UNIVERSITI TEKNOLOGI MARA

THERMO-MECHANICAL ANALYSIS OF WIRE ARC ADDITIVE MANUFACTURING (WAAM) OF AUSTENITIC STAINLESS STEEL SS316L USING NUMERICAL COMPUTATION AND EXPERIMENTAL VERIFICATION

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of the requirements for the degree of
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AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the results of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any degree or qualification.

I, hereby, acknowledge that I have been supplied with the Academic Rules and Regulations for Post Graduate, Universiti Teknologi MARA, regulating the conduct of my study and research.

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ABSTRACT

This research aims to investigate transient thermal distribution and mechanical behaviour induced by WAAM based on experiment and numerical computational analysis. Two different WAAM components were investigated additively built with five layers and three strings (5L3S) and ten layers and three strings (10L3S), consisting of low carbon steel S235 as substrate and austenitic stainless steel SS316L as feedstock. Besides, an investigation of bead-on-plate was also performed with an ER316LSi filler material deposited on SS316L substrate with 4 mm of thickness. The experimental study was executed using GMAW robotic welding system ABB IRB 2400/16 equipped with KEMPPI Pro-Evolution ProMig power source with pure Argon as shielding gas. For verification purpose, substrate deformation was measured using coordinate measurement machine prior and after the process with cross-diagonal clamping. Uniaxial tensile test was conducted on deposited parts of WAAM and raw substrate of SS316L. In the numerical simulation analysis, a solid three-dimensional FE model of bead-on-plate and WAAM which the feedstock was modelled using simplified rectangular shape and optimized mesh obtained through sensitivity analysis in accordance with actual specimen geometry using FEM simulation software MSC Marc/Mentat. The numerical simulation was executed using two different numerical methods, namely non-linear thermo-mechanical method (TMM) and linear elastic inherent strain method (ISM). In the TMM analysis, non-linear isotropic hardening rule with von-Mises yield criterion and temperature-dependent evolved material properties of SS316L was implemented which were generated by means of advanced material modelling tool based on chemical composition characterized using SEM-**EDX. The heat source was modelled using default Goldak's double ellipse and** normal distribution of rectangular heat source. The simplified rectangular heat source was developed using user subroutine uweldflux. Prior to adjustment of heat transfer coefficients, the transient thermal distribution was analysed by measuring the real-time temperature histories at specific points located in the additively built component layer inserted gradually during the process and also on the substrate implanted beforehand using type-K thermocouple. For inherent strain method (ISM), two different approaches to apply inherent strain has been presented by the software which are user defined and weld kinematics. Further, the inherent strain value is estimated empirically regarding to the process parameters, physical properties, and effective area where the weld region and heat affected zone shall be happening. The size and geometry of effective area of bead-on-plate of SS316L was calibrated using hardness test meanwhile, the WAAM components were calibrated using macrograph analysis. The prediction of substrate distortion of bead-on-plate and WAAM components using ISM were to be analysed and compared to experiment and TMM. For both numerical methods, the mean relative percentage errors of measurement points for WAAM components of 5L3S and 10L3S were laid within 10% ~ 26.95% and 23.1% ~ 30%, respectively. For bead-on-plate of SS316L, the mean relative percentage error in predicting the substrate deformation was laid between 6.18% ~ 28.53% at the respective specific measurement points. The results has shown that the application of ISM gives higher potential to be executed to predict deformations within short computational time with acceptable percentage error.

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