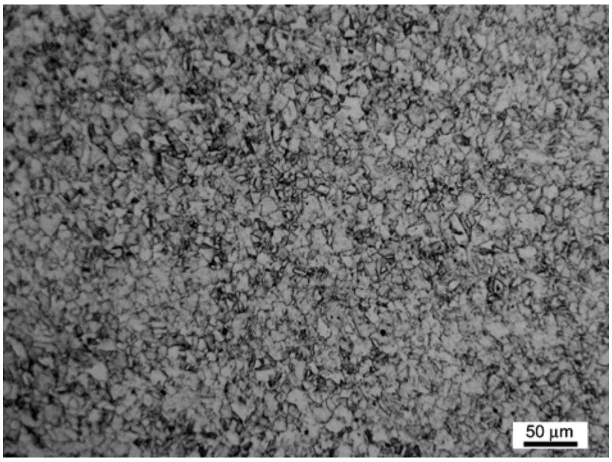


Fig-8: Optical micrograph of coating surface

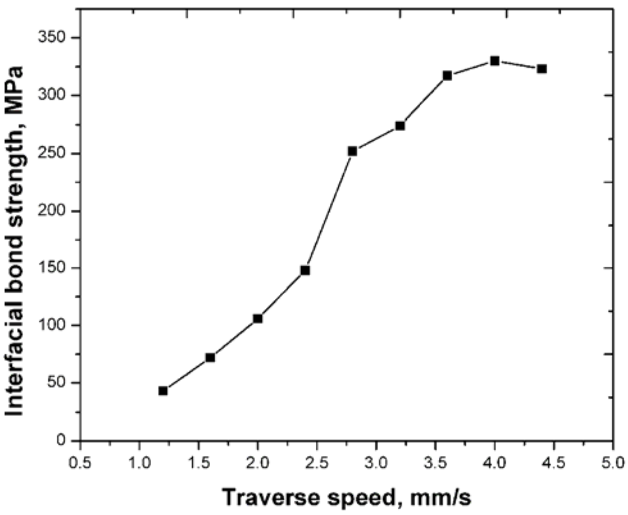
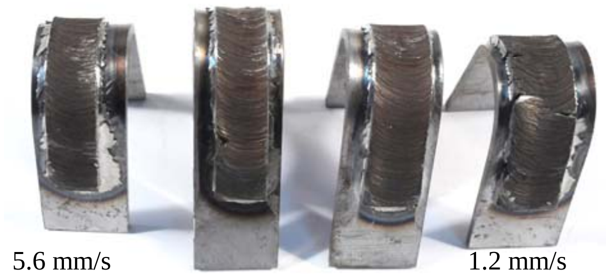


Fig-9: Bond strength as a function of traverse speed



5.6 mm/s 4.4 mm/s 2.8 mm/s 1.2 mm/s

Fig-10: Bend tested specimens

clearly seen from the corresponding interface microstructure (Fig-5) of coatings obtained from lower traverse speed, where the bonding is not continuous along the interface. On the other hand, the interface of thinner coating is intimately adhered with the substrate resulting in effective metallurgical bonding. In addition to that, the wavy nature of the interface supplements the bond strength by mechanical interlocking.

'U' bend specimens obtained from three point bend tests indicate good coating ductility (Fig-10). The bend test results can also be taken into consideration as an evidence for good bond integrity. Although minor cracks were developed in the case of thicker coatings, thinner coatings were free from any such cracks.

C. *Microhardness*

Fig-11 shows the microhardness distribution in the direction perpendicular to the coating-substrate interface. As can be seen from Fig-11, almost similar trend is observed in the microhardness profiles of all samples. Not much difference in coating hardness is observed when compared to base metal hardness. However there is an increase in hardness of coating produced with lower traverse speed and at some locations (especially near to top surface of the coating) for coatings produced by higher traverse speeds. This could be possibly due to the presence of shear bands in the coating.

The hardness of substrate region near to the interface show higher values when compared to its original hardness. The increase in hardness near to the interface can be related directly to the microstructure formed at the interface as a result of frictional heat input and plastic deformation. The combined effect of heat and plastic deformation causes a decrease in the grain size which leads to hardening at the regions close to interface.

At lower traverse speeds, longer heating times propagate more heat to the substrate resulting in wider heat affected zone (HAZ). The substrate regions which exhibit higher hardness indicate the extent of HAZ.

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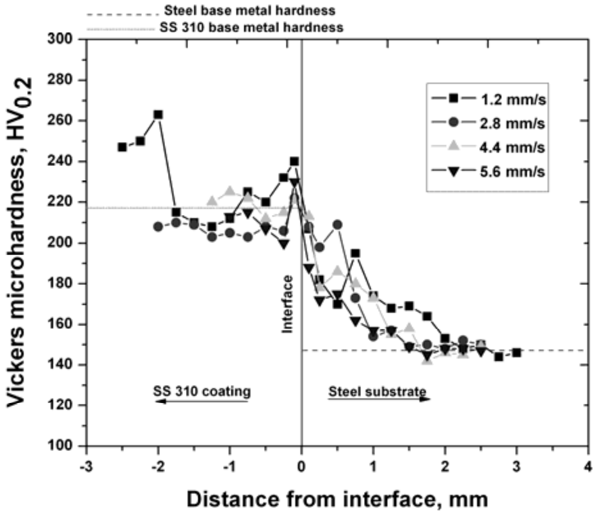

Fig-11: Hardness survey across the interface

IV. Conclusions

For getting friction surfaced coatings with good bonding and required dimensions, the speed at which the substrate traverses is one of the critical parameters. Friction surfacing can be considered as an alternative for fusion based techniques in coating stainless steel on low carbon steel for corrosion protection applications, particularly for repair and reclamation. The solid state nature of the process retains or even improves the mechanical properties of the coating in addition to zero dilution.

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