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Surface Modification of Steels using Friction Stir Surfacing

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Abstract. Friction stir surfacing is done to deposit commercial pure Al on medium carbon steel under open atmosphere conditions. Roughness of the substrate, normal load and tool rotation are the variables. Deposition is analysed with respect to continuity, width, composition and phase parameters. Good deposition is observed under a limited set of load and rotation speed. The deposit contains a mixture of steel and aluminium particles.

Introduction

Surface modification is a generic term used to present a diverse set of technologies that can alter surface properties of a component and hence can improve the reliability and performance of the component. In friction stir processing the surface of a component is modified using mechanical energy generated using a friction tool [1]. The process can be carried out with or without the addition of an alloying element. If the friction tool is a non-consumable one, the tool can penetrate the substrate and facilitate changes [2]. If the tool is a consumable one, depending on the relative strengths of substrate and tool materials, as well as temperature attained, both substrate and tool or only tool material will be undergoing plastic deformation. This will lead to alloying near the surface leading to a change in the surface properties. This is the principle behind friction stir surfacing [3].
Fe based systems are common structural materials. But Fe based systems have a drawback in the form of poor resistance to oxidation and scaling [4]. These limitations can be overcome by having a Fe-Al based compound at the surface. Having a Fe-Al based compound at the surface of a Fe based component is a beneficial one compared to a base one because it provides enhanced oxidation and sulfidation resistance at a relatively lower cost [5,6]. To effectively exploit this benefit it is essential to have a uniform and continuous deposition of Al on Fe substrate. Al and Fe are two metals with a huge difference in physical and thermal properties [7]. Hence for getting a good deposition of Al on steel substrate optimization of processing parameters is essential
In friction stir surfacing, a large number of processing parameters exists. A few of them are roughness of the substrate, tool diameter, torque, traverse speed, normal load, rotation speed, etc. Role of these parameters on friction stir welding (FSW) is fairly investigated and a few review papers are available [8-12]. Whereas friction stir surfacing is less explored and much literature is not available. This paper deals with the various deposition features during friction stir surfacing of Al on medium carbon steel.

Materials and Experiments

Commercial pure Al, available in the form of extruded rod, is used as the consumable tool. Extruded rod is machined to a dimension of 100mm length and 25 mm diameter and it is used for deposition. A carbon steel plate with approximately 0.35% carbon is used as substrate. Substrate dimensions are 150mm length, 70mm width and 8mm thickness. Controlled roughness on the steel substrate is obtained by milling the substrate using a conventional surface milling machine. Veeco optical profilemeter is used to measure the roughness and it is observed that the sample roughness

(Ra) is in the range of 5.8um to 8.3um. The friction stir surfacing is done using the machine made by M/s ETA technologies, Bangalore, India. Fig. 1 shows a schematic presentation of carbon stir surfacing.

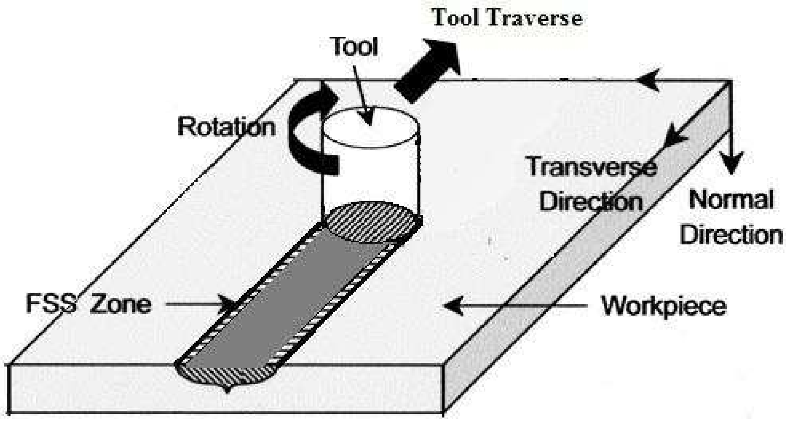


Fig.1. Scheme of friction stir surfacing

Al is deposited using different processing conditions. Normal load is varied as 3kN, 4kN and 5kN. This gave a stress level of 6.1MPa, 8.1MPa and 10.2MPa in the consumable tool. Tool spindle speed is varied as 200rpm and 400rpm. Tool plunge depth is fixed as 40mm. All the experiments are done with a fixed traversing rate of 35mm/min. For convenience the samples are labeled as S1, S2, ….S6 and they are listed in Table 1. All the experiments are done in open atmosphere and for 200s. Quality of the deposition is investigated using various parameters, namely, nature of the deposition (powdery or not), continuity, width uniformity, tool bulging, etc. This information is also listed in Table 1. Morphology and composition of the deposit is studied using Scanning Electron Microscope (JEOL make, model JSM 6480LA) coupled with an EDX attachment (Oxford make). Phase identification in the deposit is made using X-ray diffractometry (JEOL make, Model JPX 8).

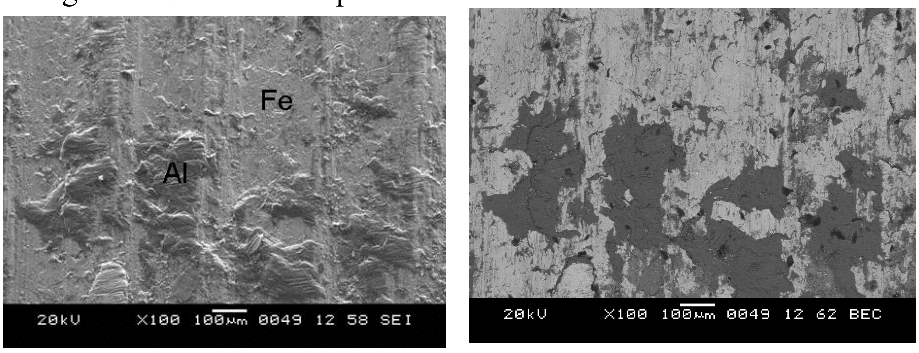
Results and Discussion

Table 1 gives various aspects regarding quality of Al deposition during friction stir surfacing. The Al deposition was either powdery, patchy or continuous (either uniform or varying width) depositions. It is basically controlled by the extent of heat generation at the interface, heat dissipation to the bulk and the material strength at that temperature. Detailed equations are available in the literature in the case of FSW [9,10,12-14]. When the tool is cold, we have rubbing of a soft surface, on to a hard surface producing powdery debris on steel surface. The situation is similar to simple abrasive wear. When Al tool is moderately hot and soft, Al material will be sheared by the penetrating Fe asperities. The sheared Al particles will be pressed between the valleys on the steel surface by the rotating tool leading to depositions in patches. Table 1 also presents condition of the friction tool during friction stirring. In few cases the tool got bulged. This occurs under the conditions of higher heat generation at the interface coupled by the higher vertical load. From the deposition point of view, powdery deposition, patchy deposition and tool bulging is not desired. A continuous and uniform deposition is desired and it is obtained under the conditions of certain normal load and rotation speed. When the processing parameters are optimum, the tool gets heated up locally, near the substrate-tool interface. The localized heating softens the tool material near the substrate and a combination of tool rotation and substrate translation leads to deposition of the tool material on to the substrate surface. Use of higher load and rotation speeds are found to increase the temperature in friction stir surfacing and similar things are expected here. Fig. 2 and 3 shows macroview and microstructural features in a sample where deposition is good. Similarly, Fig 4 and 5 shows macroview and microstructural features in a sample where deposition is poor. BSE images and EDS line scans in Fig. 3 and 5 show distinct regions consisting of Fe and Al, in the deposition. Though scanning speed is another important variable, in our work it is kept constant.

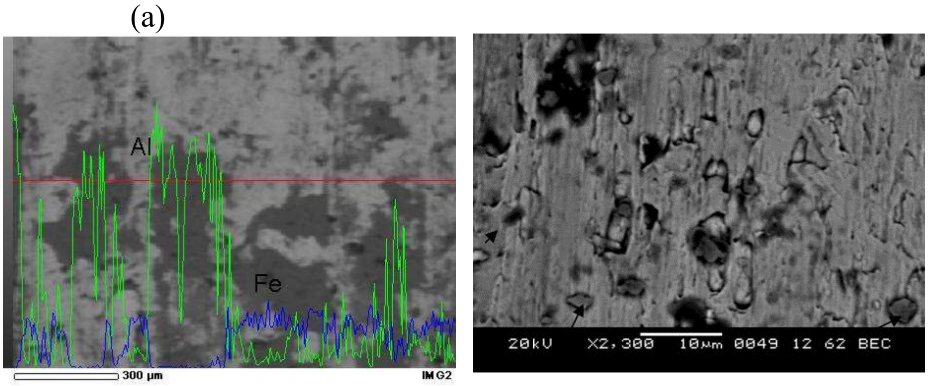
Table 1 Processing parameters for various samples and observations on tool and deposition

Sample No	Scan speed (mm/min)	Load (kN)	Spindle speed (rpm)	Comments
S1	35	3	200	Powdery deposition, No bulging of tool
S2	35	3	400	Deposition better than S1, still powdery, Slight tool bulging
S3	35	4	200	Patch like deposition, Slight tool bulging
S4	35	4	400	Good (uniform, continuous) deposition, Slight tool bulging
S5	35	5	200	Continuous, width varying deposition, Tool bulging heavily
S6	35	5	400	Good deposition, Width more than S4, Huge tool bulging

Fig. 2 Shows macroview of a sample with good deposition (S4). On the right side enlarged view of the deposition is given. We see that deposition is continuous and width is uniform.



(a) (b)



(c) (d)

Fig. 3 Micrographs and EDS information on a good deposition sample (a) Variations in the topography due to Al (b) BSE image showing Fe rich and Al rich areas (c) EDS line scan indicating mixing in microscale (d) Micrograph in an iron rich area presenting fine Al particles (arrow marks) and features showing fracture and cold welding.

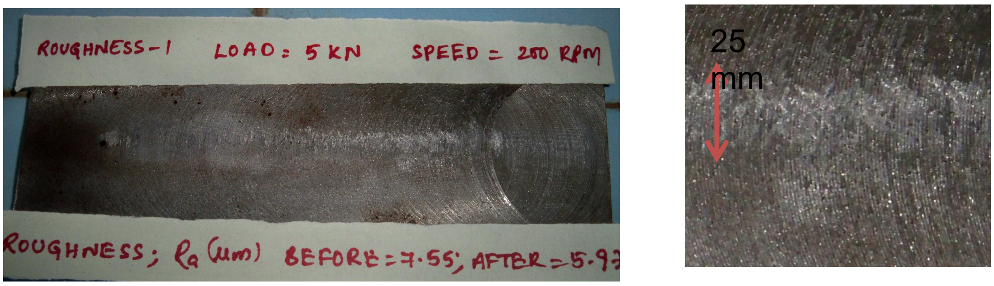
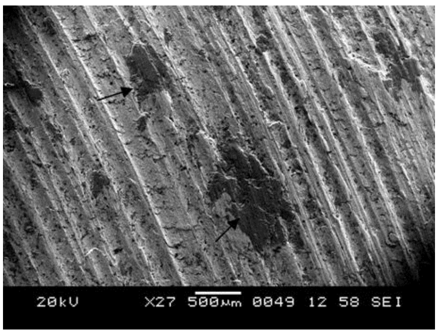
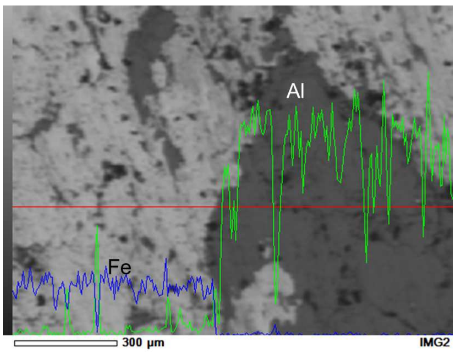


Fig. 4 Macroview of a bad deposition. On the right side enlarged view of the deposition area is presented.

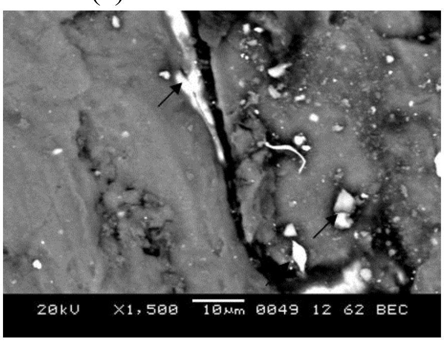
Heat generation during friction stir surfacing is due to the plastic deformation at the consumable tool-substrate interface and deformation heat in the tool away from the interface [9]. In friction stir surfacing there is no penetrating tool and hence frictional heating at the tool-matrix interface does not occur (except during initial stages). When the total heat generation is relatively less, under the conditions of present stress level, asperities which are at the line of sight will penetrate each other and local heat generation is minimum. When there is a relative motion, the asperities on the Al side get sheared (due to poor strength compared to strength of Fe). It may be recalled that though average stress in the tool is less, the actual stress value at the asperity contact will be much higher, exceeding the strength of the material. Al is soft and ductile. Hence fresh fractured surfaces can easily undergo pressure welding. After the initial stages, when the tool is sufficiently soft, it can penetrate in to the asperities of steel substrate and plastic deformation takes place. Then heat is generated at the tool work piece area due to shear deformation [9]. Under steady state conditions, the volume of the softened materials (in the consumable tool) is equal to rate of its consumption in the deposition. In contrast Fe gets strain hardened rapidly and the asperities undergo fracture easily. These fragments are easily entrapped in the deposited Al layer. Such entrapment is observed in both good and bad deposition samples (refer compositional profiles shown in Fig. 3 and 5).



(a)



(b)



(c)

Fig. 5 Various deposition aspects of a poorly deposited sample. (a) Microstructure shows initial roughness details and isolated Al deposition (arrow) (b) Line scan across Fe and Al region (c) Magnified micrograph from an Al rich area (Fe particles can be seen).

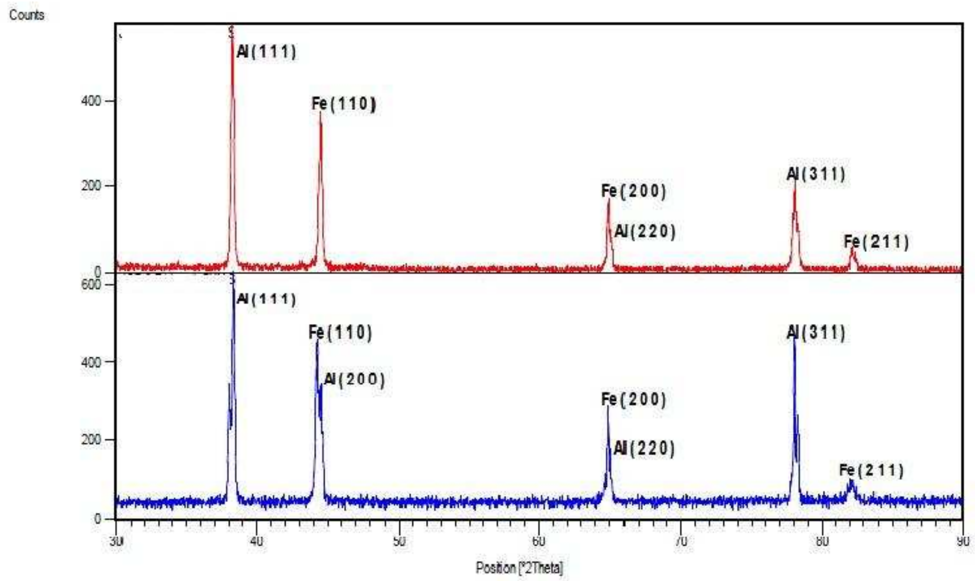


Fig. 6 XRD of two depositions, Load = 5kN, Speed = 200rpm (top) and 400rpm (bottom)

Fig. 6 shows the XRD analysis of two samples (namely S5 and S6). XRD plots for other samples are similar. XRD plot indicates that deposition is mainly aluminum and iron. From, microstructural observations and XRD results we say that the deposit is a mechanical mixture of aluminum and steel.

Conclusions

Friction stir processing is used to deposit Al on steel and good deposition occurs under limited combinations of rotation speed and normal load. Transverse speed is kept constant in our experiments. The deposit consists of a mechanical mixture of aluminum and iron.

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