UNIVERSITI TEKNOLOGI MARA

MECHANICAL AND GRAIN GROWTH BEHAVIOUR OF WIRE-ARC ADDITIVE MANUFACTURING (WAAM) OF SS316L USING EXPERIMENT AND NUMERICAL SIMULATION

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Thesis submitted in fulfillment
of the requirements for the degree of
Doctor Of Philosophy
(Mechanical Engineering)

College of Engineering

October 2022

ABSTRACT

Modern day engineering structures depends on actively designing against fatigue failures. While Wire-Arc Additive Manufacturing (WAAM) offers numerous advantages to conventional manufacturing techniques, the fatigue performance of WAAM structures must be understood before they can be safely used. This thesis aims to investigate the relationship between the grain size microstructure of SS316L austenitic stainless steel and the mechanical properties of the WAAM component. The research is divided into four phases. The initial phase is the material verification and selection of the WAAM SS316L process parameters for thick wall structure using a Robotic welding system. The material chemical composition was verified by using an Arc spectrometer. The result was used for material modelling and computation. Included in this phase is the complex experimental thermal history data acquired by using a high-temperature thermocouple connected to a Data Acquisition System (DAQ) for thermal calibration. The second phase is the development of a Finite Element Method (FEM) WAAM model procedure using general-purpose numerical computational software MSC Marc/Mentat with utility routine and subroutine capability. Further, the temperature-dependent material parameter was developed in JMatPRO. The numerical computation is based on von Mises yield criterion and isotropic hardening rules. The numerical computational heat distribution in the WAAM model was calibrated by referring to the thermal experiment for verifying the heat transfer coefficients. As modelling a complex multi-pass welding simulation is a challenge due to the longer computational time, an innovative solution to simplify the Heat Source Model (HSM) was explored. As a result, a FEM procedure for WAAM model was developed. The third phase of the research is the analysis of SS316L material grain size microstructure and the grain growth material parameters at elevated temperature. A grain size prediction algorithm was developed specifically for SS316L material based on free grain growth formula. The real material parameters for the grain growth formula was investigated using a Dilatometer at elevated temperature with different holding times. At this stage, specific material parameters for the grain growth prediction subroutine was defined, such as activation energy (Q) and modified kinetic constant (M_o). In addition, an experimental investigation of the microstructure on the initial and final grain size according to ASTM guidelines was conducted. Evolution of grain sizes was observed within the as-printed WAAM structure. In the fourth phase, the mechanical properties of the as-printed WAAM component was defined. Differentiated by the upper and lower section, specimens for tensile, hardness and fatigue test were extracted from the experimental thick wall WAAM specimen. As a result, a novel FEM procedure for WAAM component was developed, calibrated and validated by experiment. Additionally, the grain growth material parameter for SS316L was defined as a temperature dependant material property and the grain growth behaviour was investigated. According to tensile, hardness and fatigue test standards, the mechanical properties and fatigue life of the WAAM component was defined for each section. A finer grain microstructure has an absolute effect of increasing the fatigue life of the WAAM component.

ACKNOWLEDGEMENT

Firstly, I wish to thank God for giving me everything including the opportunity to embark on my PhD journey until completion, as it is a very long experience and learning curve for me. The challenges are everywhere but my journey is a success story. My highest and most sincere gratitude is towards my outstanding supervisor Prof. Ir. Ts. Dr. -Ing Yupiter HP Manurung for his guidance, knowledge sharing, and never-ending support.

My appreciation goes also to my co-supervisor Prof. Ir. Dr Wahyu Kuntjoro for his guidance and moral support.

I would like to express my gratitude to all the staff members of Smart Manufacturing Research Institute (SMRI) and Research Interest Group: Advanced Manufacturing Technology (RIG: AMT) at the Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) as well as Professorship of Virtual Production Engineering at Chemnitz University of Technology (CUT) in Germany and Montanuniversïtat Leoben (MUL) in Austria for encouraging my research.

I would like to also express my gratitude to Dr Norasiah Muhammad from Politeknik Sultan Salahuddin Abdul Aziz Shah, Malaysia, and Salina Saidin from Nusantara Technologies Material Division in Malaysia, Dr Dahia Andud from UniKL-Malaysia France Institute (Unikl-MFI) as their knowledge and experience were insightful towards my research.

Finally, this thesis is also dedicated to my loving family especially my parents, Mat @ Muhammad Yusoff and Fauziah Abd. Rahman who without fail has motivated me since childhood to always seek new knowledge. Another person is my lovely wife, who is very supportive of my decision to continue my PhD journey. There were hard times, but we manage to overcome them, especially during the Covid-19 outbreak. Last but not the least, to all my children who patiently awaits me to come home early every day. Muhammad, Humairah, Fatimah and Ibrahim, I love you.

Alhamdullilah and Allahuakbar.

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CHAPTER ONE
INTRODUCTION

1.1 Research Background

Additive Manufacturing (AM) or three-dimensional (3D) Printing refers to layer-by-layer manufacturing process from a wide range of materials namely metals and plastics. WAAM is a high-deposition rate additive manufacturing process, which can be used for the manufacture of large-scale structural parts of medium complexity. Commercial welding torches are manipulated by a robotic or Computer Numerical Control (CNC) system to deposit metal wire on a substrate, using welding arcs as a power source [1]. Metal Additive Manufacturing (MAM) uses either wire feed or metal powder with a suitable energy source for the process. Currently two types of fabrication are extensively used in metal-based AM: Directed Energy Deposition (DED) and Powder Bed Fusion (PBF). DED builds generally lack the dimensional accuracy and repeatability of PBF builds but may possess enhanced monotonic mechanical properties such as Yield Stress and Ultimate Tensile Stress (UTS), higher output, faster fabrication time, and relatively lower cost compared to PBF builds [2]. DED is more suitable for larger dimension builds without complexity towards its form or shape. In WAAM, the added metal is deposited using arc welding techniques such as Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW), or Plasma Arc Welding (PAW) [3]. GMAW can be used to deposit a wide range of metals including Stainless Steel (SS). The components manufactured by WAAM are prone to residual stresses and distortion issues [4]. Table 1.1 represents additive manufacturing categories according to International Standard Organisational (ISO) and American Society for Testing and Material (ASTM) standards.