Friction Surfacing as an alternative additive manufacturing technique for titanium alloys

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Introduction
Conventional additive manufacturing technologies for metals are fusion based processes, meaning that the melting temperature of the metal is reached during the layer-by-layer production. This frequently results in undesired microstructural features, such as pores, inclusions and high residual stresses induced by solidification. Thus, a fusionless solid-state additive manufacturing method is in high demand. One process that fulfills this requirement is the Friction Surfacing, which uses a rotating metallic consumable rod to generate heat by friction and plasticizes the materials, without melting (Fig.1).

Since this a relatively new technique, not many material combinations have been investigated, in particular titanium alloys, remaining a vastly unexplored application area.

![Figure 1: Stages of Friction Surfacing](image)

**Figure 1:** Stages of Friction Surfacing: (a) Rod is rotating with the rotational speed \(Q\); (b) Axial force \(F\) is applied in the z-direction; (c) Shear layer is formed by frictional heat (shortening stage); (d) Traverse speed \(v\) is applied to deposit the layer. (Source: Miranda et al., Friction Surfacing-A review, 2013)

Experimental Results
The aim of this work was to firstly achieve a homogenous single layer deposition of Ti-64 on a Ti-64 substrate by friction surfacing with 12 mm rods. The process parameters studied were rotational speed \(Q\), traverse speed \(v\) and axial force \(F\). The best layer in terms of homogeneity, thickness, lack of flash formation and straightness can be seen in Fig. 2, with its resulting macrograph in Fig.3.

![Figure 2: Single layer deposition with a 12 mm rod using an axial force of 0.5 kN, a traverse speed of 800 mm/min and a rotational speed of 3000 min\(^{-1}\)](image)

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![Figure 3: Micrograph of a single layer deposition with a 12 mm rod using an axial force of 0.8 kN, a traverse speed of 800 mm/min and a rotational speed of 3200 min\(^{-1}\)](image)

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Hardness was measured along three horizontal lines for both the single- and double-layer depositions. The results were plotted in comparison to the maximum height of a layer (Fig.6). Results show that hardness remained mostly constant, only having a slight increase at the top of the layer, probably attributed to the formation of the small \(\alpha\)-grains (alpha case).

![Figure 4: Double layer deposition with a 12 mm rod; 1st layer: 3200 min\(^{-1}\), 0.5 kN, 700 mm/min; 2nd layer: same as 1st but displacement during shortening stage was altered to 1.5 mm.](image)

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![Figure 5: (a) Micrograph of the double layer deposition with a 12 mm rod; (b) SEM image of the 1st layer showing a martensitic matrix, (c) Transition zone between layers with small grains of the \(\alpha\)-phase.](image)

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![Figure 6: Comparison of hardness of the single and double in relation to the maximum height, \(h\), of the layer.](image)

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Conclusions
The feasibility of Friction Surfacing to deposit smaller diameters Ti-64 rods on Ti-64 substrates was successfully demonstrated on 12 mm for the first time in the literature.

Furthermore, two consecutive layers with 12 mm rods could be deposited, without a machining step in-between. The irregular shape of the bottom layer decreased the contact surface and thus disrupting the shear layer formation during the shortening stage. Hardness measurements data for the double layer depositions showed that the values are similar to the single layer ones, suggesting homogeneity of properties. Ongoing work will help to better understand the influence of friction surfacing on material properties and improve deposition quality.