THE MECHANICAL BEHAVIORS OF SHIELD-ED METAL ARC WELDING (SMAW) OF BUTT JOINT OF MILD STEEL

BY

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ABSTRACT

Mechanical behaviours/properties are the most important engineering considerations in manufacturing, design, and constructions of products. These manufacturing usually involve assembling and joining of the components and parts to form a complete product. One of the widely used metal joining method is fusion welding method. In this study, mechanical behaviours of Shielded Metal Arc Welding (SMAW) of mild steel were studied. Welding works were performed using current, voltage and polarity parameters. Investigations of tensile testing, impact testing, hardness testing, and microstructure examination of welded mild steel have been conducted. The relation between ultimate tensile strength (UTS) and current shows a fluctuation pattern. Increasing current does not increase UTS proportionally. UTS also does not proportional with voltage. Furthermore, for correlation of UTS and current relative to polarity, the UTS for DCEN polarity were observed to be higher than UTS for DCEP polarity. For voltage from 23 to 24 volts, the UTS for DCEN polarity were higher than the UTS for DCEP polarity. However, as the voltage increase from 26 to 27 volts, the UTS for DCEP polarity eventually become higher than the UTS for DCEN polarity. In order to achieve high UTS and tensile strength, one should choose current from 68 to 120 ampere combined with voltage of 23 volts. For maximum toughness, high current ranged from 102 amperes to 120 amperes should be used with voltage varied from 24 to 26 volts in DCEN polarity. The microstructure of the weld metal shows a combination of ferrite and pearlite grain structure which signifies that the welded materials exhibit in brittle and ductile behaviors correspondingly. Three positions of indentation were used to measure the hardness of the welded materials which are fusion zone, heat affected zone (HAZ) and base metal zone. Among those three, the hardness properties at the fusion zone are the highest for most samples tested. The hardness was also observed to be highest when the current is 70 amperes. The hardness was found to be directly proportional to the voltage values.

ملخص البحث

خواص المعدن وسلوكه الميكانيكي تعتبر من اهم الاعتبارات الهندسية خلال التصنيع و التصميم وتجهيز المنتجات. عمليات التصنيع عادة تشمل التجميع و التوصيل للمكونات مع بعض لتشكيل المنتج النهائي. احدى الاستخدامات الشائعة لطرق توصيل المعادن هي اسلوب اللحام بالانصهار. في هذه البحث, تم دراسة السلوك الميكانيكي للفولاذ الطري بعد لحامه بطريقة القوس المحمي (SMAW) . تم تنفيذ اعمال اللحام باستخدام التيار و الفولتية و القطبية. وقد تم اجراء التحقيقات عن طريق اختبار الشد و اختبار الصدم و اختبار الصلادة و الفحص المجهري لعينات الفولاذ الطري الملحوم. وقد بينت النتائج ان العلاقة بين قوة الشد القصوى (UTS) والتيار اظهرت نمط متذبذب, وان زيادة التيار لاتزيد من قوة الشد القصوى. UTS ايضاً لاتتناسب مع الفولتية. وعلاوة على ذلك, العلاقة بين UTS والتيار بالنسبة للقطبية, لوحظ ان UTS لقطبية DCEN كانت اعلى من UTS لقطبية DCEP. وبالنسبة للفولتية من 23 الى 24 فولت, كانت UTS لقطبية DCEN اعلى من UTS لقطبية DCEP. ومع ذلك, بزيادة الفولتية من 26 الى 27 فولت, تصبح في نهاية المطاف UTS لقطبية DCEP اعلى من UTS لقطبية DCEN. وبهدف تحقيق اعلى UTS و قوة الشد, ينبغي اختيار تيار من 68 الى 120 امبير الى جانب الفولتية بقيمة 23 فولت. وللحصول على اعلى متانة, قيم تيار عالية من 102 الى 120 امبير يجب ان تستخدم مع فولتية من 24 الى 26 فولت خلال قطبية DCEN. واظهرت البُنى المجهرية للمعادن الملحومة مزيج من حبيبات الـ ferrite و الـ pearlite . وتم قياس الصلادة في ثلاثة مواضع مختلفة للمعادن الملحومة وهي منطقة الانصهار والمنطقة المتأثرة بالحرارة (HAZ) والمعدن الاساسي, ومن خلال ذلك تبين ان الصلادة في منطقة الانصهار هي الاعلى بالنسبة لمعظم العينات التي تم فحصها. وقد لوحظ ايضاً ان الصلادة كانت عالية عندما استخدم تيار بقيمة 70 امبير, وقد وجد كذلك ان الصلادة تتناسب طردياً مع قيم الجهد.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Manufacturing Engineering).

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Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Manufacturing Engineering).

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Md. Noor Bin Salleh
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Muhammad Saiful Adli bin Fouzi

Signature…………………...………. Date ……..…………………

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This dissertation is dedicated to my beloved parents

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Bismillahirrahmanirrahim. By the name of Allah swt., the Most Gracious, the Most Beneficial, Alhamdulillah, All praises to Allah swt.

Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

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LIST OF SYMBOLS

A	Area
I	Current
L_0	Initial length
P	Load
$\boldsymbol{s}$	Toughness
Sy	Yield Strength
σ	Tensile Stress
v	Voltage
ϵ	Strain
δ	Changes in the specimen's gauge length

LIST OF ABBREVIATIONS

ASTM	American Society of Testing and Materials
EBSD	Electron Backscatter Diffraction
et al.	(*et alia*): and others
FZ	Fusion Zone
HAZ	Heat Affected Zone
HRA	Digital Rockwell Hardness
IIUM	International Islamic University Malaysia
kN	Kilo Newton
mm	Millimeter
OAW	Oxy-Acetylene Welding
SMAW	Shielded Metal Arc Welding
UTS	Ultimate Tensile Strength
UTM	Universal Testing Machine

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The use of welding as joining method can be seen in almost all production of goods, machines and equipments. Welding, the fusing of two work pieces is a precise, reliable, cost-effective, and smart method for joining materials. Gaodi et al mentioned that no other technique is widely used to join metals and alloys efficiently and to add value to their products (Gaodi & Sangotra). Most of the familiar objects in modern society, from buildings and bridges, to vehicles, computers, and medical devices, could not be produced without the use of welding. They further elaborated that welding goes well beyond the bounds of its simple description. In industries, welding is widely used in fabrication, maintenance and repair of parts and structures. While there are many methods for joining metals, welding is one of the most convenient and rapid method available (Hussain, Lateef, Javed, & Pramesh, 2010; Kchaou, Haddar, Hénaff, Pelosin, & Elleuch, 2014; Nathan, Balasubramanian, Malarvizhi, & Rao, 2015).

The common applications and availability of welding make it important for us to know and understand about the reliability of the joints produced primarily in terms of bonding strength and hardness. The reliability of the joints produced determine whether it is safe to be used in the applications or not. This is because most of the welded parts will be subjected to many types of loading through their operating life such as impact loads, weights of objects on it, fatigue loads and bending.

Since most of welding processes involve large amount of heat input during the interdiffusion between the parent metal and filler metals, it is believed that this process will affect the strength of the joint thus shortening the overall component's operating life. During the interdiffusion of the joint material, the microstructure of the material might be altered and changed because of the liquefaction, cooling and solidification phenomenon of welding. Strength of steel is influenced by its microstructure while microstructure is controlled by the arrangement of the grain structures in the steel. Heating and cooling of the steel influences this atomic arrangement (Aweda, Dauda, Dagwa, & Dauda).

A welded joint is obtained when two surfaces are brought into contact with each other and either pressure or heat or both are applied to obtain a bond. The tendency of atoms to bond is the fundamental basis of welding. The inter-diffusion between the materials that are joined is the underlying principle in all welding processes. In welding the metallic materials are joined by the formation of metallic bonds and a perfect connection is formed (Jha, 2014).

The properties of welded joints and the feasibility of welding processes are influenced by many factors: for example, carbon migration from the low-alloy side, microstructure gradient and residual stress situations across different regions of the weld metal (Mvola, Kah, & Martikainen, 2014). Jha et al also stated that the goal of welding is to obtain the best possible combination of strength and toughness for the welded joints. Both strength and toughness are strongly influenced by the microstructure (Jha, 2014). However, with optimal selection of welding current and speed, it is possible to obtain a weld that provides strength comparable to the base steel.

Shielded metal arc welding (SMAW) is one of the welding methods which usually uses electric source to create an electric arc which melts the weld metal and consumable electrodes to produce the weld beads that bond the weld metals. Electric arc is the most popular source of heat used in welding practice. Among the several arcs welding methods the SMAW arc welding is the oldest of the arc welding processes. It is characterized by versatility, simplicity and flexibility. The SMAW process is commonly used for tack welding, fabrication of miscellaneous components and repair welding. SMAW has earned a reputation for producing high quality welds. It is dependent on operator skill for high quality welds (Jha, 2014).

1.2 STATEMENT OF THE PROBLEM

In material technology and manufacturing, the mechanical behavior of the material is the most important considerations in deciding the use of the material in the specific field of applications. Constructions material usually required a high strength material in order to sustain the high loading condition. Given an example in Ship building and repair industries, these industries require high impact and creep resistances material as it to be suitable in the future use conditions. A change in material's mechanical behavior will cause the change in their working performances primarily in their structural performances and make them no longer suit with the required working condition. Thus, it is very critical to investigate the effect of heat input on the strength of welded mild steel as it plays an important role in sustaining the strength and hardness of the materials produced.

Failure during operation should be totally avoided since it does not only involve the damages of the broken equipment but may also lead to injuries to the user or person near to the area. There are several researches done regarding this problem including (Aweda et al.; Gaodi & Sangotra; Jha, 2014; Saeid, Abdollah-Zadeh, Assadi, & Ghaini, 2008; Sathiya, Aravindan, & Haq, 2007). which try to uncover and to study about this matter. Among these researches, none of them have discussed this topic in details, so it is necessary to study on this topic to ensure higher level of understanding.

1.3 RESEARCH OBJECTIVES

The study aimed to achieve the following objectives:

1. To characterize the mechanical behaviour of SMAW welded butt joint of mild steel.
2. To analyse the mechanical behaviour of SMAW welded butt joint of mild steel due to difference in current, voltage and polarity

1.4 METHODOLOGY OF RESEARCH

Since the mechanical behavior/properties of a material is very important in determining the usage, serviceability and durability of the material, the research is focusing on obtaining the important mechanical behaviors such as ultimate tensile strength (UTS), hardness, toughness and the microstructure characteristics of “Mild Steel”

The ultimate tensile strength (UTS) is the highest value of tensile stress sustained by the material during tensile testing which usually can be seen in the stress vs strain curve. The value of UTS indicates the ability of a material to withstand the stress/loading applied on it before the material tends to fail or rupture occurred.

Meanwhile, the materials hardness can be said as the ability of the materials to resist deformation to occur typically on its surface. The hardness behavior/properties indicate the strength of the material to resist wear or scratch. It can also be defined as the resistance to permanent indentation.

In many manufacturing operations and machinery components, materials are subjected to impact or dynamic loading, for example in high speed metalworking operations such as heading to make bolt heads, in drop forging. Hence, impact testing of the specimen in this study can determined the toughness of the material which is can be said as the ability or strength of the material to sustain against impact loading or sudden load subjected on it.

The strength and hardness as well as other properties of a material are greatly influences by its microstructure. The microstructures of the welded steels were studied and reviewed under the optical microscope to reveal the structures of the welded steels.

Thus, in determining the mechanical behavior or properties of the SMAW welded butt joint of mild steel in this study; we have aimed to focus on four testings' which are tensile test, hardness test, impact test and microstructure examination to obtain UTS, hardness, toughness and the microstructure characteristics of the SMAW welded butt joint of mild steel respectively as required in the objectives of the study.

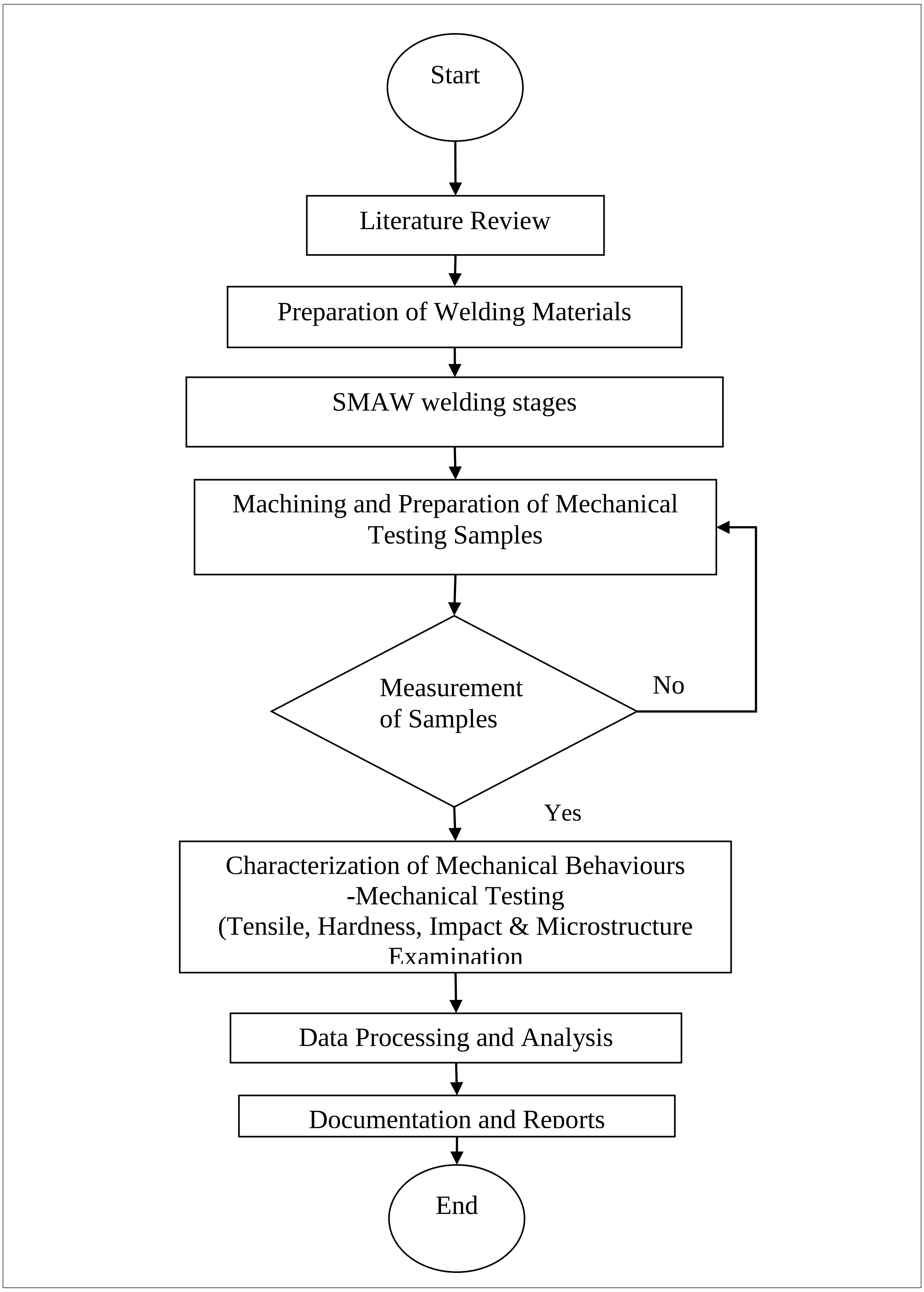

Figure 1.1 Flow Chart of Research Methodology

1.5 RESEARCH SCOPE

The scope of study is the type of welding process which is Shielded Metal Arc Welding (SMAW). Shielded metal arc welding (SMAW) is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination. Because of the versatility of the process and the simplicity of its equipment and operation, SMAW is one of the world's most popular welding processes. It dominates other welding processes in the maintenance and repair industry (Gaodi & Sangotra). SMAW process can be seen in many steel fabrications mostly for small and medium industry for example in making housing fences, grills, furniture, and home appliances.

Mild steel is the most common steel used as it is used in nearly every type of product created from steel, it is weldable, very hard and, although it easily rusts, very durable. Containing a maximum of 0.14% carbon, this type of steel is able to be magnetized and used in almost any project that requires a vast amount of metal. Its structural strength prevents it from being used to create load-bearing girders and structural beams (Gaodi & Sangotra). Because of its popularity and vast used of applications, “Mild Steel” has attracted the author’s attention to focus the study on it. The chemical composition of mild steel used in this research is shown in Table 1.1.

Table 1.1 The chemical composition of mild steel (Jha, 2014)

Material	C	Mn	Si	S	P
Mild steel	0.14	0.76	0.28	0.013	0.010

There are several different types of weld joints that can be used in this process. Each joint is joined in a different way and has different strengths and uses, and thus it is important to use the right one for the right job. When two pieces of metal joined end to end a butt weld joint is used. Butt joints are frequently used when a smooth face is desired. Some applications that use butt joint are pressure vessels and piping. There are several variations on butt joint including square joint; the single ‘V’ and double ‘V’ joint (Jha, 2014).

In this research, the author has set to use butt joint in conducting the experimental works. Since the mild steel plates used in the welding works are quite thick (≥10mm), hence the single ‘V’ butt joint had to be used. For single ‘V’ butt joint, the upper edge of the plate has been chamfered to 45° and prepared.

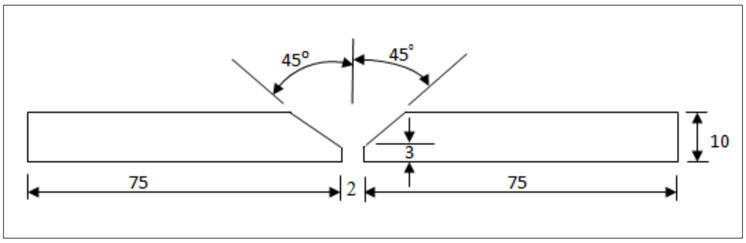

Figure 1.2 Single ‘V’ butt joint

1.6 ORGANIZATION OF THE THESIS

This thesis is organized into Five chapters. Brief descriptions of each chapter are given below: