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PROCESS PARAMETERS INFLUENCE BY FRICTION SURFACING ON SIMILAR MATERIALS FROM THE AA2024-T3

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Abstract. *The aim of this study was to produce deposits of AA2024-T3 over AA2024-T3 using friction surfacing, FS, with emphasis on the parameters and its influence on the bonding quality on the center of deposits, analyzed by bending test and hardness along the substrate to the surface deposit. FS is a promising surface technology, which produces fine-grained deposits with better properties in wear and fatigue resistance. This process enables to join dissimilar materials without reaching its melting temperatures, known as a solid-state process. Deposit analysis depicted that morphology from the surface of the deposition presents roughness and elliptical shape due to the plasticized metal transferred in layers on after the other for all condition. Hardness profile results showed that the values are higher at the deposited layer when compared with the substrate values. The process has shown fully bonded interface and absence of porosity in the center of depositions, for all conditions investigated.*

Keywords: *Friction surfacing, deposition microstructure, process parameter, AA2024-T3*

1. INTRODUCTION

Friction Surfacing (FS) is a promising technology, considered as a solid-state process, where is possible to deposit layers of metal, in temperatures below its melting range, using a rotating consumable rod under an applied axial load against a substrate (Gandra, 2014). Used as a surface engineering technology, FS can guarantee an increase in components, providing a wear, fatigue and corrosion resistance, and allows the deposition of dissimilar materials. This process evolves thermo-mechanical mechanisms, using the combination of pressure, severe plastic deformation and shear strains, where generates a viscoplastic metal layer at the rod tip, allowing to transfer material to the substrate in an elliptical shape of the layers (Fitseva, 2016). The metallic bond is generated by the inter diffusion process between the plasticized material of the rod and the substrate (Galvis et.al., 2017). The most important advantages of using friction surfacing in aluminum alloys is the deposition of a fine and homogeneous grained microstructure, lack of porosity in the bonded layer, thin heat affected zone, temperatures below melting fusion, possibility to join dissimilar materials and the absence of dilution (Khalid Rafi, 2011). The aim of this work is to compare the influence of process parameters, such as axial force and travel speed on the microstructure and hardness of AA2024-T3 deposition over AA2024-T3 substrate. Aluminum alloys from 2xxx composition family has copper as principal alloying element and the T3 designation indicate stable temper by solution heat treatment, cold working and naturally aged. These alloys are mostly used as materials for aircraft parts and components like fuselage skin, fuselage bulk-head and lower wing skins due to its high strength to weight ratio and good corrosion resistance (Ilman, 2014).

1.1 Friction surfacing process

The process consists, basically, in a rotating consumable rod, where an axial load is applied onto a substrate, and the same can be divided in four stages, as can be seen in Figure 1. First, the consumable rod is placed above the substrate, where it gains a rotational speed (a). When the desired rotational speed is achieved, an axial force is applied at

the rod onto the substrate (b). Then, due to the pressure combined with plastic deformation and shear strain, an amount of plasticized material is depicted on the rod tip and the bond interface is consolidated, identified as the initial deformation stage (c). In this stage a revolving flash is created at the rod tip with a mushroom shape. At the final stage, a travelling movement is applied continuously until the rod is completely consumed (d).

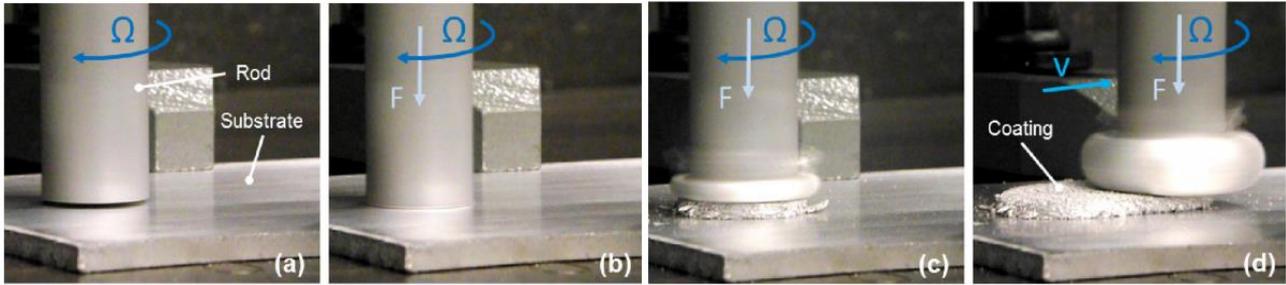


Figure 1. Step process of friction surfacing. (a) Rotation speed achievement of the rod, (b) axial force applied onto the substrate, (c) amount of plasticized metal and initial deformation stage and (d) deposition stage where a travelling movement is applied (Gandra, 2014).

2. EXPERIMENTAL PROCEDURE

Sheets with 20 mm width, 300 mm length and 1.60 mm thickness were used as substrate and consumable rod of extruded AA2024-T3 with 19.05 mm diameter and 150 mm length for the deposition. The chemical composition is presented in Table 1.

Table 1. Chemical composition of AA2024-T3 rod and substrate.

wt (%)	Al	Cu	Mg	Mn	Fe	Si	Cr	Zn
AA2024-T3 rod	93.2	4.25	1.44	0.70	0.25	0.050	0.001	0.033
AA2024-T3 substrate	93.5	4.28	1.42	0.47	0.10	0.067	0.006	0.14

The deposition process was performed in duplicate over the substrate, using a Manufacturing Technology Inc. RM 1 friction stir welding machine installed in LNNano-CNPEM in Campinas-SP. The parameters used are shown in Table 2 based on previous work.

Table 2. Process parameters used in the friction surfacing of AA2024-T3 over AA2024-T3.

Sample	Travel speed (mm/min)	Rotation Speed (rpm)	Axial force (kN)
1	500	1500	13
2	500	1500	13.5
3	500	1500	13.7
4	500	1500	14
5	450	1500	13.5
6	550	1500	13.5

For metallography, the samples were cross sectioned near at the end of each deposition, as presented in Figure 2a. Etching was executed using Keller's reagent to analyze the microstructure across section from the bonded layer for all conditions investigated. The microstructure was evaluated using Olympus BX51 optical microscopy. Hardness profile was measured by LEICA VMHT MOT hardness machine in the center of each specimen, crossing the substrate and deposit, using a load of 200gf with 0.25mm distance between indentations and 15s of time penetration. The three-point bending test was used to characterize the interface substrate/deposit resistance and was performed on a Shimadzu AG-10 testing machine, as shown in Figure 2b, according to ASTM E-290.

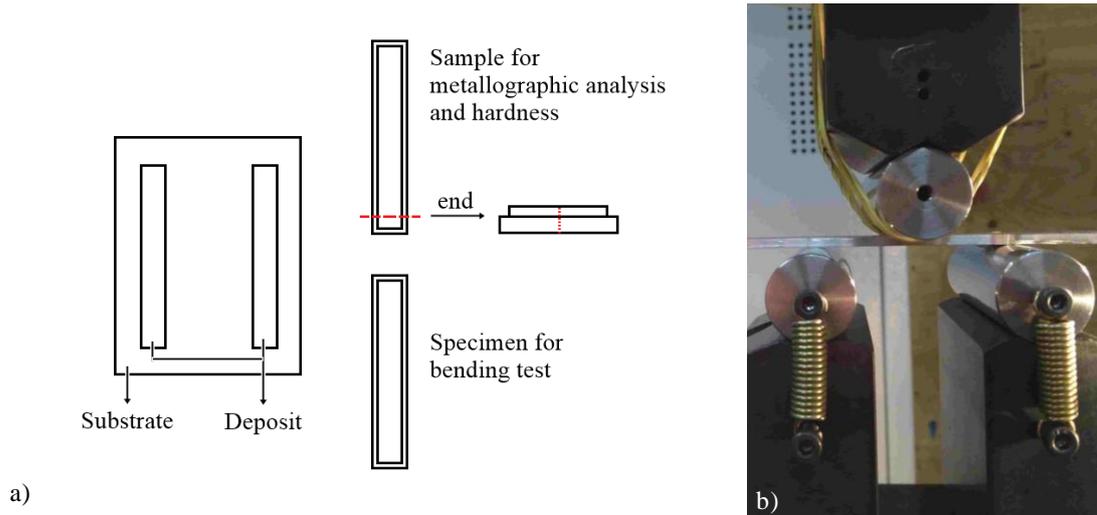


Figure 2. a) Sample extraction scheme for metallographic analysis, hardness and three-point bending tests. b) Three-point bending testing machine.

3. RESULTS AND DISCUSSION

3.1 Monitoring of axial force, displacement and torque

The monitoring of axial force, torque and displacement is depicted in Figure 3. First, the machine develops the required torque until it achieves a rotation speed of 1500 rpm (a). Upon the initial contact (b), axial force and torque have an increase, resulted from the pressure applied from the rod onto the substrate. Heat is generated from the friction between the rod and the substrate. The material on the rod tip is softened, providing a small drop on both axial force and torque. Otherwise, as the pressure and temperature start to promote the conditions for a diffusional process in the interfacial layer, axial force increases again, and the travel speed is applied (c) while the viscoplastic material is deposited in a continuous process (d).

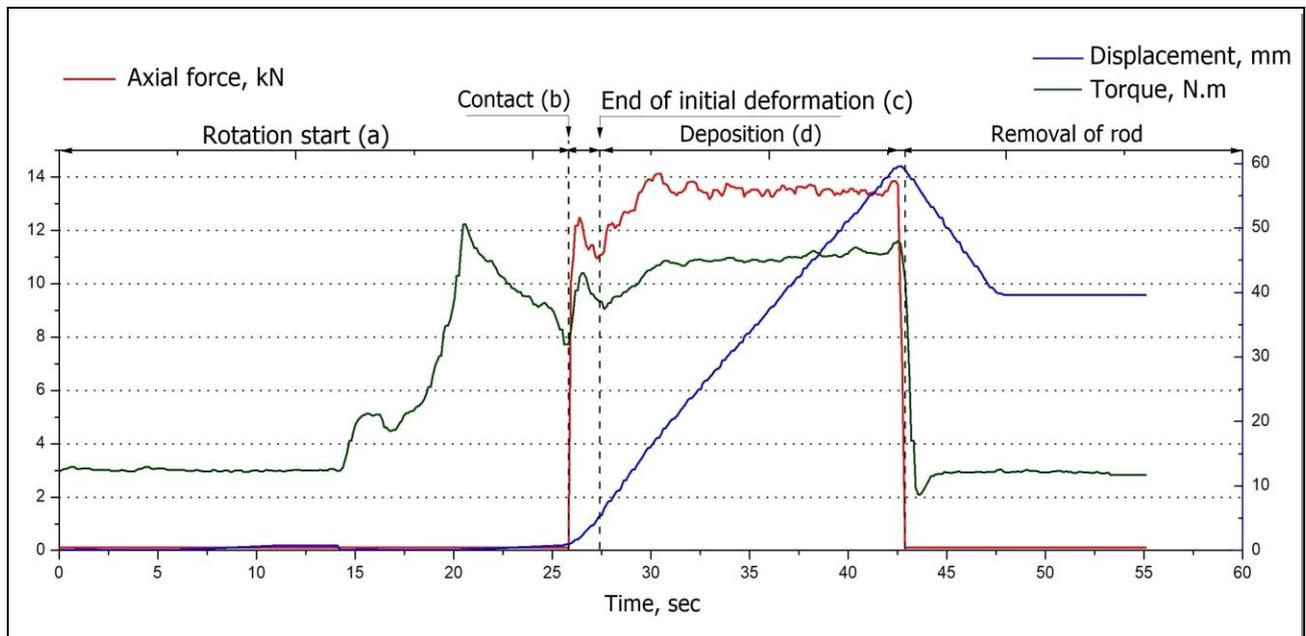


Figure 3. From sample 5 of axial force, torque and displacement monitoring during the friction surfacing of AA 2024-T3 over AA 2024-T3. Process parameters are 14 kN of axial force, 1500 rpm of rotation speed and travel speed of 7.5 mm/s. (a) rotation start, (b) contact, (c) the end of initial deformation and (d) deposition.

3.2 Deposit morphology and microstructure analyses

Figure 4 shows the surface morphological characteristic of deposits and its correspondent parameters. It is possible to notice that the morphology from the surface of the deposition presents roughness and elliptical shape due to the plasticized metal transferred in layers, one after the other, for all conditions. Although, the most regular deposition is observed, qualitatively, in sample 5 parameter condition (e).

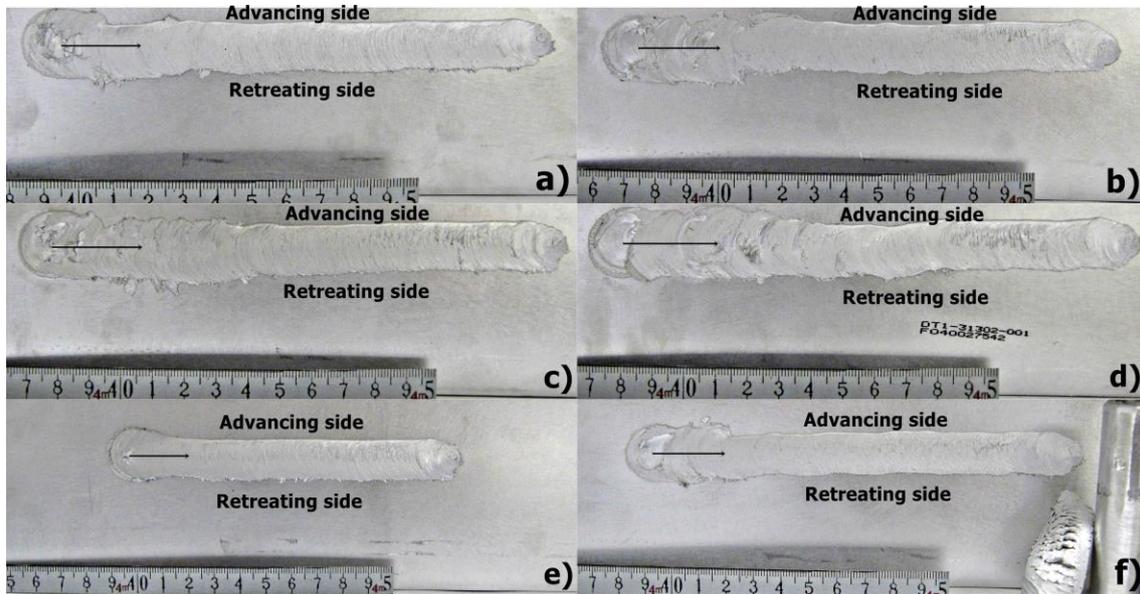


Figure 4. Top view of FS deposits. Same travel speed of 500 mm/min for a) $F_a = 13$ kN, b) $F_a = 13.5$ kN, c) $F_a = 13.7$ kN and d) $F_a = 14$ kN. Same axial force of 13.5 kN for e) $T_s = 450$ mm/min and f) $T_s = 550$ mm/min.

In Figure 5, shows the microstructure of the coating cross section. It is evident that the process provides an equiaxial fine-grained microstructure on the center of the deposit, due to the dynamic recrystallization, completely bonded to the substrate, with no evidence of porosity and intermetallic compounds, in all conditions.

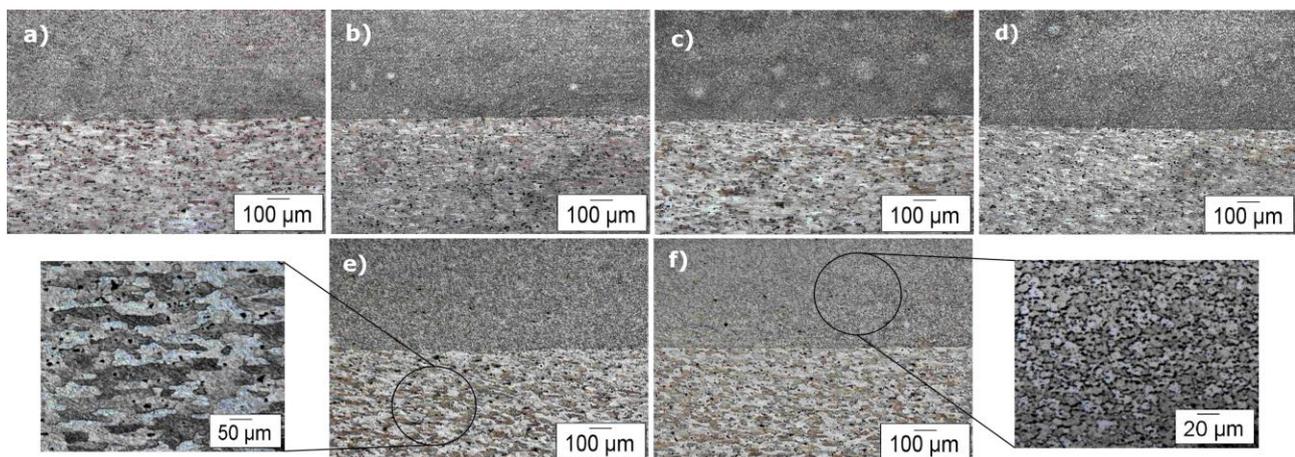


Figure 5. Micrograph showing the interfacial layer on center cross section of AA 2024-T3 over AA 2024-T3. a) $F_a = 13$ kN, b) $F_a = 13.5$ kN, c) $F_a = 13.7$ kN and d) $F_a = 14$ kN. Same axial force of 13.5 kN for e) $T_s = 450$ mm/min and f) $T_s = 550$ mm/min.

Otherwise, the rod is pressed against the substrate with no lateral confinement, providing edges with a lack of bond as depicted in Figure 6, known as the undercut or cold lap. An inherent characteristic of the process is the production of an advancing side, with a smoother edge, where the rotational movement and the dislocation movement occurs in the same direction, and a retreating side, with an uneven and rough appearance due to the opposite direction of the rotational movement and dislocation movement. This indicates that the material from the rod is not completely

transferred and bonded to the substrate because the pressure is not homogeneously applied in all the surface of the rod, creating the edges on the deposit and the flash on the rod tip, and it occurred in all conditions investigated in this work.

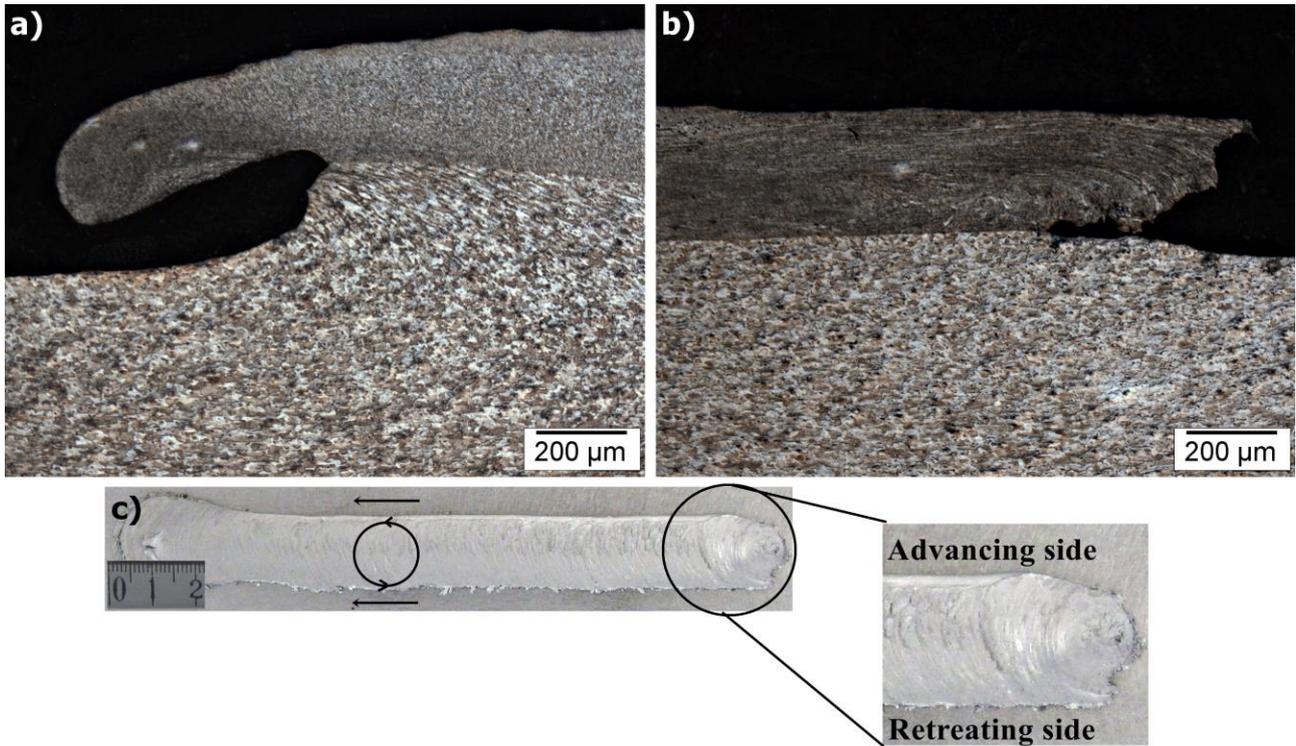


Figure 6. From sample 6 micrograph showing de unbonded edges of AA 2024-T3 from (a) advancing side and (b) retreating side of the deposition. Top view of (c) advancing and retreating side of deposit.

3.3 Microhardness profile

The hardness profile for the AA 2024-T3 is shown in Figure 7 and 8, along the substrate, interface and deposit. It can be seen that hardness values are higher at the deposited material compared to the substrate. This is due to the heat generated from friction, where the plasticized material suffers a dynamic recrystallization and generates refined grain microstructure. Hardness values for the substrate are reduced when compared to the sheet in as-received condition, before friction surfacing. This is due to the heat generated, which provides conditions for recovery phenomena, consequently producing the heat-affected zone (HAZ).

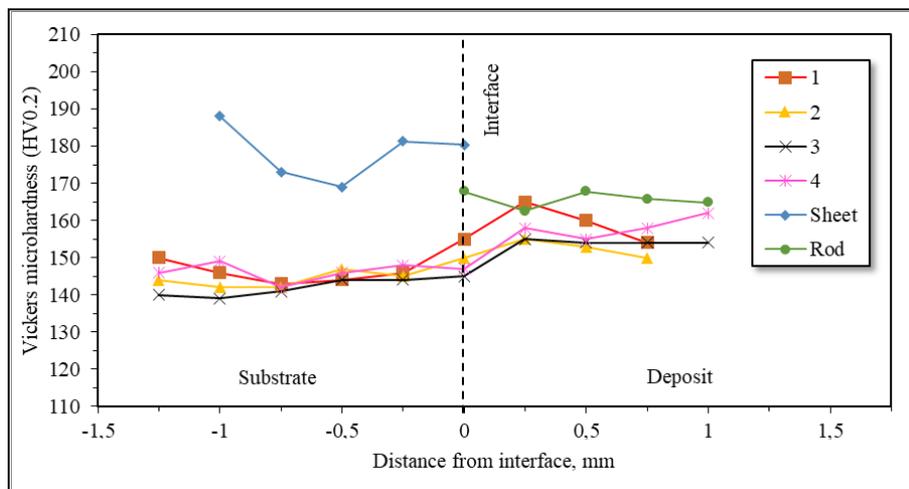


Figure 7. Microhardness profile for samples 1-4 and its chosen parameters, sheet and rod in as-received conditions.

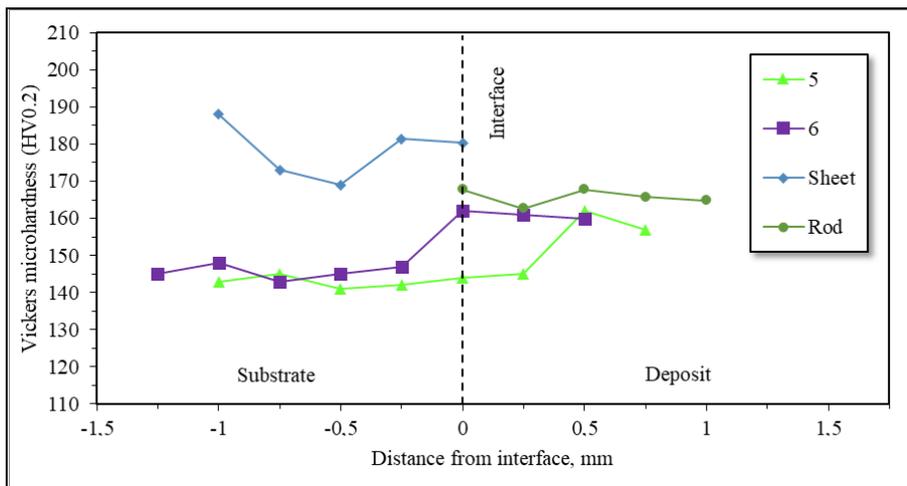


Figure 8. Microhardness profile for samples 5-6 and its chosen parameters, sheet and rod in as-received conditions.

3.4 Interface bonding resistance

Figure 9 shows the absence of defects on the interface between substrate and deposit, after three-point bending test. This result shows the efficiency and resistance of bonding interface between substrate and deposit for AA2024-T3 due to its excellent ductile properties, when compared to other results investigated in previous works for other aluminum alloys.

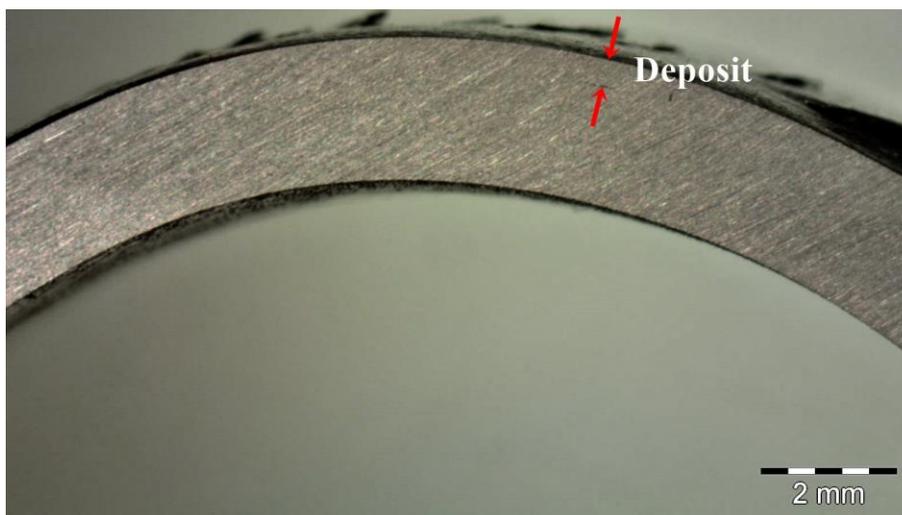


Figure 10. AA 2024-T3 sample with coating of AA 2024 after the bending test.

4. CONCLUSIONS

AA 2024 was successfully deposited over AA 2024-T3 in homogeneous layers by friction surfacing, using FSW machine adapted for FS. The process has shown fully bonded interface and absence of porosity in the center of depositions, for all conditions investigated. Thus, all parameter process investigated contribute to the refined grain deposit due to dynamic recrystallization phenomena that took place during friction surfacing process. This study indicates that FS can be used as an alternate method for deposition.

5. REFERENCES

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