Friction Surfacing of Mild Steel: A Review

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Article Info
S. Venkatesh et al. (eds.), *1st International Conference on Emerging Trends in Mechanical Sciences for Sustainable Technologies*, Advances in Computational Intelligence in Materials Science.
Doi: https://doi.org/10.53759/acims/978-9914-9946-6-7_14

Abstract - Friction coating process is a solid-state metal deposition process which is developed from friction stir welding technique. Mild steel is a low-carbon steel that is commonly used in the construction industry due to its low cost, ease of manufacturing, and excellent mechanical properties. However, its low hardness and poor wear resistance limit its usage in several applications. Frictional metal coating technique is used to coat mild steel with a variety of consumable materials including steel, aluminium, copper, nickel, titanium, etc., These coatings have been shown to greatly increase the wear, corrosive and thermal resistance of mild steel. This review shows investigations dealing with few dissimilar consumable rods deposited on the surface of mild steel substrate to enhance the surface property and also used for crack repair, dissimilar material joins and hole or gap filling applications. The potential future directions for the development and use of this technique are also presented.

Keywords - Friction Surfacing, Mild Steel, Viscoplastic State, Adherence, Microstructure, Heat Affected Zone.

I. INTRODUCTION

Friction metal coating process has a lot of attention in recent years because of its ability to produce high-quality, metallurgically-bonded coatings and structures without using any additional materials or heat [1]. The **Fig 1** illustrates the friction surfacing process using different consumable rods over the mild steel substrate. A rotating tool is used in this process to generate frictional heat and plastic deformation at the interface of two materials, resulting in a metallurgical bond [2]. The maximum temperature is lower than the rod's melting point because of friction, which prevents porosity and solidification cracking; giving dissimilar joining of materials an advantage over fusion-based technologies [3, 4]. The increased wear resistance is one of the most significant advantages of improving the properties of mild steel in friction surfacing. The friction surfacing of nickel, titanium, chromium, etc., on mild steel will enhance the wear resistance property of mild steel. This layer provides a strong, wear-resistant surface that can survive extreme working circumstances, such as abrasive wear and sliding wear environment. Research has shown that the wear resistance of mild steel can be greatly increased by utilizing friction surfacing [5]. This technique has several advantages over traditional coating and cladding processes, including lower heat input, less distortion, and better mechanical properties. Friction surfacing is best suited for processing different metals, which are highly challenging to process in conventional fusion processes, because of the material's inherent thermo-physical properties [6].

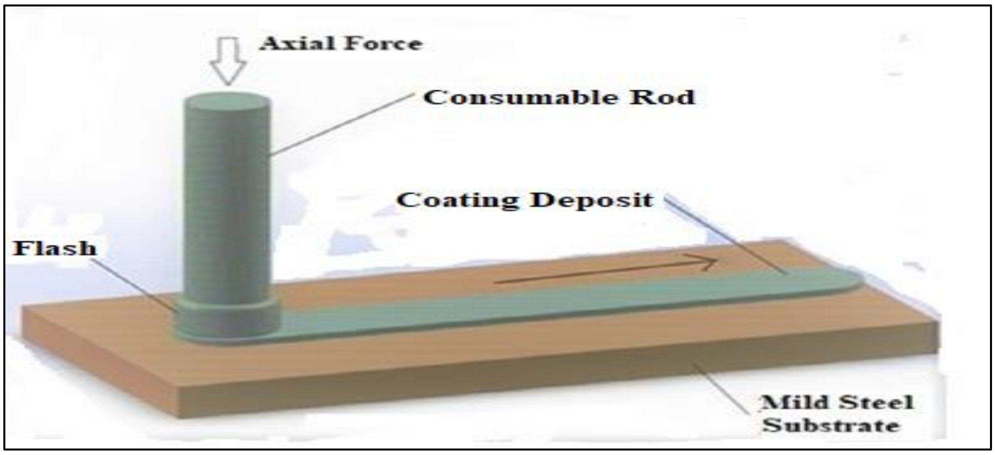

Fig 1. Schematic diagram of Friction Surfacing.

Because of its high iron concentration, mild steel is prone to corrosion at moisture or acid environment. Corrosion can reduce the material's strength and integrity, resulting in structural failure. This metal coating technique is used to increase the corrosion resistance of low carbon steels by depositing a corrosion-resistant substance on its surface. Frictional metal coating has been proven in studies to greatly increase the corrosion resistance of mild steel [7, 8]. The mechanical qualities of mild steel, such as tensile strength, hardness, and toughness, can be increased via friction surfacing. The deposited layer on the surface of mild steel can enhance its mechanical properties, making it more durable and resistant to deformation. According to research, friction surfacing can significantly improve the mechanical properties of mild steel. Friction surfacing is used in a variety of processes, including welding, coating, repairing damaged parts, hard surfacing, and corrosion prevention [9, 10].With an emphasis on superficial and microstructural characterization and the effects of the various process factors such as axial force, rotation and travel speed, material deposition rate, energy consumption, and various tool types, this review paper investigates the fundamental concepts and applications of friction surfacing as well as a survey of the most recent researches and applications. The study also presents a complete assessment of the current state of research on friction surfacing, including many areas such as properties of the coatings, applications, and future possibilities.

II. FRICTION SURFACED METAL COATING PROCESS

Process Description

A thin layer of material is deposited onto the surface boundary of the substrate is known as friction metal coating process. The process includes a revolving consumable rod or wire being brought into contact with a stationary substrate, and the ensuing friction creates heat, allowing the consumable material to soften and bond with the substrate. The resultant bond is strong, and the method is comparatively modest in cost compared to typical welding procedures [11, 12]. This coating process can be divided into four main stages: material selection, surface preparation, the frictional rubbing process, and post-processing. The choice of materials is essential to ensuring compatibility between the substrate and consumable materials, and surface preparation entails cleaning and roughening the substrate surface to promote strong adhesion.

The consumable material is rotated quickly and brought into contact with the substrate surface during the friction coating process. The heat produced by the friction those results in the consumable material softening and bonding with the substrate. Finally, post-processing involves removing any excess material and finishing the surface to the desired specifications [2-4].

Factors Affecting the Process Parameters

The speed at which the consumable metal rod rotates can affect the amount of heat generated and the rate of deposition. Faster rotating speeds result in increased heat generation and quicker deposition rates, but may also raise the danger of overheating and melting of the consumable metal [13]. The impact of rotational speed on the mechanical characteristics and microstructure of SS316L on friction-surfaced MS1018 shows that when rotational speed increased, the interfacial layer's thickness decreased and the mechanical qualities of the joints improved [3]. The amount of material deposition and the resulting bond can be influenced by the rate at which the consumable metal is fed into the friction surfacing zone. Increased feed rates can result in higher deposition rates but may also result in less control over the process [4].

The amount of heat produced and the quality of the resulting bond might vary depending on how long the consumable metal rod is in contact with the work piece. Longer friction times can result in higher temperatures and better bonding, but may also increase the risk of overheating and melting of the consumable metal [6]. The properties of the consumable metal and the work piece can also affect the friction surfacing process parameters. Different materials may require different process conditions to achieve optimal bonding, and materials with different thermal conductivities may require different rotational speeds and friction times [14, 15]. The condition and cleanliness of the work piece surface can also affect the friction surfacing quality. A clean, smooth surface can result in better bonding and reduce the risk of defects or surface contaminants affecting the process.

III. CONSUMABLE MATERIALS FOR FRICTION SURFACING OVER MILD STEEL

Aluminium Based Coatings

It is essential to provide protective coatings for mild steel in order to stop corrosion, wear, and erosion. For superior corrosion resistance, good thermal conductivity and low density of coatings the aluminium coating is quite popular. By applying the friction coating technology, thick coatings can be attained on mild steel substrates [2, 3]. The **Fig 2** illustrates that the AA6082 alloy was applied to the mild steel substrate utilizing the frictional metal coating process. In this method, a coating material made of aluminium is heated and then firmly rubbed against a mild steel substrate, producing localised melting and spreading of the coating material onto the substrate [7]. The coatings that are produced have fantastic mechanical and adhesive qualities. The frictional coating process has undergone extensive investigation for the aim of covering mild steel substrates with aluminum-based alloys. The coating characteristics are significantly impacted by process variables such rotating speed, axial force, and tool shape. A thicker coating and greater adherence are produced by high heat input and high spinning speed. The geometry of the tool has an impact on the coating quality as well; a concave tool surface produces thicker coating and greater adherence [8].

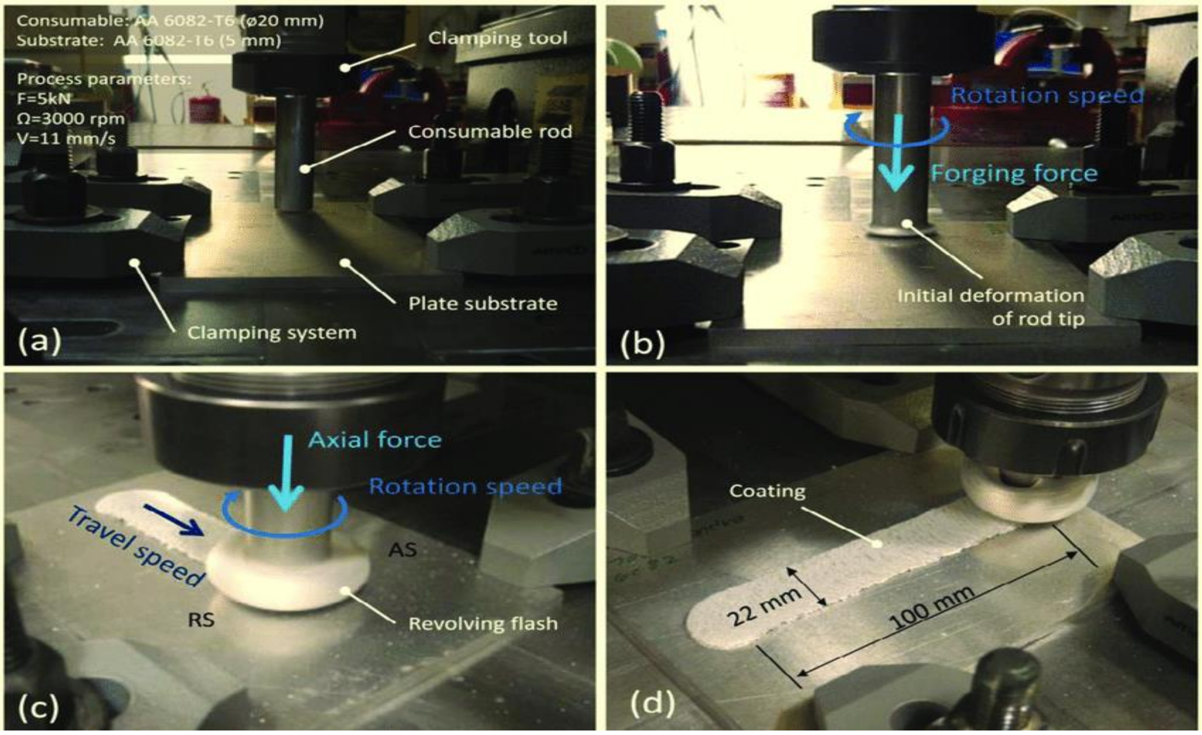

Fig 2. AA 6082 coating on Mild Steel; a) Experimental setup view; b) Process initiation stage;(c) Coating deposition stage; d) Final coated layer [7]

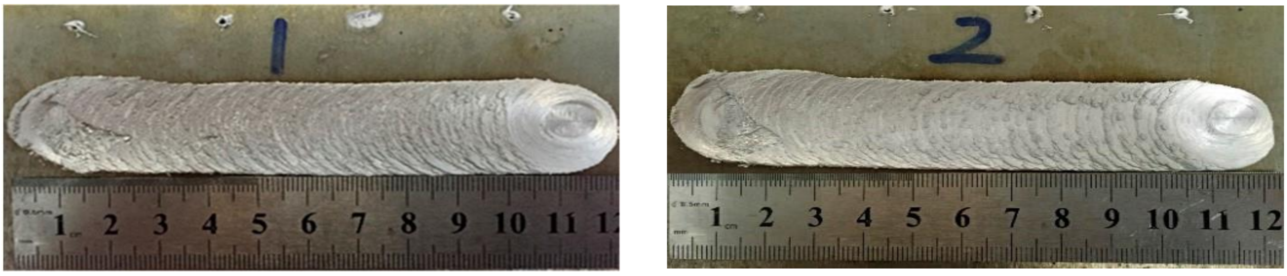

Fig 3. AA5083 on Steel by Friction Coating [2].

The aluminum alloy 5083 FS on mild steel substrate is shown in **Fig 3**. The SEM images shown in **Fig 4** revealed a well-bonded coating with a metallurgical interface between the aluminium and mild steel. The coating exhibited a fine-grained microstructure with no observable defects or cracks. The results demonstrate the feasibility of using friction surfacing to produce high-quality aluminium coatings on mild steel substrates [6]. The increase in feed rate produced better deposition bonding strength and less rougher deposition.

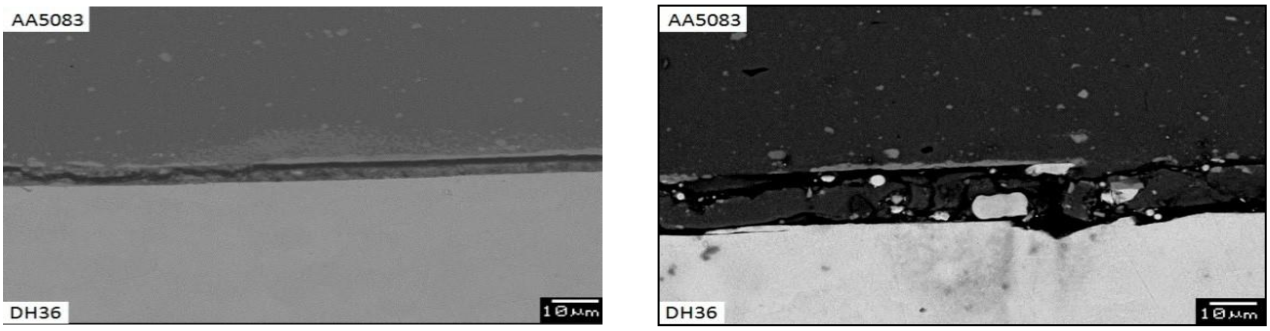

Fig 4. The SEM Images for The Coating Interface: a) Middle region b) Retreating Endregion [2].

Deposition width and surface quality declined as rotation speed increased, whereas bonding strength increased. Due to thermal mechanical processes, the materials for the interface layer included elements from both the steel substrate and the aluminium alloy. Fe was seen to be diffusing to the AA5083 side of the contact, where it formed the metallic composite of $FeAl_3$[2].

Copper-Based Coatings

A significant metal with numerous uses, copper is especially useful in the area of electrical conductivity. Copper, however, is not always easy to come by and is somewhat expensive. Using copper-based coatings on cheaper substrates is one technique to lower the cost and increase availability. In this coating method generated a metallurgical bond with good mechanical qualities, including high tensile strength and ductility is observed. By altering the process parameters, namely rotational speed as (1250, 1500, and 1750 rpm) and travel speed as (20, 30, and 40 mm/min) friction surfacing of copper on mild steel is accomplished. As a continuous axial force as 2kN load was applied. It is observed that continuous and uniform coating thickness is obtained for a parameter range of 1500 rpm at 20 mm/min feed with a constant load of 2 k [9].

It has been demonstrated that creating copper-based coatings on mild steel substrates via friction surfacing is an efficient process. Numerous studies have examined the effects of process variables like rotational speed, feed rate, and pressure on coating quality. **Fig 5** Shows Copper Is Added to Mild Steel by Friction Surfacing.

Fig 5. Copper Is Added to Mild Steel by Friction Surfacing [9].

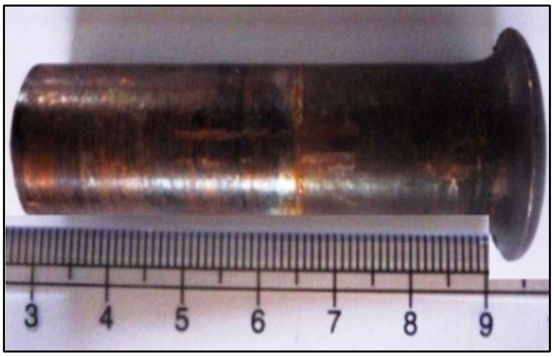

Fig 6. Copper Consumable Rods for Friction Surfacing [9].

Copper-tin coating on mild steel is accomplished by varying the process parameter, and feed rate and rotating speed have been examined for their effects on the coating characteristic. The fine grained microstructure with zero dilution is observed on the copper tin coating for higher rotational speed and discovered that raising rotational speed with lowering feed rate increased coating thickness and enhanced mechanical characteristics [17].The impact of process variables on the mechanical and microstructural characteristics of copper coatings generated by friction coating on low carbon steel substrates. It was observed that raising the pressure and rotating speed produced a harder material with a finer microstructure. **Fig 6** shows Copper Consumable Rods for Friction Surfacing.

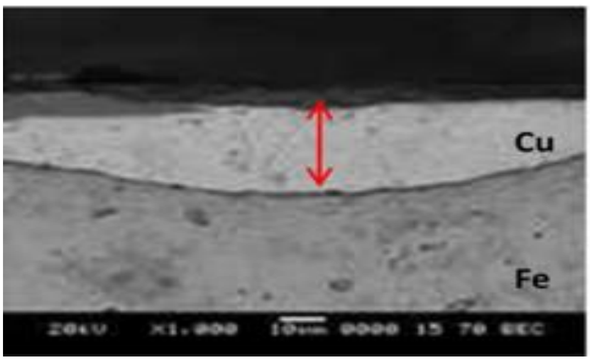

Fig 7. A High Magnification Micrograph Showing A Clean Interface Between Deposited Copper And Substrate Steel [9].

A copper-nickel alloy-based coating was applied to the surface of a mild steel substrate and it was found that the coating thickness had an impact on wear resistance. This shows that when coating thickness improved, coating wear resistance also enhanced [18]. A strong copper deposition may be achieved with the aid of a rough surface produced by rough milling.

Fig 7 Shows A High Magnification Micrograph Showing A Clean Interface Between Deposited Copper And Substrate Steel.

Nickel-Based Coatings

According to the findings, nickel-based coatings on mild steel may be created via friction surfacing that have great corrosion resistance, high hardness, and strong adhesion [10,16]. The friction surfacing process of nickel over mild steel substrate is shown in **Fig 8**.

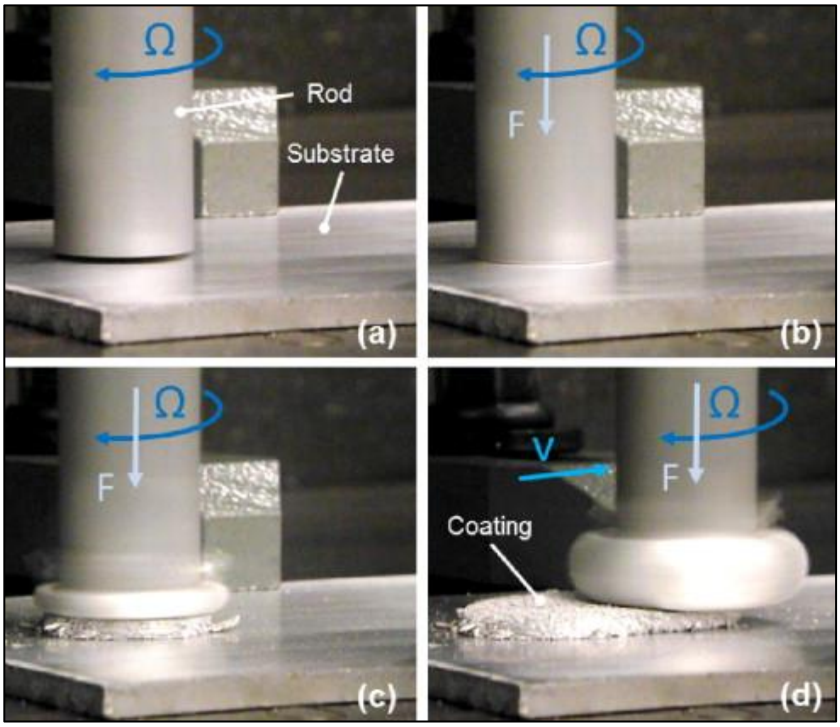

Fig 8. Friction surfacing of nickel over mild steel [16].

This method can be helpful in a variety of industrial settings where corrosion prevention is required. Due to their excellent corrosion resistance and strong adherence to metallic surfaces, nickel-based coatings have been proven to be useful at preventing mild steel from corroding. Friction surfacing one of many coating techniques has come to light as a viable technology for covering metallic substrates especially mild steel [14]. Inconel 718 an alloy of nickel is used for crack filling of mild steel substrate trough FS is shown in **Fig 9**.

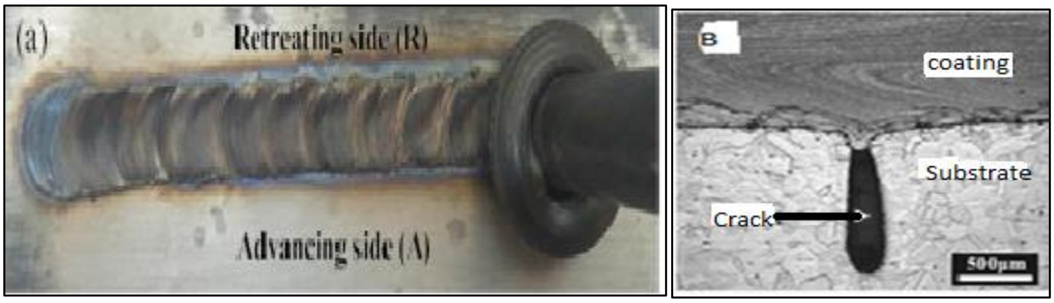

Fig 9. a) Inconel718 coating for crack repair b) Crack filling with Inconel718-optical image [14] .

According to the XRD study, the coatings are made up of intermetallic compounds such Ni3P and Ni3B as well as a solid solution based on nickel. It is also observed that the coatings are consistent and free of flaws like voids and fractures, according to the microstructure analysis [14]. The measurements of hardness show that the coatings have a high hardness value of roughly 500 HV, making them significantly tougher than the mild steel substrate. Electro -chemical Impedance Spectroscopy (EIS) tests is done to assess the corrosion behavior of the deposit (nickel-based coatings) on mild steel. EIS test shows that the coatings have high corrosion resistance [16].

Steel Based Coatings
To increase the base metal's resistance to corrosion, mild steel is coated with stainless steel. In this study AISI 316 stainless steel is deposited on mild steel using friction surfacing technique [3]. The materials selected have produced excellent overlaying capability. By performing a ram tensile test, it was discovered that the coating's bond strength could reach a high of 502 MPa. The 316-steel coated on the surface of the mild steel substrate for varying the process parameter is shown in **Fig 10**.

Fig 10. The sample's fractography shows that the two parent metals have fused together [3].

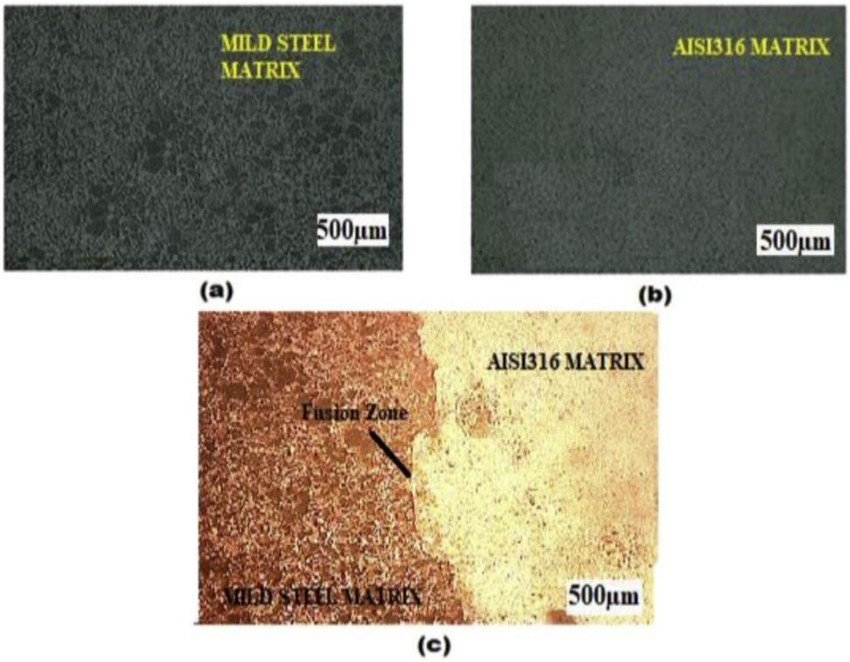

Fig 11. a) Optical Microscopic image of MS substrate. b) Optical Microscopic image of 316 Stainless steel. (c) Optical Microscopic image of friction surfaced coating of 316steel on MS substrate [3].

The sample of coating metharode and uncoated base metal is subjected to marine environment (i.e.) the specimen is subjected to 3.5% NaCl salt spray. The test result shows that, there were no visible corrosion produced on the exterior of the mechtrode[5].After coating the SS316L on MS friction surfaced joints is treated to corrosion test and is observed that the corrosion resistance of the joints increased with an increase in the thickness of the interfacial layer[24]. **Fig 11** shows a) Optical Microscopic image of MS substrate. b) Optical Microscopic image of 316 Stainless steel. (c) Optical Microscopic image of friction surfaced coating of 316steel on MS substrate.

In **Fig 12** it is observed that the interfacial layer was composed of Fe-rich phases and that the hardness of the joint increased with an increase in the amount of Fe-rich phases [5]. When compared to the consumable material, it was found that the base metal had suffered significantly more corrosion. The interface of the SS316 metal's overlaying materials displays extremely fine martensitic characteristics [3].

The wear properties of SS304 on MS friction surfaced joints under dry sliding conditions, observed that an increase in the proportion of Fe-rich phases in the interfacial layer resulted in an improvement in the wear resistance of the joints[19]. By forming a metallurgical connection between the substrate and the coating material, friction surfacing improves the coating's cohesiveness and adhesion. Because neither the substrate nor the coating is melted during the friction surfacing process, there is very little base material dilution, producing a coating of excellent quality [22].

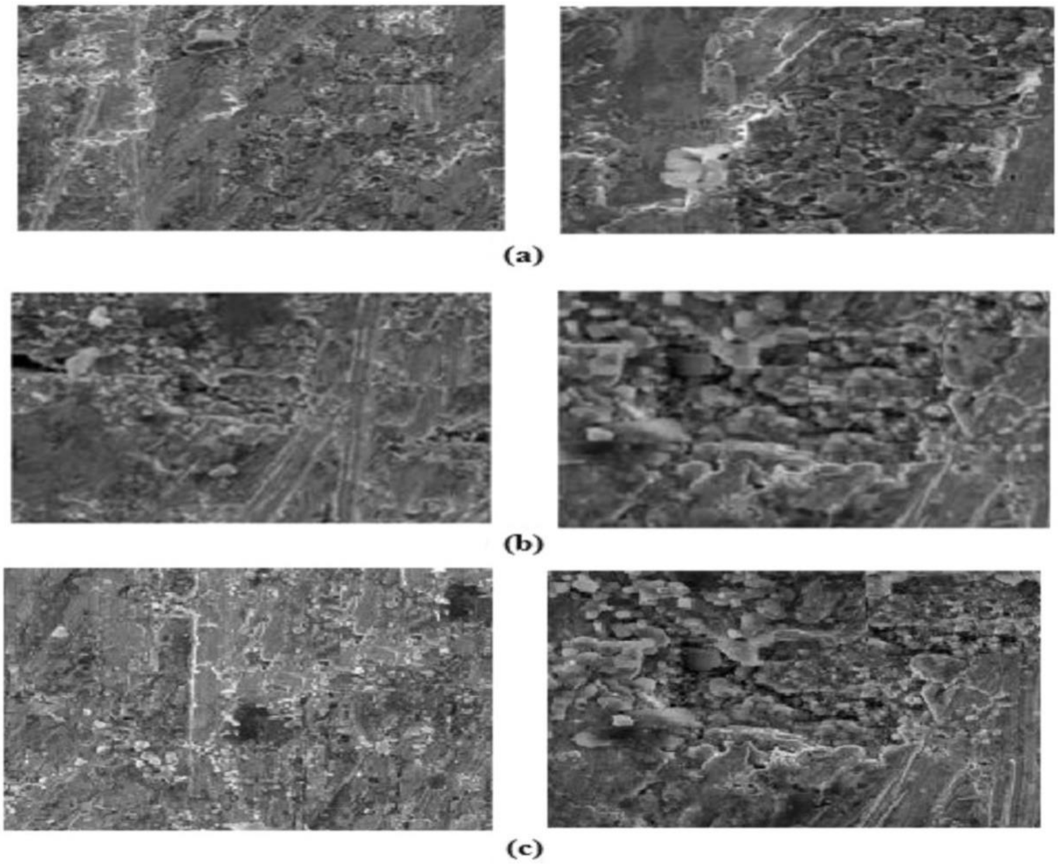

Fig 12. (a)The SEM image- Coating interface, (b) The SEM image - Coating surface, (c) TheSEM images -Mild steel substrate. [5].

IV. STRUCTURE OF THE COATINGS FORMED BY FRICTION SURFACING OVER MILD STEEL

Characterization And Microstructure Analysis

In case of frictional surfaced316 steel over low carbon steel substrate the sample's fractography shows that the two parent metals have fused together. It also shows that ferrite-pearlite grains can be seen throughout the coating surface and close to theHAZ, where they coexist with slightly deformed martensite. Due to a martensitic pattern that was incomplete, higher hardness was indicated [3]. While the source metals go through a thermo-mechanical phenomenon during friction surfacing, dynamic recrystallization creates a fine-grained microstructure.

The absence of α-ferrite is observed at the joining interface for stainless steel coating on low carbon steel this is due to the temperature generated during FS is below 1000 °C, did not rise above the limit at which α -ferrite could form at 1200 °C. Similar outcomes for various metal coatings were seen in past research. Comparing the bonding technique to a cladding procedure based on fusion, the absence of α -ferrite improves corrosion resistance [25]. In case of AA5083 on DH36, the characteristic bonded structure of equiaxed ferrite and pearlite was discovered. Aluminum suffered substantial plastic deformation and grain refinement at the interface of the deposited layer and substrate. The steel substrate microstructure was significantly less impacted than the microstructure of aluminium due to its increased hardness and strength [2].

Interfacial Layer and Its Composition

An interfacial layer that forms between the two materials during friction surfacing contributes to the joint's increased strength and longevity [19]. The interfacial layer, also known as a "transition zone" it consists of a combination of the two materials shown in **Fig 13**. Intermetallic compounds may also be present in the interfacial layer as a result of the process's high pressure and temperature conditions.

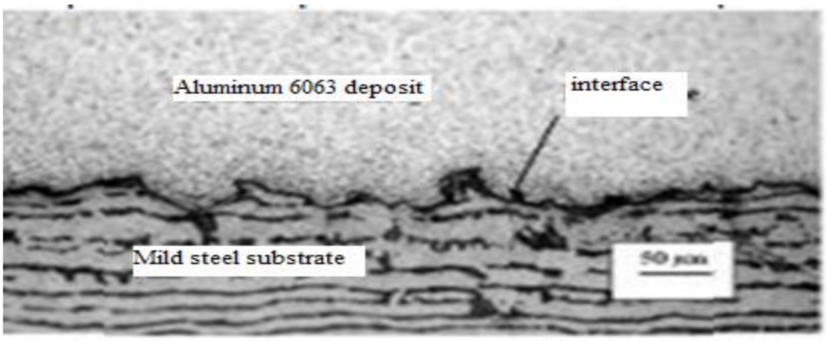

Fig 13. SEM image of substrate and coating interface [1].

For Aluminum surfacing on mild steel the interfacial layer had a thickness of roughly 10 micrometers and was made up of a combination of aluminum and steel. Moreover, they saw the emergence of intermetallic substances like FeAl3 and Fe2Al5 are formed at the joint interface [2]. In case of friction surfacing of steel and titanium alloy there is an adverse effect in the composition and microstructure of the interfacial layer. It is observed that the interfacial layer had a thickness of 20 micrometers and was made up of a combination of steel and titanium. In Ti alloy coating an intermetallic substance like TiFe and TiFe2 is formed at the joint interface [19]. The materials being bonded, the process parameters, and the particular process circumstances are only a few of the variables that affect the structure of the interfacial layer in friction surfacing. To optimize the friction surfacing procedure and enhance the strength and longevity of the final joint multiple trail processing have to made for optimizing the process parameter.

Diffusion Zone and Its Properties

The area of the substratum that has experienced metallurgical changes as a result of the heat produced during the operation is referred to as the diffusion zone shown in **Fig14**. The microstructure and physical characteristics of this zone are defined by a gradient, with deeper layers displaying less distortion and top layers being more strongly distorted.

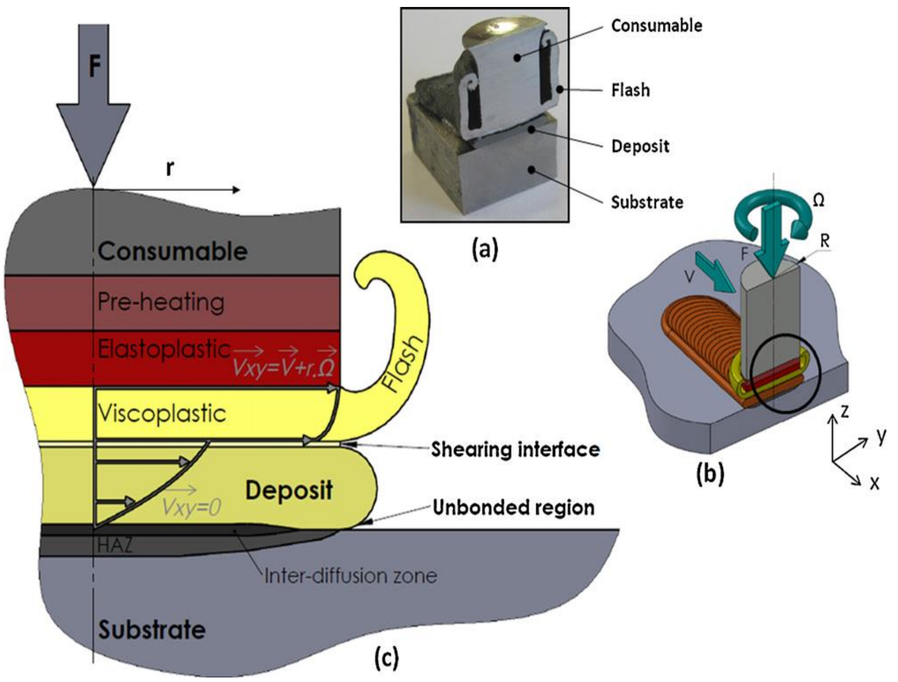

Fig 14. Cross Sectional View Indicating Various Regions in Coating Deposit [6].

The parameters of the procedure and the characteristics of the material determine the depth of the diffusion zone. A variety of variables, such as the material being connected, the process parameters and the cooling rate, affect the diffusion zone's characteristics in friction surfacing. FS creates joints with little porosity and little deformation. Moreover, the joints are strong mechanically and devoid of fractures [21]. A fine-grained microstructure and improved mechanical characteristics, such as higher hardness, wear resistance, and fatigue strength, are typical benefits of this process [20].

Heat-Affected Zone (HAZ) And Its Properties

In order to form a metallurgical link, two materials are rubbed together during the friction surfacing process, which is a solid-state joining method. A portion of the base material known as the HAZ is subjected to high temperatures but does not completely melt as a result of the process shown in **Fig 14**. The composition of the base material and the precise process conditions might affect these zones properties during friction surfacing over mild steel. The HAZ in friction surfacing is often distinguished by grain refinement. During friction surfacing, high temperatures can lead to recrystallization and grain refinement in the HAZ[22,23].It was discovered that the HAZ depth increased noticeably when substrate traverse speed decreased, indicating that the substrate was receiving more heat. In contrast, the HAZ depth was slightly impacted by the methrode rotational speed [6].

Due to thermal expansion and mechanical deformation, friction surfacing can cause considerable residual stresses in this zone. The material characteristics of these residual stresses may be significantly impacted, necessitating post-processing treatments [24].

V. CONCLUSION

Research studies have shown that friction surfacing is one of the practical and affordable ways to enhance the characteristics of mild steel surfaces. Influence of process parameters and effect of microstructure on the quality of the coating observed is stated as follows

- The consumable rod's traverse speed determines the deposition thickness primarily; hence, the deposition thickness is inversely related to the traverse speed.
- The rate at which the material cools after and during FS has a significant impact on the grain size of the deposition. Physical features of the microstructure depend on the traverse speed rather than the rotational speed.
- The rate at which the consumable metal is delivered into the friction surfacing zone can have an impact on how much material deposition occurs and how tightly the bond forms.

As research and development continue to improve the process and expand its capabilities, it is likely that friction surfacing will become even more widely used in the future. However, more research is required to optimize process parameters and develop new consumable materials that can improve the properties of mild steel even further.

VI. SCOPE FOR FUTURE WORK

- Process parameter changes that are quick and economical.
- Alternatives to fusion-based metal joining and cladding techniques can be studied to make them more energy and environmentally friendly.

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