

Experimental and Numerical Analysis of Thermomechanical Behaviour in LENS Additive Manufacturing

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1. Introduction

Additive manufacturing (AM) involves layer-by-layer material deposition until a complete part is formed. The process is characterized by thermal gradients and a complex thermal history, which significantly influence the resulting microstructure and mechanical properties. Optimized component properties can be achieved by controlling the thermal history through appropriate selection of process parameters and conditions [1]. In addition, inappropriate process parameters can result in high residual stresses within the component. These stresses may induce deformation, and when a critical threshold is exceeded, they can lead to fracture [2]. Therefore, detailed numerical modelling can be helpful to better understand the effects of specific parameters and to facilitate parameter selection. However, numerical modelling of the AM process is challenging due to its complex physical nature, and additional difficulties arise during model verification [3].

Therefore, the main aim of this work is to develop a numerical model describing the thermal history, deformation, and residual stress development during the DED additive manufacturing process. In addition, this study addresses challenges related to model verification.

2. Materials and Methods

In this work, commercial Simufact Welding software was used for numerical modelling of thermal history, deformation, and residual stress development during the additive manufacturing process performed using a LENS system.

Verification of the numerical model was carried out based on temperature measurements and substrate displacement recorded during manufacturing. For this purpose, thin-walled 304 stainless steel elements were fabricated on substrates with thicknesses of 1 and 1.5 mm, resulting in substrate deformation. Both the fabricated elements and the substrates were made of 304 stainless steel. Temperature evolution was monitored using thermocouples placed inside the substrate and pyrometers measuring the melt pool temperature. The displacement observed during deposition was validated using the Digital Image Correlation (DIC) method.

Preliminary investigations were also carried out using the DIC method to determine displacement and deformation of AM parts during the manufacturing process. For this purpose, two thin-walled specimens with a length of 90 mm were fabricated using the same process parameters, differing only in the dwell time between deposited layers. One specimen was manufactured without a pause between layers, while the second one was fabricated with a 5 s dwell time. During the entire process, the specimens were monitored using a camera, and the recorded images were analysed using the DIC method. In addition, an attempt was made to evaluate residual stress using the DIC method based on deformation induced by stress relaxation after removing the specimens from the substrate.

3. Results

Fig. 1 presents a comparison of the melt pool temperature measured during the experiment and predicted by the numerical model during fabrication

of a thin-walled specimen using the LENS system. Good agreement between the experimental and numerical results was observed, particularly for the peak temperature values, whereas larger discrepancies were observed during cooling

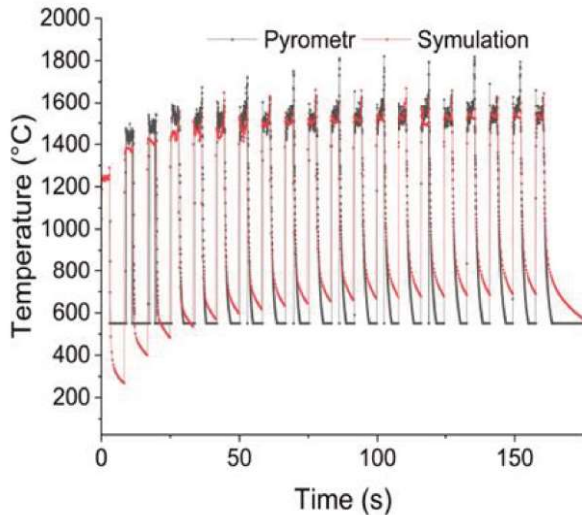


Fig. 1 Comparison of numerical and experimental temperature distributions measured using pyrometers.

The mechanical response of the model also shows a strong similarity with the experiment (Fig. 2). Although the absolute displacement values at selected points differed, the relative values between points were similar, confirming that the overall deformation behavior of the specimen was accurately captured.

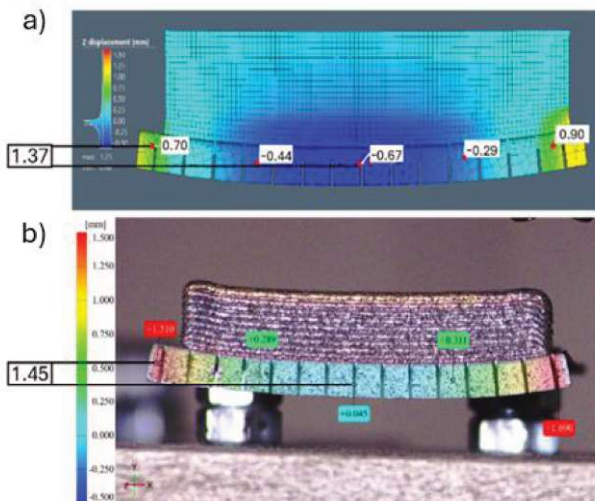


Fig. 2 Comparison of numerical and experimental displacement obtained after the AM process.

Initial in situ deformation tests show that specimen built without pause between the layers is characterized by lower deformation during the printing than the specimen with 5 s dwell time (Fig. 3). However, the results are affected by significant measurement uncertainty, potentially caused by the

surface roughness of the samples and the resulting signal noise.

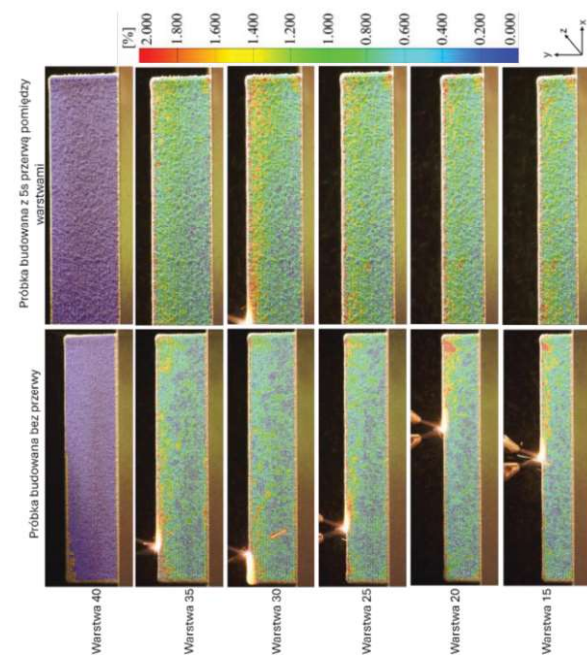


Fig. 3 Equivalent strain distribution in 304 stainless steel specimens monitored during the LENS additive manufacturing process.

4. Conclusions

The results indicate that good agreement between the experimental data and the numerical model can be achieved for the thermomechanical behaviour of the LENS-fabricated element. In addition, initial in-situ deformation tests show promising results and may support improved model validation in future work.

Acknowledgments

References

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