Effect of Arc Welding Current on the Mechanical Properties of A36 Carbon Steel Weld Joints

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Abstract

This research work focuses on the effect of temperature as a function of current toward the mechanical properties of a welded joint of A36 carbon steel using Shielded Metal Arc Welding (SMAW). With the melting point of A36 steel at about 1426-1470^{0}C, the range of the welding current was chosen from 70A -120A to give a varying amount of heat input. The hardness, impact and microstructure test were conducted to determine the mechanical properties of the welded joint. Increasing the current from 70A - 120A caused a corresponding increase in the temperature of the welded joint which affected the microstructure of the weld. The weld microstructure was controlled mainly by the cooling cycle. At 70A (i.e. with low level of current) the time for solidification was less. The rapid cooling promotes smaller grains. At 120A, the time required for solidification increases and therefore cooling rate slows down which yielded coarse grains. At 120A the grain size was most coarse with a hardness and toughness value of 60BHN and 11 Joules respectively indicating reduced strength and hardness.

I. INTRODUCTION

In manufacturing, welding is one of the important processes. It is used widely to join metals using metals or fillers. There are many types of welding such as Arc welding, Metal Inert Gas welding (MIG welding), oxy acetylene welding; Tungsten Inert Gas welding (TIG welding), laser welding and friction welding.

Shielded metal arc welding is usually performed manually. According to the American Welding Society, common application includes construction, pipelines, machinery structures, ship building, job shop fabrication and repair work. It employs the use of a consumable electrode, electrode holder, source of an electrical power (AC or DC) and a welding Machine.

It is a process which produces coalescence of metal by heating the with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used. Filler metal is obtained from the electrode.

According to the steel construction manual 8th Edition, ASTM A36 steel is the most commonly available of the hot rolled steel. It is generally available in round rod, square bar, rectangular bar as well as I beam, H beam, angle and channels. It finds its application in areas like, bridge, ship, machine frame, and railway constructions. The chemical composition of A36 mild steel by weight (wt %) is given as follow C-0.26, Mn-0.75, Cu-0.2, P-0.04, S-0.05 and Fe. Welding Joint can be a difficult task in some industries with the problem of cracking, and altered mechanical properties compared to the parent material. Due to limited knowledge in effect of current towards weld, this research is therefore aimed at investigating the effect of temperature arising from changes in current values when using shielded metal arc welding (SMAW) on the mechanical properties such as hardness and impact strength of A36 low carbon steel with the aid of Charpy hardness testing procedures on welded joint.

II. LITERATURE REVIEW

Shielded metal arc welding is the most common metal fabrication technique in industry due to its reliability and capability of producing good quality welds. During operation, the bare metal end of the melting stick (opposite the welding tip) is clamped in the electrode holder that is connected to the power source, the holder has an insulated handle so that it can be held and manipulated by human welder. Current typically used in SMAW is 30-300A and voltage from 15 -45v. Shielded metal arc welding are usually performed manually. Common application includes construction, pipelines, machinery, structures, shipbuilding, job shop fabrication and repair work.

The disadvantage of shielded metal arc welding as a production operation is the use of the consumable electrode stick. As the sticks are used up, they must periodically be changed. This reduces arc time with this welding process. Another limitation is the current level that can be used. Because the electrode length varies during the operation and this length affects the resistance heating of the electrode. Current level must be maintained within a safe range or the coating will overheat and melt prematurely when starting a new welding stick. Some of the AW (arc welding) process overcomes the limitations of welding stick length in SMAW by using a continuous feed wire electrode.

A. Chemical Aspect of Welding

It is quite understandable that composition of base metal, electrode wire and flux impose profound effect on mechanical properties of the welded joint, which in turn depends on microstructure of weld metals and heat affected zone (HAZ). According to [14]. A Shielded Metal Arc(SMA)electrode consists of a metal core rod and a clay-like covering and a powdered minerals such as fluoride carbonate oxide, organic minerals and alloying additives. A silicate binder is used to help extrude the flux ingredient into the metal core rod. During welding both base metal and electrode are melted by the heat generated from arc. Many factors are responsible for the transfer mode of SMA welding. The major ones are the current, voltage, electrode diameter, melting temperature of the core material, coatiing thickness and temperature of the electrode. [7] reported about higher penetration due to increase in Sio_2 content of the flux. It was reported that sodium and potassium salt and other elements which improved arc stability and reduced cathode spot wandering generally increased penetration.

B. Electrode Melting Rate

Literature depicts that ample work has been done to study the effect of parameter variations, base metal and flux composition on electrode melting rate during SMAW. [3] studied the characteristics of the weld bead penetration, melting rate under variable operating current conditions and found that those increase in current. They also investigated that increase in welding voltage produced flatter and wider beads with increased flux composition [15] studied the effect of welding parameters on weld bead geometry as well HAZ and concluded that welding parameters and influx basicity appreciably influenced the depth of penetration of the weld bead. [9] conducted experiments employing modified refractory flux welding and studied the effects of welding variables on formation of root (backside) welds, including the root bead (deposit inside the groove) and root reinforcement (deposit outside the groove). The work also revealed that welding variable produced profound and sometimes conflicting effects on the root weld's shape. For example increasing the current increased the deposition rate and the depth of joint penetration; however root bead shape detoriated and slag pockets formed, which might invoke defects in the weld.

C. Metallurgical and Mechanical Properties of Weldment

Metallurgical characteristics of the weld metal as well as heat affected zone (HAZ) are very important because this directly influence the weld mechanical properties and joint performance. It is well known that the micro structure of base metal as well(HAZ), are somewhat different with respect to distributions of pearlite, ferrite, and grain size depending on the weld condition adopted.

In a pass of the welding touch, the material is rapidly heated to the maximum temperature and allowed to cool more slowly by conduction of heat into the bulk of the parent metal. Phase changes can occur depending on the temperature reached. Sufficiently far from the weld pool, the material remains unaffected. The region next to the fusion zone where microstructure changes have occurred but no melting of base metal has affected is known as heat affected zone HAZ. Such microstructure changes can affect the mechanical properties of the weld and need to be controlled. The weld metal microstructure is controlled mainly by the cooling cycle. At lower energy input (i.e. with low level of current), the time for solidification is less. The rapid cooling promotes smaller grains. With higher energy input, the time required for solidification decrease, and therefore cooling rate slows down which yields coarse grain. Coarse grain in the microstructure indicates lower hardness and low tensile strength.

Mechanical properties are important characteristics of the weldment that must confirm to the application feasibility as well as functional requirement of the welded joint. These include hardness, impact strength (toughness), yield strength, ultimate tensile strength, percentage elongation, resistance to wear and corrosion etc. These mechanical properties greatly depend on weld microstructure, which in turn is related to cooling condition, composition of base metal, wire electrode as well as flux. Moreover welding process parameters also improve direct/indirect influence on weld mechanical properties and microstructure.

[16] examined the effects of two fluxes of different basicity's when used with two experimental wires and a Columbian bearing base plate. The flux basicity was seen to have an effect on the transfer of hardenability element of the weld deposit and on the result and microstructure and impact properties. The use of the fully basic flux with Mo-Ti-B wire aided in the suppression of pro-eutectoid ferrite in the weld metal microstructure and thereby improves the notch toughness of the weld metal microstructure and thereby improves the notch toughness of the weld. Quantitative

image analysis was used to document the effect of flux basicity on microstructure and not metallic inclusion.

[17] found that filler material and flux composition in SMAW would influence the growth of austenite consideration. [18] demonstrated that the notch toughness of the coarse grained HAZ decreased with increased in energy input. They also found that stress relieving reduced the notch toughness of both the weld metal and HAZ as a result of embrittlement caused by carbide precipitation.

[13] gave quantitative relationship between microstructure and mechanical properties so that the variety of models could be consolidated and used directly in the design process. The paper provided some information to deal with a few of the important mechanical properties and described some of the innovative treatment under development for the production of better welds or for the exploration of welding technologies in novel application.

[10] investigated mechanical properties of nuclear pressure vessel steel, A508CL3, and its welded joints by using the micro shear test method. The fracture toughness of A508CL3 steel and its weld were also estimated. Moreover, a comparison had been carried out between the conventional test, micro shear test and mechanic's test. In addition, the possibility of using the micro shear test on the surveillance program nuclear pressure vessel embrittlement and the results indicated that the micro shear test can be used successfully to estimate the degradation of mechanical properties both for A508CL3 steel and its welded joint. It has been found that the lower the micro shear toughness, the smaller the charpy V-notch impact toughness, as well as the tearing modulus. Finally, the results showed that the micro shear test method may be developed as a supplement test method

[12] investigated the effect of coarse initial grain size with varying heat input on microstructure and mechanical properties of weld metal and heat affected zone. It was concluded that the coarse initial grain size had a great influence on the microstructure, hardness and toughness of HAZ of low carbon steel. The investigators recommended a higher heat input to obtain maximum toughness of the HAZ in the welding of grain-coarsened low carbon steel, taking into consideration the plate thickness. [11] made an experiment with all weld metal deposited with various types of electrodes and reported the role of different alloying elements such as manganese, carbon and chromium on the tensile properties. Hardness as well as in the microstructure of SMAW weldment. They suggested criteria for selecting the weld metal com[position of tensile strength and toughness. It was concluded that an increase in Mn, C or Cr individually produced an increase of tensile strength and hardness.
[6] developed a technique that would allow evolution of the fusion boundary to be studied under controlled thermal condition. In the report, non- dendrite grain microstructure were simulated in Li-bearing Alloy 2195.

Tin could pin the prior austenite grain boundaries of the heat affected zone and inhibit the growth of austenite grain boundaries and suppress the growth of pro eutectoid ferrite The relationship between microstructure and toughness of weld deposit was studied by means of hardness, V-Charpy notch and metallographic test in specimens at transversely the weld beads.

[5] quantitative and quantitative analysis of microstructure constituents and fine phases were made by light optical and scanning electron microscopy respectively. In this investigation, a selective etching method was employed in order to distinguish the mantesite - austenite (M/A) constituents from carbides. The result showed that chromium impairs impact toughness, although it promotes an increase in the percentage of acicular ferrite (AF). In addition, it was observed that an increase in carbon content promoted a further decrease in impact toughness due to the higher volume fraction of the M/A constitute [2] in an investigation made an attempt to obtain the best value of current, voltage, speed of welding and external magnetic field to produce the best quality of weld in respect of depth of penetration. Result revealed that an artificial neutral network is one of the alternative methods to predict the weld bead geometry in terms of depth of penetration. Hence it can be proposed for real time work and the neutral network modeling, the following conclusions are drawn.

- A strong joint of mild steel is found to be produced in the work using SMAW
- If amperage is increased, depth of penetration decreases
- If voltage of the arc is increased, depth of penetration of weld decreases
- If travel speed is increased, depth of penetration of weld decreases
- If magnetic field is increased, depth of weld decreases

Artificial neutral network based approaches can be used successfully for predicting the output parameter. Like weld width, reinforcement height and depth of penetration of weld, however the error is rather high as in some cases of predicting the depth of penetration is more than 6 percent increasing the number of hidden layer and literature can be used to summarize the error.

D. Types of Weld

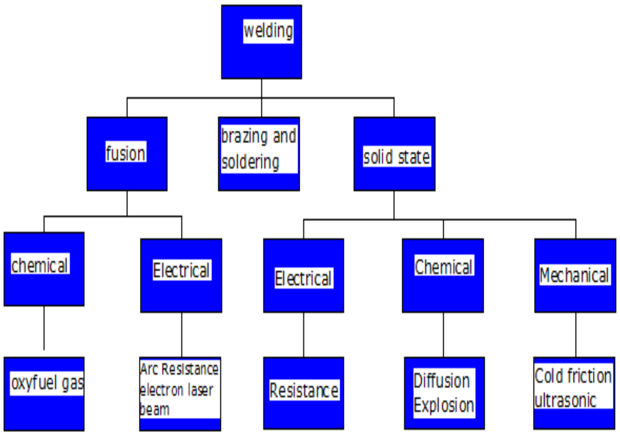


Fig1 : Types of Welding[1]

1) Fusion Welding:

Fusion welding can be defined as the melting together and coalescing of materials by means of heat, usually supplied by chemicals or electrical means. Filler metals may or may not be used.

In solid state welding joining takes place without fusion, consequently, there is no liquid (molten) phase in the joint. The basic processes in this category are diffusion bond and cold, ultrasonic friction, resistance and explosion welding. Brazing uses filler metal and involve lower temperature than welding. Soldering uses similar filler metal (solder) and involves even lower temperature.

2) Oxy Fuel Gas Welding

Oxyfuel gas welding is the type of chemical welding in fusion welding. Oxyfuel gas welding (FW) is a general terminology used to describe any welding process that uses a fuel gas combined with oxygen to generate a flame. The flame is the source of the heat that is used to melt the metals at the joint. The most common gas welding process uses acetylene gas welding (OAW) and it is used for structural metal fabrication and repair work

3) Arc Welding Electrode

The welding process is mainly divided into 2 categories which are:

- Non consumable Electrode
- Consumable electrode

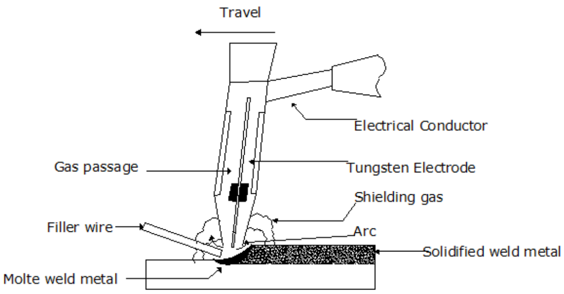


Fig 2. Tugsten Inert Gas Welding Process Schematic Drawing [1]

In consumable – Electrode welding processes, the electrode is typically a tungsten electrode. Because of the high temperature involved. An extremely supplied shielded gas is necessary to prevent oxidation of the weld zone. Typically DC, (direct Current) is used, and its polarity (the direction of current flow) is important. The selection of current levels depends on such factors as the type of electrode, metals to be welded, and depth and width of the weld zone

4) Shielded Metal Arc- Welding:

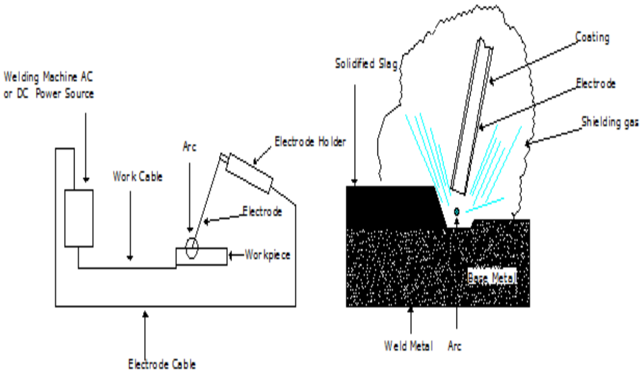


Fig.3:Schematic Illustration of the Shielded Metal Arc Welding Process[1]

In this project, the author will focus on the part of welding. Shielded metal arc welding (SMAW) is one of the oldest, simplest and most versatile joining processes. About 50% of all industrial and maintenance welding currently is performed by this process. The electric arc is generated by touching the tip of a coated electrode against the work piece and with drawing it quickly to the distance sufficient to maintain the arc.

The SMAW process has the advantage of being relatively simple, versatile and does not require a huge variety of electrode. The equipment consists of a power supply, cable and an electrode holder. The SMAW process commonly is used in general construction, shipbuilding, pipeline and maintenance work

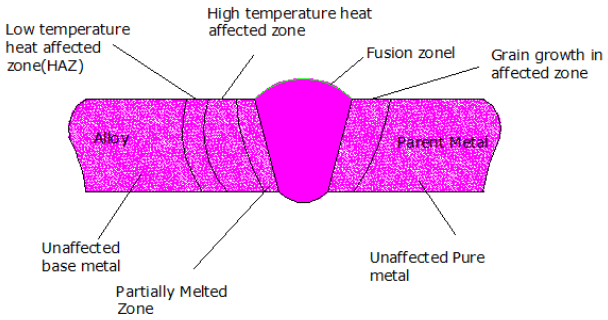


Fig.4 Distinct Zone of Welded Joint [1]

- Base Metal
- Heat affected zone
- Weld Metal

The metallurgy and properties of the second and third zones depends strongly on the type of metal joined, the particular joining process, the filler joined used (if any) and welding process variable. A joint produced without a filler metal is called autogenous, and its weld zone is composed of the re -solidifies base metal. A joint made with a filler metal has a center zone called weld metal and is composed of a mixture of the base and the filler metal.

E. *Heat Affected Zone*

The heat affected zone (HAZ) is within the base metal itself. It has a microstructure different from that of the base metal prior to welding because it has been temporary subjected to elevated temperature during welding the portions of the base metal do not undergo any microstructure changes during welding as they are far enough away from the heat source and far lower temperature to which they are subjected.

The properties and microstructure of the HAZ depends on

- The rate of heat input and cooling
- The temperature to which the zone was raised. In addition to metallurgical factors (such as the original grain size, grain orientation and degree prior cold work), physically properties influence the size and characteristics of the HAZ

The Microstructure of weldment (WM) and parent metal is known that it undergoes considerable changes because of the heating and cooling cycle of the welding process. E.g as discussed in [8] to reveal the heat affected zone (HAZ) around a weld, hardness measurement, metallurgical and electrochemical etching techniques have been commonly used for instance [4] investigated the HAZ in an Inconel 718 sheet using those aforementioned methods. It has been found that the hardness measurement is simple and effective as it clearly shows the hardness variation around the weld and HAZ. A welding process usually reduces the hardness and impairs the strength and fatigue behavior of welded structure.

III. EXPERIMENTAL ANALYSIS

A. *Material And Method*

A36 Mild Steel of the required dimension was purchased from the local market and the test specimen was prepared from it. The chemical composition of A36 mild steel by weight (wt %) is given as follow C-0.26, Mn-0.75, Cu-0.2, P-0.04, S-0.05 and Fe.

B. *Preparations of The Specimens*

The test specimen for analysis of mechanical properties of hardness and toughness were prepared as per ASTM standard and its description is given below:

1) Specimen for Toughness Test

An impact test specimen as per ASTM A370 is prepared with the following dimensions

Length	5.5cm
Width	1cm
Thickness -	1cm

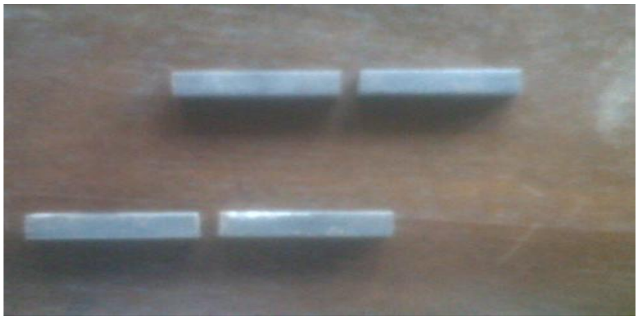


Fig.5: A36 Grade Mild Steel for Toughness

2) *Specimen for Hardness Test*

The hardness is determined from the same specimen of (5.5cm×1cm×1cm)

Fig. 6: A36 Grade Mild Steel for Hardness (5.5cm×1cm×1cm)

According to ASTM A956, dynamic hardness testing method apply an instantaneous load. A test takes a mere 2 seconds and using a standard probe D.

C. Welding The Sample

The A36 Mild Steel has been join together using SMAW at different current which is at 70A, 80A,90A,100, 110A, 120A and 120 A. The electrode that is used for this experiment is E6013

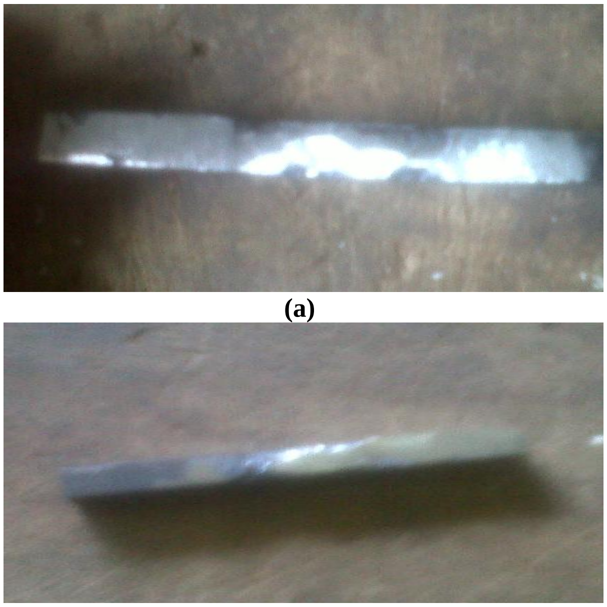
Fig.7: Welding Electrode (E6013)

D. Temperature Measurement

The temperature of the welded joint was measured using a K type infrared Pyrometer of 2000^{0}C capacity

E. Grinding the sample

Grinding was done to remove the splatter on the metal to make



(a)

(b)

Fig. 8(a)&(b): Welded and Grinded Sample

F. Preparing the Notch

The notch of 2mm was made on a shaping machine using a tool having a 45^0 nose.

G. Hardness Test

The hardness test used in this project is the Dynamic hardness testing. The basic principle as with all common measures of hardness is to observe the questioned ability to resist plastic deformation from a standard source. The dynamic hardness tester can be used for all metals. The unit of hardness given by the test is known as Brinnel Hardness number.

FIG. 9: Dynamic Hardness Tester

According to the leeb principle, hardness value is derived from the energy loss of the defined impact body after impacting on a metal sample. The leeb quotient (v_i, v_r) is taken as the measure of the energy loss by plastic deformation. The impact body rebounds faster from harder test sample than it does from softer ones, resulting in a greater value $1000\times\left(\frac{v_r}{v_i}\right)$. The quotient $1000\times\left(\frac{v_r}{v_i}\right)$ as the hardness value

H. Impact Test

Testing impact test is practical for the assessment of the brittle fracture of metals and is also used as an indicator to determine suitable service temperature. The Charpy test sample has 55 by 10 by 10mm dimensions, a 45^0 V notch of 2mm depth and a 0.25mm root radius will be hit by a pendulum at the opposite end of the notch as shown to produce a fractured sample.

The absorbed energy required to produce two fracture surfaces will be recorded in the unit of joule. Since the energy depends on the fracture area.(excluding the notch area). Thus standard specimens are required for a direct comparison of the absorbed energy.

Table 1: Specification For Impact Tester

nical Data	Measuring Unit	Value
Capacity Nominal Energy	Joules	
Pendulum Weight	Newton	215.76
Hammer Mass	Kg	21.9
PendumumLength	Meter	0.7486
Impact Velocity	Meter / second	5.23
Weight of Machine	Kg	600
Machine Base	Kg	h399

As the pendulum was raised to a specific position, the potential energy (mgh) equal approximately 300j was stored. The potential energy was converted into the kinetic energy after releasing the pendulum. During specimen impact, some of the kinetic energy was absorbed during specimen fracture and the rest of the energy is used to swing the pendulum to the other side of the machine, the less energy absorbed during the fracture surface. This means the material fracture in a brittle manner. On the other hand, if the absorbed energy is high, ductile fracture will result and the specimen has high toughness.

FIG 10: Impact Testers

I. *Microstructure Test*

The test was done by using the optical microscope to observe the characteristics of the microstructure of the welded joint (HAZ). Before the test can be done, the sample needs to be grinded to ensure the surface is flat and polishing is done to give a mirror-like finish. Then, etching was done to reveal the microstructure under the optical microscope.

The basic technique for acid metal aching is to apply a resist to the area of metal plate, specifically on the surface of the A36 grade steel. The surface of the material was swabbed and immersed into a specific solution that reacts with the specific metal

J. *Preparation of Samples for Microstructure*

1) Grinding of the surface: The surface is grinded with the various sizes of emery cloth. 120, 220, 320, 400 and 800 grain/M^2. Grinding was done at 90^0 in a straight line. The direction of the straight line is changed with change emery cloth.

2) Polishing. Polishing is accomplished using gamma alluminuim powder manually.

3) Etching

Table 2: Etching Process

Etchant	Concentration	Condition	Comment
Nital Ethanol Nitric Acid	98ml 2ml	Immersion up to 3minutes	Most common etchant for carbon and alloy steel

4) Washing in alcohol then dry with the use of electric hand dryer.

IV. RESULTS AND DISCUSSIONS

A. *Hardness Test*

Table 3: Average Hardness Properties Of Weld Joint At Different Current (A) Settings

S/N	Brinnel Hardness Number (BHN)				Current (A)
	Trail 1	Trail 2	Trail 3	Average	
1	120	114	109	114	70
2	105	101	98	101.1	80
3	92	95	98	95.0	90
4	83	87	86	85.3	100
5	73	74	74	73.6	110
6	60	61	59	60	120

Table3 shows the average hardness results. The value shown on the graph is the calculated average value taken from table 3. The piece with the greatest hardness is the one with 70A with a value of 114BHN.

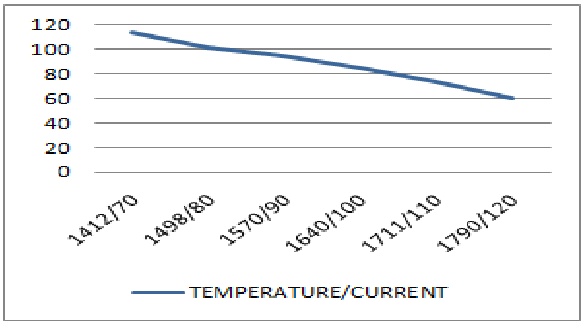


Fig.11: Effect Of Current/Temperature On Hardness

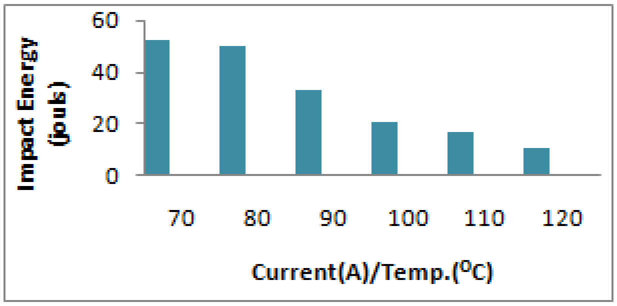


Fig 12:Effect of Current on Toughness

As the probe (D1) was moved towards different regions of the weld, the trend of the hardness varied. This increase accounts for the variation in trial results from the test samples. It was also observed that the entire perimeter of the sample was affected by the heat input making the entire area the Heat affected Zone (HAZ). From the experiment, it is shown in this range of current 70-120A that the hardness of the welded joint of A36 grade steel using E6013 electrode decreases with increase in current.

B. *Impact Test*

Table 4: Variation of the impact strength of A36 steel weldment with current

CURRENT	70	80	90	100	110	120
JOULES	52	50	46	39	32	18

The ability of the material to withstand an applied load is referred to as toughness From Fig.12, it was observed that the impact strength of A36 grade steel with 70A has the best value of 52 joules while the value of 120A welded joint sample has the lowest impact strength of 11 joules.

As the current increases, the heat input increases and it gives an effect decreasing the impact strength within this value of current.

From this experiment, it is shown that for the range of current 70A-110A, the impact strength of the weld and heat affected zone of the metal reduces

C. *Microstructure Test*

Magnification:
Eye Piece =10
Camera = 40
Magnification = 10 × 40 =400

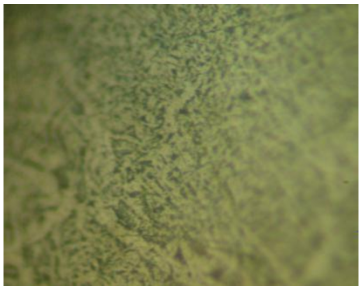


Fig 13: Microstructure of the Weld Zone at 70A.

Fig 14: Microstructure of the Weld Zone at 80A

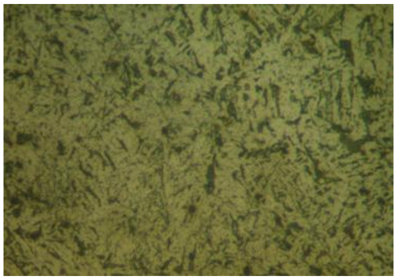


Fig 15: Microstructure of the Weld Zone at 90A

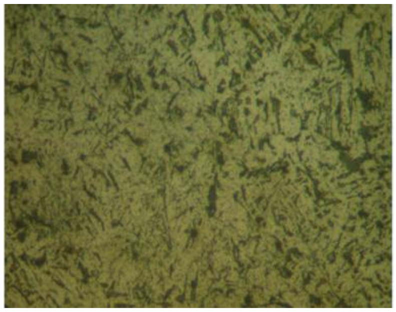


Fig 16: Microstructure of the Weld Zone at 100A

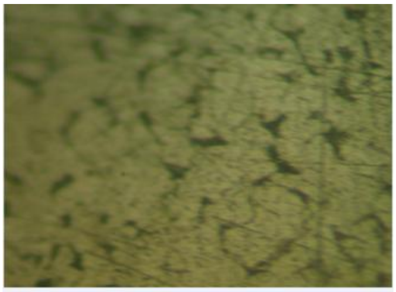


Fig 17: Microstructure of the Weld Zone at 110A

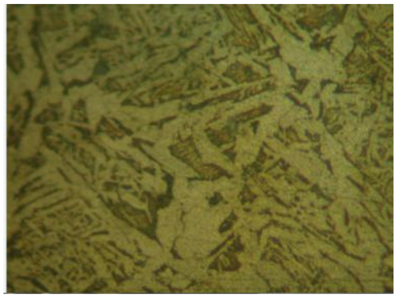


Fig 18: Microstructure of the Weld Zone at 120A

Fig (13) shows the microstructure of the weld zone at 70A. As the current increases, the heat input also increases. The micro structure becomes more coarse as the current increases from 70-120A.

The weld Microstructure is controlled mainly by the cooling cycle. At lower energy input (i.e. with low level of current) the time for solidification is less. The rapid cooling promotes smaller grains with higher energy input, the time required for solidification decreases and therefore cooling rate slows down which yields coarse grain. Coarse grain in the microstructure indicates lower hardness and low strength.

V. CONCLUSION

As a conclusion, increasing of the arc welding current from 70-120A in A36 carbon steel will increase the welding heat input, it will affect the microstructure of the weld itself and give impact on the strength and hardness of the material. The increase in welding current results in increases in temperature of the weld and results in the depletion of toughness and hardness as a result of increased cooling time which gives rise to rapid growth of the grain. Thus the objective of this project which is to investigate the Mechanical properties of the welded joint part using SMAW and to investigate the effect of current towards the weld is achieved.

REFERENCES

[1] Kalpakjian (2010): Manufacture Engineering and Technology. Prentice Hall, Singapore.

[2] Singh R.P, Gupta R.C and Sarkar S.C (2012): “The Effect of Process Parameters on Penetration of Shielded Metal Arc Welding under Magnetic Field usingArtificial Neutral Networks,” International Journal of Application or Innovation in Engineering and Management (IJAIEM), volume 1Issue 4.

[3] Renwick, B.G And Patchett M.M. (1976):“Operating Characteristics Of The Submerged Arc Process,” Welding Journal 55 (3). Pp 66 – 76.

[4] Huang C.A, Wang T.H, Han W.C, Lee C.H (2007): “A Study Of The Galvanic Corrosion Behavior Of Inconel 718 after Electron Beam Welding,” Journal of Material Chemistry and Physics.104:293 – 300.

[5] Jorge L. G. and Rodolfo L. M. (2012) : “Rietveld Quantitative Analysis Of Super Duplex Stainless Steel,” International Center For Diffraction Data, Department Of Metallurgical Engineering Universidad De Santiago De Chile, Casilla 10233, Santiago Chile.

[6] Kostrivas A. and Lipold J.C. (2008): ”Weldability Of Li-Bearing Aluminum Alloys”, Welding Journal. Pp 32.

[7] Schwemmer and Oslon(1979): Relationship Of Weld Penetration To The Welding Flux. Welding Research Supplement. Pp 153 – 160

[8] Gunaray V, Murugan N. (2002):”Prediction and Optimization
(Part 2),” Welding Journal 79(10). Pp286 – 294.

[9] Malin V. (2001): “Root Weld Formation in Modified Refractory Flux, One Sided Welding (Part 2),” Welding Research Supplement. Pp227 – 229.

[10] Zhang X.P, Dorn L. (2006):”Correlation of The Micro Shear Toughness and Fracture Toughness For Pressure Vessel Steels and Structural Steels,” International Journals Of Pressure Vessels and Piping Joints. Pp. 445 – 450.

[11] Sarian S. and De Vadia L.A. (1999):”All Weld Metal Design For AWS E10018M, E11018M And E12018M Type Electrode,” Welding Research Supplement. Pp 217 – 219.

[12] Eroglu M, Aksoy M , Orhan N. (1999): “Effect of Coarse Initial Grain Size on Microstructure and Mechanical Properties of Weld Metal and HAZ of a Low Carbon Steel,” Material Science and Engineering, Volume 2, Pp.59 – 66

[13] Bhadeshia H.K.P.H (1997):“Model For The Elementary Mechanical Properties of Steel Welds” Institutes of Materials, London Pp 229 – 284

[14] Bracarense A.Q and Lui S. (1994):“Control of Covered Electrode Heating by Flux Ingredients Substitution” Welding & Metal Fabrication 62A. (5) Pp 18 – 32

[15] Gupta S.R. and Arora N. (1991): “Influence of Flux Basicity on Weld Bead Geometry and Heat Affected Zone in Submerged Arc Welding,” India Welding Journal 24(7) PP 27 – 133 [20]

[16] Charles H, and Entrekin J.R (1979): “The Influence of Flux Basicity on Weld Metal Microstructure,” Metallography 12:295-312

[17] Fleck, N.A Grong O, Edward G.R and Matlock O.K.(1986): “The Role of Filler Metal Wire and Flux Composition in SMAW Transformation Kinetics,” Welding Journal, 65:113 - 114

[18] Smith N.J, Mc Grath J.T, GiaNetto J.A and ORR .F.(1989): Microstructure/Mechanical Property Relationships of Submerged Arc Welds In HSLA 80 Steel. Welding Research Supplement. Pp. 113 – 117.