Numerical study of rolling process on the residual stress and plastic strain distribution in wire + arc additive manufactured Ti-6Al-4V

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Abstract. Wire + arc additive manufacturing (WAAM) is an additive manufacturing (AM) process that employs wire as the feedstock and an arc as the energy source, to construct near net-shape components at high build rates [1]. Ti-6Al-4V deposits typically form large columnar prior β grains that can grow through the entire component height, leading to a anisotropic and lower mechanical properties compared to the equivalent wrought alloy [4].

Rolling is a cold-working technique that was initially used to reduce residual stresses in Ti-6Al-4V WAAM parts [5], however it is now used to promote grain refinement, thus increasing strength and reducing anisotropy concomitantly [6]. It has been shown experimentally that the minimum value of the required plastic strain to refine Ti-6Al-4V is approximately 10 % or larger [6]. The aim of this paper is to understand the effect of rolling process parameters on the plastic deformation characteristics in WAAM structures to refine the microstructure; this is needed to produce suitable design guidelines for practical applications. The effect of different rolling process parameters, in particular, rolling load, roller profile radius on the plastic strain distribution is investigated based on the finite element method. FIGURE 1 illustrates an example of a rolling simulation and the resulting stress and strain distribution. Additionally, the effect of friction coefficient between roller and wall, as well as the modelling for the roller (e.g. deformable vs rigid roller) are investigated. Initial results show that the plastic strain distributions are insensitive to the initial stress state. For an identical rolling load, the deformable roller produces lower equivalent plastic strain. Lower friction coefficient produces higher equivalent plastic strain near the top surface but, it has an insignificant effect in the depth. However, higher friction coefficient increases the simulation time by factor two. Although larger roller profile radii lead to higher compressive residual stresses, it has nearly no noticeable effect on the depth of compressive residual stresses.

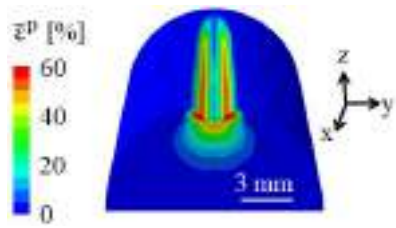

FIGURE 1 Finite element model to simulate rolling process. Distribution of equivalent plastic strain after rolling.

Keywords: Cold-working, finite element method, profiled rolling, longitudinal stress, equivalent plastic strain

References

[1] Williams S W, Martina F, Addison A C, Ding J, Pardal G and Colegrove P 2016 Wire + Arc Additive Manufacturing *Mater. Sci. Technol.* **32** 641–7

[2] Cunningham C R, Flynn J M, Shokrani A, Dhokia V and Newman S T 2018 Invited review article: Strategies and processes for high quality wire arc additive manufacturing *Addit. Manuf.* **22** 672–86

[3] Ding J, Colegrove P, Mehnen J, Ganguly S, Almeida P M S, Wang F and Williams S W 2011 Thermo-Mechanical Analysis of Wire and Arc Additive Layer Manufacturing Process on Large Multi-Layer Parts *Comput. Mater. Sci.* **50** 3315–22

[4] Wang F, Williams S ., Colegrove P and Antonysamy A . 2013 Microstructure and Mechanical Properties of Wire and Arc Additive Manufactured Ti-6Al-4V *Metall. Mater. Trans. A* **44** 968–77

[5] Martina F, Roy M J, Szost B A, Terzi S, Colegrove P, Williams S W, Withers P J, Meyer J and Hofmann M 2016 Residual Stress of As-Deposited and Rolled Wire + Arc Additive Manufacturing Ti–6Al–4V Components *Mater. Sci. Technol.* **32** 1439–48

[6] Donoghue J, Antonysamy A A, Martina F, Colegrove P A, Williams S W and Prangnell P B 2016 The effectiveness of combining rolling deformation with Wire-Arc Additive Manufacture on β-grain refinement and texture modification in Ti-6Al-4V *Mater. Charact.* **114** 103–14