UNIVERSITI TEKNOLOGI MARA

NUMERICAL SIMULATION AND EXPERIMENTAL VERIFICATION ON DISTORTIONS INDUCED BY WIRE-ARC ADDITIVE MANUFACTURING COMPONENTS AND COSTING ANALYSIS

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ABSTRACT

This thesis focuses on the substrate and part distortion induced by wire arc additive manufacturing (WAAM) which is predicted by means of numerical computation followed by experimental verification. The material used for this study is the commercial S235 low carbon steel and filler material stainless steel SS316l. On analysing the distortion effect by means of numerical computation method, a commercial specialized simulation software Simufact.Welding was used in the development of the numerical model. The development of numerical simulation model started by the geometrical modelling followed by material modelling based on real scanned material using JMATPRO. A mesh sensitivity analysis was executed in order to determine the most optimized element numbers which are followed by the selection of optimized WAAM parameters based on the result of preliminary experiment process. To enlighten the application of method and procedure of numerical computation, this research is divided into two case studies. The first case study is modelling, simulating and fabricating the twenty layers deposition of hollow rectangular WAAM and the second case study is to examine pipe flange WAAM where the substrate and part distortions was be examined. In order to minimize the computational time of numerical WAAM simulation, two method has been proposed. The first method is utilizing the lumping layering of WAAM deposition to minimize the numbers of elements and the second method is by using Inherent Strain Method (ISM) with the help of commercial finite element software MSC Marc/Mentat. A series of comprehensive WAAM experiment was conducted in order to verify the result prediction of numerical simulation which was completed using robotic welding machine ABB IRB 2400/16 and power source KEMMPI Pro Evolution ProMIG 540 MXE where the WAAM trajectory depositions were developed by using RAPID programming in ABB RobotStudio software. The completed WAAM parts undergone substrate removal process and was measured using a 3D scanner GOM Atos Q. A result of investigation shows that the substrate distortion proposed by four different numerical models shows an acceptable range of error when compared to numerical simulation with the average of 10.77% until 20.32%. Once the substrate has been removed, the component distortion comparison is examined by means of modified substrate removal algorithm where the error percentage of the models ranges from 2.96% until 8.05%. The result with optimized parameters and boundary conditions were transferred towards second case study which is a Pipe Flange WAAM component based on ASME B16.5 standard where the development of numerical simulation and fabrication of WAAM parts followed similar procedures with the first case study. Three numerical models which consists of TMM and two different lumping layers were developed and the pipe flange WAAM component was fabricated using robotic welding machine ABB IRB 1250/16 and Power Source FRONIUS TP 400. Furthermore, the costing analysis based on the method created by ESAB was developed on determining the price value for each of WAAM components where the calculated price of the hollow rectangular part is RM 61.80 while cost needed to develop a single ASME 16.5 series ¾ pipe flange using WAAM process is RM 89.25 excluding fee for surface machining.

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CHAPTER ONE

INTRODUCTION

1.1 Research Background

Many methods, including direct metal deposition, electron beam melting, selective laser sintering, and direct metal deposition, have been developed for the additive production of metal structures. Wire Arc Additive Manufacturing (WAAM), an additive manufacturing technique based on multi-layer welding that serves as one of the main focuses in the concept of Industry 4.0 which have a purpose on implementing the rapid prototyping in the modern manufacturing environment.

A high-deposition rate manufacturing technology that can be utilized to create large-scale, somewhat complicated structural components such as WAAM process where metal wire is deposited on a substrate using commercial welding torches that are controlled by a robotic or Computer Numerical Control (CNC) system using welding arcs as the power source. The term Additive Manufacturing, or AM, refers to a layer-by-layer manufacturing process that has recently gained a lot of interest from corporations and academics due to the benefits of its high deposition rate. The National Aeronautics and Space Administration (NASA) developed the medium-sized bicycle frame (MX3D), which weighs more than 1 tonne, and finally the small rocket nozzle using 3D printing. Currently, Directed Energy Deposition (DED) and Powder Bed Fusion (PBF) are two fabrication techniques that are widely employed in metal-based.

DED works better for highly customized product that don't require much in the way of form or shape complexity. Utilizing arc welding processes like Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW), or Plasma Arc Welding (PAW), the additional metal is deposited in WAAM. Many different types of metals, including stainless steel, can be deposited using welding process.