UNIVERSITI TEKNOLOGI MARA

ANALYSIS OF ADDITIVE MAFACTURING (AM) MULTI MATERIAL BEHAVIOUR USING NUMERICAL SIMULATION WITH EXPERIMENTAL VERIFICATION

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ABSTRACT

The field of Metal Additive Manufacturing (MAM) has made significant strides, especially in creating components with diverse material properties. Wire Arc Additive Manufacturing (WAAM) offer numerous advantageous over the conventional manufacturing process such as producing AM's components with distinctly localized mechanical and metallurgical properties commonly known as functional grading. Previous studies have shown that the hardness of WAAM structures varies along the building direction, primarily due to effect of process parameters and the thermal gradient between the deposited layers. This can be attributes to the formation on non-equilibrium phase transformation. A precise hardness prediction considering the phase fraction with the Finite Element Method (FEM) requires optimal material data which can be measured from Time Temperature Transformation (TTT) and Continuous Cooling Transformation (CCT) diagrams. Most of commercial material modelling are able to predict thermomechanical properties of the materials. However, CCT and TTT generated are used for heat treatment in steels which not applicable for the WAAM process. This method of material modelling prediction often results in inaccuracy to reality. Thus, this thesis aims to optimize material modelling for numerical simulation of High-Strength Low-Alloy (HSLA) steel, ER100S-G to predict the mechanical and metallurgical properties in functional graded WAAM structure which exhibit multi material properties behaviour with experimental verification. The research is structured into three phases. The first phase investigates the impact of varying travel speed on the hardness properties of bead on plate WAAM. Four distinct travel speeds were used to evaluate its effect on hardness. Combine with thermal analysis to validate the numerically predicted cooling rates, the results show the cooling rate for bead on plate deposited with a travel speed of 3 mm/s differs by a factor greater than nine which is 26 °C/s compared to travel speed of 15 mm/s which yield cooling rates of 244 °C/s. The second phase focused on optimizing the TTT curve and CCT data of ER100S-G generated by commercial material modelling software. It was observed that the experimental measured hardness and cooling rates differed significantly from the simulation. To address this, the CCT data was calibrated considering the measured cooling rates and hardness guided by phase fraction and empirical formula. Additionally, the position of the TTT transformation curves was optimized to align with the cooling time $T_{8/5}$ of optimized CCT data ensuring that the phase transformation was accurately represented. The final phase focuses on developing FEM model using Simufact Welding 2022 for functionally graded WAAM structure by adjusting travel speeds and inter-pass temperature while incorporating optimized phase transformation data for ER100S-G. The WAAM structure consisted of low heat input (LHI) region deposited on high heat input region (HHI). The highest error percentage of hardness prediction between simulation and experiment is 10.77% with average error percentage of 5.43%. The experimental hardness measurements indicated the LHI region exhibited 76 HV higher hardness compared to HHI region. This study highlights the develop optimization method can improve the accuracy of hardness prediction after WAAM process by optimizing CCT and TTT with measured data from the WAAM process. Additionally, this study demonstrates the potential to achieve multi-material behavior of functional grading by altering process parameters of WAAM, providing opportunities for tailored properties in AM components.

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Research Background

The Fourth industry Revolution, or Industry 4.0, has garnered substantial attention in academic and industry domains over the last decade, indicating a dramatic change in the future of manufacturing. Additive Manufacturing (AM) has become a prevalent substitute for conventional machining techniques among the principal technologies facilitating this transformation. AM is an advanced technique that constructs three-dimensional metallic components incrementally, progressively forming the final result. This technique is extremely efficient for fabricating complex components from materials that are either expensive or challenging to process, such as titanium alloys, which are particularly advantageous for additive manufacturing due to their high buy-to-fly ratios. Presently, additive manufacturing processes are primarily classified into three groups according to the material utilised: liquid-feed, powder-feed, and wire-feed [1].

Wire Arc Additive Manufacturing (WAAM) represents a significant development in wire-feed AM, integrating electric arc heating sources with a metallic wire feeding mechanism. WAAM functions based on arc welding principles, employing an electric arc to melt metallic wire and construct layers of material, rendering it particularly efficient for fabricating big components of medium complexity with elevated deposition rates relative to other additive manufacturing processes [2]. WAAM employs several arc-welding heat sources, such as Tungsten Inert Gas (TIG), Metal Inert Gas (MIG), and Plasma Arc Welding (PAW). MIG is the most frequently employed method owing to its simplicity and efficacy [3]. It employs a continuous wire spool connected to the welding torch, whereas TIG and PAW necessitate additional wire feeding systems. WAAM systems can be established by combining traditional wire-feed welding apparatus with industrial robotic arms, rendering it a versatile and adaptable technique for large-scale manufacturing. This study uses a GMAW robotic welding system to produce metallic components utilising the WAAM technique.