EFFECTS OF NEW AND RECYCLE ELECTRODES ON THE MECHANICAL PROPERTIES OF SHIELDED METAL ARC WELDING (SMAW)

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Field of Study: Welding

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EFFECTS OF NEW AND RECYCLE ELECTRODS ON THE MECHANICAL PROPERTIES OF SHIELDED METAL ARC WELDING (SMAW)

ABSTRACT

Shielded Metal Arc Welding (SMAW) is a manual simple and common welding process using electrodes as filler material. There was a requirement welding electrode are recommended to be used once after opened from Vacuum pack followed by baking. It not recommended to rebake few times after removed from oven. This project is a study on the effect of welding from newly baked electrode, electrode after 1st rebake, 2nd rebake and 3rd rebake on the mechanical properties. The mechanical properties of the welding in this study are tensile test, impact test, bend test and hardness test. Based on the research all the mechanical properties was in acceptable range for all the multiple rebaked electrodes. There were no visible cracks found for all the bend test specimens. There was a slight trend of tensile properties reduction as the electrodes was more frequently baked. But the impact properties increase as the electrodes were more frequently baked. Hardness value is inconsistent but as average the hardness value increase as the electrodes were baked more times. The changes in the mechanical properties are estimated below 3% and can be consider almost insignificant. Hence there is an insignificant changes in the mechanical properties due to the multiple rebaking of electrodes.

Keywords: Welding, SMAW, electrode, mechanical properties.

KESAN ELEKTROD BARU DAN ELEKTROD YANG DIKITAR SEMULA TERHADAP SIFAT-SIFAT MEKANIKAL KIMPALAN ARKA LOGAM DILINDUNGI (SMAW)

ABSTRAK

Kimpalan Arka Logam Dilindungi (SMAW) adalah sejenis kimpalan manual yang biasa and mudah dilakukan dengan mengunakan elektrod sebagai bahan pengisi kimpalan. Terdapat syarat-syarat menyatakan elektrod kimpalan ini hanya dapat digunakan sekali selepas dikelurkan dari pek vakum dan dibakar sebelum digunakan. Elektrod kimpalan ini tidak digalakan untuk dibakar semula selepas dikeluarkan dari ketuhar. Projek ini akan membuat kajian elektrod kimpalan kesan keatas sifat mekanikal bagi elektrod kimpalan yang baru dibakar, dibakar semula sekali, dibakar semula kali kedua and dibakar semula pada kali ketiga. Sifat mekanikal pada kimpalan yang dikaji adalah ujian tegangan, ujian hentaman, ujian bengkok dan ujian kekerasan. Berdasarkan kajian ini kesemua sifat mekanikal adalah dalam julat yang boleh diterima untuk kesemua elektrod yang dibakar semula. Terdapat sedikit penurunan dalam sifat tegangan apabila elektrod lebih kerap dibakar. Tetapi terdapat sedikit kenaikan dalam sifat hentaman apabila elektrod lebih kerap dibakar. Tiada retakan ditemui bagi semua specimen ujian bengkok. Bagi nilai kekerasan terdapat sedikit ketidakstabilan tetapi secara keseluruhan nilai kekerasan menunjukan kenaikan apabila elektrod lebih kerap dibakar. Perubahan sifat mekanik dianggarkan di bawah 3% dan boleh dianggap hampir tidak penting. Oleh itu, secara kesimpulan tiada perubahan yang ketara pada sifat mekanikal bagi elektrod kimpalan bila elektrod lebih kerap dibakar

Keywords: Kimpalan, SMAW, elektrod, sifat meknikal

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	:	Alternating current
ASME	:	American Society of Mechanical Engineers
ASTM	:	American Society for Testing and Materials
DC	:	Direct current
DCEN	:	Direct current electrode negative
DCEP	:	Direct current electrode positive
HV10	:	Vickers hardness at 10kg testing load (unit)
ISO	:	International Organization for Standardization
J	:	Joule
ksi	:	kilopounds per square inch
MPa	:	mega Pascal (unit)
psi	:	pounds per square inch
PWHT	:	Post weld heat treatment
SMAW	:	Shielded Metal Arc Welding
WPS	:	Welding Procedure Specification

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background

Welding process is the most common used to join two metal parts. There are various welding processes used for joining process. Shielded Metal Arc Welding (SMAW) process is one most common welding process used in joining metals in various industries. Shielded Metal Arc Welding is used in pipe welding, pressure vessel welding, as well as structure welding.

Shielded Metal Arc Welding process is preferred as this is the simplest welding process. There is no requirement of additional gasses for shielding during welding. And the welding machines are very portable as the welding equipment is very simple. The welding process is not so sensitive to wind and can be used in wide range of environments such as in fabrication shops, on outdoor pipelines, refineries, ships, bridges and other areas.

Shielded Metal Arc Welding electrodes will have spatter and clean-up is required and have a disadvantage due to humidity. When electrodes were stored in high humid areas, moisture will be absorbed by the flux which is shielding the electrodes and may influence the weld ability.

1.2 Research Problem

The requirements on not allowing to rebake electrode for more than one time on the usage of electrodes will cause manufactures unable to utilize the unused electrodes for welding and are required to be scrapped. The notion that rebaking of electrodes more than one time has no concrete evidence on the affect the mechanical properties. Thus, in this study the proper investigation will be conducted to determine the effect of rebaking electrode on the welded samples.

1.3 Research Objective

The objective of this research work is to study on the effect of new and multiple rebake electrodes on the welding. The objectives include:

1) To investigate the effect of newly baked electrodes on the mechanical properties of Shielded metal arc welding (SMAW) welding

2) To determine the effect of multiple rebaked electrodes on the mechanical properties of Shielded metal arc welding (SMAW) welding

1.4 Scope and Limitation

This research scope is limited to one grade of material and one electrode grade. The test coupons used are SA 516 Gr 70 plates with E7018 SMAW electrodes with the same electrode diameter size. Besides that the welding parameters was also maintained based on the previously welding qualified range to ensure the weld quality.

Welding was conducted using electrodes under four conditions i.e. newly backed electrodes, after 1st rebaking, after 2nd rebaking, & after 3rd rebaking. The welded coupons was only subjected to mechanical testing i.e. tensile test, impact test, bend test & hardness test.

1.5 Thesis Organization

This thesis is divided to five chapters. Chapter one describes on the background, research problem, objective, scope and limitation of the research. Chapter two illustrate literature review on Shielded metal arc welding Chapter three describes the research methodology on the material used and the types of testing conducted. Chapter four present the result of the testing followed by discussion. Finally chapter five includes the conclusion of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Principle

There are various welding process available currently. Few of the most commonly used welding processes are GTAW, SMAW, FCAW, GMAW, SAW and Laser Welding. Each of the welding process have their own advantages and disadvantages if compare to each other. SMAW is one of the early welding methods is still being used in the market. SMAW is still on the most popular welding method compared to other welding methods mainly due the simple setup in welding as well as the portability of the welding equipment (Chomsrimake, 2012).

Shielded metal arc welding (SMAW) is a manual welding method using electrode. The electrodes used are having a metal rod in the center as core for welding which is protected by a flux coating. The welding process occurs as arc is initiated between the core and the surface to be welded. The heat generated due to the electric arc will decompose the flux and also melt the core rod.

The decomposition of the flux will create vapor which will displace the air from the weld zone and play a role as shielding gas. Besides that the decomposition of the flux will provide the weld metal with a protective layer of slag. The purpose of the shielding gas to prevent from atmospheric contimanination during the deposition of the weld. Due to this SMAW is more preferred for external welding as no additional gases are required for shielding during the welding process (Singh, 2012). The core on the other hand will melt due to the arc and form as molten pool which will become the weld.

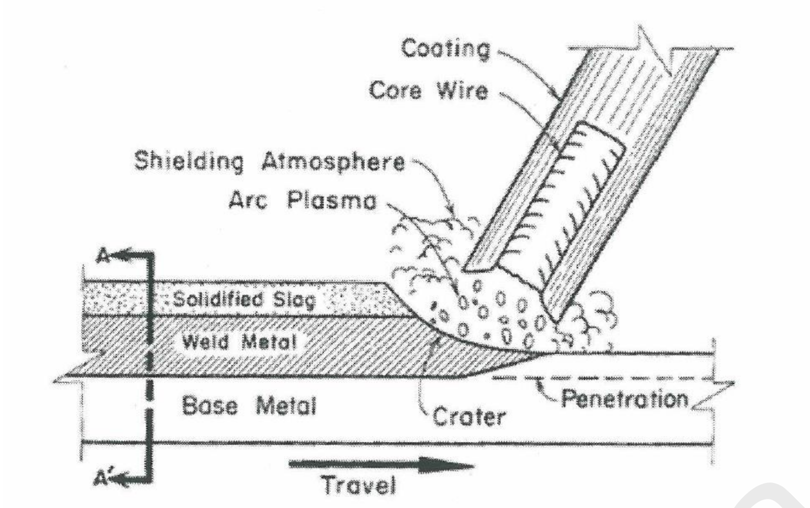

Figure 2.1: Illustration of SMAW Welding process (Jackson, 1973)

The welding machine for SMAW welding is rather the most portable equipment compared to other welding processes. The welding machine will be using electric current to maintain the arc. The power source used can be either alternating current or direct current. The power source usually made of a generator which consist of transformer for alternating current equipment or a rectifier to convert from AC to DC. The transformer used will reduce the voltage thus will increase the current to ensure sufficient current for the welding (Anren et al, 2012). As the current flowing through the electrode hence to complete the circuit insulated clamp will be connected from the work piece back to the welding equipment.

The welding power or the heat input is measured in current and voltage and travel speed (Quintino et al, 2013). The voltage is influenced by the diameter of electrode and the arc length between the work piece and the electrode. Current is measures in amperes and voltage is measured in volts which are two electrical values in power and heat input calculation. SMAW welding process should be equipped with a proper power supply to ensure a constant current output so the heat output will be relatively constant even if there is come voltage changes due to arc distance. As the arc distance effect the voltage and it is difficult for the welder to maintain a constant arc distance throughout the welding hence if a constant voltage power source is used the heat input varies as the arc distance varies and the welding will be more difficult and will result in poorer weld quality (Ravisankar 2014).

For welding equipment's power supply consist of step-down transformer to reduce the voltage and a rectifier for DC models, to convert from AC to DC. The common power source is high voltage AC power of minimum 220V. Hence a transformer is used to reduce the voltage and increase the current. With a common power supply of 240V and 50 Amp current, the transformer will drop the voltage to a range around 20 V so the current can reach around 600Amps. Multiple transformers will be used including multiple coil and inverter machines, to manipulate the welding current.

The polarity connection of the welding machine is also flexible depends on the then connection and the grounding was connected. If the setup of the connection is such the current flow to the base metal through electrode and return back to the equipment through the clamp attached to the base metal hence this connection is called as direct current electrode positive (DCEP). On the other hand an opposite direction flow of current through the base metal to the electrode is called direct current electrode negative (DCEN). But the most commonly used connection is DCEP connection where the work piece is connected to negative terminal and the electrode is connected to the positive terminal with direct current supply for consistent and steady current to create consistent arc. The choice of the electrode may be based on the welding procedure specification or will may be decided by the welder. The decision on the polarity for SMAW welding is depending on few variables such as depth of the required penetration, rate of the filler material deposition, joint type, base metal thickness and base metal (Mandal, 2017).

Based on the constant electric power supplied to the welding equipment, the welding equipment has the ability to adjust the current and voltage to suit the welding process. The arc length of the welding process which was influenced but the type of electrode metal and electrode size will be supported with the adjustment in the voltages to get a better welding result (Nagesh & Datta, 2002). Besides that current will be adjusted to control the heat input during the welding. The arc distance shall be manually controlled by the welder when the current was already specified.

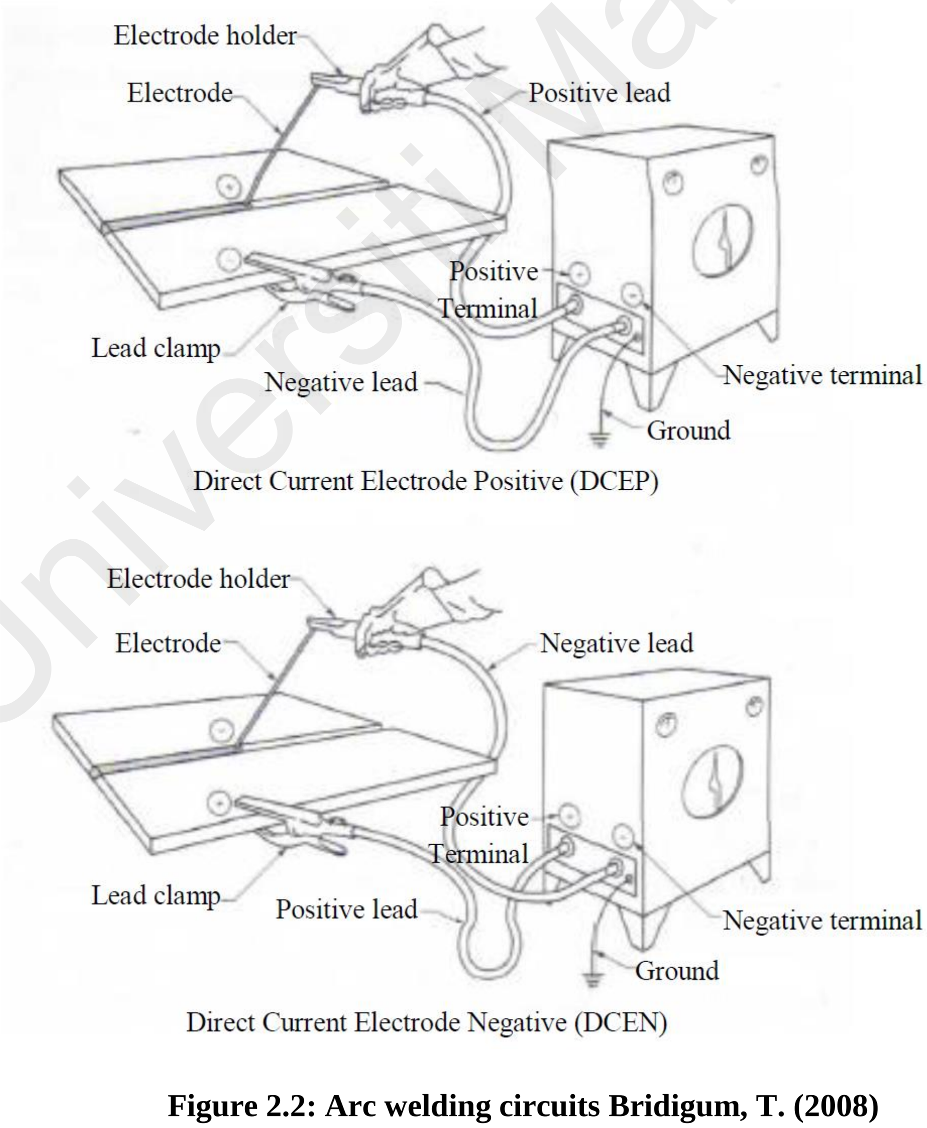

Figure 2.2: Arc welding circuits Bridigum, T. (2008)

2.2 SMAW Electrodes

There are few different electrodes which vary in terms on metal type, strength and also flux coating. Besides that there are few different sizes of electrodes in terms of the electrode diameter. Typical length of an electrode is 230mm to 460 mm and the core diameter is usually between 1.6 to 8.0mm. Commonly electrodes are produced by mixing a proportions of individual company's proprietary ingredients to form the core as well as the flux to coat the core. The core can be made of various material such as mild steel, cast iron, stainless steel, copper, aluminum and others. The various core material used depends on the material to be welded. E.g. stainless steel core material will be used for welding of stainless steel material. The core rod usually is manufactured by hot rolling followed by drawing the wire down to the required diameter.

Electrodes can be divided to fast-fill, fast-freeze and fill-freeze. Fast-fill electrodes are designed to melt quickly to maximize the welding speed. Electrodes which are designed to solidify quickly are called as fast-freeze. This is suitable for welding in various positions possible as the will prevent the weld pool from shifting or flowing before solidifying (Sharma and Chhibber, 2009). While intermediate electrodes are called as fill-freeze or also known as fast-follow electrodes which will melt quickly and the filler metal also will solidify quickly.

The flux which cover the metal core on the other hand is made using various material to form a solid flux with electric conductive properties. Cellulose from plants is used together with powdered iron and hydrogen for flexibility properties for the flux. Sodium and potassium is used as binding agent to ensure the flux stays as solid rod. The flux coating on the metal rod also helps the current flow evenly during the welding process. Besides that various industrial grade ingredients will be mixed together with the flux to ease weld ability. The flux composition is correlated to the core rod composition, desired mechanical properties, welding performance and also economic factors.

The main function of the flux of the electrode is provide stable arc to protect the molten metal from atmospheric contamination and by adding additional alloy to refine the weld pool. The flux ingredients will have the function to stabilize the arc by ionizing the gap as it release electrons and control the arc resistivity (Weman 2012). Besides the ingredients used will provide a layer of shielding gas to shield the arc and to prevent atmospheric contamination of the molted weld metal. The ingredients also have the ability to provide deoxidizers, scavengers and fluxing agents to clean the welds and to provide a protection layer of slag with suitable melting temperature to protect the molten weld from air as well as to improve mechanical properties.

The ingredients used will add alloying elements during melting and refine the weld pool while producing a low density of slag. Besides that the ingredients has the ability to provide proper viscosity for welding in uncommon positions such as vertical or overhead and promote slag detachability. The ingredients used also has the ability to produce a smooth weld contour with good wetting as well as reduce spatter and fume (Ramesh, 2012). Basic, acidic and amphoteric oxides are the three main types of slag forming components in welding electrodes. These oxides will affect the slag properties in terms of viscosity, thermal expansion, and density, melting temperature, electrical and thermal conductivity.

The flux portion is prepared by mixing all the required ingredients based on the proportion required based on the formulation and mixed thoroughly. Then the binder will be added to the mixture and the mixture will be thoroughly blended to ensure even mixture. Once ready the flux coating will be extruded on the metal core using high load press. The coating formulation is made for ease extrusion as well as consistency adhesion of the flux to the metal core especially for shipping and handling. Good quality electrodes will have good adhesion between the core and the flux and concentric and uniform flux coating along the complete electrode length. The flux coating should also have smooth coating surface with no transverse and longitudinal cracks. The flux coating shall also maintain its integrity with heat during the welding process. The flux coating ratio which is the thickness of the flux coating divided by the radius of the flux covering the electrode and the concentricity of the flux coating play an important role on the arc stability, consumable heating and chemical composition.

The welding arc stability is important for the weld ability of the electrode and the weld properties integrity. Ingredients such as rutile, sodium silicate, potassium silicate and potassium titanate are used to enhance the welding arc. Besides that these ingredients also help to stabilize the welding arc by continuously emitting electrons and producing ions to form a passage of electrical conductivity. Stable arc is important in direct current and also alternating current connection method as the arc is extinguished and re-established several times per second.

During the manufacturing of the electrodes multiple stage inspection will be performed to ensure the electrode have uniform flux and concentric metal rod during the fabrication process. For each batch of electrode manufacturing, welding performance test will be done including as welded mechanical test to ensure the quality of the products before released to the market.

The different type of electrodes are classified based on the electrodes welding position, coating type, material and additional added elements. All the SMAW electrodes are assigned with a prefix E and four digit number such as E7018 based on the system established by AWS. Each electrode has its own designation which will indicate its tensile strength, welding position, coating type, current coding and additional added elements.

All SMAW electrodes shall meet the requirements as per AWS A5.1/A5.1M Specification for Low-Alloy Steel Covered Arc Welding Electrodes. The prefix E, R or ER is carried by all covered electrodes where E denote as electrode, R is used for rods and ER designates the electrode or rod usage. For an example, for an electrode with the designation E7018, the prefix E denote it's an electrode. The first two digits indicate the minimum tensile strength in in ksi. Hence for electrode with designation E7018, the minimum tensile strength is 70 ksi or 70,000psi. The third digit will indicate the recommended welding position for the electrode. For the welding positions, value "1" indicate all positions such as flat, horizontal, vertical down, vertical up, and overhead as these are fast-freeze electrodes where the weld metal will not move significantly. While notation 2 indicate flat and horizontal only which is normally for fast-fill electrodes. Notation 3 is used for electrodes for flat welding only. While notation 4 on the other hand indicate flat, horizontal, overhead, vertical down positions only.

The last digit will specify the welding current and last two digits will indicate the type of electrode flux. Where required there will be additional suffix used to indicate additional alloying elements added or any special ability for the electrodes

2.3 Electrode baking

The flux coating of the electrode has the ability to absorb moisture. The amount of moisture that can be absorbed by the flux coating is depending on atmospheric conditions. The temperature and humidity of the exposed electrodes after removed from the packing will determine the moisture absorbed by the flux. The longer the electrodes were exposed to the atmospheric, the higher the amount of moisture absorbed. The moisture was already removed during the manufacturing process as the electrodes were baked at high temperature to dry all the moisture and finally the electrodes will be sealed in vacuum packed packing.

Electrodes shall be left in the original sealed pack and stored in dry location until it is required for welding. Once opened the electrodes are required to be stored in cabinet with desiccant or heating cabinet with temperature around 6-8ºC higher the ambient temperature. Electrodes which have absorbed excessive amount of moisture should be re-baked in oven at 315ºC±15°C for an hour or 260ºC±15°C for two hours. During re-baking the electrodes shall be removed from the original container and only the electrodes placed in the oven. While baking the electrodes should not be stacked in large quantity to endure even heat distribution for the moisture removal. After baking the electrodes shall be transferred to holding over which will maintain a temperature of around 50 ºC. This is to prevent moisture absorption after the moisture removed during the baking process.

This baking process is vital especially for low hydrogen electrodes which is currently widely used. Any welding done with electrodes with high moisture content will effect the integrity of the welding. During the welding the moisture in the flux will decompose and will create hydrogen and oxygen particles. The oxygen particles which trapped in the weld pool will cause porosity. Porosity in the welding joint is not recommended as it will effect the weld integrate. Hydrogen on the other hand which is trapped in weld may cause crack in the weld. But this crack will not occur instantly as it may take time to occur and this is called as delayed cracking.

2.4 Welding variable

Different type of welding process and different type of material welding have different type of welding variable. These variables shall be adjusted to obtain the best possible weld condition for that particular weld. There are various welding variables such as preheat condition, weld sequence, single or multi pass, and welding parameters (voltage, current, speed, etc.) that needs to be adjusted based on the design and application of the welding. All these welding variables are classified as either essential or non-essential variables based on ASME or AWS.

Essential variables are variables that will effect on the mechanical properties of the weldment and if changed beyond the limits specified by the standard. Any changes in the essential variables will require requalification of the welding procedure. Non-essential variables are variables that are specified in the welding procedure but do not have a significant effect on the mechanical properties if some adjustments are made. Non-essential variables can be changed without requalification of the welding procedure again. Essential variables have significant effect on mechanical properties hence any welding outside the range qualified may lead to unsound weld or they may not have the required mechanical properties.

Based on ASME Sec IX, Table QW-253 will indicate all the essential variables and non-essential variables for SMAW welding process. The essential variables are base material thickness range qualified, as well as the material grouping which is also known as “P” number. As for the welding electrodes which are the filler material the material grouping is essential. Besides a decrease in preheat temperature of more than 55°C and any post weld heat treatment require the welding to be requalified. Post weld heat treatment will usually reduce the tensile value as well as hardness value. Any welding outside the qualified range will not guarantee the required properties as proved in the procedure qualification (Bahadori, 2017)

2.5 Summary

SMAW is still on the most popular welding method compared to other welding methods mainly due the simple setup in welding as well as the portability of the welding equipment Shielded metal arc welding (SMAW) is a manual welding method using electrode. The welding machine for SMAW welding is rather the most portable equipment compared to other welding processes. The welding machine will be using electric current to maintain the arc.

The electrodes used are having a metal rod in the center as core for welding which is protected by a flux coating. The welding process occurs as arc is initiated between the core and the surface to be welded. Electrodes can be divided to three groups which are fast-fill, fast-freeze and fill-freeze. Fast-fill electrodes are designed to melt quickly to maximize the welding speed. The flux portion is prepared by mixing all the required ingredients based on the proportion required based on the formulation and mixed thoroughly.

The flux coating of the electrode has the ability to absorb moisture. The amount of moisture that can be absorbed by the flux coating is depending on atmospheric conditions. Any welding done with electrodes with high moisture content will effect the integrity of the welding. During the welding the moisture in the flux will decompose and will create hydrogen and oxygen particles. Electrodes which have absorbed excessive amount of moisture should be re-baked in oven to remove the moisture.

Welding variable shall be adjusted to obtain the best possible weld condition for that particular weld. There are various welding variables such as preheat condition, weld sequence, single or multi pass, and welding parameters (voltage, current, speed, etc.) that needs to be adjusted based on the design and application of the welding. All these welding variables are classified as either essential or non-essential variables based on ASME or AWS.

CHAPTER 3: METHODOLOGY

In order to perform the testing, first of all the test plates will be welded using the electrodes condition proposed in this research. The electrodes used are newly baked electrodes, electrodes after 1st rebaking, electrodes after 2nd rebaking, and electrodes after 3rd rebaking. All the test plates will be welded using previously approved WPS to ensure good quality weld as the welding parameters were tested before. Once all the four test plates were welded mechanical test will be conducted on the welds. The mechanical testing conducted are tensile test, impact test, bend test and hardness test.

3.1 Materials

For this research all the material used are carbon steel material as carbon steel material is the most widely used material beside mild steel which is more common for structure steel. There are few grades on carbon steel material but for this research ASME grade carbon steel plate SA 516 Gr 70 is used which is mainly used for pressure vessels and boilers. The thickness of the base material choose n is 12mm thick which is suitable for all testing and the size of the plate is 150mm by 300mm. Then the two pieces of the test plate will be welded using SMAW welding method.

Table 3.1: Chemical Composition of Base Materials

Element	Composition, (%)
Carbon	0.27 max
Manganese	0.85 – 1.20
Phosphorus	0.025 max
Sulfur	0.025 max
Silicone	0.13 – 0.45

Table 3.2: Tensile properties of base material

Property	Value
Tensile Strength	485 – 620 MPa
Yield strength	260MPa

The welding electrode used is LC-318 from Chosun Welding which is a high tensile welding electrode. The electrode is bearing the AWS classification number of E7018 which should have a minimum 70 ksi tensile value, all position welding electrode and basic low hydrogen with iron powdered electrode which shall be welded with direct current and electrode as positive.

Table 3.3: Chemical Composition of Weld Materials

Element	Composition, (%)
Carbon	0.07
Manganese	0.96
Phosphorus	0.013
Sulfur	0.007
Silicone	0.61

Table 3.4: Chemical Composition requirement for weld materials

Element	Composition, (%) max
Carbon	0.15
Manganese	1.60
Phosphorus	0.035
Sulfur	0.007
Silicone	0.75
Nickel	0.30
Chromium	0.20
Molybdenum	0.30
Vanadium	0.08

Table 3.5: Mechanical properties of weld material

Property	Composition, (%)
Tensile Strength	490 MPa
Yield strength	400MPa
Impact test	27J @ (-20°C)

3.2 Welding

Welding is performed by a qualified welder. To ensure smooth welding of the SMAW process, the current setup and the power supply polarity was setup correctly as per the WPS. The setup required which will influence the quality of the weld was taken in consideration as well. The main influence to the weld quality is the arc length which will cause changes in the current hence the stability of controlling and holding the electrode need to be taken care. The welder should also ensure the welding work piece is cleaned before begin welding. The clamp which will used for grounding to complete the welding circuit shall be clamped as close as possible to the welding area.

Figure 3.1: Welded test plate

The electrode required for the welding shall be inserted in electrode holder. Current for the weld shall be adjusted based on the electrode diameter as smaller electrode diameter require lesser current. Usually the electrode manufacturers will provide the recommendation weld amperage settings required for each diameter electrodes. The electrode holder holds by the welder during welding to control the arc is an insulated handle which clamps the electrode. The welding surface appearance depends on the stability of the welder holding the electrode while welding. The arc length shall be maintain consistent for good welding appearance. With a short arc length there will be a sharp with the correct amperage. During welding slag will be developed which is required to be removed by chipping off after every weld. If right heat input and correct technique is used the slag may peel off by itself. After stop welding the welder shall remove the slag with chipping hammer or wire brush. The weld beads shall be checked and cleaned before making another pass. During welding the best welding method by holding the electrode to obtain a short arc. The electrode shall be feed downwards at a constant rate as it melts while moving at a uniform speed. The electrode shall be hold at a tilt angle about 10 to 30° in the direction of travel.

The welder's skill is the key for SMAW welding as SMAW welding is categorized as manual welding process. As the welding arc is strike and the arc is stabilized, the electrode will start melting and will form weld pool. To ensure good weld there are few characteristics which must be controlled by the welder manually. The arc length will vary slightly based on different electrode diameter. If the arc length is too far then the arc will be thin and wide and will spatter will be created near the weld pool. A short arc on the other hand will cause the weld to be too tall. During welding to check the arc length is proper is to listen the arc sound. If the arc length is proper the welder can hear a cracking or hissing sound. The welder should determine proper travelling speed by observing the bead width and noise of weld. The weld will be in round shape in a normal travel speed, thin and wide in slow speed, tall and narrow in higher speed.

A deep crater is left at the base metal when the welding was stopped without completion. The previous bead need to be cleaned before restarting the welding again. The welding should start about 3/8" ahead of the forward edge and welded slightly backward until the weld molten pool build but before continue to weld forward again (Kin 2009). The ripples of the new and the old bead will match if this is done correctly. For welding completion, run-off tab method can be used by adding extra plate with same material and thickness so the welding will be continued till the additional piece of plate with the same bevel design as the welding will be tacked welded at the end of the weld joint to extend the welding. Another method to complete welding is to reverse the direction of the electrode when reaching the end of the weld. The electrode is moved towards the edge of weld pool and when the weld pool is filled, the electrode shall be lifted until the arc is broken.

To ensure the weld quality the welder must consider the welding machine output current, electrode type, diameter & polarity as well as arc and its manipulation. Besides that the type of base metal and preparation of the base metal should also be taken care by the welder.

3.3 Mechanical testing

Mechanical testing of welded joint is to determine the mechanical strength of the welded joint. Testing of the welding joints can be categorized to types ie destructive testing and nondestructive testing but mechanical testing are destructive test.. Destructive testing are testing which destroy the material such as tensile test, impact test, bend test and hardness test. Hence for the material which had gone through destructive mechanical testing, the material cannot be used for application purpose anymore. All the mechanical test will be conducted based on ASTM standard which worldwide recognized standard and to be more specific ASTM A370 – Standard Test Methods and Definitions for Mechanical Testing of Steel Products. The dimension for all the test specimens and the testing method is indicated in ASTM A370.

Tensile testing is done by pulling the tensile test specimen until the specimen till it break. During the pulling process, the specimen will elongate and thickness of the material will be keep on reducing till it fracture. The load used for the pulling will cause the specimen to elongate and be under tensile stress. During the elongation process the stress and strain values shall be obtained and stress versus strain will be plotted in order to determine the yield stress and ultimate tensile strength of the specimen. Tensile strength of a material is the maximum stress the material can withstand and this is obtained based on the amount of force required divided by the original cross section area of the specimen. Another value which is also obtained during the tensile test is the yield strength which will indicate the ability of the material to withstand within its elastic limit. Based on ASTM A370 there are 3 types of specimen that can be selected for tensile test ie standard specimen plate type, standard specimen sheet type and sub size specimen. A mechanical Lab based 100kN Universal Tensile testing machine is used for the testing of the tensile test. Figure 3.2 indicate the tensile test specimens dimension based on ASTM A370. Figure 3.3 indicates the condition of the specimen while the tensile test is being conducted.

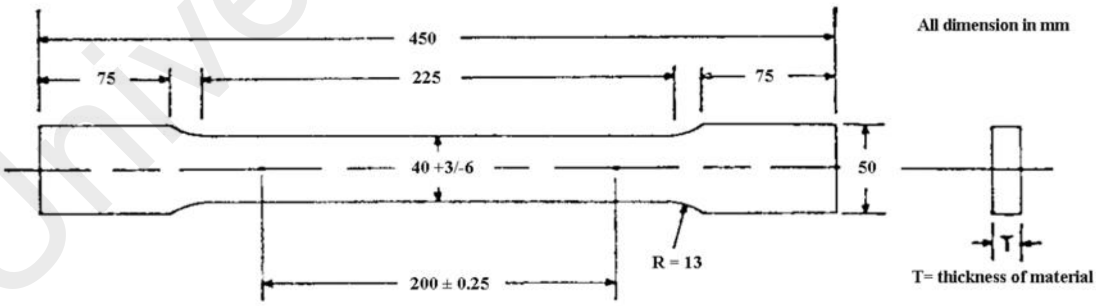

Figure 3.2: Specimen dimensions for tensile test according to ASTM A370

Figure 3.3: Specimen condition while tensile test in progress

Impact test determines the amount of energy absorbed by a material during fracture. In this research, charpy impact test method is utilized with 150N striker to impact the notched specimen. The energy absorbed will measure the toughness of the material to determine whether the material is brittle or ductile. The impact test specimen will be machines to the specimen size as stated in Figure 3.4. The welded samples were notched in the weld metal centre perpendicular to the welding direction. All the impact testing will be conducted at room temperature by excluding the condition of the impact properties at low temperature. The impact test specimen before testing is shown in Figure 3.5

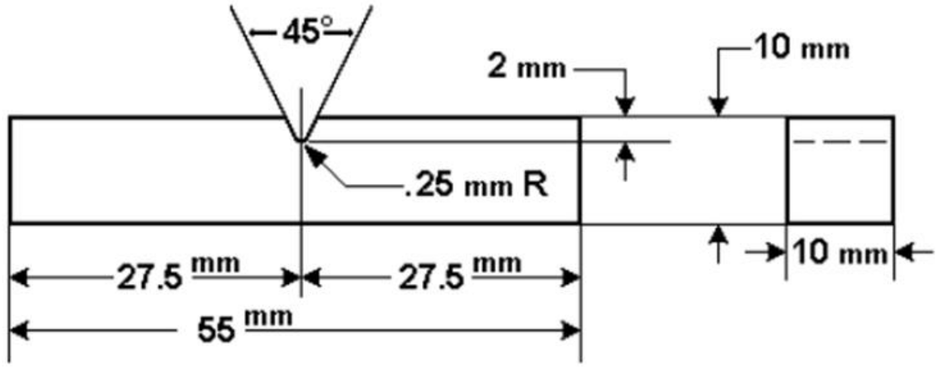

Figure 3.4: Specimen dimensions for impact test according to ASTM

Figure 3.5: Impact test specimen before testing

Bend test is a method to determine the ductility and the soundness of the weld material. In this research a guided bend test is performed as the bend test specimen is placed horizontally across two supports where force is applied from the top at the specimen midpoint to let the specimen deform into a "U" shape. Based on this test we are able to determine whether the weld was properly fused to parent material. For an acceptable weld there should be no visible fracture notices after the guided bend test performed on the specimen. Figure 3.6 indicates the bend test specimen dimensions. Figure 3.7 shows the condition of the specimen as the specimen bending is in progress.

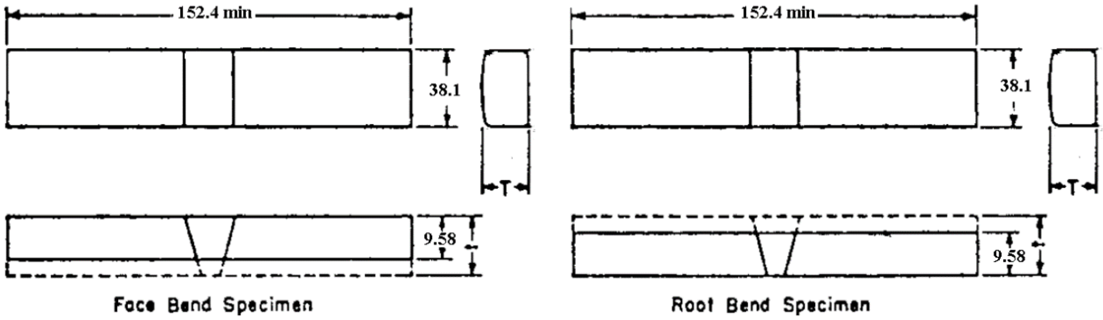

Figure 3.6: Specimen dimensions for bend test according to ASTM

Figure 3.7: Specimen condition while bend test in progress

There are few types of hardness test such as Vickers hardness test, brinell hardness test, Rockwell hardness test and others. The hardness test used in this project is Vickers hardness test. Hardness test is any ability test to within stand external force from moving towards plastic deformation. An indentation was made using a diamond indenter. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) The hardness value will be determined based on the size of the impression left by the indenter. (Maier et al, 2012). The diagonals of the indent are measured in order to determine the hardness of the test specimen. Figure 3.8 indicate the hardness tested used and is being verified based on the verification block before testing.

Figure 3.8: Hardness equipment verification before measurement

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Result

Once all the welding specimens was welded, mechanical testing was conducted to check on the mechanical properties of the weld. Table 4.1 illustrate the acceptance criteria of the mechanical testing for SA 516 Gr 70. The mechanical test shall meet the minimum or maximum acceptance criteria based on the test. The weldment shall meet the minimum tensile strength based on the mechanical properties of the based metal. Based on the toughness design properties, the minimum absorbed energy shall be above the acceptance criteria. For the bend test there shall be no significant crack to ensure ductility property. The hardness value shall be below the maximum value to avoid brittle properties.

Table 4.1: Mechanical Tests Acceptance Criteria for SA 516 Gr 70 Welding

Test	Acceptance Criteria
Tensile Strength	485 MPa
Impact test	27J @ (-20°C)
Bend Test	no open discontinuity in the weld or heat - affected zone exceeding 3 mm
Hardness	Maximum 248 HV10

Based on the test conducted all the test passed compared to the acceptance criteria as specified in the specification and can be used for welding. For bend test all specimens passed without any crack indications based on the picture shown in Figure 4.1.

Figure 4.1: Bend test specimen result

For Tensile impact and hardness all the test results are indicated in Table 4.2. For welding using newly baked electrodes, the average tensile strength is 543 MPa. Average impact test for welding using newly baked electrodes is 125J. While the average hardness value is 220 HV10. As for welding with electrodes after 1st rebaking, the average tensile value is 542MPa, average impact energy absorbed is 126J and average hardness is 226HV10. For welding with electrodes after 2nd rebaking, the average tensile value is slightly decreased to 539MPa, while the average impact energy absorbed is maintained at 126J compared to 1st rebaked electrodes but the average hardness decrease to 225HV10. While for welding with electrodes after 3rd rebaked electrodes, the average tensile value is 537MPa, average impact energy absorbed is 128J and average hardness is 228HV10.

Table 4.2: Mechanical Test Results for Welding

Electrode Condition	Specimen	Tests		
		Tensile Strength (MPa)	Impact Energy (J)	Hardness (HV10)
Newly baked	Sample 1	541	115	222
	Sample 2	543	128	228
	Sample 3	546	132	210
	Average	**543**	**125**	**220**
After 1st rebaking	Sample 1	544	126	226
	Sample 2	542	138	224
	Sample 3	540	114	229
	Average	**542**	**126**	**226**
After 2nd rebaking	Sample 1	539	132	223
	Sample 2	541	124	227
	Sample 3	538	122	226
	Average	**539**	**126**	**225**
After 3rd rebaking	Sample 1	539	125	224
	Sample 2	535	131	229
	Sample 3	537	129	231
	Average	**537**	**128**	**228**

Figure 4.1-4.3 showed the trend of the mechanical test result for Tensile strength, impact energy absorbed and hardness based on different electrode conditions. Based on the graph it was noticed the trend of the tensile strength was decreasing as the electrode was rebaked more times. The tensile value drop by just 1 MPa from 543MPa to 542 MPa if compared to newly baked and after 1st rebaking. This is followed by drop of another 3MPa after 2nd rebaking followed by another 2 MPa after 3rd rebaking. The drop in tensile values is minimal as overall it only dropped 6MPa if compared between newly baked electrodes and electrodes after 3rd rebaking.

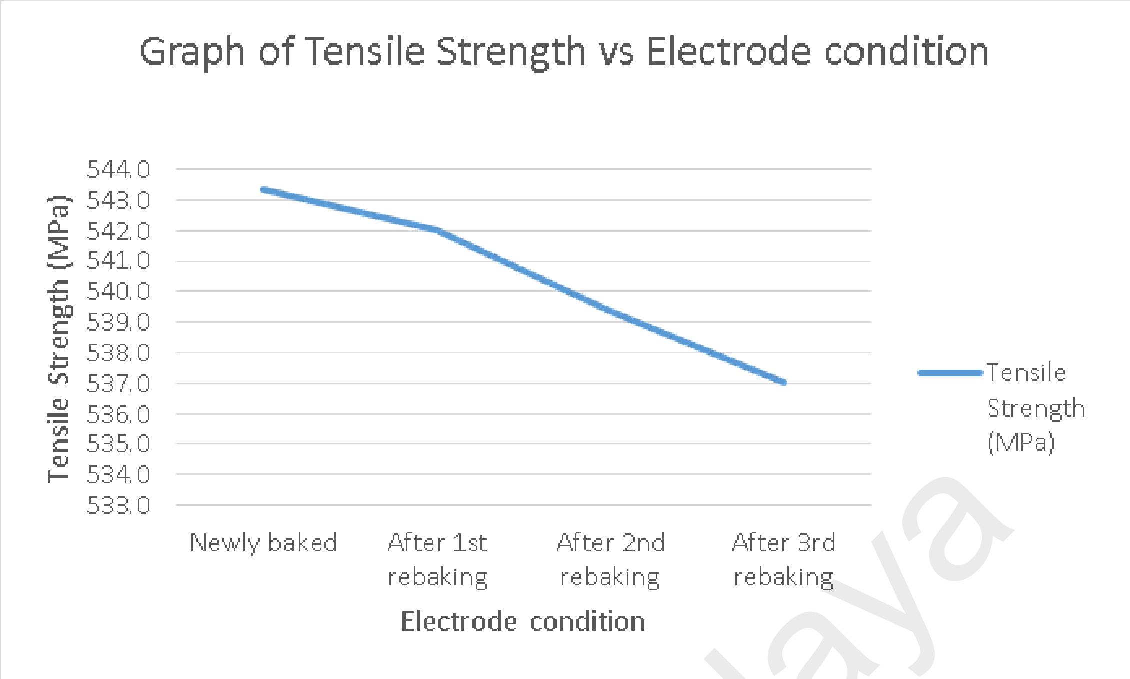

Figure 4.2: Graph of tensile strength vs electrode condition

An opposite trend was noticed on the impact energy absorbed if compared to tensile values. The impact energy absorbed is having an incremental trend as the no of baking increased. The impact energy absorbed by the newly baked electrode welding is 125 J. For welding with electrodes after rebaked 1st and 2nd time the impact energy absorbed in 126 J. While the weld with electrode after 3rd rebake absorbed an impact energy of 128J.

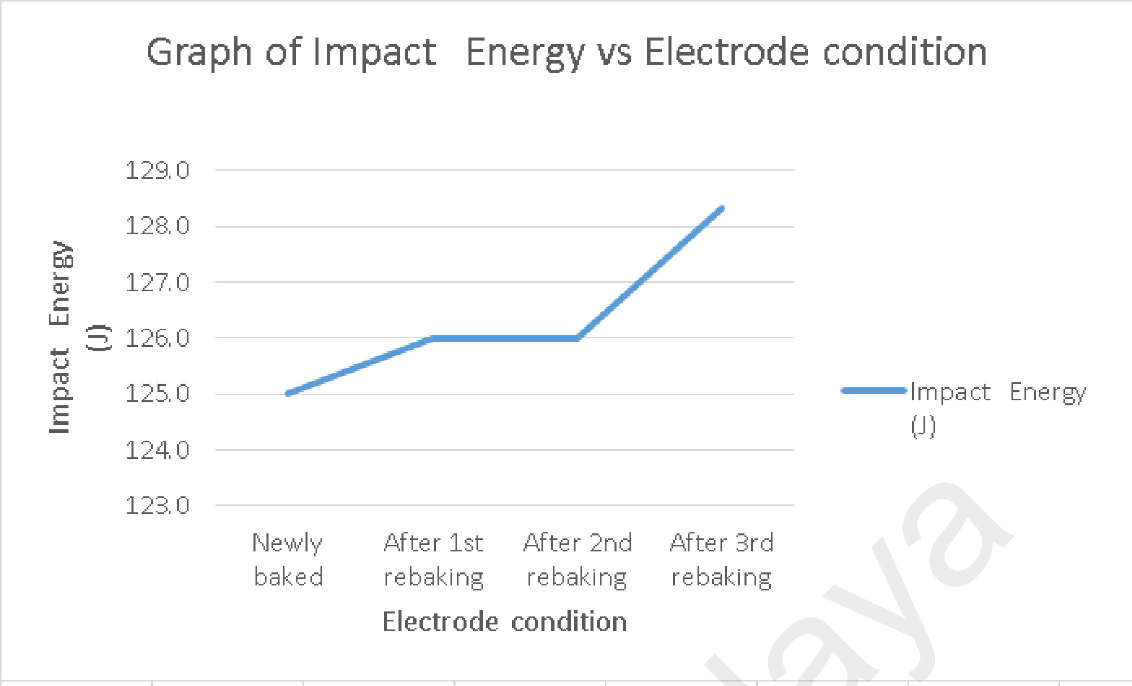

Figure 4.3: Graph of Impact Energy vs electrode condition

The trend of the hardness value is in increment trend but not consistent as there is a minor drop for the welding with electrode after 2nd rebaking. The hardness for the welds welded with newly baked electrode was 220 HV10. There was an increase in hardness for the weld welded with electrode after 1st rebake. But the average hardness value drop by 1 unit to 225 HV10 for the weld welded with electrode after 2nd rebake. There was an increase in hardness for the weld welded with electrode after 3rd rebake back to 228 HV10 which is the highest.

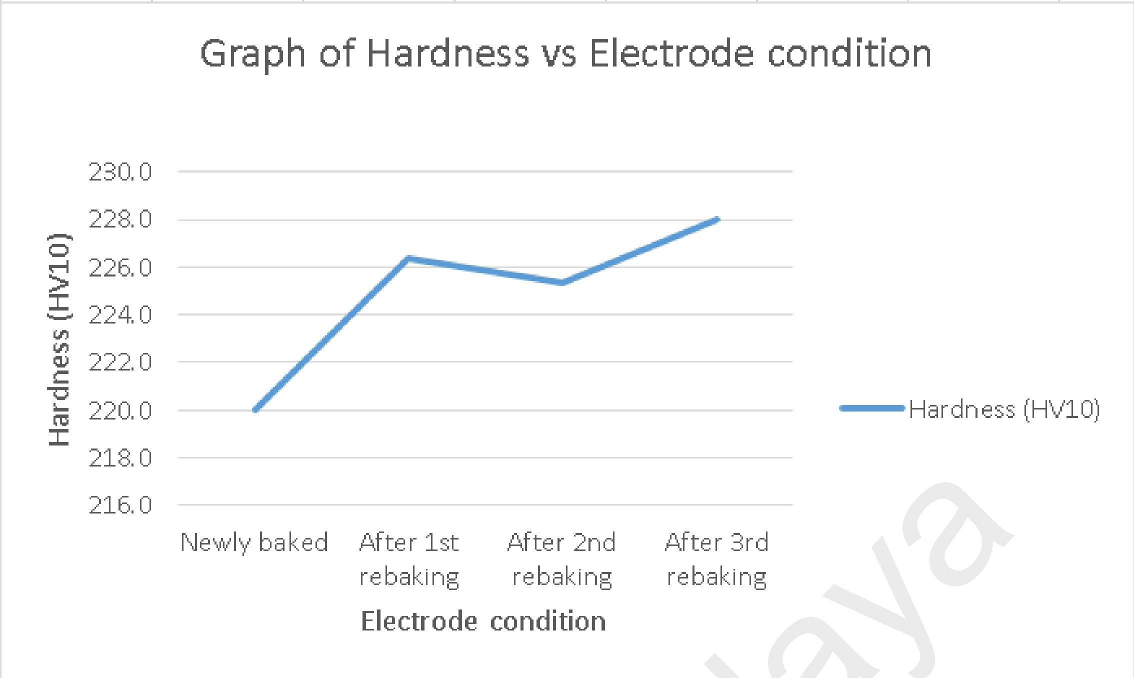

Figure 4.4: Graph of hardness value vs electrode condition

4.2 Discussion

Based on the results obtained there is some minor effects on the mechanical properties of the weld due to the number of times of electrode baking. Based on the results the tensile strength of the weld reduce slightly as the number of baking times increase. But the situation is in the opposite manner for the impact energy absorbed by the welds. As the no of times the electrodes was baked increases the impact energy absorbed by the weld specimen also increases but there was two condition of electrodes after 1st rebake and 2nd rebake having the same average impact absorbed values. There were no visible cracks found for all the bend test specimens hence all the bend test specimens were accepted. The trend of the hardness value on the other hand is having an upward and downward trend. The hardness value obtain from the weld with electrode of 2nd rebake having slightly lower value compared to the 1st rebake whereas the rest of the values are in the upward trend of hardness value increase as the electrode was rebaked more times. So far there were no any research on multiple baking of electrodes conducted so far. The nearest related research done is a study of baking electrodes with different temperature and based on this study the higher the baking temperature the higher the hardness value obtained (Syaripuddin & Setyawan, C. W. 2019).. This study may correlate towards the trend on the increase of hardness as the electrodes we baked multiple times.

Even there was noticed a trend on decrement in tensile value and increment in impact and hardness values but some of the individual values are almost similar or very close to each other and some are even having same values. The estimate changes in the mechanical test values are found as below 3% and are considered as very minimal changes and can be considered as insignificant. Hence based on the research we can determine there is an insignificant changes in the mechanical properties due to the multiple rebaking of electrodes. Due to this companies are able to save on their consumable cost as they can reuse back the electrodes and there is no requirement to scrap the electrodes after baking one time. The variation of the values due to the testing equipment was not considered yet in this study.

CHAPTER 5: CONCLUSION

Mechanical testing was conducted on welding from new baked electrode, electrode after 1st rebake, 2nd rebake and 3rd rebake. The type of mechanical testing conducted are tensile test, impact test, bend test and hardness test. Based on the study the tensile test value was decreasing as the number of times the electrodes were baked increases. An opposite trend was discovered for impact test which increases as the electrodes were baked multiple times. For the hardness test. All the bend test specimens were accepted as there was no visual cracks found. The trend of the hardness value on the other hand is having an upward and downward trend. Hardness value is having an inconsistent trend but as average the hardness value increase as the electrodes were baked more times. Based on this research it was found that there is a very minor or an estimate below 3% variation in increment or decrement in the values which is consider very minimal and can consider almost insignificant. Hence it can be concluded there is an insignificant changes in the mechanical properties due to the multiple rebaking of electrodes.

Further research need to be conducted on the non-destructive testing to identify the soundness of the weld. Volumetric non- destructive can be performed to determine any defect in the welds as not all defects can be determined based on mechanical testing.

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