UNIVERSITI TEKNIKAL MALAYSIA MELAKA

REMANUFACTURING AND ANALYSIS OF DEFECTIVE PARTS USING 3D METAL PRINTING

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MASTER OF MECHANICAL ENGINEERING
(PRODUCT DESIGN)

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Faculty of Mechanical Technology and Engineering

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A thesis submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "Remanufacturing And Analysis of Defective Parts Using 3D Metal Printing" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....

Name : Syamimi binti Muhamad

Date : 17.4.2024

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Product Design)

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Date : 17.4.2024

DEDICATION

To my beloved mother, Sehrah binti Zakaria and father, Muhamad bin Roslan, in-laws Zakaria bin Sharif and Roseminah binti Arshad.

Muhammad Hafizzullah bin Zakaria

Muhammad Irfan bin Muhammad Hafizzullah

Muhammad Asyraf bin Muhammad Hafizzullah

Muhammad Luqman bin Muhammad Hafizzullah

Aina Sofia binti Muhammad Hafizzullah

Associate Professor Ir. Ts. Dr. Mohd Rizal bin Alkahari

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ABSTRACT

Metal 3D printing offers a huge potential to diverse industries, such as construction, aerospace, biomedical, and machining. This method is known to reduce material consumption and wastage. Integration of reverse engineering and metal 3D printing offers faster and cheaper production with unlimited part sizes. One of the applications of metal 3D printing is for part manufacturing. This thesis aims to remanufacture the defective parts using wire arc additive manufacturing (WAAM) with Cold Metal Transfer Technology (CMT) as the heat source. In this study, the damaged parts are components used in automated machines for metal fabrication. The part was restored and repaired as new parts using WAAM and reusable. The defective part usually cannot be supplied to the factories, which wastes the metal and costs operation for the company. This study demonstrates the use of WAAM to repair the damaged parts. The two specimens of dog bone remanufacturing using WAAM with different direction deposition were observed. The microhardness of damaged parts was tested before and after repair. The composition of the damaged part and wire was identified. The result shows the horizontal direction deposition dog bone has higher force, tensile strength, elasticity, and yield strength than the vertical dog bone. However, the elongation of vertical dog bones is higher than horizontal. The initial crack during the tensile test of horizontal dog bone is at the middle of the gauge length, while the vertical dog bone is at the bottom. After repairing the damaged part, the microhardness test decreased from 398.828 Hv to 350.288 Hv.

PEMBUATAN SEMULA DAN ANALISIS BAHAGIAN YANG ROSAK MENGGUNAKAN CETAKAN LOGAM 3D

ABSTRAK

Percetakan 3D logam menawarkan potensi besar kepada pelbagai industri, seperti pembinaan, aeroangkasa, bioperubatan dan pemesinan. Kaedah ini diketahui dapat mengurangkan penggunaan bahan dan pembaziran. Integrasi kejuruteraan terbalik dan percetakan 3D logam menawarkan pengeluaran yang lebih pantas dan lebih murah dengan saiz bahagian tanpa had. Salah satu aplikasi percetakan 3D logam adalah untuk pembuatan bahagian. Tesis ini bertujuan untuk mengilang semula bahagian yang rosak menggunakan pembuatan aditif arka dawai (WAAM) dengan Teknologi Pemindahan Logam Sejuk (CMT) sebagai sumber haba. Dalam kajian ini, bahagian yang rosak adalah komponen yang digunakan dalam mesin automatik untuk fabrikasi logam. Bahagian itu telah dipulihkan dan dibaiki sebagai bahagian baharu menggunakan WAAM dan boleh digunakan semula. Bahagian yang rosak biasanya tidak dapat dibekalkan kepada kilang, yang membazirkan logam dan kos operasi untuk syarikat. Kajian ini menunjukkan penggunaan WAAM untuk membaiki bahagian yang rosak. Dua spesimen pembuatan semula tulang anjing menggunakan WAAM dengan pemendapan arah berbeza diperhatikan. Kekerasan mikro bahagian yang rosak telah diuji sebelum dan selepas pembaikan. Komposisi bahagian dan wayar yang rosak telah dikenalpasti. Hasilnya menunjukkan tulang anjing pemendapan arah mendatar mempunyai daya yang lebih tinggi, kekuatan tegangan, keanjalan, dan kekuatan hasil daripada tulang anjing menegak. Walau bagaimanapun, pemanjangan tulang anjing menegak adalah lebih tinggi daripada mendatar. Retakan awal semasa ujian tegangan tulang anjing mendatar berada di tengah-tengah panjang tolok, manakala tulang anjing menegak berada di bahagian bawah. Selepas membaiki bahagian yang rosak, ujian microhardness menurun daripada 398.828 Hv kepada 350.288 Hv.

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In the Name of Allah, the Most Gracious, the Most Merciful. First and foremost, I owe the successful completion of this thesis to the exceptional support of many people. Firstly, my most profound gratitude goes to my supervisor, Associate Professor Ir. Ts. Dr. Mohd Rizal Alkahari guided me through this journey. Thank you for your guidance and support during the difficult process of finishing the research and writing.

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
PLA	-	Polylactic Acid
ABS	-	Acrylonitrile Butadiene Styrene
PETG	-	Polyethylene Terephthalate Glycol
CAE	-	Computer-Aided Engineering
CAD	-	Computer-Aided Design
DED	-	Directed Energy Deposition
GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
PAW	-	Plasma Arc Welding
CMT	-	Cold Metal Transfer
WAAM	-	Wire Arc Additive Manufacturing
SEM	-	Scanning Electron Microscopy
UV	-	Ultraviolet
SLA	-	Stereolithography
FFF	-	Fused Filament fabrication
FLM	-	Fused layer modeling/manufacturing
FDM	-	Fused deposition layer
PBF	-	Powder Bed Fusion
SLS	-	Selective Laser Sintering
SLM	-	Selective Laser Melting
DMLS	-	Direct Metal Laser Sintering

WBAM	Wire-Based Additive Manufacturing
IoT	Internet of Thing
IR 4.0	Fourth Industrial Revolution
AP	Additive Production
AI	Artificial Intelligence

LIST OF SYMBOLS

A	-	current
V	-	*Voltage*
s	-	*second*
mm	-	*millimeter*
HV	-	*Vickers Hardness*

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CHAPTER 1

INTRODUCTION

1.1 Background

Metal 3D printing has great promise in a variety of industries, including construction, aircraft, biomedical, and machining. This technique is referred to as cutting down on material usage and waste. This process also applied reverse engineering. It offers faster and cheaper production with unlimited part sizes. In addition, the CMT process is also known for high weld efficiency compared to other metal welding and has low heat input compared to MIG, which enables rapid heating and cooling (Balasubramanian et al., 2020). This process emerged as a new study area among the researchers because of its benefits compared to the conventional method.

This thesis aims to remanufacture the defective parts using wire arc additive manufacturing (WAAM) with Cold Metal Transfer Technology (CMT). The damaged part collected from the Taman Merdeka Jaya, Melaka casting and molding company. The parts are defective due to an automated machine's failure during metal fabrication. The defective parts were restored and automatically repaired as new parts and reusable. The composition of damaged parts and wire feed, tensile strength, and hardness were analyzed.

The remanufacturing of defective parts is expected to be deposited successfully on a damaged area. The connection between the parent and regenerated area should increase the hardness (Lee et al., 2022; Oh et al., 2019). This proposal reduces industry costs for fatigue parts, cracks, and failure during fabrication. The lifecycles of the damaged parts can be used

as new ones without fabricating metal parts. It saves time, making the DED process sustainable and more environmentally friendly. Figure 1.1 shows three types of additive materials: liquid-based, powder-based, and wire-based. Wire Arc Additive Manufacturing (WAAM) is in the category of Wire-Based Additive Manufacturing (WBAM). WBAM has high potential and efficiency in 3D metal printing. Furthermore, there are no limitations on the build volume. The wire AM is fully deposited into the metallic parts. According to the researcher, the arc welding power source has the highest energy efficiency, about 90% (Li et al., 2019).

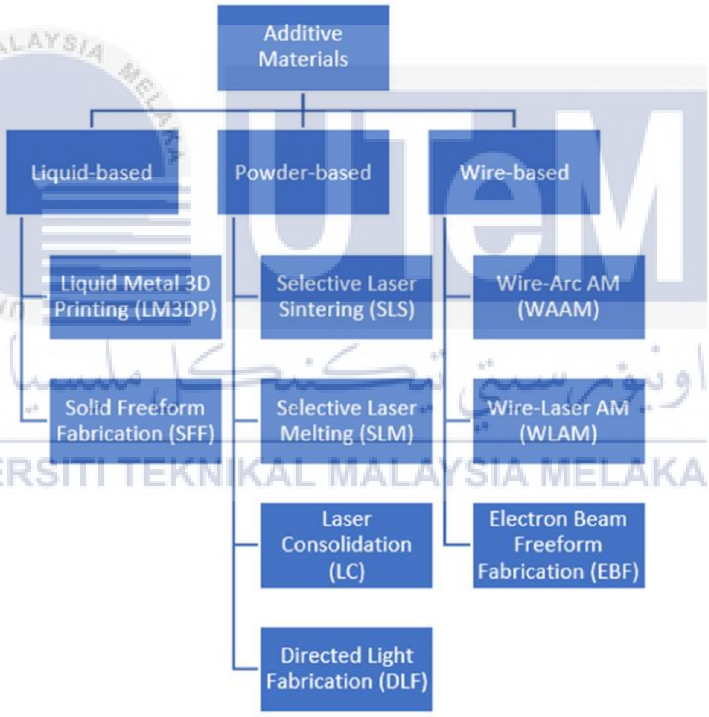

Figure 1.1 Additive materials for 3D metal printing (Li et al., 2019)

Figure 1.2 shows different arc welding technologies used. Cold Metal Transfer (CMT) is a short-circuit GMAW process modification based on controlled dip transference. PAW is conventional welding, while TopTIG is the evolution of GTAW (Li et al., 2019).

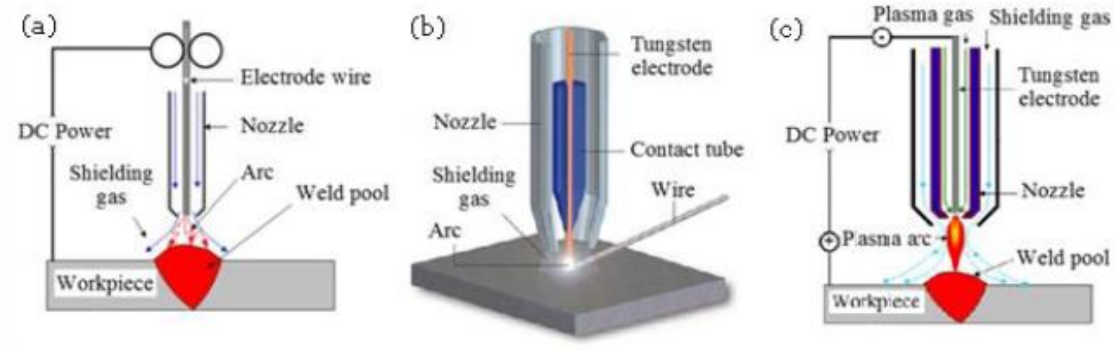

Figure 1.2 Schematic view of the (a) GMAW, (b) GTAW, and (c) PAW process (Li et al., 2019)

1.2 Problem Statement

This defective part usually cannot be supplied to the factories, and it wastes the metal and costs operation for the company. The mechanical drawings of defects are generally hard to retrieve because they discontinue production suppliers. This problem was solved by using 3D metal printing. The wire arc additive manufacturing and the heat input CMT technology repair damaged parts.

1.3 Research Question

The research questions of this research are:

i) What is the composition of the remanufactured part and wire?

ii) How are the mechanical properties of remanufactured parts affected by different orientations?

iii) How to fabricate defective parts using wire arc additive manufacturing and reverse engineering?

1.4 Research Objective

This research proposes remanufacturing and analyzing defective parts using 3D metal printing. The objectives are as follows:

i) To study the composition of remanufactured parts and wire.

ii) To investigate the mechanical properties of remanufactured parts at different orientations.

iii) To fabricate the remanufactured defective part using wire arc additive manufacturing (WAAM) and reverse engineering.

1.5 Scope of Research

The scope of research is as follows:

i) Remanufacturing uses Wire Arc Additive Manufacturing (WAAM) with a Cold Metal Transfer (CMT) heat source.

ii) Analysis of mechanical properties focuses on strength and hardness.

iii) The WAAM process was performed using ABB robotic arm equipment.

iv) The metal wire used in the WAAM process is stainless steel.

1.6 Thesis Outline

Based on the objectives previously presented and on the approach proposed before, this thesis is made up of five (5) chapters, which contents are summarized as follows:

- Chapter 1. Introduction. This chapter presents the background of the study, research problems, objectives, scopes, contributions, and significance of the research.

- Chapter 2. Literature review. This chapter starts with a brief review of 3D printing. 3D printing has seven categories, including an explanation of each category. A review of additive manufacturing focuses on defect types, tensile strength, and remanufacturing damaged parts using WAAM. Then, this chapter presents various literature references on the survey of process flow for remanufacturing parts.
- Chapter 3. Methodology. This chapter presented the method of analyzing the composition of filler wire and damaged parts. The process of remanufacturing defective parts and tensile test of different depositing direction dog bone.
- Chapter 4. Result and Discussion. In this chapter, the SEM analysis is identified. The tensile test of two samples of dog bone is discussed in this chapter. This chapter also shows the result of the microhardness test of remanufacturing the damaged part.
- Chapter 5. Conclusion and Recommendations for Future Research. This chapter summarizes the main findings and achievements of the work undertaken in this research and suggests areas for future work.