Residual Stresses in Inconel 625 Parts Produced Using Atomic Diffusion Additive Manufacturing (ADAM)

Nida Naveed[1], Bilal Ahmad[2]

[1]Faculty of Technology, School of Engineering, University of Sunderland, Sunderland, SR1 3SD, UK
[2]Centre for Manufacturing and Materials, Coventry University, Gulson Road, Coventry, CV1 2JH, UK

ABSTRACT

Metal additive manufacturing, also known as metal 3D printing, is a cutting-edge manufacturing process that involves building metal parts layer by layer from a digital 3D model. This paper describes the distribution of residual stress in a 10 mm thick Inconel 625 plate fabricated using Atomic Diffusion Additive Manufacturing (ADAM). This study aims to investigate the effects caused by the ADAM process, focusing on the formation of residual stresses in Inconel 625 3D printed parts. The contour method, a district technique, was employed for measuring residual stresses. This method, although destructive, offers a two-dimensional stress map. The results revealed that the ADAM process produces lower tensile residual stress compared to other metal additive manufacturing methods, making it ideal for applications demanding precise dimensional accuracy and enhanced structural integrity.

KEYWORDS: Additive manufacturing, Atomic Diffusion Additive Manufacturing (ADAM), 3D printing, Inconel 625, residual stresses

INTRODUCTION

Metal additive manufacturing (MAM), referred to as metal 3D printing, is an advanced manufacturing technique where metal components are fabricated layer by layer based on a digital 3D model [1]. Atomic Diffusion Additive Manufacturing (ADAM) is one of the metal additive manufacturing techniques which prints metal parts layer-by-layer and then uses a sintering process to fuse these layers [2]. Through controlled atomic diffusion, this process allows for enhanced precision and the creation of parts with complex geometries, making it a valuable tool for modern manufacturing applications. However, for the application of high-integrity structural components that operate under extreme conditions of high temperature, pressure such as turbine engine components in aerospace applications, it is vital to understand the complete landscape of material properties of these printed parts, as well as the effects of the ADAM process on 3D printed metal parts, specially for internal residual stress. Residual stresses develop in almost all fabrication and manufacturing processes. Residual stresses, present in a material without external loads, self-equilibrate throughout its volume, exhibiting varying compressive and tensile stresses. They can reach high magnitudes with significant gradients, potentially causing fatigue, stress corrosion cracking, and premature failure. While externally applied loads can be accurately calculated, predicting residual stresses requires a more complex approach due to their unpredictable nature [3]. There is a wide range of techniques available to measure residual stress, categorised as destructive, semi-destructive, and non-destructive. The contour method, a destructive technique for engineering component analysis, provides a two-dimensional stress map. The contour method involves cutting the test component in half, The cut surfaces deform due to residual stress relaxation. Measurements of this deformation are utilised to back calculate a two-dimensional map representing the original residual stresses normal to the cut plane [4]. For this study, Inconel 625, a nickel-chromium-based superalloy known for its exceptional corrosion resistance and strength at high temperatures, was fabricated using the ADAM 3D printing technique. The contour method was employed to analyse the residual stresses induced by the ADAM process.

RESIDUAL STRESS MEASUREMENTS

The dimensions of the sample plate were 60 mm in length, 50 mm in width, and 10 mm in thickness. For stress measurement, a contour cut was performed at the mid-length of the sample to capture the longitudinal residual stress component. The cut was executed using a Fanuc Robocut α-C600i wire electro-discharge machine (EDM), using a brass wire with a diameter of 0.25 mm. The sample was symmetrically and rigidly clamped during the wire EDM cut. The cut progressed through the thickness and along the width of the sample at a cutting speed of approximately 0.5 mm/min. Figure 1 illustrates the Inconel 625 sample fabricated using the ADAM 3D printing technique after being cut with WEDM. Subsequently, surface displacement profiles of the cut surfaces were measured using a Zeiss Contura g2 coordinate measuring machine (CMM) with a 3 mm diameter probe in scan mode. Following this, precise data analysis steps were conducted to measure the residual stresses, involving data smoothing over an optimal length-scale and selection of an appropriate finite element mesh density. A cross-sectional map of the longitudinal residual stress measured using the contour method for the Inconel 625 ADAM 3D printed part is presented in Figure 2.

RESULTS

The contour method measurement results reveal a low value of tensile stresses within the longitudinal stress map, indicating that the ADAM process generates lower tensile residual stress compared to other metal additive manufacturing techniques such as Wire-feed Additive Manufacturing (WFAM) and Wire Arc Additive Manufacturing (WAAM) [5], [6]. While both WFAM and WAAM utilise welding arcs to melt wire feedstock, ADAM employs a focused energy beam, such as a laser or an electron beam, for precise melting of metal powder or wire feedstock. This focused energy beam allows for precise control over the melting process, resulting in reduced residual stresses.

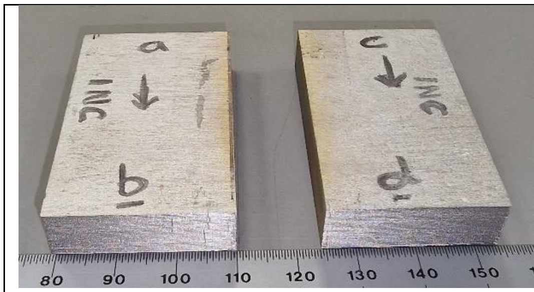

Figure 1: the Inconel 625 sample produced through ADAM 3D printing, post-WEDM cutting.

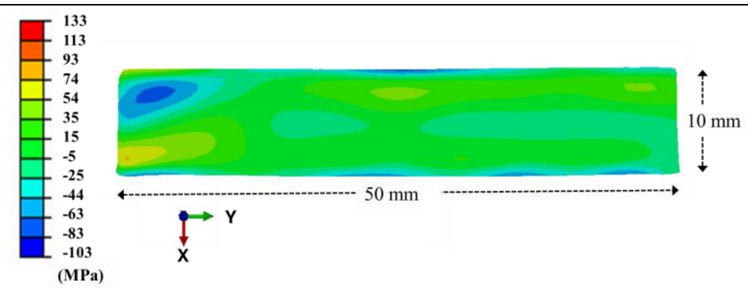

Figure 2: Map of the longitudinal stresses for the Inconel 625 ADAM 3D printed part.

CONCLUSION

The contour method can be successfully employed to characterise the residual stress in Inconel 625 material parts produced by the Atomic Diffusion Additive Manufacturing (ADAM). The findings from the contour method measurements show a low presence of tensile stresses in the longitudinal stress distribution, suggesting that the ADAM process produces significantly reduced tensile residual stress when compared to alternative metal additive manufacturing methods.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Carl Gregg for his assistance in fabricating the 3D printed samples at the University of Sunderland, and to Dr. Hua Guo for conducting the CMM measurements at Coventry University.

REFERENCES

[1] M. Armstrong, H. Mehrabi, and N. Naveed, ‘An overview of modern metal additive manufacturing technology’, *Journal of Manufacturing Processes*, vol. 84, pp. 1001–1029, Dec. 2022, doi: 10.1016/j.jmapro.2022.10.060.

[2] ‘Evaluating energy consumption in atomic diffusion additive manufacturing versus sand casting - SURE’. Accessed: Feb. 15, 2024. [Online]. Available: https://sure.sunderland.ac.uk/id/eprint/16448/

[3] P. J. Withers, ‘Residual stress and its role in failure’, *Rep. Prog. Phys.*, vol. 70, no. 12, p. 2211, Nov. 2007, doi: 10.1088/0034-4885/70/12/R04.

[4] M. Prime and A. Kastengren, ‘The Contour Method Cutting Assumption: Error Minimization and Correction’, in *Conference Proceedings of the Society for Experimental Mechanics Series*, vol. 6, 2011, pp. 233–250. doi: 10.1007/978-1-4419-9792-0_40.

[5] K. S. Derekar *et al.*, ‘Effects of Process Variants on Residual Stresses in Wire Arc Additive Manufacturing of Aluminum Alloy 5183’, *Journal of Manufacturing Science and Engineering*, vol. 144, no. 7, p. 071005, 2022.

[6] B. Ahmad, S. O. Van Der Veen, M. E. Fitzpatrick, and H. Guo, ‘Measurement and modelling of residual stress in wire-feed additively manufactured titanium’, *Materials Science and Technology*, vol. 34, no. 18, pp. 2250–2259, Dec. 2018, doi: 10.1080/02670836.2018.1528747.