FRICTION SURFACING OF AA5083 ON AA7075: INFLUENCE OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES

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ABSTRACT:

Friction Surfacing is a solid-state coating technique with applications in rehabilitating worn parts, hard-facing, or providing corrosion protection. It is suitable for processing aluminium alloys as it does not require the fusion of either the coating or the substrate, relying on a solid-state diffusion bonding mechanism. The present study investigates the deposition of AA5083 on AA7075 using friction surfacing, with a focus on the effect of process parameters, including axial force, rotation, and travel speed. It characterizes the resulting tensile, bending, and microhardness properties. Good aluminium (AA5083) coatings were produced with limited intermetallic formation at the bonding interface. It was observed that low travel and rotation speeds contribute to an increase in coating thickness and width. The characterization results indicate a change in the tensile and hardness properties of the substrate due to the heat-affected zone.

1. INTRODUCTION:

Friction surfacing is a friction-based solid-state layer process that uses the frictional energy dispersed during the operation and induces a molten state metal without the participation of any extraneous heat source, and generates high-strength and high-quality linkages with fewer deformations in an extensive variety of material lengths and thicknesses. In the process of Friction surfacing, the substrate plate is fixed between the two fastened plates. The rotating consumable rod known as mechrode moves lengthwise on the substrate material with firm transverse speed or travel speed, and at the interface of two materials, heat is generated as a result of the frictional effect. The principle of the friction surfacing process is displayed in Fig. 1. Depending upon the comparative strengths of the tool and substrate material and accumulation to the achieved temperature, frictional plastic deformation may occur only at the tool material, base material, or both the tool and substrate material. This deformation leads to coating of the consumable rod on the substrate surface or alloying near the base material surface, leading to a change in the surface properties of the base material. The physical, mechanical properties, and bond quality mainly rely on numerous process parameters such as rotational speed of the consumable rod (rpm), vertical axial load on the substrate, and transverse speed of the substrate material (mm/s). Hence, they were referred to as fundamental process parameters. The quality of deposition, width, thickness, surface finish, and the intermetallic bonding quality depend greatly on the selection of the process parameter combination.

Aluminium and its alloys have been extensively used in industrial applications due to unique properties such as good ductility, high electrical and thermal conductivity, and corrosion resistance. AA5083 is known for its excellent corrosion resistance and moderate strength, particularly in marine environments. AA7075, on the other hand, is a high-strength aluminium alloy but exhibits lower corrosion resistance than AA5083. Depositing a layer of AA5083 onto an AA7075 substrate could create a component with a high-strength core (AA7075) and a corrosion-resistant surface (AA5083) in specific areas. This localized modification can be advantageous in applications where both properties are desired but not inherently present in a single alloy.

The friction surfacing process, occurring below the melting point of the materials, avoids the common defects associated with fusion welding, such as solidification cracking and porosity. The heat generated through friction between the rotating AA5083 rod and the AA7075 substrate softens the AA5083 material at the interface, allowing it to be mechanically transferred and bonded onto the AA7075 surface as the rod traverses. The resulting clad layer's properties, such as thickness, microstructure, and bond strength, are heavily influenced by the FS process parameters, including rotational speed, axial force, and traverse speed.

The deposition of AA5083 on AA7075 using friction surfacing involves mechanical characterization like microhardness, tensile test, and bending to know the bond strength.

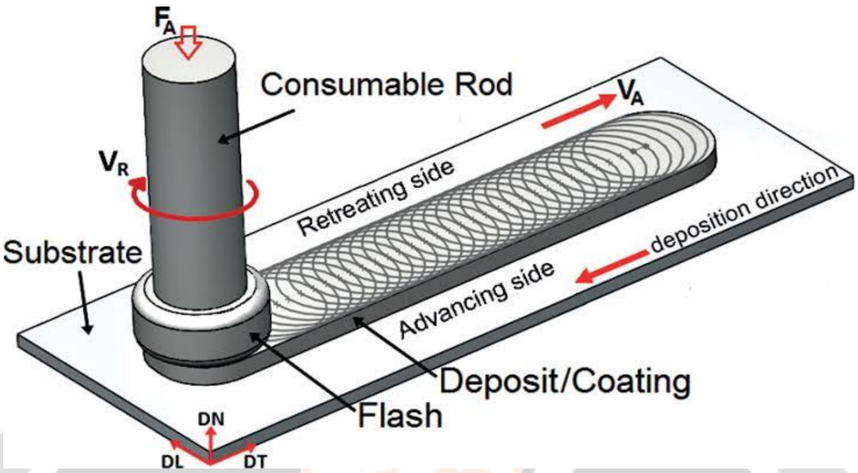


Fig 1: FRICTION SURFACING

Gandra et al. (2013) investigated the deposition of AA6082-T6 over AA2024-T3 using friction surfacing, focusing on mechanical and wear characterization. Their study demonstrated that the process produced defect-free coatings with refined microstructures due to severe plastic deformation. The deposited layers exhibited improved hardness and wear resistance compared to the substrate, attributed to grain refinement and thermal effects. The work highlighted friction surfacing as a promising solid-state technique for producing protective coatings on aerospace-grade aluminum alloys, offering enhanced surface properties without compromising bulk material integrity. These findings support its potential for extending component life in demanding environments. Bararpour et al. (2019) explored mechanical alloying through the friction surfacing process, demonstrating its capability to produce fine, homogeneous microstructures. The study showed that alloying elements were effectively distributed in the matrix, highlighting friction surfacing as a viable method for solid-state alloying with improved material properties and structural integrity. Wang et al. (2024) studied friction surfacing of AA6061 on AA5083 with added 316 stainless steel powders, focusing on the effect of reinforcement volume fractions. Results showed improved hardness and wear resistance with increasing powder content, demonstrating enhanced surface properties and potential for tailored composite layer formation using friction surfacing. Li et al. (2019) investigated the friction surfacing of aluminum alloy 5083 onto a DH36 steel substrate, aiming to create a strong, metallurgically bonded interface between dissimilar materials. The study revealed that the process produced defect-free coatings with refined microstructures and no harmful intermetallic compounds. Mechanical testing indicated good adhesion and enhanced surface properties, making the technique suitable for applications requiring corrosion resistance and mechanical strength.

2. METHOD AND MATERIALS:

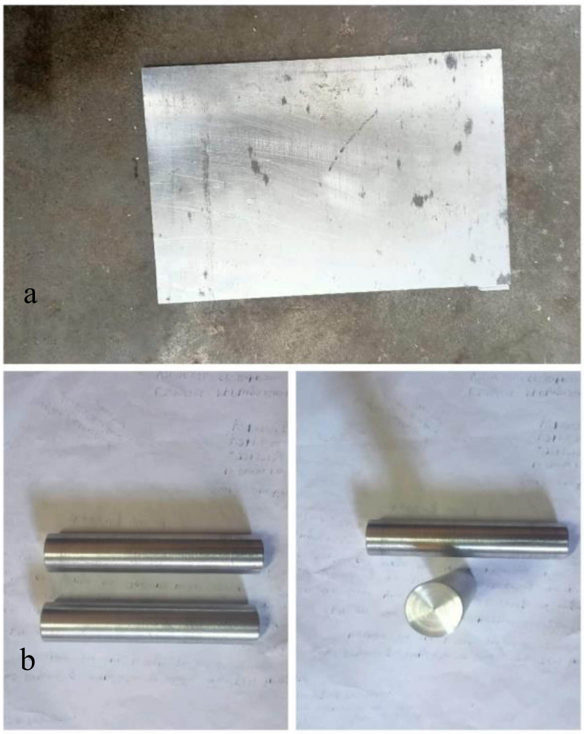
The materials used in this study are AA7075 plate with a 6mm thickness as substrates and AA5083 consumable rod with a 20mm diameter. The chemical compositions of both materials are given below in Table 1.

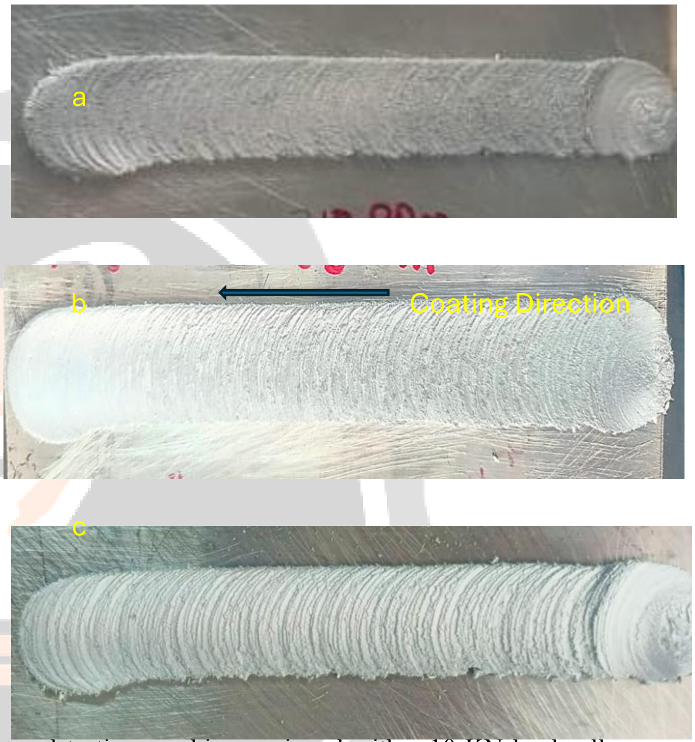
Friction surfacing was performed using a friction stir welding machine with position and load controls. The substrate surface is rubbed with SIC paper before deposition. Coatings were produced using three different speeds at the same axial load and traverse speed. The speeds are 710 rpm, 1120 rpm, and 1400 rpm. The axial load and travel speed are 9 KN and 200mm/min, respectively. These parameters are taken from different previous works (Gandra et al., 2013). Micro-hardness indentations were performed under a load of 500 g, separated by a 2 mm distance, using a Micro-Vickers hardness testing machine. Tensile and three-point bending tests were used to characterize the coatings produced. Specimens for tensile tests were machined according to ASTM E8.

The specimen for the tensile test was machined using wire cutting and produced as a gauge with a length of 60 mm and a width of 10 mm. The specimen was machined to a 60mm length and 10 mm width for bending to remove crack nucleation sites at the unbonded edges and to even the coating's rough surface.

Table. 1: Chemical composition of test materials

Element	Cr	Cu	Fe	Mg	Si	Ti	Zn
AA5083	0.05-0.25%	0.1%	0.4%	4.0-4.9%	0.4%	0.15%	0.25%
AA7075	<0.5%	1.2-1.6%	<0.5%	2.1-2.5%	<0.5%	<0.5%	5.6-6.1%





Both the tensile and bending tests were performed using a universal testing machine equipped with a 10 KN load cell. Three-point bending test specimens were produced as shown in Fig.7. Specimens with poorly bonded edges were also tested to assess their effect on damage tolerance. A 50 mm gap was maintained between the rollers. The punch and rollers had a diameter of 10 mm.

3. RESULT AND DISCUSSION:

3.1. Monitoring of process parameters

Based on the evolution of torque and temperature, the friction surfacing process can be broadly divided into two main stages: (1) an initial deformation phase and (2) the deposition phase. The process begins as the machine builds up the necessary torque to reach the desired consumable rod rotation speed- 710, 1120, or 1400 rpm. Once the target speed is achieved, the machine moves the rod downward along the Z-axis at a constant feed rate of 200 mm/min.

Upon contact with the substrate, the rotating rod is pressed against the surface, leading to a sharp rise in both axial force and torque. This interaction generates frictional heat, which creates a boundary layer at the rod tip. As the consumable rod begins to deform, both the force and torque gradually decrease. This change indicates that suitable pressure and temperature conditions have been achieved to promote diffusion bonding between the softened rod material and the substrate. The generated heat also conducts into the substrate, aiding in the consolidation of the material near the interface. As a result, the shear plane moves slightly away from the substrate surface, thereby increasing the thickness of the deposited layer. After an axial displacement of about 1 mm, lateral movement begins, and the softened material is continuously deposited along the surface. At this stage, the primary heat source transitions from interfacial friction to plastic deformation. Experimental results further indicate that rotational speed significantly affects the coating's thickness and surface finish.

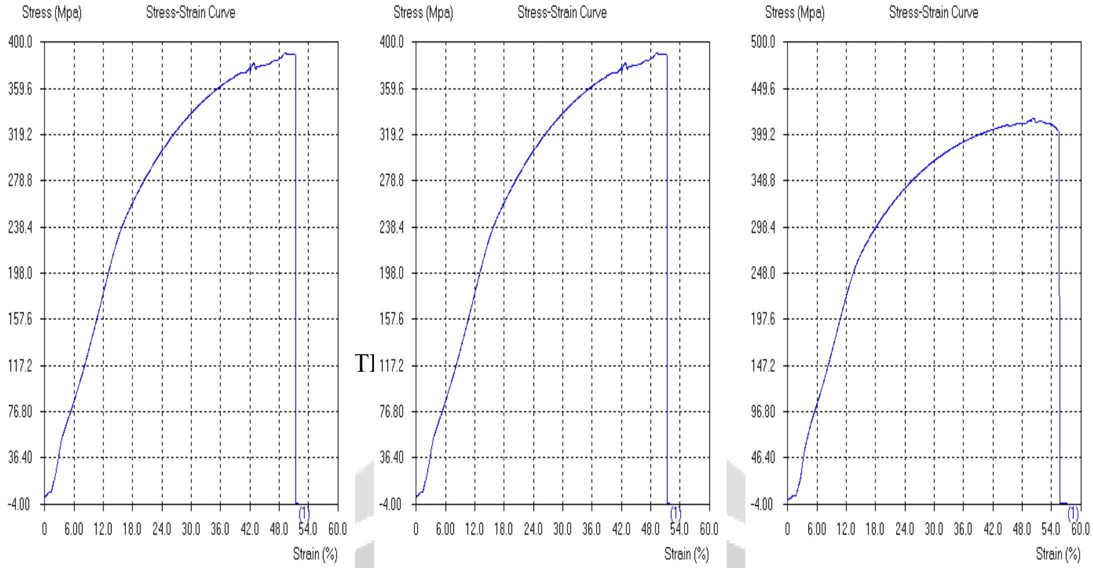
At a lower speed of 710 rpm, the deposited layer was noticeably thicker than those formed at higher speeds, as shown in Fig.4(a).

This can be attributed to reduced centrifugal force, which allows more material to remain near the contact area rather than being flung outward. In contrast, higher rotational speeds, such as 1120 and 1400 rpm, produced thinner but more uniform layers due to the greater centrifugal forces and improved material spreading, as shown in Figs. 4(b) and (c). These conditions also tended to yield smoother surface finishes, as the faster rotation promotes better levelling of the deposited material.

Fig.4: Thickness of the coating

3.2. Tensile tests

Tensile tests were conducted on the universal testing machine. The tensile strength values were 390.62 MPa, 392.91 MPa, and 416.80 MPa, while the yield strength values were 251.27 MPa, 269.19 MPa, and 275.85 MPa, in the same order. These results show that as the rotational speed increased, both the tensile and yield strength of the specimens also increased. This suggests that higher speeds helped improve the bonding between the AA5083 and AA7075 layers, likely by generating more heat and better mixing at the interface. The specimen made at 1400 rpm (Specimen 3) showed the highest strength values, indicating the most effective bonding and the least number of defects. Overall, it can be concluded that increasing the rotational speed during friction surfacing results in improved mechanical performance of the joint. Fig.5 shows the stress-strain graphs of the coated specimen.



3.3. Bending test

A three-point bending test was conducted using a Universal Testing Machine (UTM) to evaluate the flexural strength of coated specimens. The specimens were cut to a uniform length of 60 mm using a wire cutting machine to ensure dimensional precision. The test was performed in a root bending configuration, where the coated layer was placed on the upper surface to subject it to tensile stress during loading, as shown in Fig. 7. Three specimens were tested, each coated at different spindle speeds of 710 rpm, 1120 rpm, and 1400 rpm, respectively. The ultimate bending strength was recorded for each specimen. The specimen coated at 710 rpm exhibited the highest ultimate bending strength of 1365 MPa, while those coated at 1120 rpm and 1400 rpm showed lower strengths of 875 MPa and 774 MPa, respectively. The superior performance of the 710-rpm specimen suggests that a lower coating speed promotes better coating adhesion.

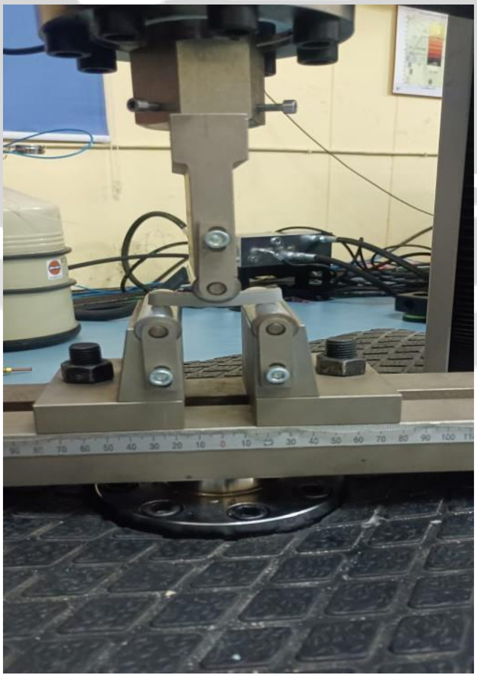


Fig.7. Bending test pieces

Reduced porosity and improved structural uniformity. In contrast, higher rpm coatings may suffer from issues such as poor bonding, increased surface roughness, or internal stress, which compromise mechanical integrity. The results emphasize the critical influence of coating parameters, particularly rotational speed, on the flexural behaviour of coated materials, indicating that careful optimization of processing conditions is essential for achieving high mechanical performance.

3.4. Micro-hardness test

The microhardness test is conducted on a Vickers hardness machine. The indentations are taken on the substrate and coating as well. Results show that the hardness of the coating is decreased compared to the substrate. The hardness of the coating is slightly higher at the interface surface, reaching a peak of a maximum of 93 HV 0.5.

4. CONCLUSION:

From the present work, the following can be concluded:

- AA5083 was successfully deposited on AA7075 by friction surfacing, featuring sound bonding with no porosity or intermetallic formation at the interface.
- High travel speeds contribute to a decrease in coating thickness, width, and bonded width.
- Lower rotation speeds were beneficial for joining.
- High rotational speed specimens contribute to higher tensile strength than low rotational speed coated specimens.
- Lower rotational speed significantly improved bending strength, suggesting better coating adhesion and enhanced structural uniformity.

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