ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Investigation of Microstructure and Mechanical Properties of Heat Affected Zone in Manual Arc Welded Mild Steel

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering (Mechanical Design Stream)

By Okelo Fekadu

Advisor: Daniel Tilahun (PhD)

October, 2018

Addis Ababa

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Investigation of Microstructure and Mechanical Properties of Heat Affected Zone in Manual Arc Welded Mild Steel

MSc Thesis

By Okelo Fekadu

Approved by the Board of Examiners

Daniel Tilahun (PhD)	______________	____________________
Advisor	**Date**	**Signature**
Endalkachew Mekonnen (PhD Candidate)	______________	____________________
Internal Examiner	**Date**	**Signature**
Tamirat Tesfaye (Dr.Ing.)	______________	____________________
External Examiner	**Date**	**Signature**
Yilma Tadesse (PhD)	______________	____________________
School Dean	**Date**	**Signature**

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AISI	American Iron and Steel Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing Materials
AWS	American Welding Society
BM	Base Metal
CEV	Carbon Equivalent Value
CGHAZ	Coarse Grain Heat Affected Zone
CSA	Canadian Standards Association
CVN	Charpy V Notch
FGHAZ	Fine Grain Heat Affected Zone
HAZ	Heat Affected Zone
MIDI	Metal Industry Development Institute
MMAW	Manual Metal Arc Welding
SAE	Society of Automotive Engineers
SAW	Submerge Arc Welding
SMAW	Shielded Metal Arc Welding
WM	Weld Metal

Abstract

Heat affected zone properties has been investigated in order to find changes in property of material due differences in welding parameters and conditions to achieve properties fulfilling the requirements put on welded structures. During welding, the high-temperature fusion process causes micro-structural and mechanical property changes adjacent to the weld line in the heat affected zone, which significantly alter the mechanical properties of the parent material.

This work investigates mechanical properties and width of heat affected zone and microstructure of mild steel welded using manual metal arc welding process by preparing specimens with different thicknesses and welding parameters. Experiments carried out to understand the effect of heat input with focus on welding current and welding speed on hardness, tensile strength, toughness, width of heat affected zone and micro structure,.

The results of the investigation indicate that significant increase in hardness with increase in heat input. Increase in welding speed which means decrease in heat input resulted in decrease in value of hardness of heat affected zone. From the experiment average HAZ hardness is higher than parent metal hardness by 16.5 % and HAZ toughness and tensile strength is lower than that of the parent material by 6.5% and 18.5% respectively. Varying the welding current found to cause more significant changes on mechanical properties of heat affected zone than varying welding speed. Thinner plates have wider heat affected zone compared to thicker plates for same heat input and with increase in heat input toughness and tensile strength decreased. Microstructure examination results show larger grain size in heat affected zone compared to the parent metal. Results from this work will be applicable in fabrication of low bed semi-trailer chassis components namely platte form and ramp. Moreover results from this work will be applicable in non-destructive testing of materials.

Key Words: *Micro structure, fusion, Heat Affected zone, Manual metal arc Welding, Parent Metal, Welding parameters, mild steel.*

Acknowledgement

I would like to forward the deepest of my appreciation and gratitude to my advisor Daniel Tilahun (PhD) for his constructive advice throughout the course of the thesis. Not only did he help me with invaluable advice, I have also learned a lot from him. The brotherly treatment he accorded me has served as an inspiration for the completion of this study. I am immensely grateful for your kindness, patience, time and professional contributions to the success of my study. Thanks for always pushing me for more.

My appreciations also go to my employer International Development Enterprises (iDE) for encouraging me to pursue my MSc study and cover some of my laboratory expenses. I am also grateful for Metal Industry Development Institute (MIDI), School of Mechanical and Industrial Engineering of Addis Ababa University and Addis Ababa Science and Technology University for allowing me to use their testing facility to conduct my experiments.

My friends and colleagues Biniyam, Djalalie, Abreham, Abiy and Tadele are greatly appreciated for helping me making my test pieces and conducting experiments. For me your contribution to this research is a lot.

Chapter 1. Introduction

1.1. Background

Welding is a method of repairing or creating metal structures by joining the pieces of metals through various fusion processes by application of high heat input. It is one of the most common fabrication techniques which are extensively used to obtain good quality joints for various structural components. Manual metal arc welding is one of the efficient and economical methods for joining of metals. The arc welding process is a remarkably complex operation involving extremely high temperatures, which produces severe distortions and high levels of residual stresses[1]. These extreme phenomena tend to reduce the strength of a structure, which becomes vulnerable to fracture, buckling, corrosion and other type of failures. Hardness is very important mechanical property of material but during welding high heating and rapid cooling influence the hardness of the weld as well as the Heat affected zone[1-4].

The heat affected zone is within the base metal itself and 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. During the welding process some portion of the metal achieves the liquid state while the surrounding material suffers from the influence of the diffused heat. As result, three main regions can be distinguished in the weld microstructure: the base metal, the weld metal and the heat affected zone. HAZ is generally some millimeters in width, possesses an inhomogeneous microstructure accompanied with a steep gradient on mechanical properties[1,2]. As result a study of weld metallurgy is very important because the overall mechanical properties, of a weldment are determined by the characteristic properties of individual microstructure present in the weld deposit and the weld heat affected zone.

A weldment introduces a structural heterogeneity with a corresponding change in hardness and other mechanical properties relative to the base steel. Every position in the HAZ relative to the fusion line experiences a unique thermal experience during welding, in terms of both maximum temperature and cooling rate. Thus, each position has its own micro structural features and mechanical properties. The partially melted region is usually one or two grains into the HAZ relative to the fusion line. It is characterized by grain boundary liquation, which may result in cracking.

In addition to metallurgical factors (such as the original grain size, grain orientation and degree prior cold work), the properties and microstructure of the HAZ highly depends on the rate of heat input and cooling rate. The microstructure of parent metal is known that it undergoes considerable changes because of the heating and cooling cycle of the welding process.

1. 2. Statement of the problem

Mild steel plates are popular in fabrication industry in our country and globally for their versatile application, excellent weldability and relatively low price. High demand and wide application of this material needs practical designs that fully utilize its structural capacity. The most significant challenge for using mild steel as structural material is the loss of strength after welding is involved [1,2]. During welding, the high-temperature fusion process causes microstructural changes adjacent to the weld line in the Heat-Affected Zone (HAZ), which significantly affect the mechanical properties [1]. It is expected that this phenomenon affect the final material properties across the weld line.

The effects of welding on mild steel vary with the distance from the weld center; this effect may be categorized into areas that reflect the heat attained by the metal. The width of the HAZ, as well as the extent of metallurgical changes depend on the rate of heat input and heat dissipation. Heat input and heat dissipation are influenced by the welding process, thickness or geometry of the part, welding speed, and boundary conditions.

Studies revealed change in material property after welding could be some of the factors that were not appropriately considered in design methodologies. The welding procedure can influence the strain response near weld toe in two ways: one is by generating residual stress, and the other is changing material properties in the heat affected zone.

So, it is crystal clear that it is necessary to study changes in mechanical properties, microstructures and width of heat affected zone to minimize effects of welding on original properties of parent metal and contribute for design and inspection considerations.

1.3. Objective of the study

1.3.1 General objective

This study investigates mechanical and microstructure properties of heat affected zone (HAZ) of mild steel plates having different thickness and welded using manual metal arc welding by employing different welding parameters compare the results with parent metal and understand the changes in mechanical properties, microstructure and width of heat affected zone.

1.3.2 Specific objective

The following points were assessed to attain the general objective of the study:

- Investigating mechanical properties of the heat affected zone and compare with parent metal properties.
- Investigating the effect of heat input which is highly related to weld parameters (welding current and welding speed) on mechanical properties and width of heat affected zone.
- Investigating the effect of material thickness on width of heat affected zone.
- Investigating micro structure of weld heat affected zone and compare with parent metal

1.4. Limitation of the study

This work investigates microstructure, mechanical properties and width of heat affected zone of mild steel welded using manual metal arc welding process with reference to the weld and parent metal by preparing specimens with different thickness and welding parameters. This to the right and left of weld toe and the depth of HAZ across the thickness didn't considered. In addition due the power load on the electric line from grid the current output from welding machine is lower than the machine reading, as a result higher current values than the recommended values used to weld test pieces. The effect of cooling rate which is believed to have some effects on HAZ properties is also not considered in this work [3].

1.5 Organization of the study

This study is organized into five chapters. Chapter1 is an introduction and back ground to the thesis which includes sub sections namely statement of problem, general and specific objectives, and organization of the study and limitations of the study. Chapter 2 presents literature review for the study. Literatures available around this topic reviewed in way it can contribute to this works and lessons and out puts from previous works properly captured in this section. Chapter 3 focuses on experimental methods and conditions. Material, dimensions, test conditions and methods discussed in detail in this chapter. Chapter 4 deals with results from the study and discussion on research out comes. The last section, chapter 5 presents conclusions and recommendations for future work.

Chapter 2. Literature Review

2.1 Introduction to HAZ

A heat affected zone (HAZ) of a weld is that part of the welded joint which has been heated to a temperature up to solidus of the parent material resulting in varying degree of influence on microstructure which can result in change in mechanical properties as a consequence of heating and cooling cycle [1-3]. The temperature distribution around a metallic arc butt weld the leading edge of the temperature pattern is compressed, because the arc is continually moving cold metal and the trailing edge becomes extended because the arc leaves preheated metal in its wake. Conventional zones of the HAZ are described in Figure 1 and divided into four main regions.

Part of HAZ which is heated to beyond the critical temperature of grain growth and extend up to the fusion boundary zone is called grain coarsened heat affected zone (CGHAZ). In this region, adjacent to the fusion boundary, the original microstructure has been reaustenitised at temperatures and retention times sufficient for marked grain growth to occur. The austenitic grain size attained will vary according to a number of factors like distance from the fusion boundary, being greatest immediately adjacent to it. Weld energy input, as a function of peak temperature and relative retention time. Original grain size; under the non-equilibrium conditions, finer austenite grain sizes may result from finer original microstructures. Steel compositions, particularly with respect to the presence of refractory carbides or nitrides which are difficult to dissolve in the available timescale at high temperature have also effect in this region. Composition may also affect the austenitising temperature itself and, hence, the extent of coarsening. The subsequent transformation products will be defined by the cooling rate, over the transformation range, and the composition and grain size of the prior austenite, and so may differ in detail from steel to steel, depending on the prior thermal history. In general, the grain coarsened region will consist of a variable mixture of constituents. These include one or more of the following, in order of decreasing transformation temperature: proeutectoid ferrite at prior austenite grain boundaries form; areas of high carbon content ranging from pearlite to morphologies in which carbides precipitate as rods or spheroids, bainitic colonies in which the ferrite plates may interlock or grow side-by-side in a manner resembling classical upper bainite, with plate widths dependent on transformation temperature; lower bainite and martensite [1].

The fine grain growth portion of the heat affected zone (FGHAZ), is only exceeded in the high carbon constituents of the original microstructure, and the original ferrite is largely untouched. Some dilution of the high carbon austenite regions may occur by dissolution of the surrounding ferrite, and the subsequent transformed structure will depend on their composition and the local cooling rate. As the peak temperature progressively decreases, the size of the reaustenitised regions decreases, and the limit of the visible HAZ is defined by a region in which the structure of the pre-existing pearlite is merely degraded by some extent of spheroidisation [1-3].

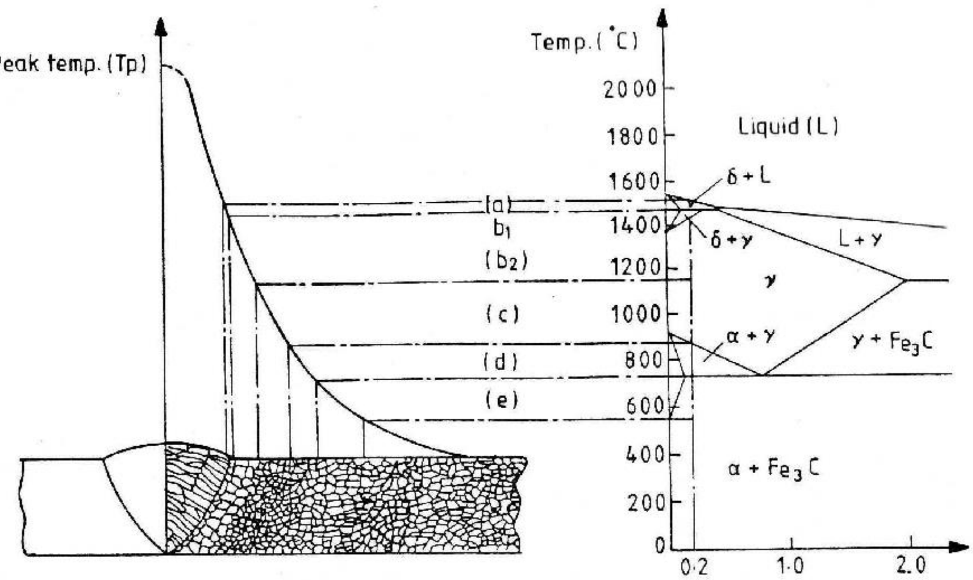


Figure 1: Sub-divisions of HAZ for plain carbon steel on iron-carbon equilibrium diagram.

Temperature ranges from 950^0C to 1150^0C, in the gran refined heat affected zone (GRHAZ), as the peak temperatures fall, the situation will eventually arise where the HAZ has been reheated just into the austenitising temperature range, bearing in mind the rapid heating rate and short retention time. This will give rise to very fine austenite, which coupled with the slower cooling rates at the increased distance from the fusion boundary, transforms to a fine equiaxed ferrite matrix with small areas of ferrite/carbide aggregate mixtures.

In the partially transformed/ tempered heat affected zone, temperature ranges from 750 to 950^0C. Outside the visible HAZ is a relatively broad zone in which the temperature peaks are low, but the heating times are long. This region was of great importance with C and Mn steels, since it was possible for nitrogen strain ageing to occur, and was, indeed, the reason for the development of the original wells wide plate test, to investigate the effect of the consequent loss in cleavage fracture resistance, in full thickness welds [2-5].

2.1.1 Metallurgical and mechanical properties of HAZ

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 [1,2].

The region next to the fusion zone where microstructure changes have occurred but no melting of base metal will be affected by heat generated due to welding process. Such microstructure changes can affect the mechanical properties of the weld and need to be controlled. 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 [5].

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. 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. Quantitative image analysis was used to document the effect of flux basicity on microstructure and not metallic inclusion found that filler material and flux composition in MMAW would influence the growth of austenite consideration. It is 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 [4].

The other 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 [3].

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 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 [1, 5].

An experiment made 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 MMAW weldment. The experiment suggested criteria for selecting the weld metal composition 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 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 [4].

2.1.2 The nature of the heat affected zone

The visible weld heat affected zone (HAZ) is by definition, that part of the weld joint lying between the fusion boundary with the weld metal and that part of the structure retaining, at the optical microscopy level, the original as-delivered microstructure. Within this narrow band, a few millimeters wide, the steel will have been subjected to one or more thermal cycles due to heating by the individual weld beads laid down. The nature of these thermal cycles at a given location in the HAZ is a function of the position relative to the weld bead, and the factors affecting heat flow (thickness, initial steel temperature, weld energy input).

The reheated areas of HAZ's can often be observed in macrographs of multi run welds. Within this narrow band of material, there exists a continuum of heating cycles, decreasing in peak temperature and overall cooling rate, from the fusion boundary to the outer HAZ edge, giving rise to microstructures which change continuously over this region. A number of general zones, within the visible HAZ, can be identified, the extent and nature of which will vary with steel composition, the thermal cycle sustained and, to a variable extent of the original microstructure.

These factors are adequately dealt with in the more modern fine grained CMnNb and CMnNbAl steels, and nitrogen strain ageing is no longer the potential problem it was. The various regions described above merge into each other and it would be impossible in most instances to decide on a distinct boundary between them. In practice, there is no great necessity to do so, since, so far as fracture resistance is concerned, it is the grain coarsened region which shows the greatest degree of degradation from the original properties. The extreme heterogeneity of even the HAZ adjacent to a single run weld, to which must be added the variability of tempering by subsequent runs, in a multirun situation, delineates the problem facing the research worker investigating the properties, or even the microscopy, of real welds. The process zone associated with the smallest mechanical test piece is bound to encompass regions of markedly different microstructures and properties, tending to blur any relationships sought between structure and properties and, possibly, to introduce scatter in repeat tests taken from nominally the same position with reference to the weld. To some degree, the original steel is itself heterogeneous with variable structures from surface to center and center to edge in plate products, and between regions of differing thickness in rolled sections [1,3,5].

2.1.3 Importance of heat affected zone properties

The overall aim in a welded joint, with respect to fitness-for-purpose, must be to obtain a joint in which the three component parts consists of parent steel, HAZ and weld metal, are each capable of withstanding the demands which the application places upon them, bearing in mind the probable size and location of defects either present after fabrication or developing during service. The degree of attention which the engineering industry has focused on each of these three types of material has varied from time to time, depending on the major current problems [1-5].

In the early days of brittle fracture, the major cause of concern was the fracture toughness of the parent material, leading to the wide spread use of the Charpy impact test to classify materials, as an aid to selection of steel for applications of varying severity [6]. Other studies of the factors affecting toughness led to a long process of improvements in steel composition and processing, has led to a situation where, it is possible to conclude that, for the majority of structural applications, the range of steels currently available is adequate to guarantee safety against fast fracture over those parts of the structure unaffected by welding. As steel properties have improved, and as welded structures have developed into larger and more complex designs, increasingly operating under more severe conditions and with serious commercial and safety penalties in the event of failure, complementary developments in welding consumables and procedures have been necessary [2,8]. The offshore oil and gas field exploitation, and the accompanying distribution systems and processing plants, have resulted in a marked increase in fundamental work and commercial development work on both manual and automatic consumables and procedures, such that the properties required, particularly fracture toughness, have been achievable in massive complex structures. Defect tolerance approaches to design, facilitated by improved stress calculation methods and inspection techniques have played a vital role. Interest in the HAZ has varied from time to time, in technical terms, and has in more recent years assumed strong commercial aspects.

In the past, the importance of HAZ toughness has been closely considered with the incidence of hydrogen induced cold cracking, on which a vast amount of research work has, and is being carried out. It is now clearly understood that three conditions must be present for H_2 cracking to occur: - An HAZ with a susceptible hardened microstructure, promoted by higher carbon equivalent values (CEV) and faster cooling rates [2,3].

Until relatively recently, the properties of the HAZ have only been regarded in the sense of their ability or otherwise to tolerate the presence of spasmodic hydrogen cracking. The relative defect tolerance of the HAZ against other potential failure modes has, by comparison, received much less attention, historically, perhaps for the very good reason that it is almost impossible to discover any failures in which the HAZ has been the prime cause, except in the presence of H2 cracks. The measures taken to design out hydrogen cracking (lowering of CEV, reduced cooling rates, etc.) will also tend to improve the fracture toughness of the HAZ a dual gain in joint reliability. Therefore, the potential failure modes are initiation from lack of fusion/penetration defects, after fabrication, or due to environmental effects during service (fatigue, stress corrosion, corrosion fatigue)[7]. The toughness required to withstand preexisting fabrication defects can be assessed using well established defect tolerance approaches, based in this case on the grain coarsened HAZ properties, together with knowledge of the service stresses and NDT discrimination level. The situation with respect to in-service cracking is extremely complex, particularly when corrosive environments are involved. Design procedures against fatigue in normal atmospheres are well established and now being included in British Standards. HAZ's are of interest because the likely initiation sites at the edges of the weld reinforcement, for instance, will ensure that the growing crack will, firstly, have its tip located in the HAZ for the first part of its growth, and, secondly, will, during this period, be subjected to the maximum stress concentration factors due to the weld profile and any geometric effects associated with the weld location. It is relatively easy, however, to define a worst case after the potential fatigue initiation sites have been identified and to calculate the fracture toughness required to ensure the survival of the structure over this interval of fatigue crack growth. A number of factors combine to reduce the probability of failure from fatigue cracking: The region of lowest toughness, the grain coarsened HAZ, usually has the highest strength, and an advancing crack will tend to turn rapidly away into softer material, of higher toughness [3,8]. This phenomenon presents constant problems in the fatigue pre cracking of HAZ test pieces, particularly where cracks adjacent to the fusion boundary are required. The outer areas of the HAZ and the parent plate, which come into play as the crack grows, are of higher toughness and can provide the necessary increased defect tolerance, once this initial danger period is over. In many instances, e.g. fillet welds, the stress concentration factor associated with the fatigue crack initiation sites decays very rapidly, and this effect coupled with the probability of increasing crack tip toughness, can cause a progressive decrease in crack growth rate [4].

The crack tip fracture toughness, per se, may be reduced, resulting in a lower tolerable defect size. Crack growth can continue under lower stress ranges, making the situation of sessile non-critical cracks less likely. The relatively high strength of some parts of the HAZ, in comparison to the parent plate, and the presence of residual stresses from welding can sensitize the areas adjacent to welds to certain forms of environment cracking. In some cases, the resistance of the parent steel to more generalized types of cracking will be important. The consideration of these environmental effects, which are of prime interest at present in the oil and gas recovery and processing fields, are, however, outside the scope of this report, but may have some influence on attitudes towards the properties of welded joints under less severe conditions.

Steel and/or weld procedure selection may be constrained, for instance, by a maximum HAZ hardness criterion. Another important aspect which has reduced the effect of local embrittlement is the narrowness of the band of material worst affected, generally 1 mm or less. Unless the properties are at or, near the lower shelf of the transition behavior, or loading is extremely rapid, the plastic zone at the crack tip will be able to grow, under increased loading, to such an extent that tough material on either side becomes involved in the pre fracture process zone, giving increased crack tip toughness. Ductile crack growth, if it occurs and the mechanical constraints on crack propagation are not too severe, will tend to favor movement into softer and tougher HAZ regions. There is a close similarity to the situation referred to above for advancing fatigue cracks, in that once an initial danger period is past, the situation at the crack tip can improve markedly. This inability of most HAZ's to contain a critical event is the most likely reason for the absence of failure case histories citing the properties of sound HAZ's as a cause of failure, and has led to the recommendation in the UK that it is unnecessary to carry out HAZ testing, on the normal types of structural steels, where the weld energy lies between 1.5 kJ/mm and 4-4.5 kJ/mmt1-7)- There is, of course, great commercial interest in increasing productivity by using higher weld energies, but it becomes advisable then to assess the effect of HAZ degradation, since the increased HAZ width may allow the HAZ to assume a potentially more significant role in possible failure modes [16].

Heat affected zones in electro slag welds are an extreme case, being not only extremely wide, of the order of 5-8 mm, but having an extended region of very coarse austenitic grain size adjacent to the fusion boundary. The combination of low toughness and large width make the reliability of the HAZ for structural purposes very suspect. The weld metal, similarly, with a coarse as-cast structure, has very poor toughness, and it has been usual to normalize electro slag welds intended for service at ambient temperatures. The economic advantages of the process still motivate development work, directed towards improving the as-welded properties of electro slag welds, such as narrow gap welding to reduce heat input, improved alloyed weld metals, and the use of steels more tolerant of high heat inputs [5].

2.2 Influence of welding parameters on HAZ properties

In order to understand the developing microstructure in a weld metal it is important to consider the welding parameters applied. It has been well researched that the microstructure that develops in the weld joint is influenced by the chemical composition of the base metal, the filler metal, the flux and the actual cooling rate experienced by the weldment [1-3]. These factors includes the heat input, alloy chemistry and weld pool geometry all of which affect the actual cooling rate experienced by the weld joint and, consequently, its microstructure and mechanical properties.

2.2.1 Effect of heat input on HAZ

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because, like preheat and interpass temperature, it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ [1,3,4]. It is calculated from equation 1 below

$$H = \frac{60EI}{1000s} \quad \text{.......} \quad (1)$$

H = Heat input (kJ/inch or kJ/mm)

E = Arc voltage in Volts

I = Current (Amps)

S = Travel speed (inch/min or mm/min)

Starting from the universal differential Eq. (2), Analytical models of heat conduction in welding were derived that describe the effect of momentary and movable heat sources on individual models of solids being welded.

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \quad \text{.......} \quad (2)$$

α – coefficient of thermal diffusion m^2/s.

This is a second order homogenous partial linear differential equation of parabolic type that provides the connection between the temperature change rate of a given point and the temperature distribution in the environment of that point. If a workpiece is influenced by a heat source F(x,y,z,t) and simultaneously heat transfer from a metal object to its environment occurs, the heat conduction Eq. (2) will have the following form:

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{1}{\rho.c} \, . \, F(x,y,z,t) - b.t \quad \text{.......} \quad (3)$$

Whereas: c, λ, ρ − material’s physical properties; b − coefficient of temperature drop intensity due to heat transfer from the object into the environment, s^{-1}. The differential Eq. (2) resulted in solutions for cooling upon the action of a fixed momentary (impulse) heat source for common combinations of solid shape and the shape of fixed heat sources.

The effect of heat input on microstructure has been extensively investigated by researchers. For example, Kumar et al. [16] studied the influence of heat input on the microstructure and mechanical properties of gas tungsten arc welded 304 stainless steel (SS) joints. Three heat input combinations designated as low heat (2.563 kJ/ mm), medium heat (2.784 kJ/mm) and high heat (3.017 kJ/mm) were selected from the operating window of the gas tungsten arc welding process. The results of the investigation indicate that significant grain coarsening was observed in the heat affected zone (HAZ) of all the joints and it was found that the extent of grain coarsening in the heat affected zone increased with increase in the heat input. The average dendrite length and inter-dendritic spacing in the weld zone was found to increase with increase in the heat.

2.2.2 Effect of cooling rate on HAZ

The cooling rate of weldments depends on the heat input by the welding arc. Heat input is controlled by three variables, namely: current, voltage and travel speed. It is generally believed that travel speed affects heat input and heat input affects the cooling rate. With higher heat input the cooling rate is faster and vice versa. During welding, a large amount of heat is applied. Solidification of the weld pool takes place followed by cooling to room temperature. The heat applied is transferred during and after welding by conduction from the molten pool to the base metal and creates the heat affected zone. The cooling rate is a primary factor that determines the final metallurgical structure of the weld and HAZ. There are many models developed for understanding the concept of cooling rate in a welded joint. The results showed a significant cooling rate near the HAZ. It was found that the major influential property in connection with cooling rate, is heat loss. It is well established that microstructure and micro-hardness depend on the cooling rate. Increasing cooling rate generally will lower the austenite to ferrite transformation start temperatures [20]. The effect of cooling rate on residual ferrite content and composition was evaluated [15]. It showed that as the cooling rate increased, the amount of retained ferrite increased, the ferrite's chromium content decreased, and its nickel content increased.

The effect of cooling rate on the evolution microstructural product such as allotriomorphic ferrite and pearlite was studied [3]. The study concluded that lower cooling rates cause the development of other phases such as allotriomorphic ferrite or pearlite but a high volume fraction of acicular ferrite can be achieved using two stage continuous cooling cycles. The role of cooling rate in a welding process is critical in obtaining improved toughness, ductility and minimal residual stresses in the weld. It is also necessary to understand the stability of ferrite under multiple-pass welding conditions or during elevated-temperature applications by utilizing cooling rate information.

2.3 Manual metal arc welding

Welding is one of the most common fabrication techniques which is extensively used to obtained good quality weld joints for various structural components. Shielded metal arc welding is one of the world's most popular welding processes, accounting for over half of all welding in some countries. Because of its versatility and simplicity, it is particularly dominant in the maintenance and repair industry, and is heavily used in the construction of steel structures and in industrial fabrication. In recent years its use has declined as flux-cored arc welding has expanded in the construction industry and gas metal arc welding has become more popular in industrial environments [1].

Manual metal arc welding was first invented in Russia in 1888. Manual metal arc welding (MMAW) is also known as shielded metal arc welding (SMAW), flux shielded arc welding or informally as stick welding. The development of coated electrodes did not occur until the early 1900s when the Kjellberg process was invented in Sweden and the quasi-arc method was introduced in the UK [1]. It is worth noting that coated electrodes were slow to be adopted because of their high cost. However, it was inevitable that as the demand for sound welds grew, manual metal arc became synonymous with coated electrodes.

Manual metal arc welding is a process that melts and joins metals by heating them with an arc established between a sticklike covered electrode and the metals, as shown in Figure 2. It is often called stick welding. The electrode holder is connected through a welding cable to one terminal of the power source and the workpiece is connected through a second cable to the other terminal of the power source. The core of the covered electrode, the core wire, conducts the electric current to the arc and provides filler metal for the joint. For electrical contact, the top 1.5 cm of the core wire is bare and held by the electrode holder. The electrode holder is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely. The heat of the arc causes both the core wire and the flux covering at the electrode tip to melt off as droplets. The molten metal collects in the weld pool and solidifies into the weld metal. The lighter molten flux, on the other hand, floats on the pool surface and solidifies into a slag layer at the top of the weld metal. [1]

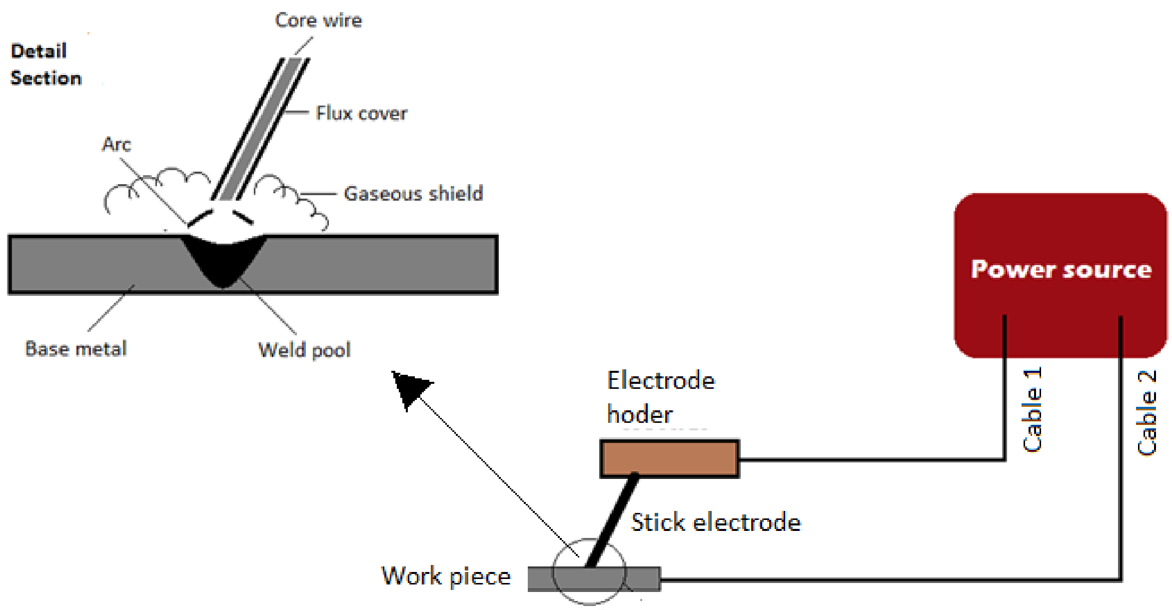


Figure 2: Schematic diagram of manual welding process

When an arc is struck between the metal rod (electrode) and the work piece, both the rod and work piece surface melt to form a weld pool. Simultaneous melting of the flux coating on the rod will form gas and slag which protects the weld pool from the surrounding atmosphere. The slag will solidify and cool and must be chipped off the weld bead once the weld run is complete (or before the next weld pass is deposited).

Welding has made significant impact on the large number of industry by raising their operational efficiency, productivity & service life the plant and relevant equipment. The present trend in the fabrication industries is to automate welding processes to obtained high production rate. Shielded (manual) metal Arc welding, which is heat-type welding, is one of the most important manufacturing operations for the joining of structural elements for a wide range of applications, including guide way for trains, ships, bridges, building structures, automobiles, and nuclear reactors, to name a few [4-5].

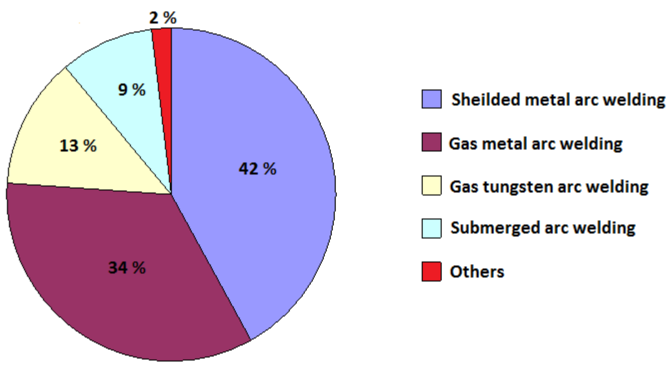


Figure 3: Range of application for different type of welding

MMAW requires a continuous supply of either direct or alternating electric current, which create an electric arc to generate enough heat to melt the metal and form a weld. The arc welding process is a remarkably complex operation involving extremely high temperatures, which produces severe distortions and high levels of residual stresses. These extreme phenomena tend to reduce the strength of a structure, which becomes vulnerable to fracture, buckling, corrosion and other type of failures. Hardness is very important mechanical property of material but during welding high heating and rapid cooling influence the hardness of the weld as well as the heat affected zone (HAZ).

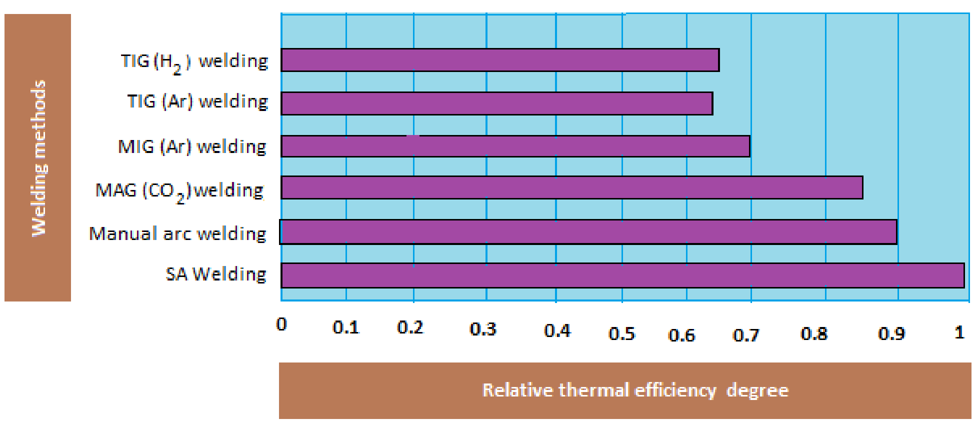


Figure 4: relative thermal efficiency of different welding types

2.3.1 Chemical aspect of manual metal arc welding

It is quite understandable that composition of base metal, electrode wire and flux impose profound effect on chemical properties of the welded joint, which in turn depends on microstructure of weld metals and heat affected zone (HAZ). A manual metal arc (MMA) electrode consists of a metal core rod and a clay-like covering and powdered minerals such as fluoride carbonate oxide, organic minerals and alloying additives [1]. 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 MMA welding. The major ones are the current, voltage, electrode diameter, melting temperature of the core material, coating thickness and temperature of the electrode. Literatures reported about higher penetration due to increase in Sio2 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 [5].

2.3.2 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 MMAW. Studied the characteristics of the weld bead penetration, melting rate under variable operating current conditions and found that those increase in current and also investigated that increase in welding voltage produced flatter and wider beads with increased flux composition 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. 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 [1, 5,7].

2.4 Mild carbon steels

The first recorded use of iron was the ancient Assyrians about 3700 B.C. This given them an advantage compares to other nation since it was in making weapons [11]. Low/mild carbon steel is steel that contain fine grain and it started being designed since years of 1960. Mild carbon steel can be classified when the carbon content is lower than 0.2 percent (American Society for Testing and Materials).

Low carbon steel is widely used in fabrication industry due to excellent to weight ration and one of the applications are in automobile industry [11,17] This material is suitable to use in automotive industry because it can absorb high impact force without cracking. This happen because it has low carbon which make it as ductile material compare to high carbon steel that more brittle and easy to crack although it have more strength. The used of low carbon steel is not limited just on creating the frame for bridge construction or building construction only but low carbon steel also is used a lot in making car chassis for automotive industry because of the high strength, brittle and easily to welding. This material also good in weight because it reduces the weight of material that being used which can help to reduce oil consumption at once decrease the gas emissions and improves crash safety . Now through studies and sophisticated technology will expand the application of low carbon steel in the used for bridge construction industry. Low carbon steel is used as a bridge frame. Low carbon steel also work as a link for bridge construction in many way purposely for strengthen the bridge frame structure to make sure it will not easily deflected or strain experienced because of high loading force. Other than that, it also will be welding between two part of low carbon steel is carried out to combine and usually strengthen the frame of bridge.

2.4.1 Properties of mild steel

Mild carbon steel is a steel that contain fine grain with ferrite phase structure. The mechanical properties for low carbon steel are better because of soft matric ferrite with good ductility. These become the factor to low carbon steel to have good mechanical properties which is from the high in yield and tensile strength and also high absorption force. Other than that, mechanical properties for low carbon steel is depends on others various factor such as ferrite mechanical properties which contains carbon and fine grain size. Final strength for ferrite structure is determined through the decrease of carbon content in the material. The reduction of carbon indirectly will increased the elongation of low carbon steel when there is a tensile load. This shows that a ductility property of the material is increased. The ductility of the low carbon steel is also being influence by the increment of fraction grain boundaries which will increase the number of dislocation sources which in turn would increase the frequency of the dislocation density and high strength carbon steel [1,11].

Low carbon steel will be able to absorb a high shock impact and this mechanical properties is really needed in construction industry to absorb any force that being given to the bridge frame to make sure the structure of bridge always in strong condition and did not collapse easily. Welding process that created on the low carbon steel material is a one of the factor that influence the change in mechanical properties because this process will control the material phase size, volume fraction and others phase formation in low carbon steel material. This is because, welding process will created heat which is being called heat affected zone (HAZ). The heated given on low carbon steel will come from welding process which change the ferrite phase to and austenite phase and back into ferrite phase. This will increase the strength of material but the ductility will decreased because of hardness material is increased. Next it will decreased the level of absorption shock that being given to the material.

Low carbon steel is produce for various applications such as in automotive industry and construction industry. Mechanical property for low carbon steel is greatly influenced by the phase structure of the material and others alloy elements that being added into low carbon steel. The content in low carbon steel influenced the ferrite phase structure in the material.

Chapter 3. Experimental Methods and Conditions

3.1 Materials

Chemical composition of materials used specifically test plate and welding electrode in the experiments are discussed in brief in this section. These materials and welding techniques were selected because of their availability and wide range of application in medium and small scale metal fabrication industries in Ethiopia and globally [17].

3.1.1 Test metal

Probably the most important factor relating to the weldability of steels is their chemical composition. The term weldability has no universally accepted meaning and the interpretation placed upon the term varies widely according to individual viewpoint. The American Welding Society defines weldability as the capacity of a metal to be welded under the fabrication conditions imposed, into a specific, suitably designed structure, and to perform satisfactorily in the intended service. The selected carbon steel plate has excellent weld ability and instantly welded by all the conventional welding processes, Good balance of toughness, strength and ductility. The material also has a wide range of application in fabrication industry.

The chemical composition, mechanical and physical properties of test piece is given in table 1 and 2 below respectively. Spectrometer test has been done to know the chemical composition of test piece and from the table comparing chemical composition the specimen is equivalent to carbon steel SAE 1003.

Table 1: chemical composition of test sample

Material	***Chemical composition***					
SAE 1003	***Carbon, C***	***Manganese, Mn***	***Iron, Fe***	***Phosphorus, K***	***Sulfur, S***	***Chromium, Cr***
	0.026	***0.27***	***99.4***	***0.023***	***0.004***	***0.015***

Table 2: Mechanical and physical properties of mild steel

Material	*Mechanical & physical properties*					
SAE 1003	***Tensile Strength, Ultimate***	***Tensile Strength, Yield***	***Elongation before fracture***	***Poisson's Ratio***	***Shear Modulus***	***Density***
	380 MPa	*205MPa*	*25.0 %*	*0.290*	*80.0 GPa*	*7.87 g/cc*

3.1.2 Electrode

Carbon steel welding electrode is suitable to work in all positions with excellent welding technological properties, stable arc, less splash and shaped good appearance, Due to this property AWS E6013 mild steel welding electrodes are selected.

Table 3: Electrode conditions

Electrode type	E 6013
Electrode diameter	3.2 mm
Electrode extension	20mm
Electrode feed rate	180mm/min
Work angle	30^{o} from vertical
Type of welding	Horizontal

3.2 Dimensions

Cut 100mm X 110mm pieces using shearing machine, do not use any thermal cutting devices to avoid interruption on test results due to heat generated in the cutting process. (12 pieces needed for one thickness).

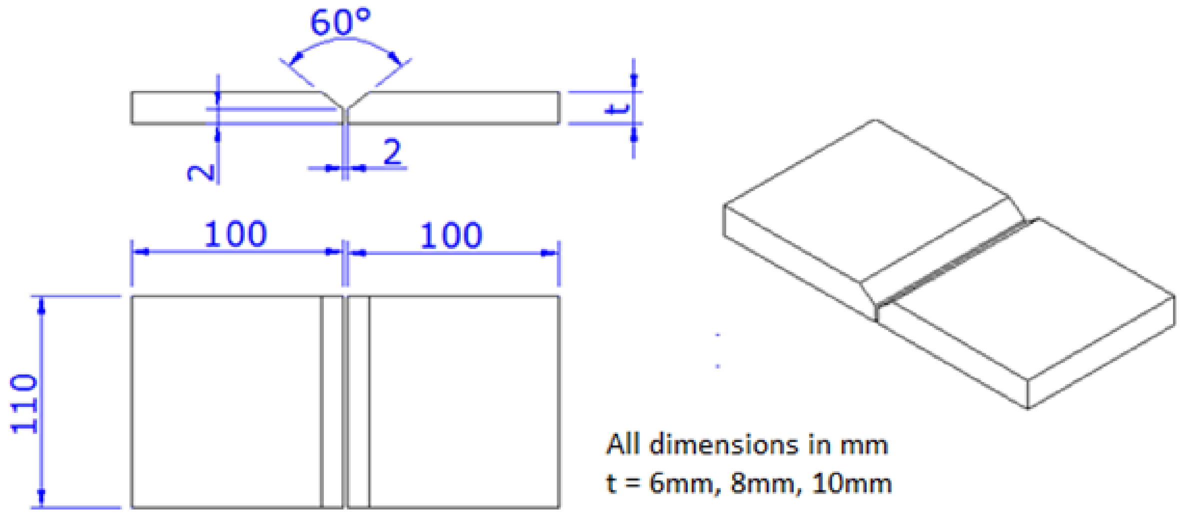


Figure 5: Sample dimensions

3.3 Conditions

3.3.1 Welding method

Manual Metal Arc Welding (MMAW) is selected as a welding process; this process involves striking an arc between a covered metal electrode and a work piece. Manual Metal Arc welding is the most flexible and one of the most widely used arc welding processes. Manual metal arc welding is one of the efficient and economical methods for joining of metals. For this specific work CEMONT Welding Machine having the following specification used.

Figure 6: Welding machine used for experiment

CEMONT YARD power sources are rectifiers for MMA coated electrode welding. They are well suited for both workshop and outdoor working conditions. Easy to use with adjustment using the shunt, they are for professional and intensive applications.

Table 4: Specification of welding machine

Input power	22.8 KVA – 13 KW
Maximum input current	57 A – 30 A
Input voltage	bi tension 230 V three phase 400 V
Effective input current	34 A – 19.5 A
Welding current range	50 A – 325 A
Connector size	13 mm

3.4 Experimental method

The systematically organization of this study is represented in flow chart in figure 7. To investigate the properties of heat affected zone it is important to come up with optimum welding conditions for experiment first. As a result three of the most influential welding parameters namely welding current, welding speed and arc voltage on quality of welding identified. Then investigation of welding parameter optimization for weld bead quality using manual arc welding technology is done. This customizes system to ensure the optimum welding current and travel speed of welding process of experiment sample. Manual arc welding is extensively used for making straight welds using the same welding machine and electrode used for making final experiment samples. The work pieces are then clamped in a steady position on the working bench. In this work, mild steel plate AISI 1003 and electrode AWS E6013 which is similar to be used to make the test samples chosen to optimize the welding parameter

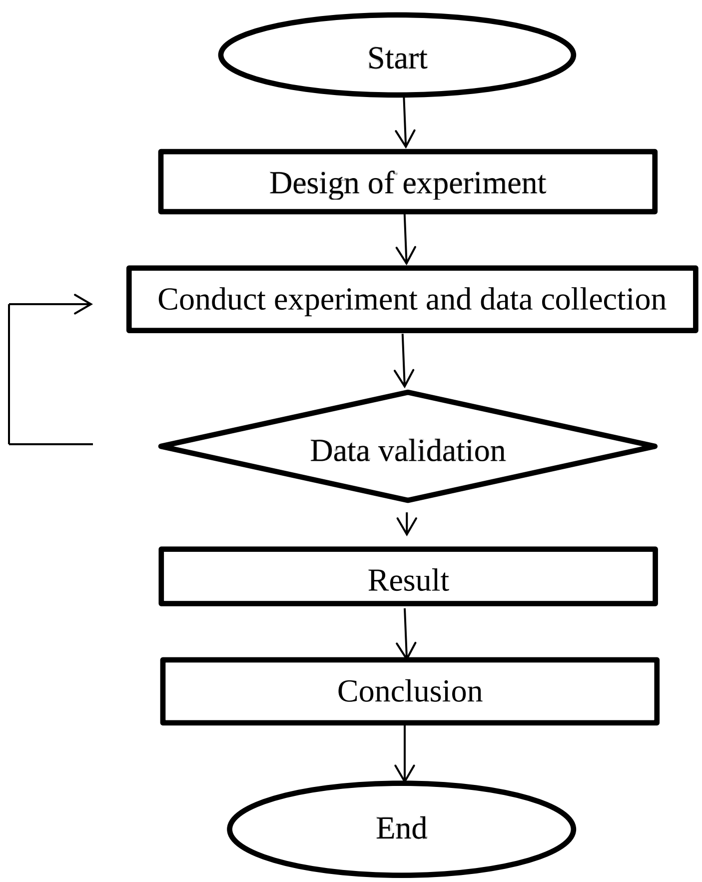


Figure 7: Methodology flow chart

3.5 Design of experiment

In this project, design of experiment considers multiple factor interaction effects. The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run) to come up with optimum welding condition before setting parameters for this specific work oh heat affected zone of weld. The response data from each run of the noise factors in the outer array are aligned in a row, next to the factors settings for that run of the control factors in the inner array. Taguchi Technique is applied to plan the experiments to decide optimum welding parameters for making experiment samples. The Taguchi method provide good improvement productivity during this work and development, so that high quality weld can be produced quickly and at low cost for experiment. The DOE using Taguchi approach can significantly reduce time required for experimental investigations. In this investigation, in the first stage, Taguchi's orthogonal arrays were used to conduct the experiments to find the optimum welding condition for selected material. Analysis using Taguchi design L9 (3**3) which represents,

- L9 9 RUNS
- 3 3 LEVELS
- 3 3FACTORS

The following are the 3 Levels which are considered in Taguchi design

- High
- Medium
- Low

The combination Design of Experiments with optimization of welding control parameters to obtain best results can be achieved in the Taguchi Method and table 5 below shows the selected welding parameters and their level.

Table 5: Electrode conditions

Welding parameter	Level 1	Level 2	Level 3
Welding current (A)	200	240	280
Welding speed (mm/min)	80	90	100
Arc voltage (V)	22	25	28

To optimize welding parameters for this experiment nine set of specimen of welded AISI 1003 samples with different set of combination of parameter had been carried out.

Table 6: Taguchi design L9 (3**3) for input value parameter setting of weld bead

Sample of weld bead	Welding current (A)	Welding speed (mm/min)	Arc voltage (V)
A	200	80	22
B	200	90	25
C	200	100	28
D	240	80	25
E	240	90	28
F	240	100	22
G	280	80	28
H	280	90	22
I	280	100	25

The welds are inspected visually for penetration and hardness of the weld bead measured using Vicker's hardness. Welds with better penetration and welded bead surface that showed highest reading of HV value was the most preferable criteria.

Optimization of control parameters to obtain best results for surface roughness and highest value of hardness is achieved by using the Taguchi Method.

In Taguchi method, there are 3 Signal-to-Noise ratios of common interest for optimization. There are 3 Signal-to-Noise ratios of common interest for optimization

i. Smaller-The-Better:

   n = -10 Log10 [mean of sum of squares of measured data]

ii. Larger-The-Better:

   n = -10 Log10 [mean of sum squares of reciprocal of measured data]

iii. Nominal-The-Best:

$$n = 10 \text{ Log10} \frac{square\ of\ mean}{Variance}$$

From the optimization experiment 200A, 80mm/min, and 25V found to be optimal Welding current, welding speed and arc voltage values respectively for 6mm thick plate. . 240A, 80mm/min, and 25V found to be optimal Welding current, welding speed and arc voltage values respectively for 8mm thick plate. 280A, 100mm/min, and 25V found to be optimal welding current, welding speed and arc voltage values respectively for 10mm thick plate. Optimum welding currents are 200A, 240A and 280A while optimum welding speeds are 80mm/min and 100mm/min In this work welding parameters to be considered to study mechanical properties and microstructure of heat affected zone are,

- Current and
- Welding speed

Welding voltage kept constant at optimum. The tested welding current value set combining optimum currents set by different thickness to see its effect when this parameter is at optimum or below and above the optimum values by varying the current values..

Table 7: Selected welding current for the experiment

Welding Parameters	**Current values for experiment (A)**		
Current	**200**	**240**	**280**

Welding speed is the linear rate at which an arc is moved along the weld joint. With any combination of welding voltage and welding current, the effect of changing the welding speed confirms to a general pattern. Weld penetration is affected more by welding speed than any variable other than current. Controlling welding speed is one of the challenges provided manual arc welding technique As a result the welding is done with accuracy of +/- 3 seconds to weld the pieces. The tested welding speed set by optimization experiment, while voltage kept constant at optimum value.

Table 8: Selected welding speed for the experiment

Welding Parameters	**Welding speed values for experiment (mm/min)**	
Welding speed	**80**	**100**

3.6 Sample preparation

Appropriate sample design and preparation is crucial to come up with valid results. The following figure shows the general procedure followed for sample preparation and details are discussed under section 3.6.2

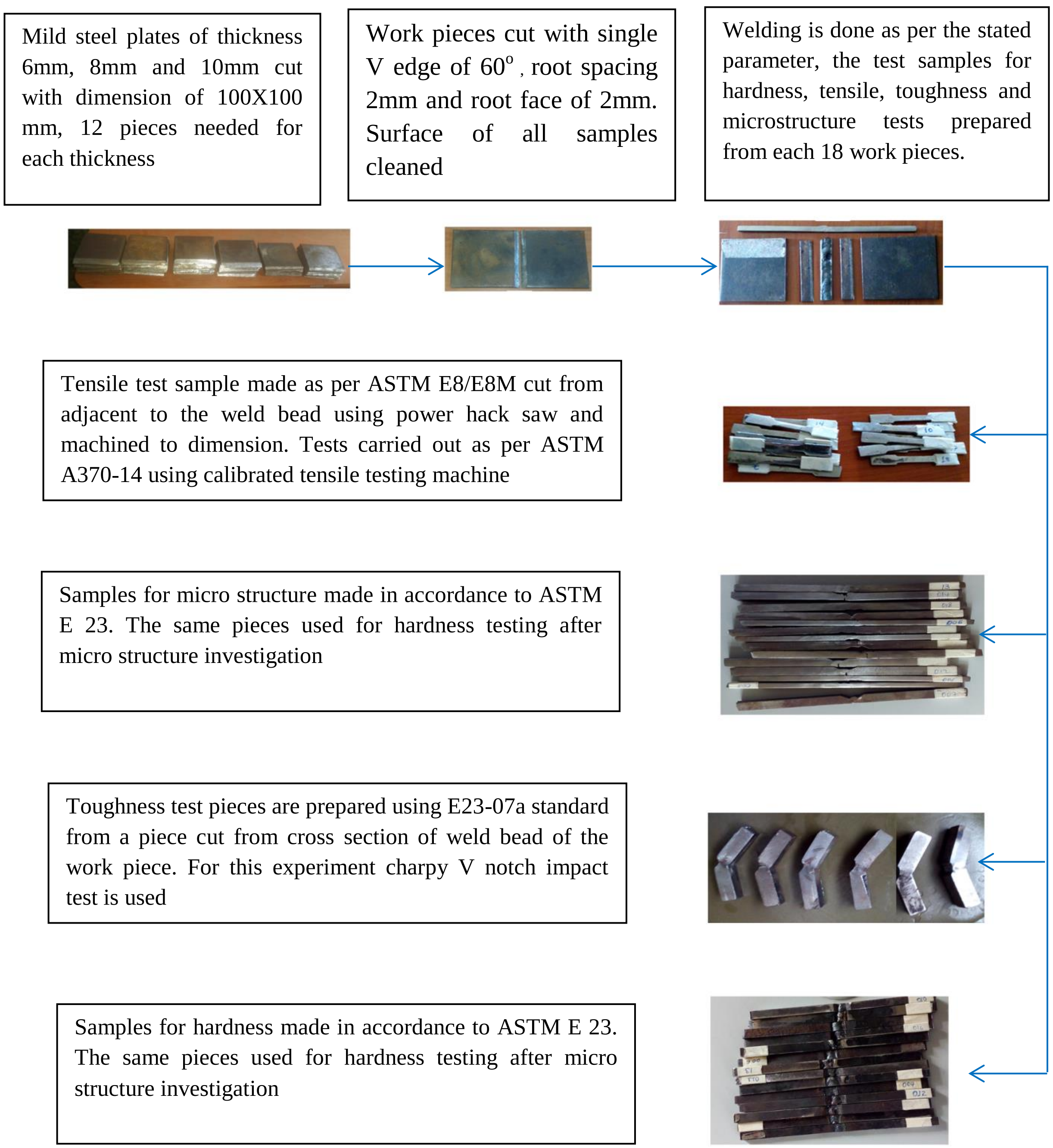


Figure 8: Process flow chart for test piece preparation

3.6.1 Welding work piece

3.6.1.2 Pre weld surface cleaning

The surfaces of edges of the work pieces are suitably prepared by removing surface contaminations like dirt, metal particles, oil grease, paint and moisture with wire brush and alkaline cleaner.

3.6.1.3 Edge preparation

Edge preparation and type of joint before the welding at the mating edges improves joint strength. So, in this work the type of joint selected is single V with broad root spacing as per ISO 9692 joint preparation recommendations. Thus the work piece cut with groove angle of 60^{o}, root spacing of 2mm and root face of 2mm. Surfaces of the all samples were cleaned mechanically and finished for a single V-edge of 6o degree as shown in Figure 9 below.

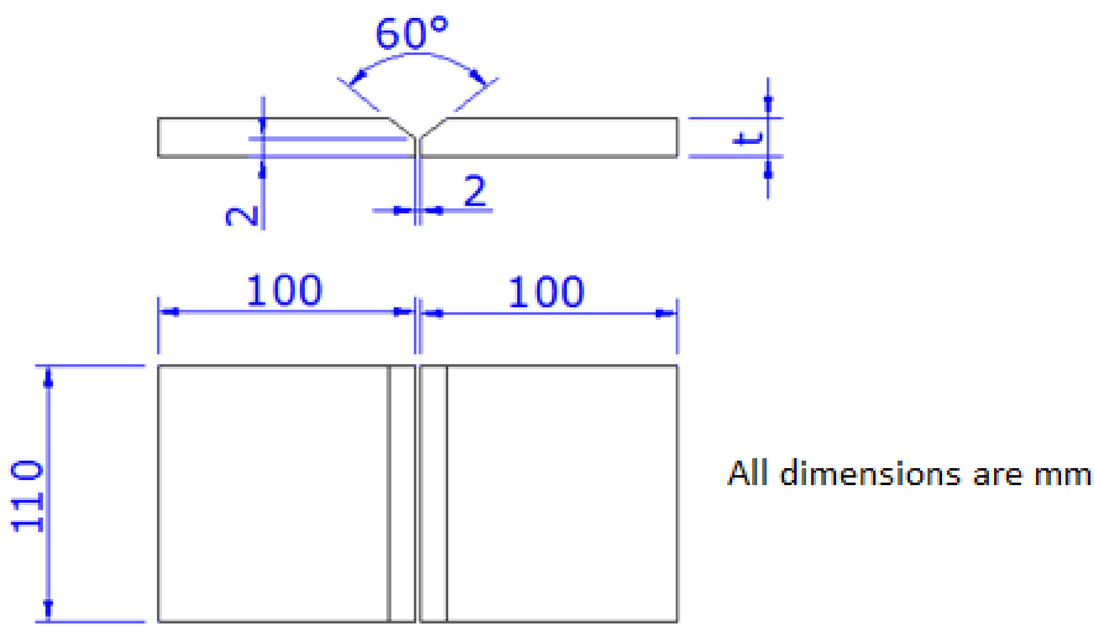


Figure 9: Edge Preparations

3.6.1.4 Welding samples

Once the edge preparation for all workpieces is done then the work pieces are welded using manual metal arc welding using welding parameters explained in section above. Test pieces thickness and welding parameters are shown in the tables below. The 36 work pieces prepared are welded in to 18 test pieces using the following welding parameters and thickness. Certificates of the welder are annexed.

Table 9: 6mm thickness specimen with different weld parameters

Sample No.	Thickness	Welding current (A)	Welding speed (mm/min)
1	6 mm	200	80
2			100
3		240	80
4			100
5		280	80
6			100

Table 10: 8mm thickness specimen with different weld parameters

Sample No.	Thickness	Welding current (A)	Welding speed (mm/min)
1	8 mm	200	80
2			100
3		240	80
4			100
5		280	80
6			100

Table 11: 10mm thickness specimen with different weld parameters

Sample No.	Thickness	Welding current (A)	Welding speed (mm/min)
1	10 mm	200	80
2			100
3		240	80
4			100
5		280	80
6			100

3.6.2 Preparing samples and conducting tests

Once the welding process is done each workpieces cut in to test samples using power hack saw with application sufficient coolant to avoid unnecessary heat generated from cutting process as shown in the figure below. Then there will be test pieces for hardness testing, micro structure testing, tensile testing and impact/compression testing. The preparation process of each test piece and test procedures are discussed below.

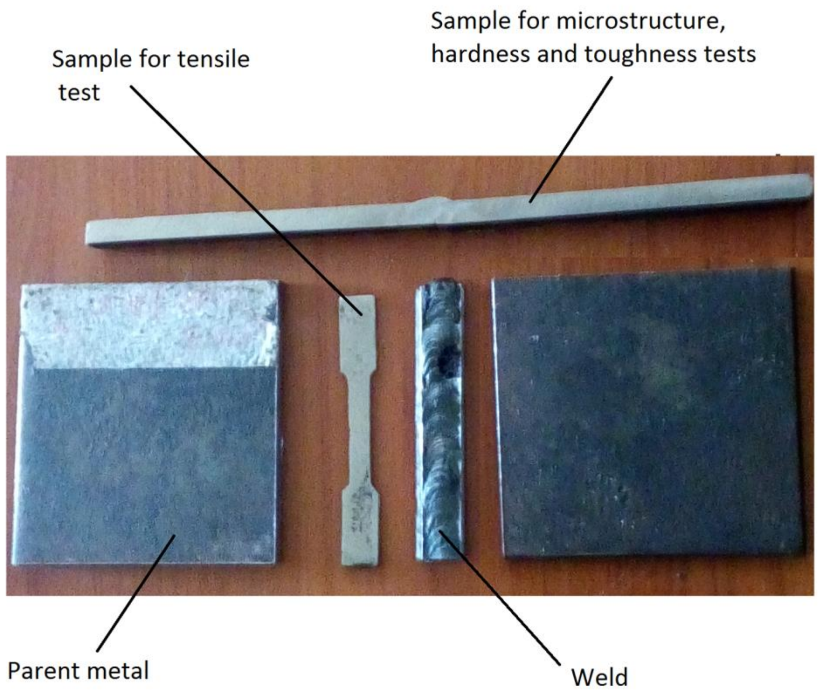


Figure 10: Test pieces preparation

3.6.2.1 Hardness testing

Hardness is the ability of materials to resists penetration, abrasion, scratching or cutting. It is the property by which material resists permanent deformation. Various hardness tests are available such as Rockwell Hardness Test, Vickers Hardness Test, Brinell Hardness Test, Knoop Hardness Test, Scleroscope Test and Durometer Test. Hardness testing of this specimen was performed in accordance to ASTM A370-14 standard using Vickers Hardness Testing Machine. The sample specimen was placed with the surface on the anvil, and slowly turning the hand wheel until the specimen was raised to touch the indenter.

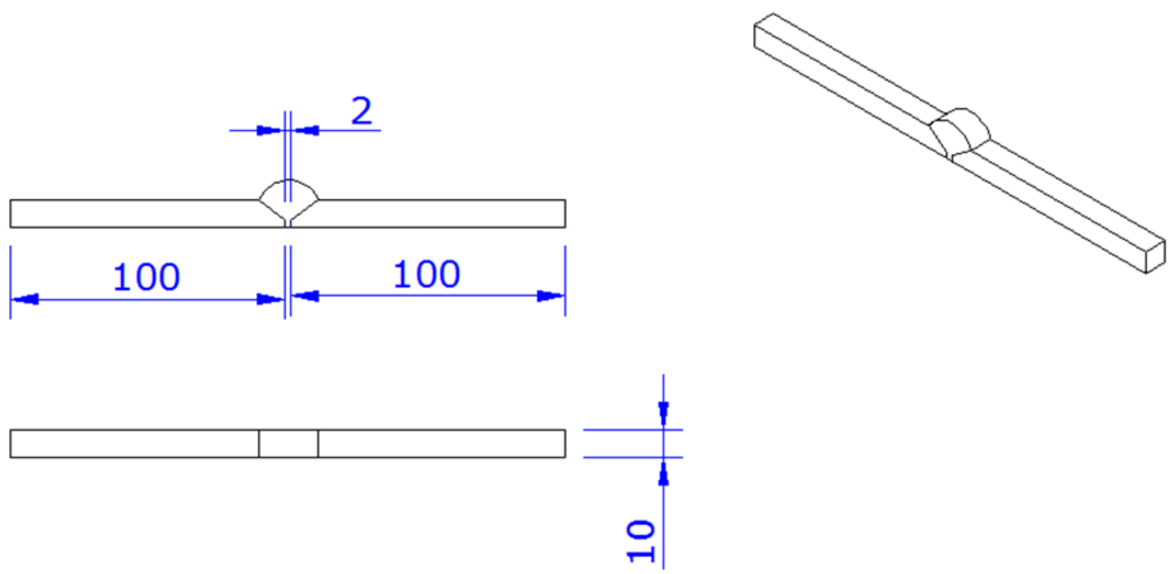


Figure 11: test piece for hardness

Because the weld bead was not flush with the rest of the material, the surface to be tested for hardness was grinded down so that it would fit flat on the base area of the testing machine. The relatively small impression made by a Vickers indenter requires that the surface be flat and perpendicular to the indenter and the surface have a fine surface finish. Vickers hardness measurements made on a metallographically prepared surface. The surface of the specimen should be prepared in such a way that the ends of the indentation diagonals are clearly defined. Care has been taken in preparing the surface so that tempering during grinding or work-hardening during polishing is avoided and used surface grinder with adequate coolant.

From the hardness test there are two major parameters to be tested. Analyzing the change in hardness in the weld heat affected zone and sizing the width of heat affected zone following changes in hardness value as we move from the weld bead to parent metal.

Figure 12: Vicker's hardness testing machine used for hardness test

The reference manual for the hardness testing machine recommends using a load time of 10-15 seconds while the loading speed remains around 70 micrometers per second. The same loading time and speed was used for every test done on this machine to minimize the variability of each test and to compare hardness tests with each other. The indenter on the Vickers Hardness machine is a diamond in the form of a square-based pyramid.

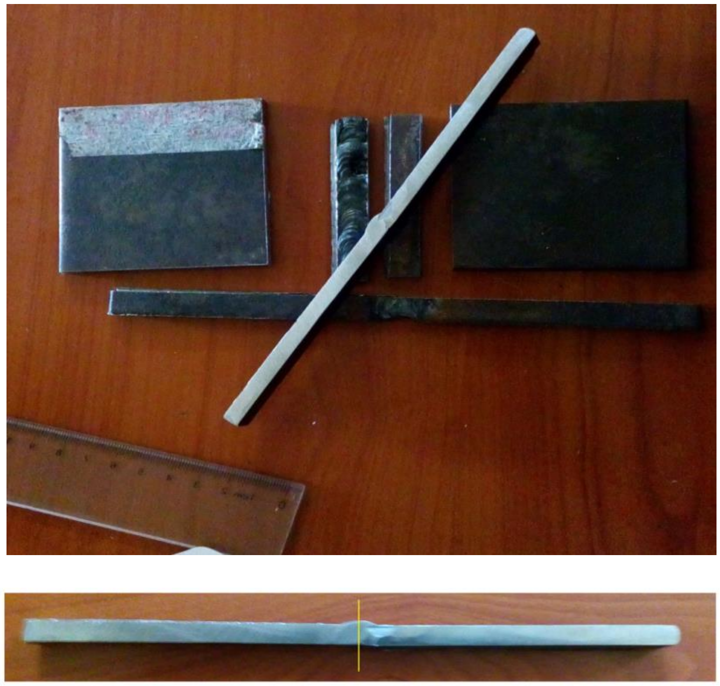


Figure 13: test piece for hardness testing

3.6.2.2 Tensile testing

Tensile strength is the maximum stress that a material can sustain in tension. In other words we can say the amount of applied load per cross sectional area that a material can withstand before failure. Mathematically it is calculated as the ratio of maximum tensile load to the original cross section area. One of the most common ways to test a material's strength is by using tensile testing. Tensile tests measure the stress over the strain of a material under uni-axial loading conditions. Because testing is done under one stress state (only one direction), it can be concluded from the test that the strengths in this tests are the maximum a specimen at a certain thickness and temperature can withstand. Tensile test was conducted on sub size the sample made as per ASTM E8/E8M cut from Adjacent to the weld bead using a hydraulic extensometer with prepared machined specimen dimensioned 100 × 10 × 2 mm. Tensile samples were prepared by milling of the top and bottom surfaces to remove flashing and other surface irregularities. The standard shape is obtained using milling machine as shown in the figure 15 and 16 below.

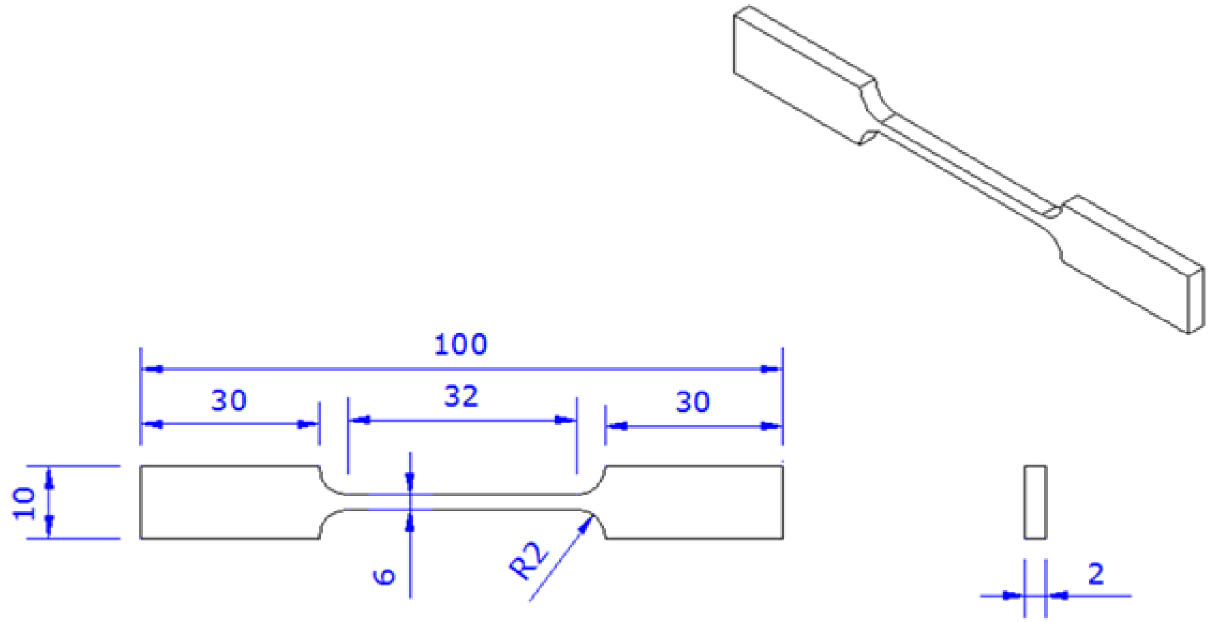


Figure 14: Tensile testing piece

The ultimate tensile strength of the machined specimens measured on a calibrated **Controlab** testing machine. Tensile test was carried out according to ASTM A370-14 standard, which is the "Destructive tests on welds in metallic materials-Transverse tensile test".

Figure 15: test piece for tensile testing

During uni-axial tensile testing, the upper head or grip moves upward hydraulic force, while the lower head or grip stays stationary.

Figure 16: Tensile testing machine

For tensile testing, it is considered a “static” test, meaning the force is to be applied slowly. Applying the load too fast may result in skewed results, therefore a slow speed is chosen to best represent static loading. Once all the parameters have been specified, the test begins to run and the lower head begins to drop at a constant rate. The force required to keep the head continuing upward at the constant speed is recorded as a function of displacement. After the specimen breaks, the test is stopped and the digital screen displays the load in KN and elongation in mm.

Figure 17: Tensile test pieces after destructive testing

3.6.2.3 Impact/toughness testing

Fracture toughness is one of the most important mechanical properties of the HAZ since it represents the crack resistance of HAZ in industrial application for a given welding procedure. It remains the key to the structural integrity of major steel structure. Toughness is the capacity of a material to absorb energy by deforming plastically before fracture. It is determined by combined strength and ductility of material and usually is measured by the amount of work absorbed during the propagation of crack through a structural member or a standard specimen. Consideration of toughness during design of a part will permit selection of materials with low probability of failure by fracture.

For this experiment charpy V notch impact test is used. The positioning of the notch for all CVN test specimens done by first machining the specimens from the test weld at the appropriate depth as shown in Figure 19. The specimens should be made slightly over length to allow for exact positioning of the notch. Next, the bars etched with a mild etchant such as 5% nital, to reveal the location of the weld fusion zone and HAZs. The longitudinal centerline of the specimens shall be transverse to the weld axis and the base notch shall be perpendicular (normal) to the surface. The centerline of the notch shall then be located in the HAZ of sample at a distance of 2mm from the fusion line. All the test samples are prepared using ASTM E23 and AWS D1.1/D1.1M standards from a piece cut across section of weld and HAZ region of the work piece. The prepared sample placed on the machine and the Pendulum was set to predetermined level and released to strike and fracture the positioned specimen. The value of energy Impacted recorded.

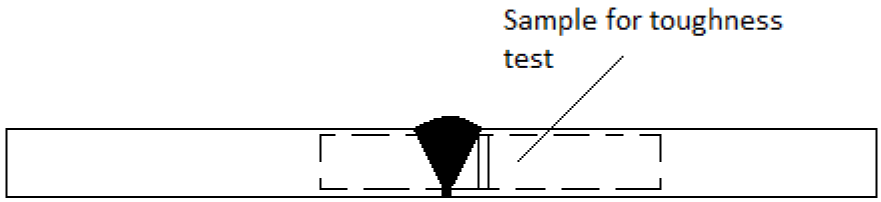


Figure 18: Location of sample for toughness

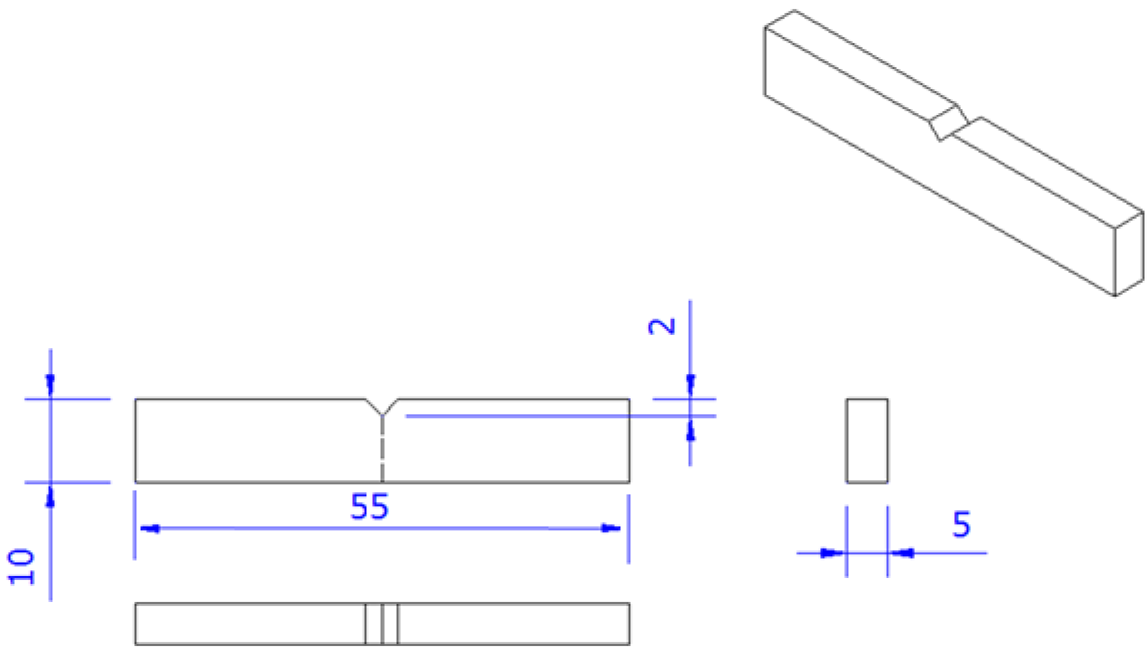


Figure 19: Sample preparation for toughness test

The difference in potential energy from before the hammer strikes the specimen to after it strikes is the amount of energy that the material can withstand before it fails. Because the hammer swings from a bearing, simulating that of a pendulum, there are friction forces that are involved that contribute to the energy loss before and after striking the specimen.

Figure 20: Toughness test pieces after impact test

The machine used in this experiment accounts for those losses and displays the amount of energy that was expended in breaking the sample. The machine that was used in this research project was ENKAY pendulum Impact Machine, Model EKEMAT20 and serial no. 2011/41

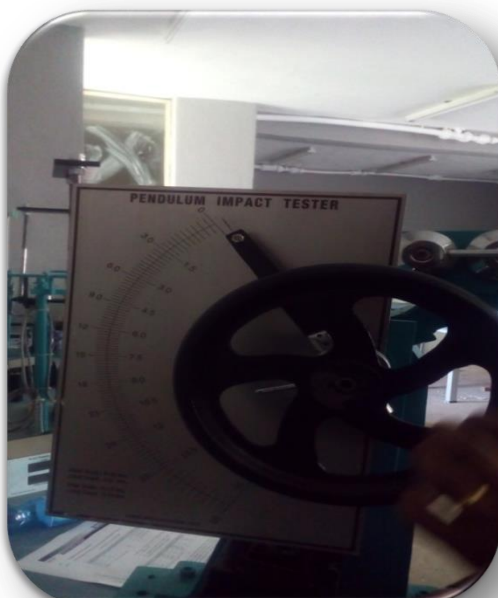


Figure 21: pendulum impact testing machine

3.6.2.4 Metallographic Testing

Metallographic samples were produced from welds in accordance to ASTM E 23. Grinding, Polishing, etching and metallographic examination of butt and groove welds, HAZ and parent metal were performed using Olympus optical microscope with magnification ×100 at scale of

10µm. Metallographic specimen preparation was started with sectioning operation. In order to get a representative specimen from the bulk welded specimens, a convenient size which includes the weld metal, HAZ region and base metal is removed by using a power hack saw. There are several process needed to be done before the microstructure can be analyzed which is sectioning, grinding and polishing and etching. At the end, free of scratches, a bright mirror like polished surface was obtained. Finally the samples were ready to be viewed. Images being scanned on a digital imaging system be taken by using an attached camera. Mounting operation was not performed since the cut specimens were large enough for handling during preparation and examination. However, sharp edges and corners were eliminated to increase safety and to avoid damage to the papers and cloths used in preparation.

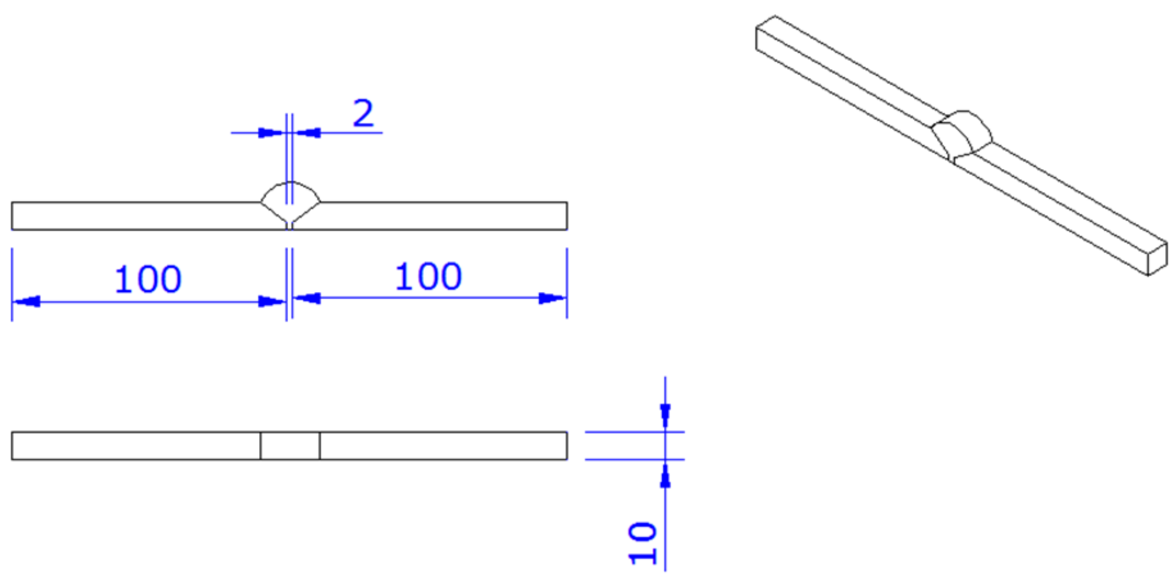


Figure 22: Sample for microstructure test

Figure 23: specimens for different tests

4. Results and Discussion

4.1 Mechanical properties

4.1.1 Hardness

Figures below shows the hardness profile across the HAZ of the 18 test pieces. From the figures, as we go through the section from the weld center a higher hardness value reaching 271 HV compare to HAZ which has an average value of 197.5 HV as well as the parent metal with an average value of 173 HV, the variation in the stress across the weld may be attributed to several factors such as residual stresses developed just after welding. Average heat affected zone hardness values are 209.5 HV, 209HV and 194.4 HV, for thicknesses 6mm, 8mm and 100mm respectively. From the experiment in general HAZ hardness is higher than parent metal hardness by 16.5 %.

In some of test pieces One of the factors contributing to lower hardness in the HAZ zone is high heat input below it melting point and hence retention of heat in this region. This phenomenon is observed in test pieces with small thickness and high input. The lower hardness in the HAZ might be explained by the intense grain growth in this region resulting from high heat input below it melting point.

Although there are different parameters that affect hardness such as microstructure and phase composition, it is usually expected that the maxima in hardness should correspond to the maxima of compressive residual stress, since the hardness of the material is also a measure of dislocation density. Therefore the observed hardness profile in the present weld samples does show a direct correlation with the residual stress.

As we can see from the graph between distance from the weld center and hardness there is nearly constant variation of hardness but there is sudden increase in hardness on the parent metal next to weld metal. This is because there is a thermal gradient between welding heat and atmospheric temperature due to this sudden cooling by air there is formation of martensitic structure in HAZ causing increase in hardness [3]

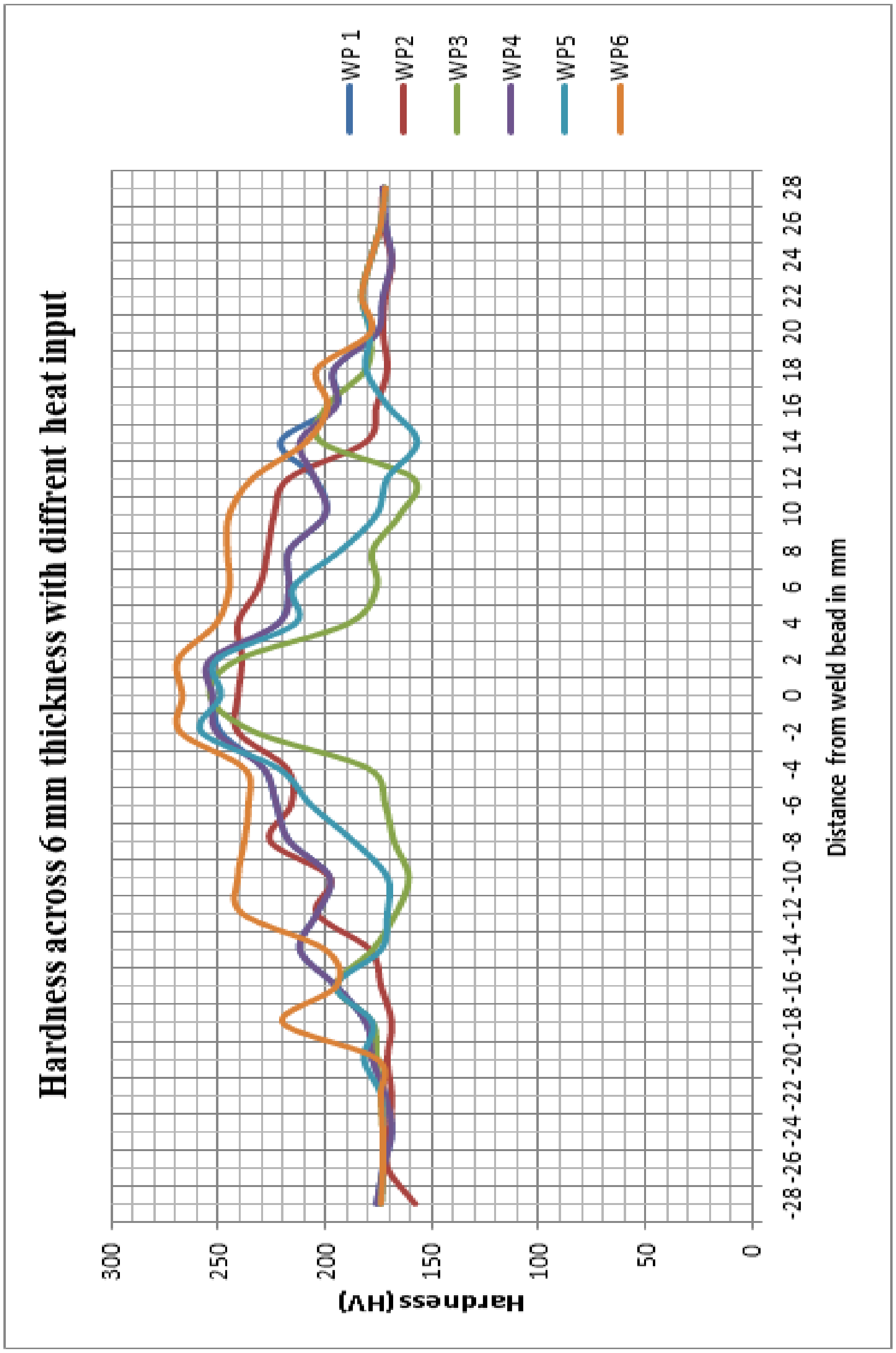


Figure 24: hardness graph for 6 mm thick samples

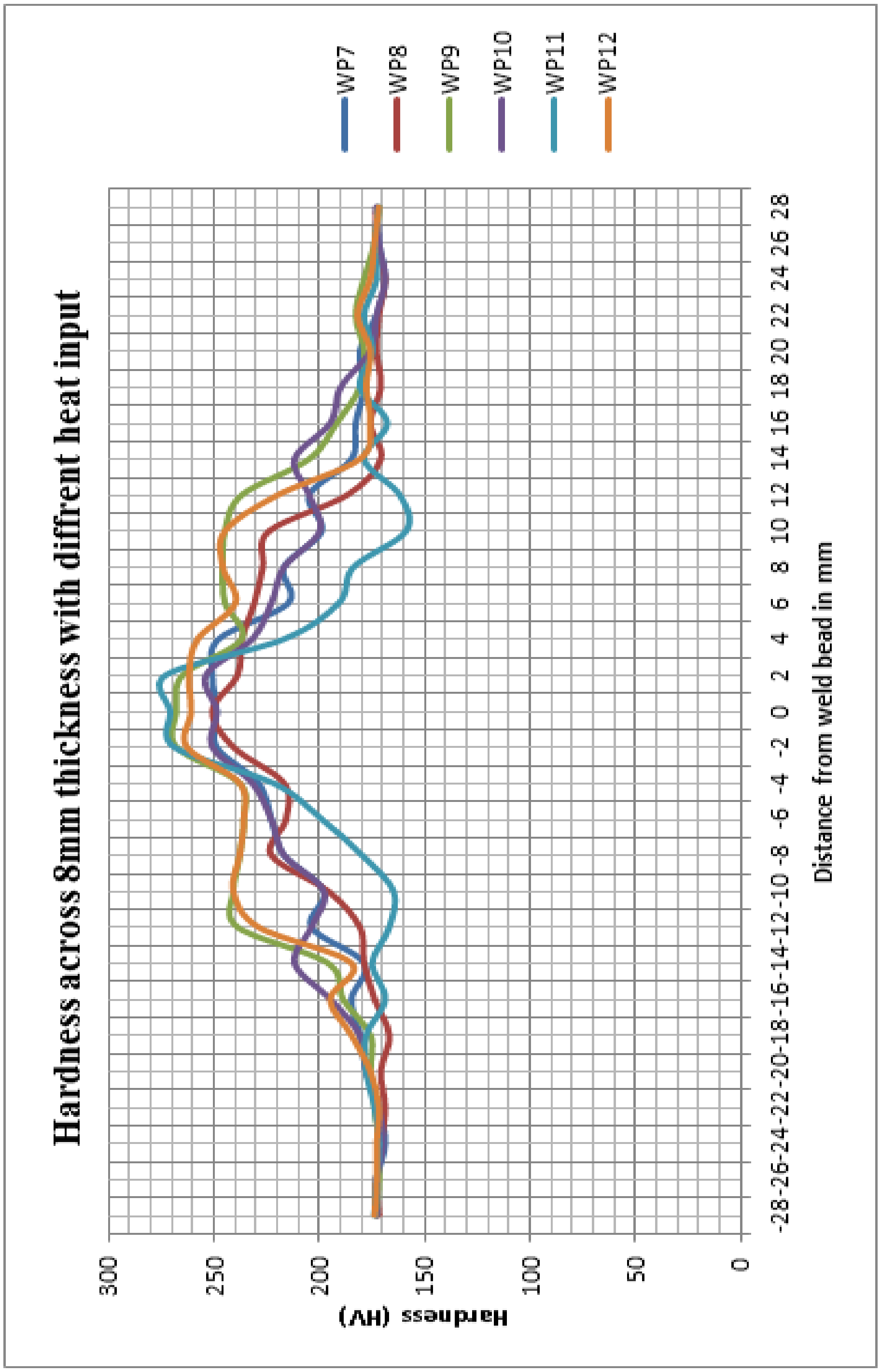


Figure 25: hardness graph for 8mm samples

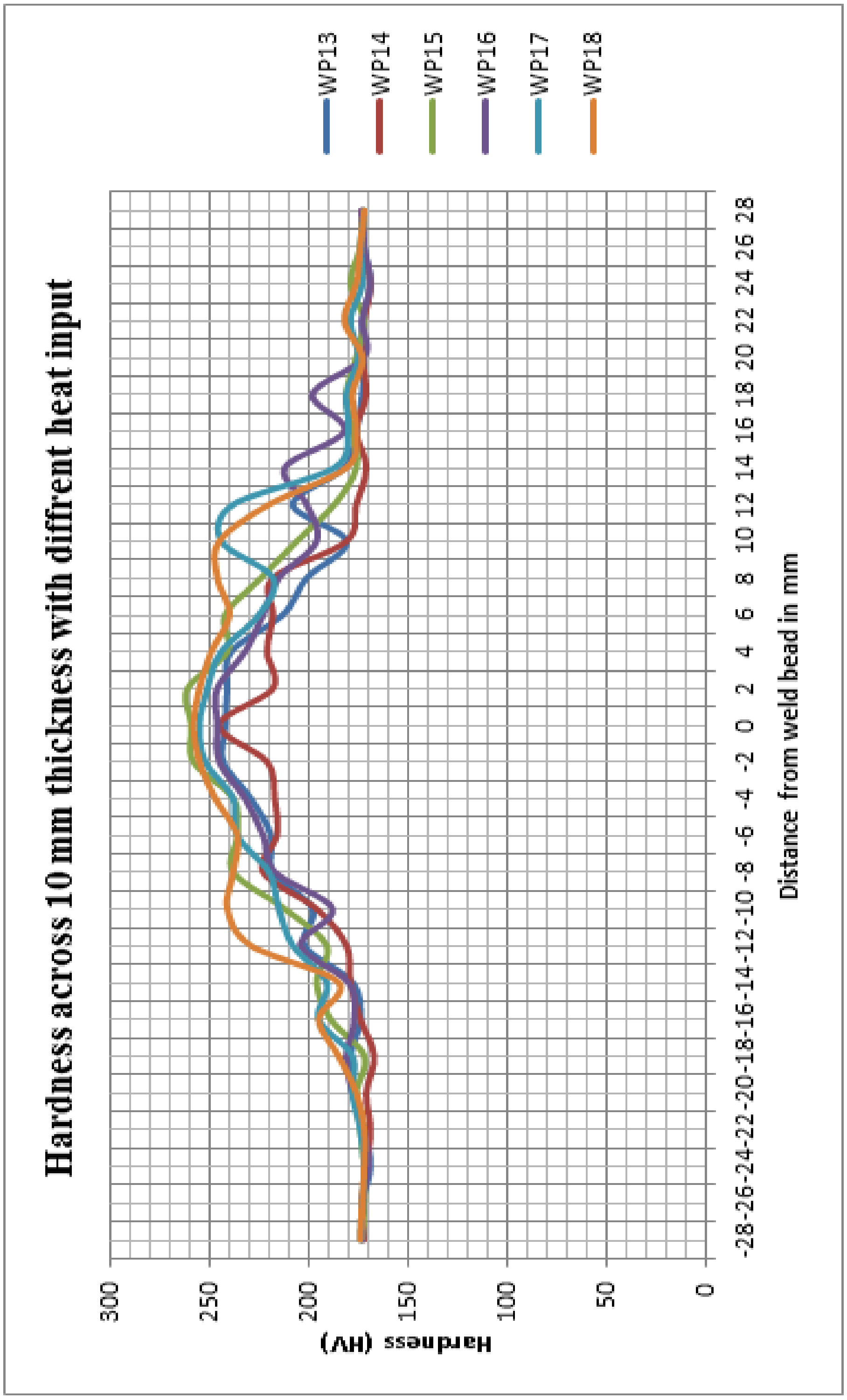


Figure 26: Hardness graph for 10 mm thick samples

4.1.1.1 Effect of heat input (current and welding speed) on hardness of HAZ

Heat input is found to be the most significant factor for controlling hardness and width of Heat affected zone (HAZ). Heat input is a factor welding current and speed. The effect of heat input on hardness of HAZ has been investigated by this work. The results of the investigation indicate that significant increase in hardness with increase in heat input. Increase in welding speed which means decrease in heat input resulted in decrease in value of hardness of HAZ. As a result, proper control on welding speed is become the important parameter for controlling the HAZ hardness.

From graphs below with increase in heat input which is increase in current and decrease in heat input the hardness of heat affected zone increased (heat input calculated using equation 1).

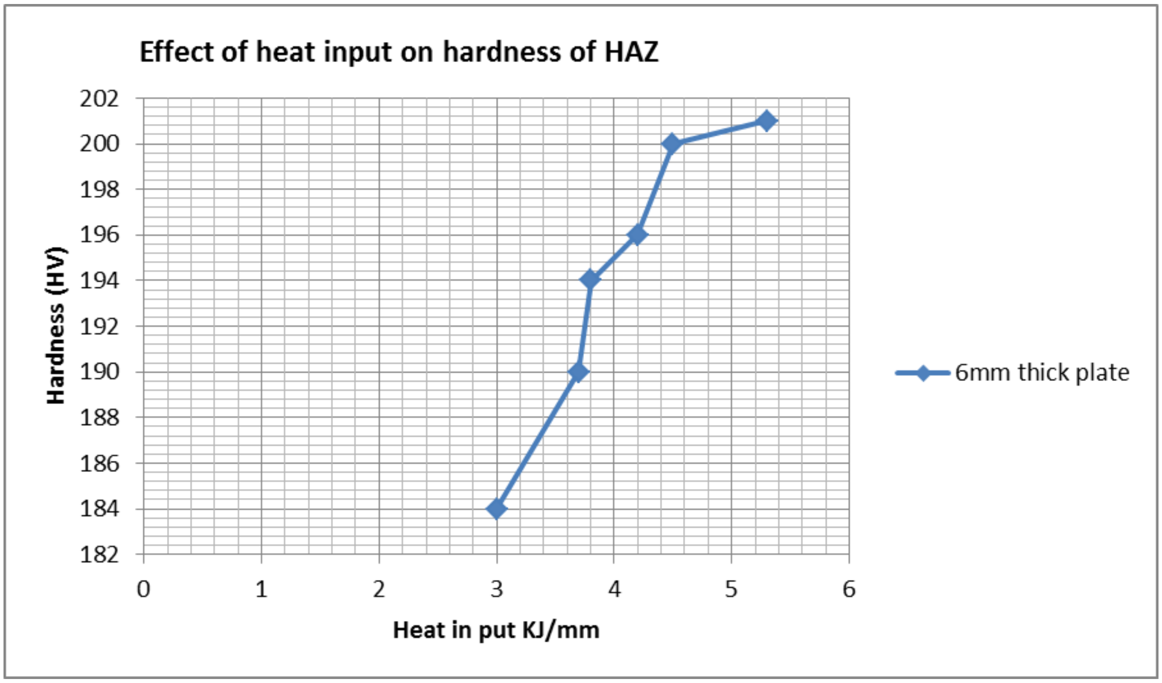


Figure 27: Heat input Vs Hardness 6mm thick plate

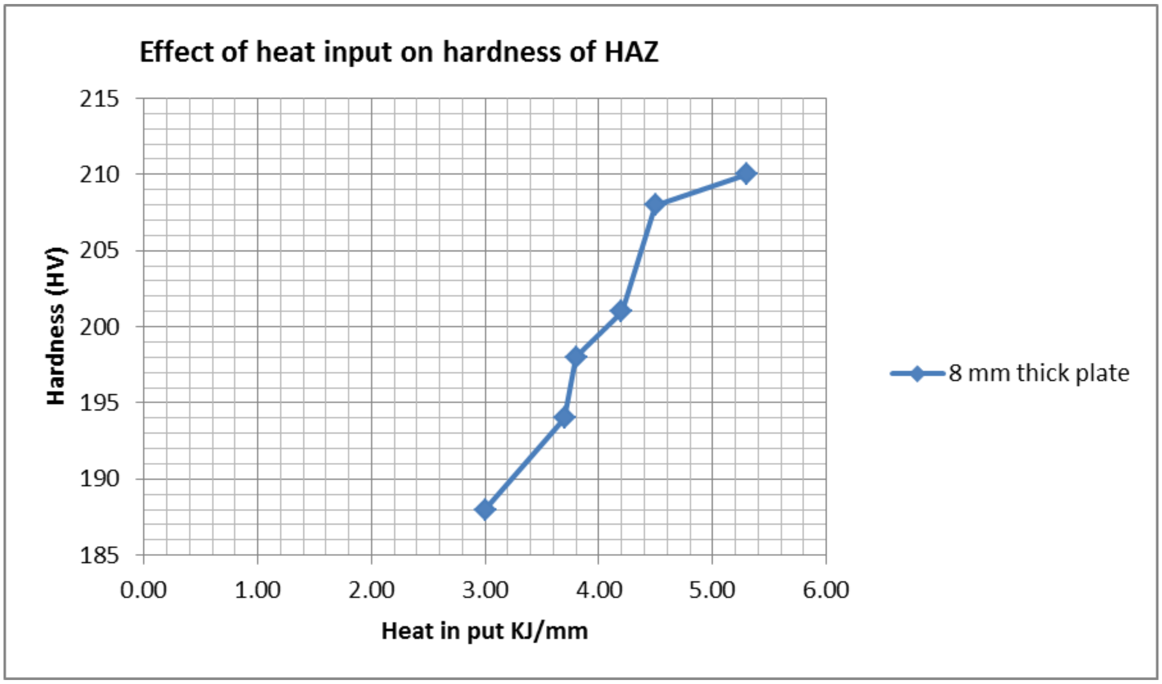


Figure 28: Heat input Vs Hardness 8mm thick plate

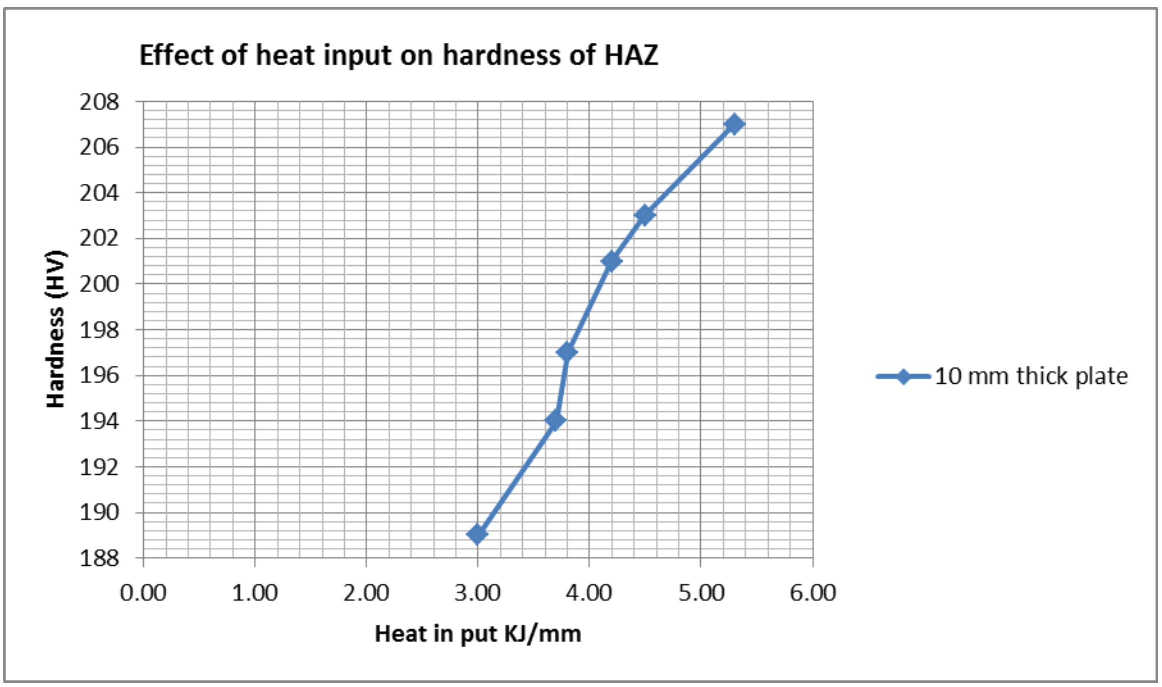


Figure 29: Heat input Vs Hardness 10mm thick plate

The speed of movement of the welding arc determines the welding speed. Broadly it may be defined as the rate of travel of the electrode along the seam or the rate of the travel of the work under the electrode along the seam. Hence it can be concluded that at constant arc voltage and welding current the hardness will increase with decreasing welding speed and is found to be maximum at optimum value after which hardness starts increasing with decrease in welding speed. When we compare the effect of welding speed and current on hardness, the effect of current is more significant than the effect due to welding speed.

4.1.1.3 Effect of material thickness on hardness of HAZ

The results of the investigation indicate insignificant change in hardness across different thickness for similar heat input values. Smaller thicknesses have quite bigger hardness values than thicker plates.

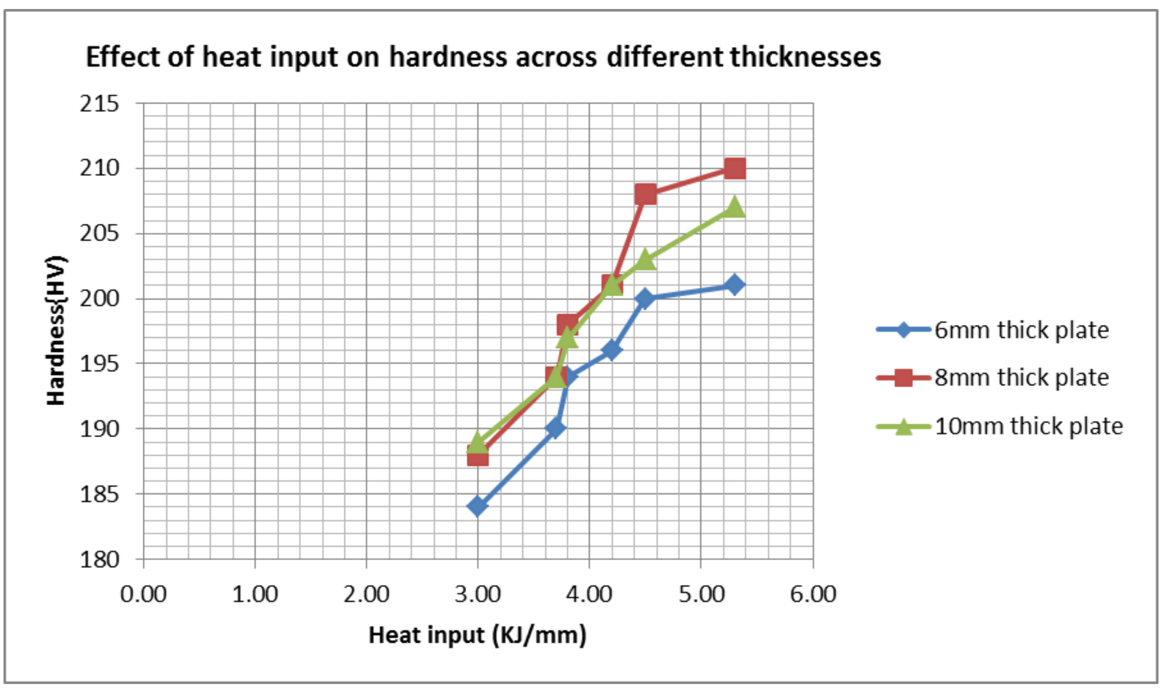


Figure 30: Heat input Vs Hardness of the three thickness

4.1.2 Tensile Strength

The effects of heat input (current and welding speed) on ultimate tensile strength of the weld heat affected zone are shown in figures below. A significant decrease in ultimate tensile strength value was recorded as the heat input increased which means current increased and welding speed decreased or kept constant. Heat affected zone tensile strength is lower than that of the parent metal by 18.5 %. The decrease in strength may be associated with the presence of void and other defects occurring as a result of increasing current. Excessive grain growth could also lead to the decrease in the tensile properties [1].

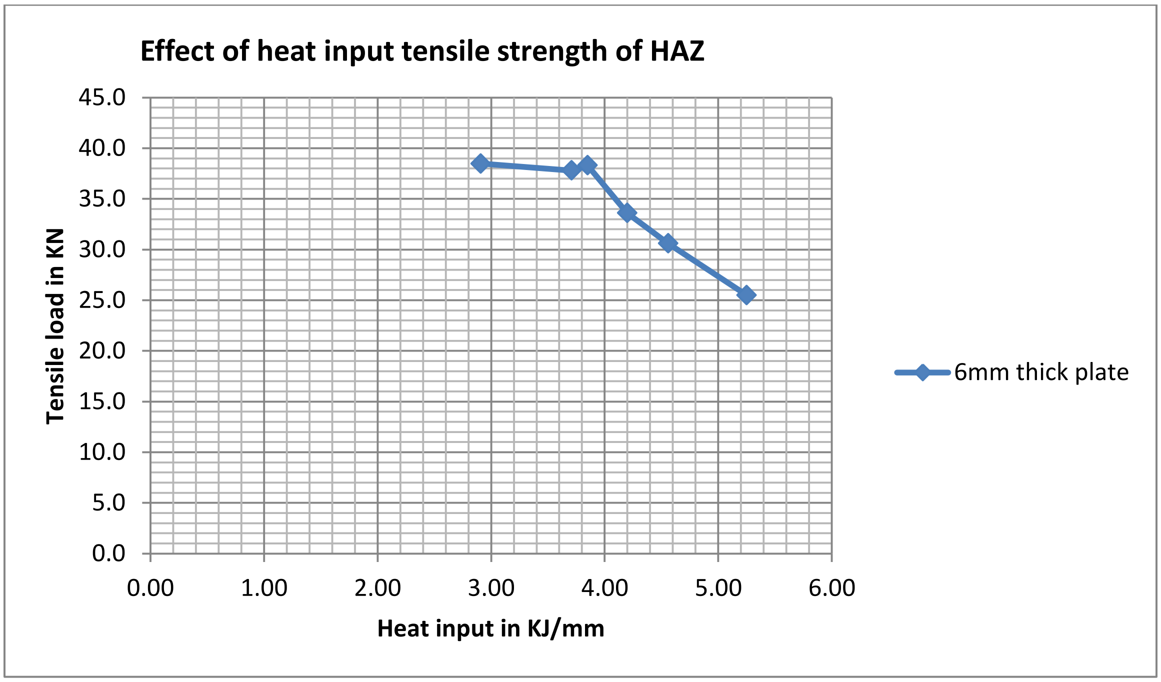


Figure 31: Heat input Vs tensile load 6mm thick plate

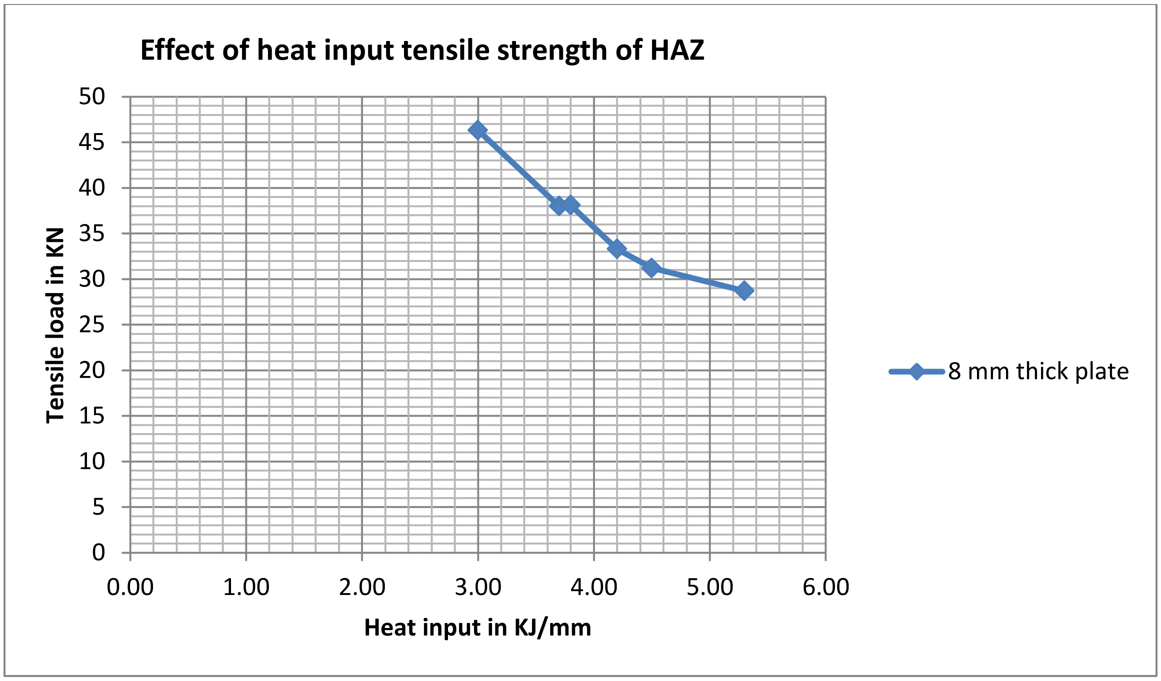


Figure 32: Heat input Vs tensile load 8mm thick plate

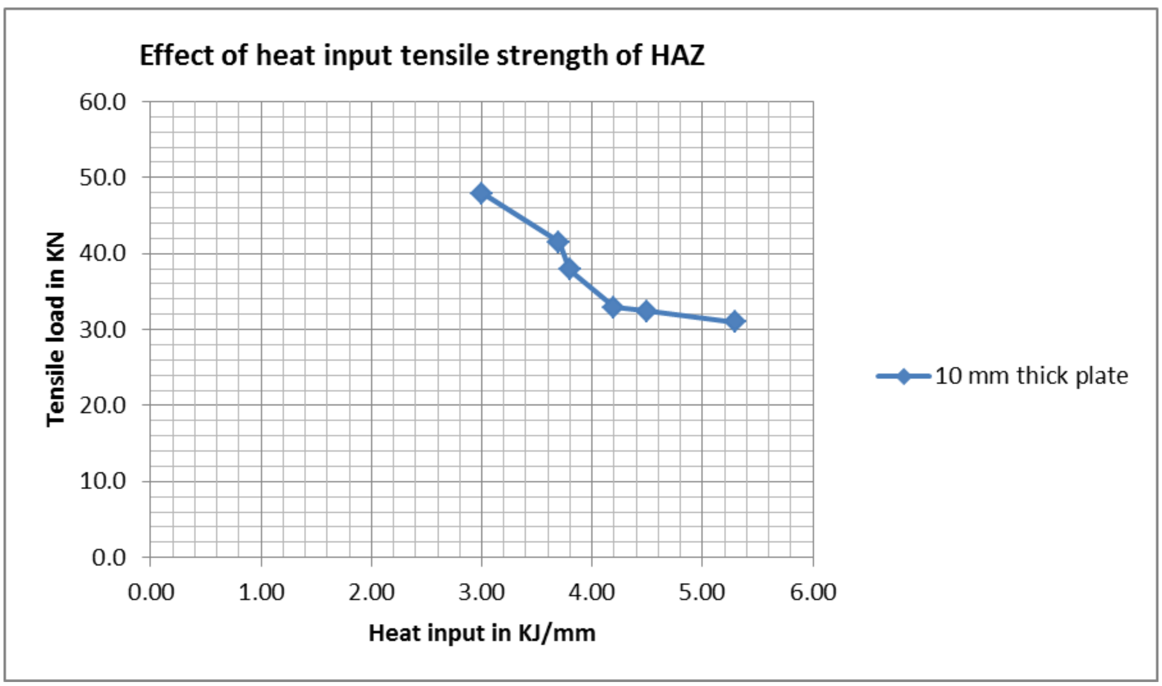


Figure 33: Heat input Vs tensile load 8mm thick plate

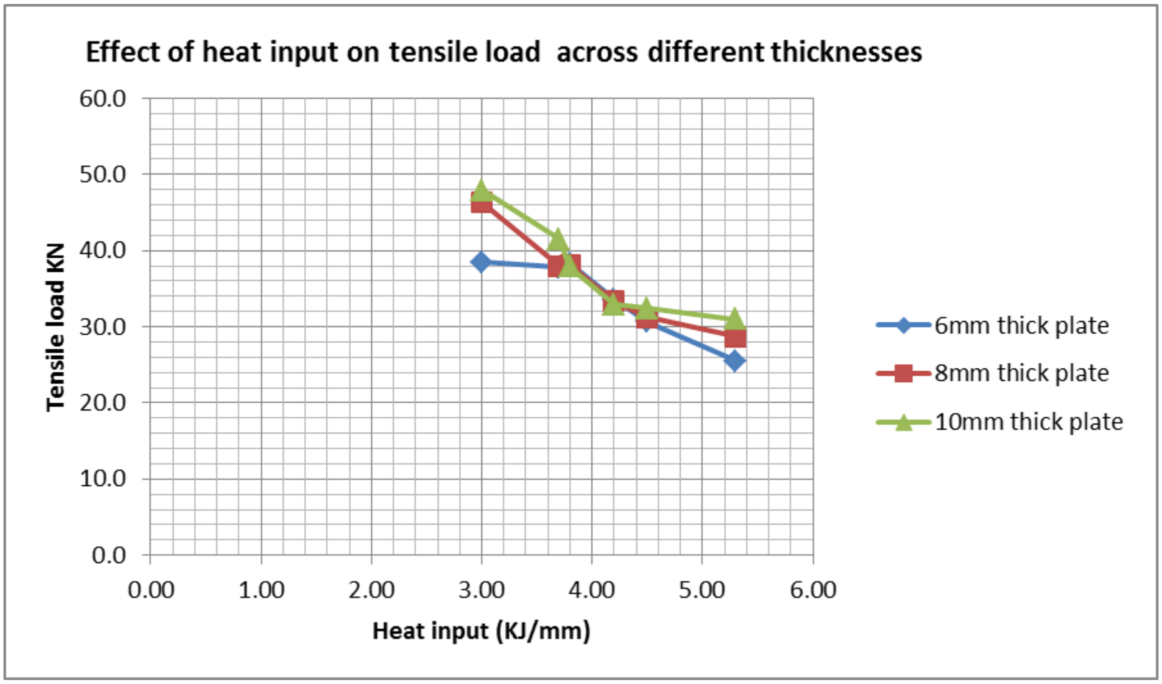


Figure 34: Heat input Vs tensile load all thickness

4.1.3 Toughness

With increase in heat in put a decrease in impact (CVN) value has been recorded in the experiment. The change in across thickness recorded is not significant but there a small increase in CVN value across different thickness. The toughness decreases with an increase of heat input in most cases, so, increase of heat input brings out appearance of more proeutectoid ferrite which affect to toughness decrease [1].

One of the reasons of the lowest toughness of the sample 1 and 9 is the fact that the two samples were tested with high heat input and thickness low, resulting in fine-grained structure.

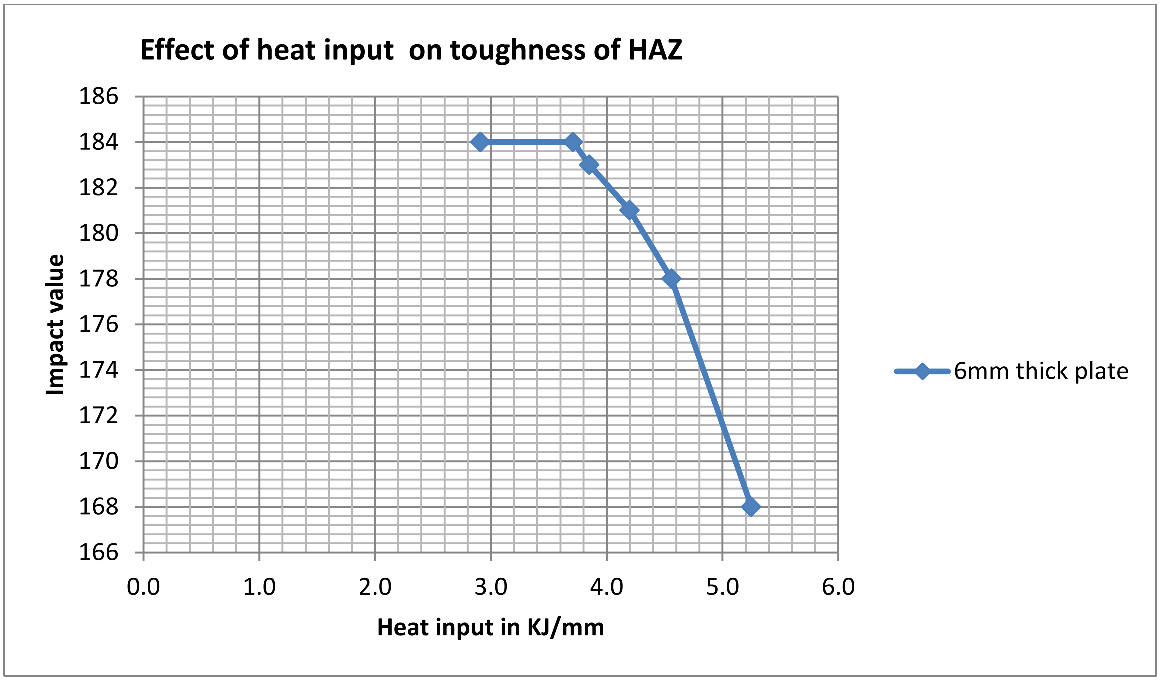


Figure 34: Heat input Vs Impact 6mm thick plate

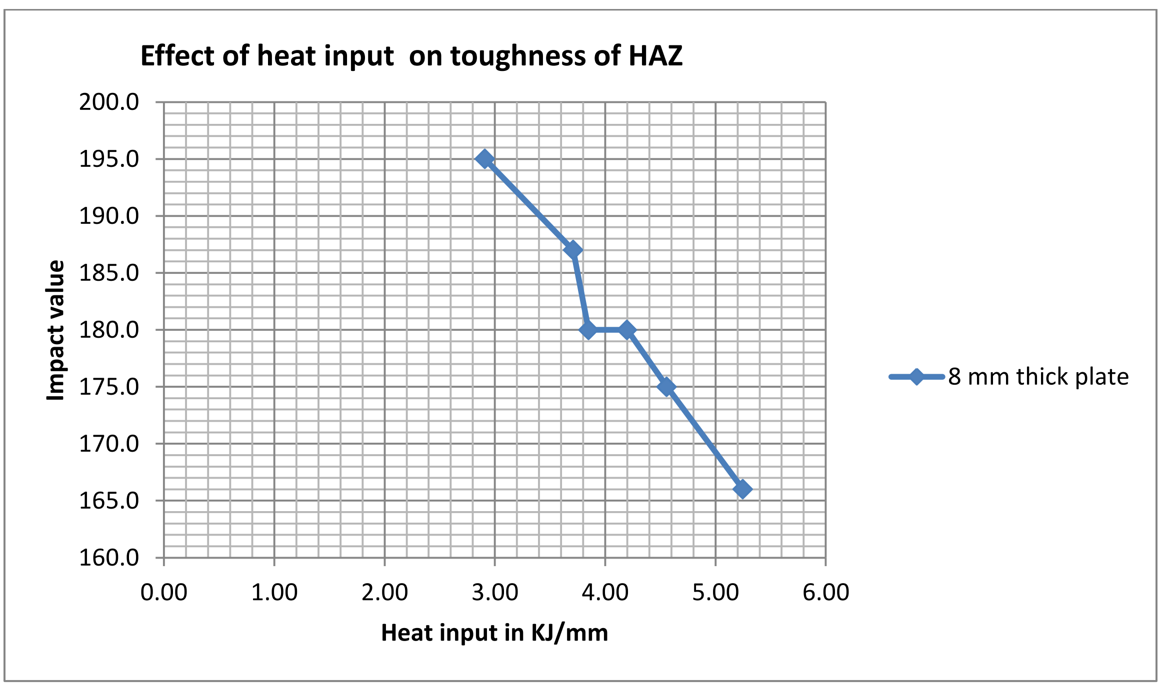


Figure 35: Heat input Vs Impact 8mm thick plate

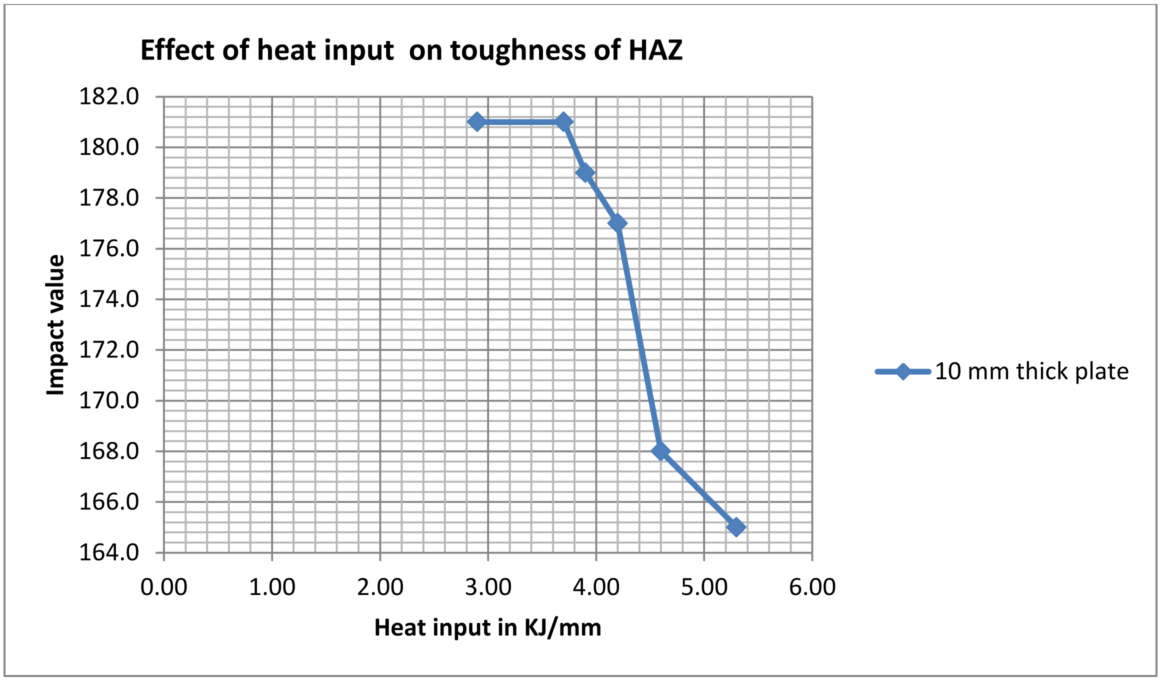


Figure 36: Heat input Vs Impact 10mm thick plate

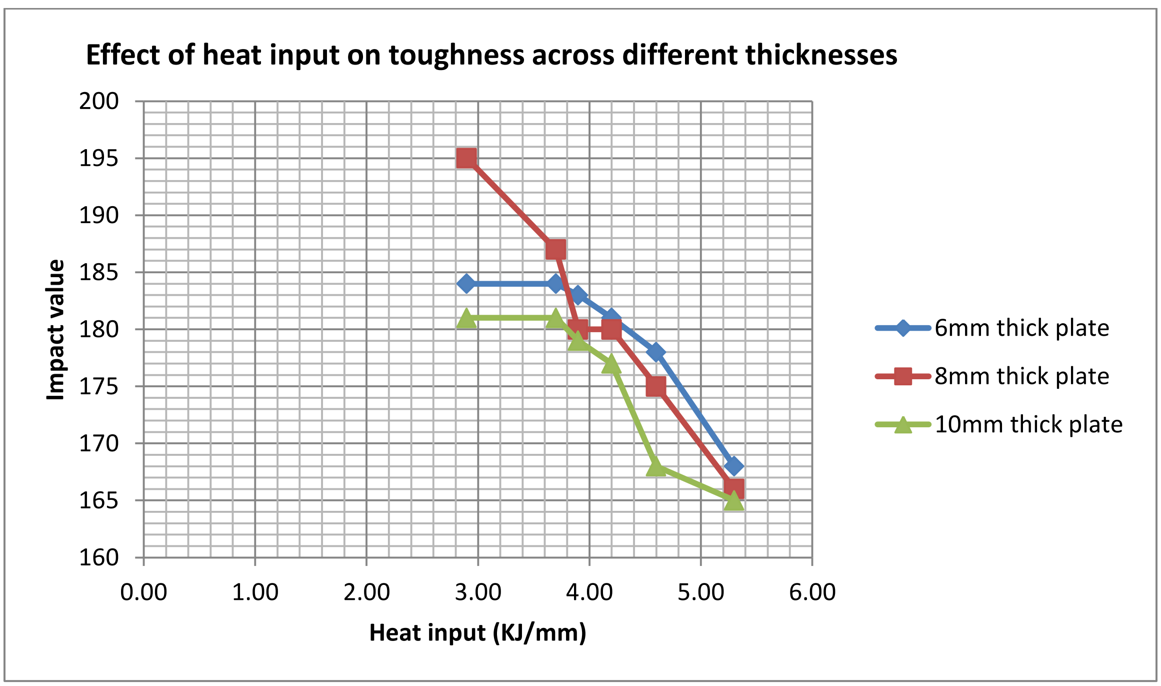


Figure 37: Heat input Vs Impact all thickness

4.2 Width of heat affected zone

4.2.1 Effect of heat input (current welding and speed) on width HAZ

From the experiment with increase in heat in put there is an increase in width of Heat affected zone. As we can see from the graph between distance from the weld center and hardness there is nearly constant variation of hardness but suddenly the parent metal next to weld metal i.e. HAZ there is increase in hardness because there is a thermal gradient between welding heat and atmospheric temperature due to this sudden quenching by air there is formation of martensitic structure in HAZ causing increase in hardness.

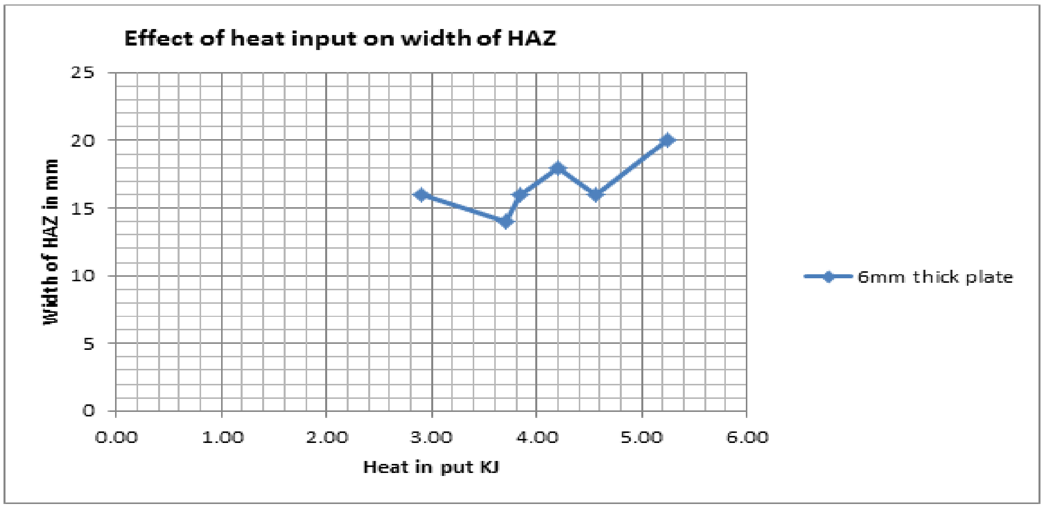


Figure 38: Heat input Vs width of HAZ 6mm thick plate

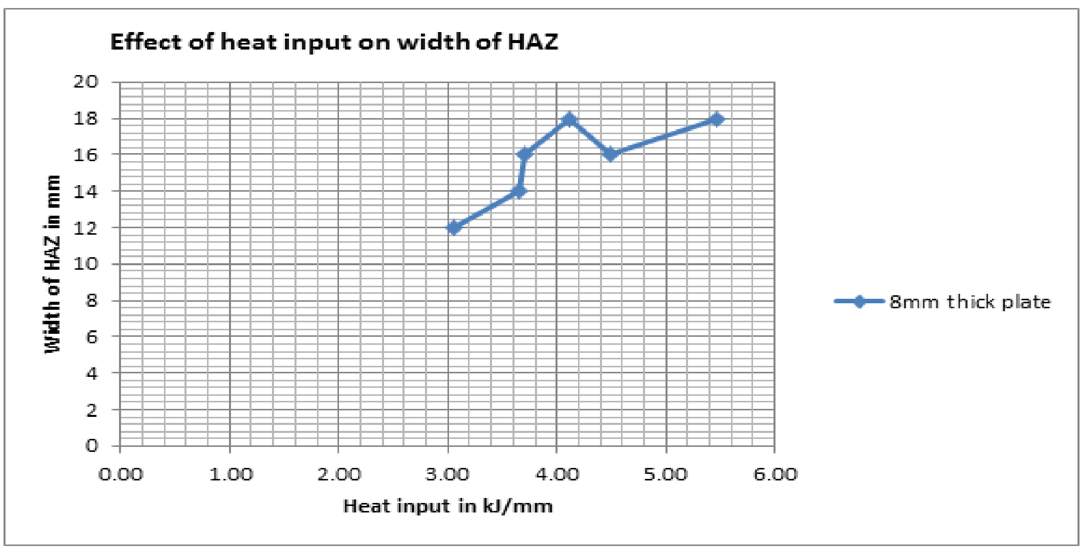


Figure 39: Heat input Vs width of HAZ 8mm thick plate

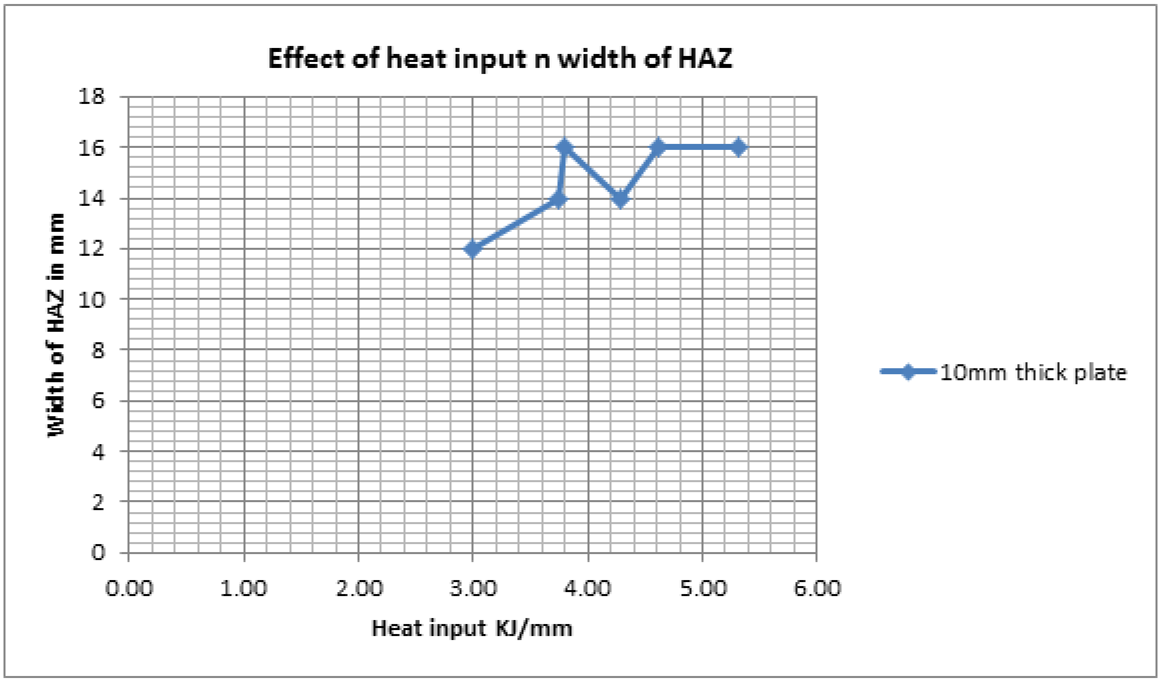


Figure 40: Heat input Vs width of HAZ 10mm thick plate

4.2.2 Effect of variation of thickness on width of HAZ

At constant heat input there is a decrease in width of heat affected zone with increase in thickness and the increase in amount of heat input increases the width of HAZ. Figure below shows the variation of width of HAZ with the change in Heat Input across different thicknesses. Figure 43 show the hardness profiles for various section thicknesses of mild steel plate. From the experiment average width of heat affected zone was 17mm, 15mm and 14mm for thicknesses 6mm, 8mm and 10mm respectively. The decrease in width of the HAZ as the section thickness increases that is due to the effects of the heat sink [1]. This is because a thicker workpiece acts as a better heat sink to cool the weld down. The graph is not very linear because the welding is done manually and there is a slight deviation across the weld on welding speed.

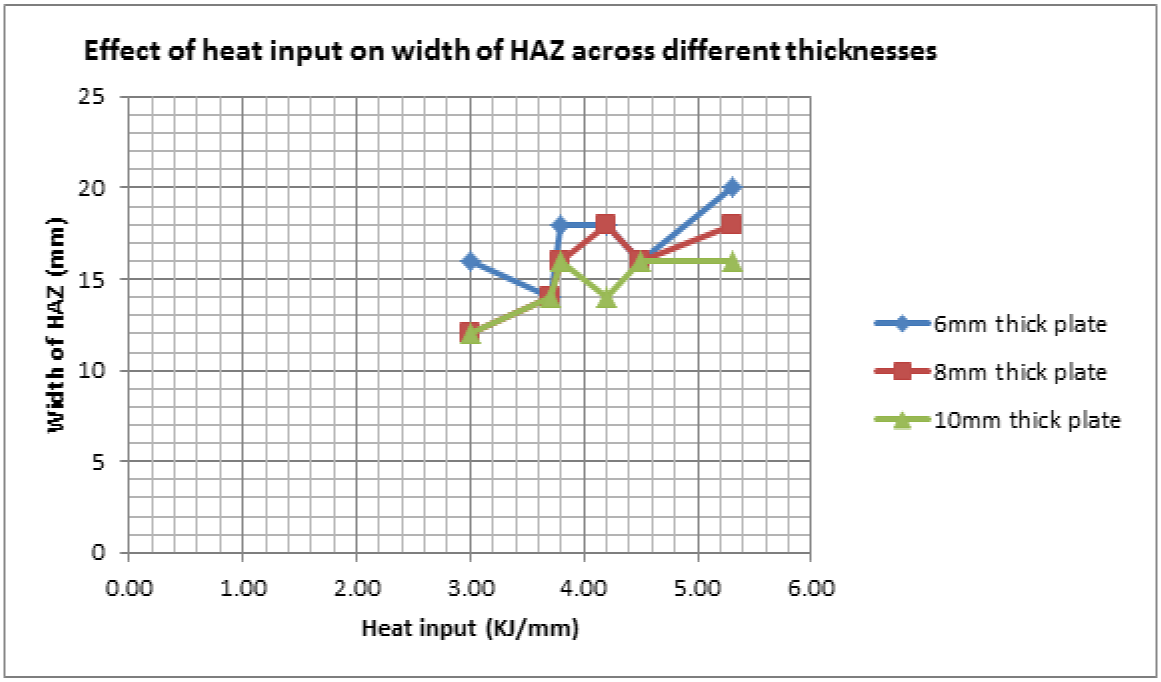


Figure 41: Heat input Vs width of HAZ all thickness

4.3 Micro structure

The microstructure of a mild steel plate welded by manual metal arc welding has been evaluated and microstructure of each of the specimen at the weld, heat affected zone and parent metals are investigated.

The results of the investigation indicate that significant grain coarsening was observed in the heat affected zone (HAZ) of all the joints and it was found that the extent of grain coarsening in the heat affected zone increased with increase in the heat input. The average dendrite length and inter-dendritic spacing in the weld zone was found to increase with increase in the heat input.

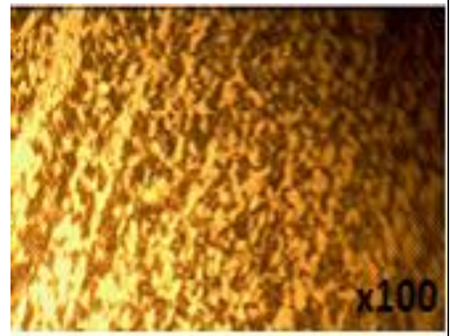
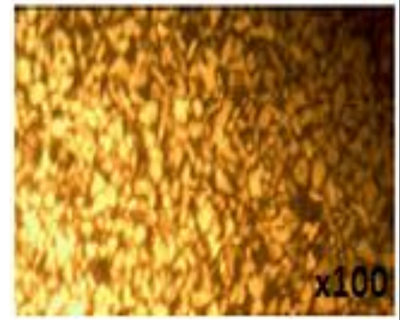
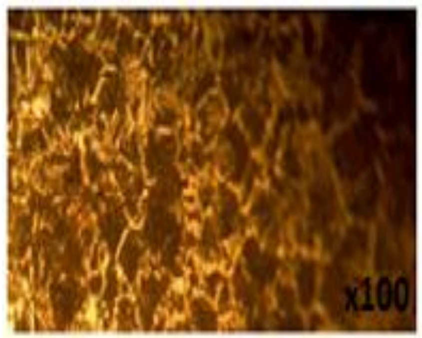
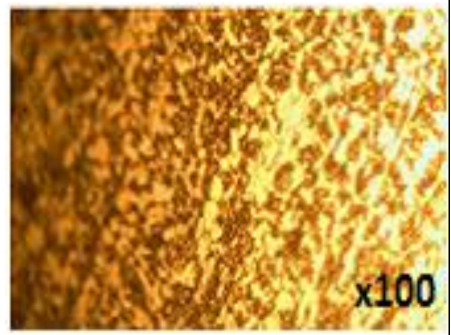
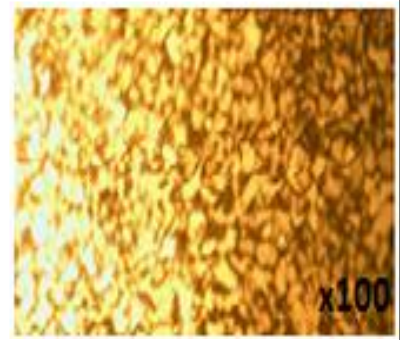
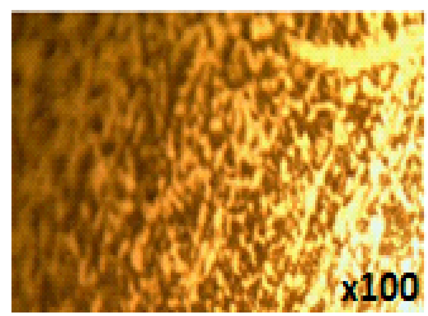
Sample No.	Metallographic image (10μm)		
	Weld	Heat affected zone	Parent metal
1			
2			
3			

Figure 42: Microstructure of Sample 1,2 and 3

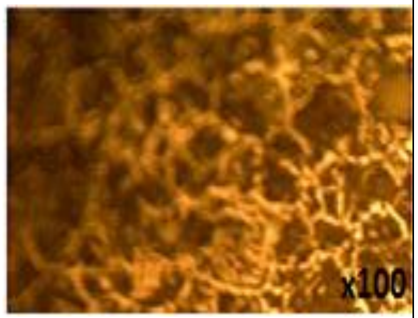
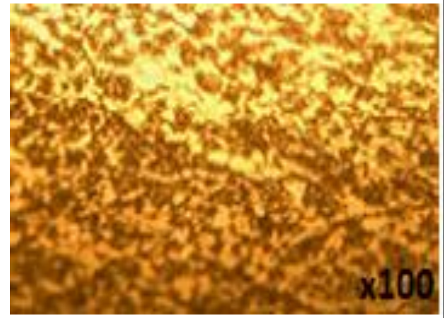
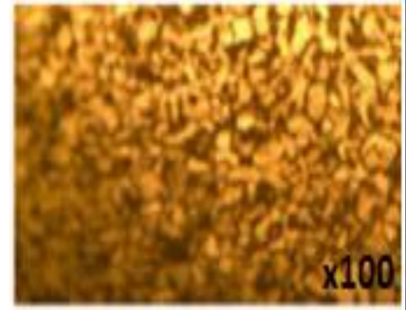
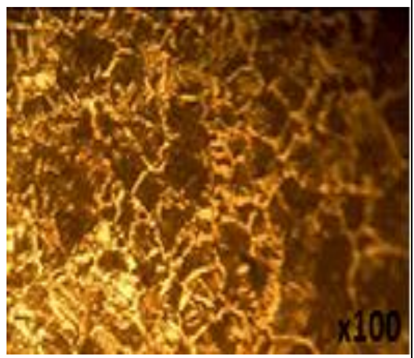
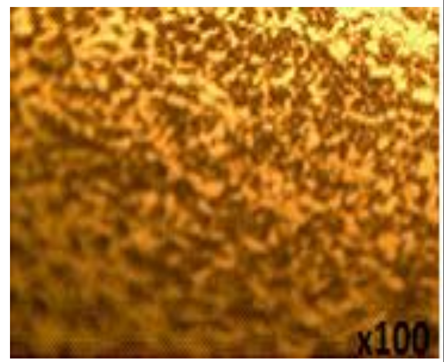
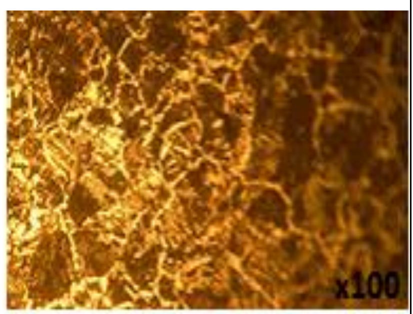
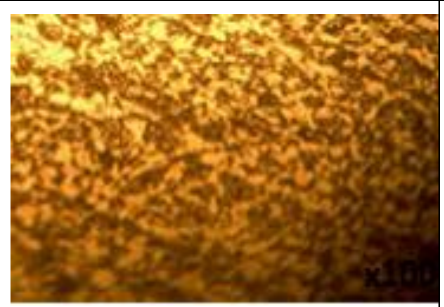
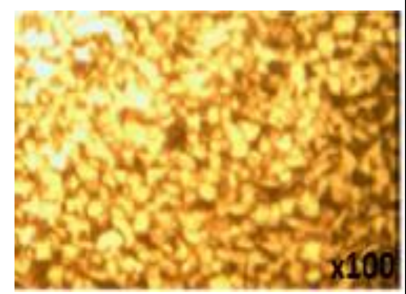
Sample No.	Metallographic image (10µm)		
	Weld	Heat affected zone	Parent metal
4			
5			
6			

Figure 43: Microstructure of Sample 4,5 and 6

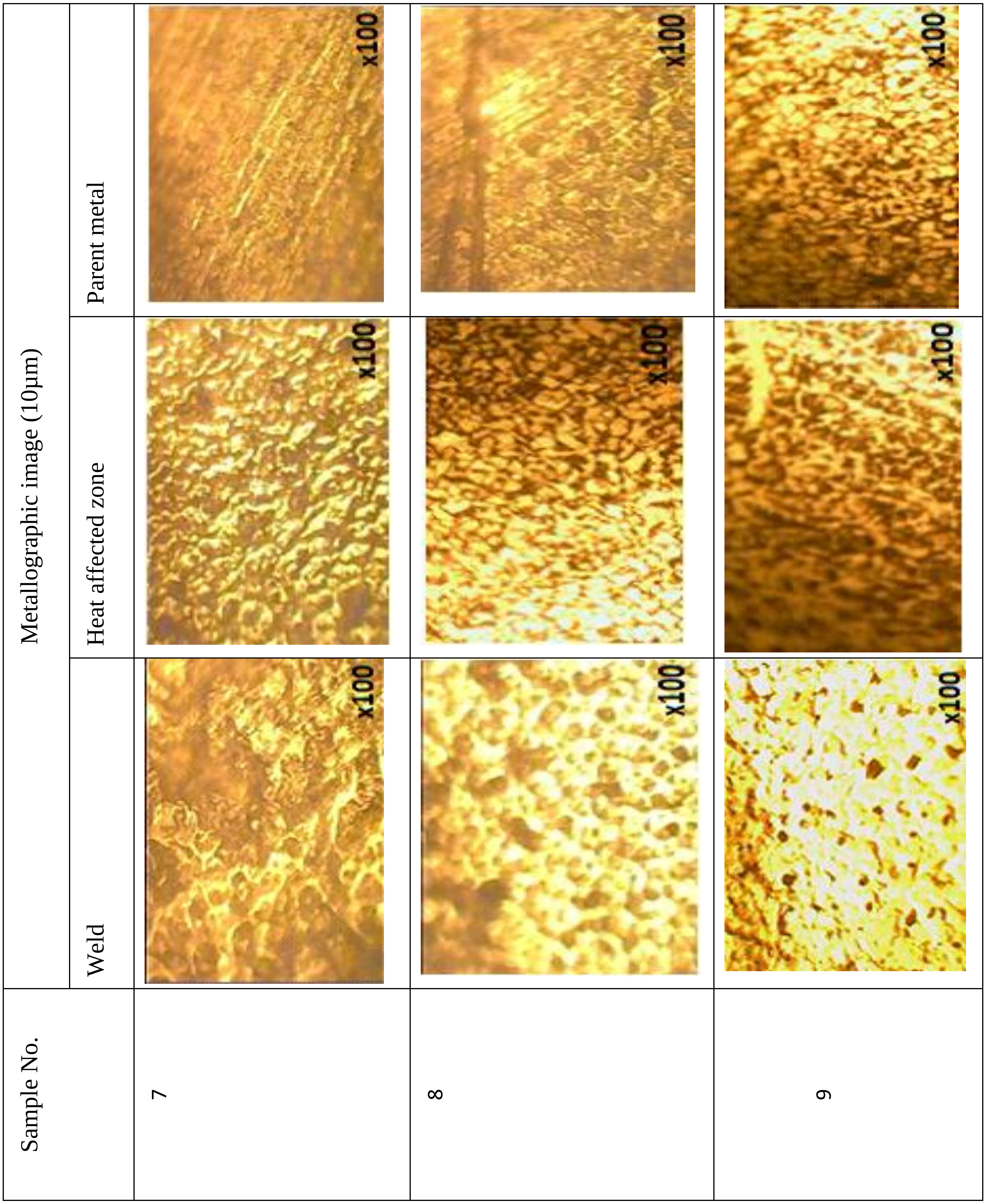
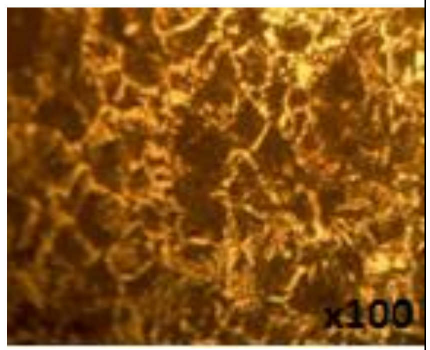
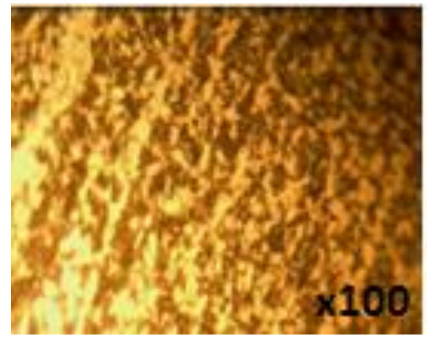
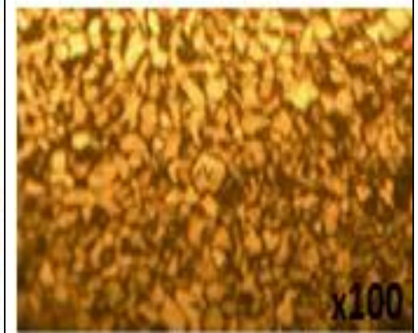
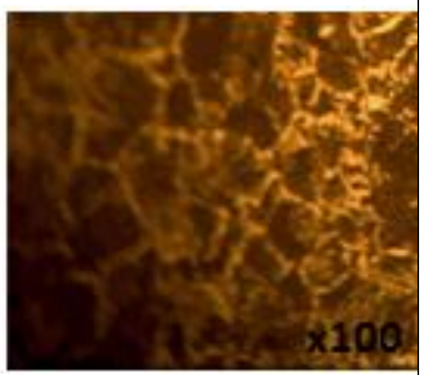
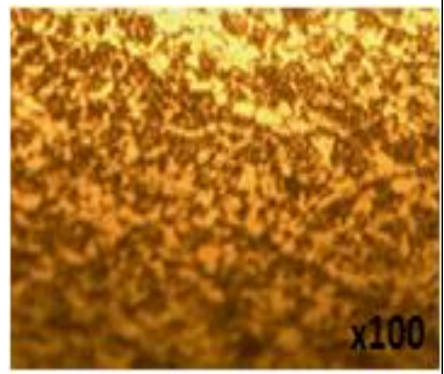
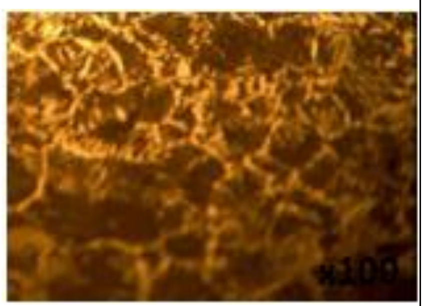
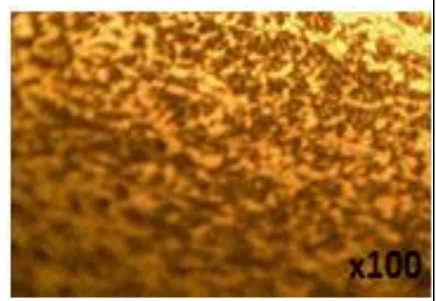
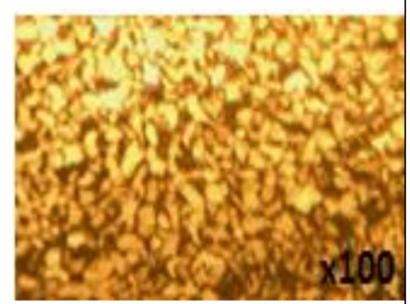


Figure 44: Microstructure of Sample 7,8 and 9

Sample No.	Metallographic image (10µm)		
	Weld	Heat affected zone	Parent metal
10			
11			
12			

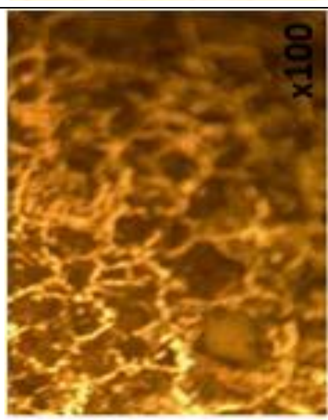
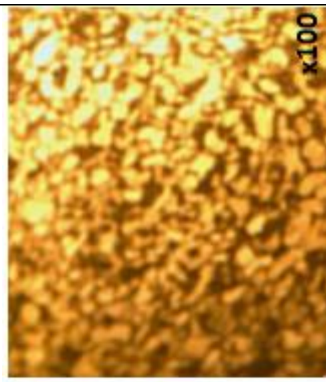
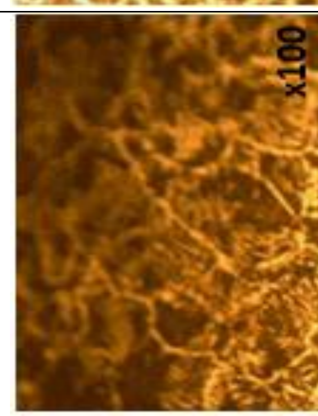
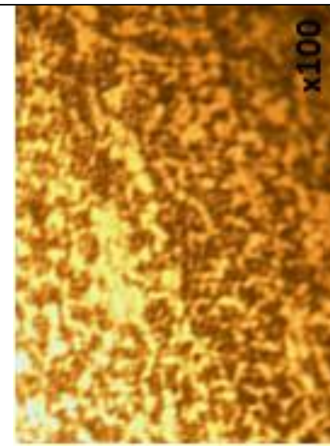
Sample No.	Metallographic image (10µm)		
	Weld	Heat affected zone	Parent metal
13			
14			
15			

Figure 46: Microstructure of Sample 13,14 and 15

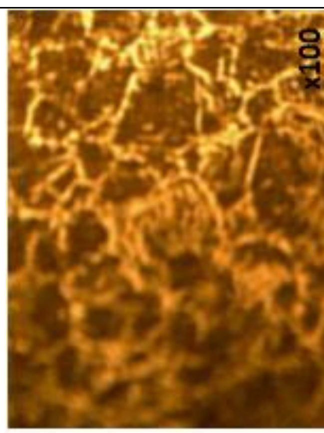
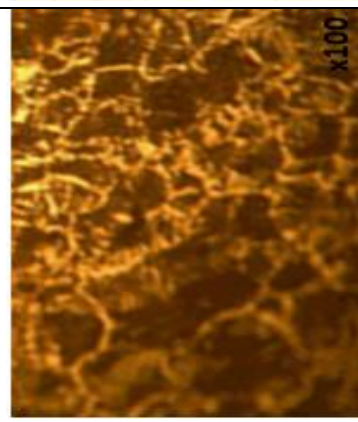
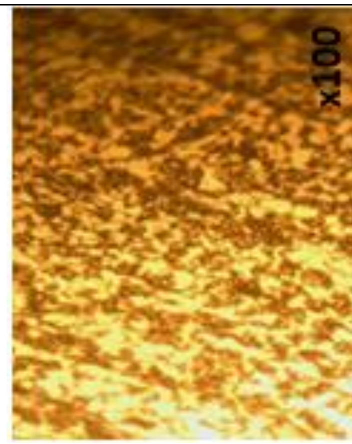
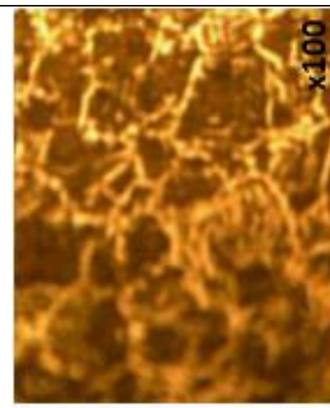
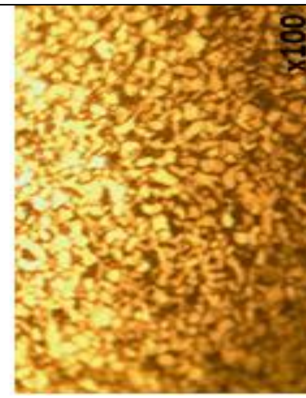
Sample No.	Metallographic image (10µm)		
	Weld	Heat affected zone	Parent metal
16			
17			
18			

Figure 47: Microstructure of Sample 16,17 and 18

5. Conclusion and Recommendations

5.1 Conclusion

The mechanical properties and microstructure of a mild steel plate welded by manual metal arc welding process has been evaluated and it has been observed that,

- The input of heat tended to increase the hardness of the joints with increasing intensity. As we go through the section from the weld center a higher hardness value reaching 271 HV compare to HAZ which has an average value of 197.5 HV as well as the parent metal with an average value of 173 HV, As we go from the weld center and there is nearly constant variation of hardness but suddenly the parent metal next to weld metal, there is increase in hardness because there is a thermal gradient between welding heat and atmospheric temperature due to this sudden cooling. From the experiment in general average HAZ hardness is higher than parent metal hardness by 16.5 %.

- A significant decrease in ultimate tensile strength value was also recorded as the heat input increased which means current increased and welding speed decreased or kept constant. The decrease in strength could be associated with the presence of void and other defects occurring as a result of increasing current. From the experiment in general average HAZ hardness is higher than parent metal hardness by 18.5 %.

- With an increase in heat in put a decrease in impact value has been recorded in the experiment. The change in across thickness recorded is not significant but there a small increase in CVN value across different thickness. Average heat affected zone toughness is lower than the parent metal's toughness by 6.5 %.

- From the experiment with increase in heat in put there is an increase in width of Heat affected zone. When we compare the effect of welding speed and current on hardness, the effect of current is more significant than the effect due to welding speed. that the microstructure of each of the specimen at the Heat Affected Zone, has a direct effect on the hardness of the welded joint with respect to the distributions of the ferrites, pearlites and some infusions.

- The results of the investigation indicate that significant grain coarsening was observed in the heat affected zone (HAZ) of all the joints and it was found that the extent of grain coarsening in the heat affected zone increased with increase in the heat input. Excessive grain growth could also lead to the decrease in the tensile properties. The average dendrite length and inter-dendritic spacing in the weld zone was found to increase with increase in the heat input. It is also observed that the difference in microstructure of across different thicknesses tested is not significant.

5.2 Recommendations

This study revealed that welding significantly affect mechanical properties and micro structure of heat affected zone. Based on the understanding of effect of welding parameters on microstructure and mechanical properties of heat affected zone the following are recommended to be considered in design of steel structures and materials testing industries.

- It is important to use optimal heat input conditions which is a factor welding current and welding speed to minimize these effects on HAZ. When we compare the effect of welding speed and current on mechanical properties, the effect of current found to be more significant than the effect due to welding speed. Therefore, more attention should be given to control welding current.

- It is important to consider the changes in mechanical properties parent metal due to effect of heat during welding. In this case HAZ hardness is higher than that of the parent metal by 16.5 % and HAZ toughness and tensile strength low than that of the parent metal by 6.5 % and 18.5 % respectively.

- At constant heat input there is a decrease in width of heat affected zone with increase in thickness and the increase in amount of heat input increases the width of HAZ. As a result it is important to keep the width of heat affected zone as minimum as possible by using different optimum welding condition for different thicknesses.

- As heat affected zone is the most susceptible part of weld structure for failures like cracks it is important to be sure on the width of heat affected zone to be covered by nondestructive testing of materials. This work showed the average width of heat affected zone ranges from 12 mm to 18 mm for the specified thicknesses.

- As heat affected zone is revealed to be the weakest part due to changes in material property after welding, HAZ properties should be appropriately considered in addition to parent metal properties in design of welded structures.

References

[1] Kou, S. Welding Metallurgy. 2nd Edition, John Wiley& Sons, Inc., Hoboken, New Jersey, 2003

[2] Sacks and Bohnart, Welding Principles and Practices, third edition, McGraw-Hill Companies Inc, 2006

[3] Willy Pang, The Structure and Properties of Heat Affected Zone of Structural Plate Steels Welded by High Productivity Process, University of Wollongong, 1993.

[4] Omale Idokoh Joseph, Microstructure and Mechanical Properties of Welds in Pipeline Steel, University of Saskatchewan, July 2016.

[5] Z. Sloderbach, J. Pająk, Determination of Ranges of Components of Heat Affected Zone Including Changes of Structure, Archives of Metallurgy and Materials, Volume 60, issue 4, 2015

[6] American welding society, The Everyday Pocket Handbook for Arc Welding Steel, 1994

[7] V.Yu. Krasnykh , V.A. Grigoriev , A.N. Patrushev , Ye M. Tolmachev and V.N. Korolev Determination of The Dimensions of the Heat Affected Zone in Welding Gas Pipeline Components, Ural Federal University , Yekaterinburg , Russia Published online: 2013.

[8] M.J. George , Albert Embankment , Measurement of Toughness in the Heat-Affected Zone of Welded Structural Steels, British Steel Corporation, 1985.

[9] W Pang, N Ahmed, D Dunne, Hardness and Microstructural Gradients in the Heat Affected Zone of Welded Low-Carbon Quenched and Tempered Steels, University of Wollongong Research Online, 2011.

[10] M. A. Bodude, I. Momohjimoh, Studies on Effects of Welding Parameters on the Mechanical Properties of Welded Low-Carbon Steel, Journal of Minerals and Materials Characterization and Engineering, 2015, PP 142-153.

[11] American Welding Society, "Welding processes", Welding Handbook, Eight Edition, Volume 2, 1991. Chap.4

[12] Jodh Singh, Surinder Singh Bhinder, Effect of Welding Speed on Depth of Penetration During Arc Welding of Mild Steel Plates, IJRMET Vol. 4, Issue 2, 2014

[13] P. Cico1, D. Kalincova, M. Kotus, Influence of Welding Method on Microstructural Creation of Welded Joints, Res. Agr. Eng., 57 (Special Issue): 2011, PP 50–56.

[14] R. A. Mohammed, M. Abdulwahab, E. T. Dauda, Properties Evaluation Of Shielded Metal Arc Welded Medium Carbon Steel Material, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 8, August 2013.

[15] M. A. Bodude, I. Momohjimoh, Studies on Effects of Welding Parameters on the Mechanical Properties of Welded Low-Carbon Steel, Journal of Minerals and Materials Characterization and Engineering, 2015, 3, 142-153.

[16] Rakesh Kumar, Satish Kumar, Study Of Mechanical Properties In Mild Steel Using Metal Inert Gas Welding, IJRET: International Journal of Research in Engineering and Technology, Volume: 03 Issue: 04, Apr-2014.

[17] Samson Dinbassa, Weld Design of Heavy Duty Vehicle Bodies, AAU, 2007

[18] Praveen Kumar Yadav, Md Abbas and Shishir Patel, Analysis Of Heat Affected Zone Of Mild Steel Specimen Developed Due To MIG Welding, International Journal of Mechanical Engineering and Robotics Research Vol. 3, No. 3, July, 2014.

[19] V.Yu. Krasnykh , V.A. Grigoriev , A.N. Patrushev , Ye M. Tolmachev and V.N. Korolev Determination of The Dimensions of The Heat Affected Zone in Welding Gas Pipeline Components, Ural Federal University , Yekaterinburg , Russia Published online: 2013.

[20] H.R. Ghazvinloo, A. Honarbakhsh-Raouf and N.Shadfar, Effect of Arc Voltage, Welding Current and Welding Speed on Fatigue Life, Impact Energy and Bead Penetration of AA6061 Joints Produced by Robotic MIG Welding, Indian Journal of Science and Technology, Vol:3, Issue: 2, 2010

[21] Ajay N.Boob, Prof.G. K.Gattani, Study on Effect of Manual Metal Arc Welding Process Parameters on Width of Heat Affected Zone (HAZ) For MS 1005 Steel, International Journal of Modern Engineering Research (IJMER), Vol. 3, Issue. 3, 2013 PP 1493-1500.

[22] Zakaria Boumerzoug, Chemseddine Derfouf, Thierry Baudin, Effect of Welding on Microstructure and Mechanical Properties of an Industrial Low Carbon Steel, Journal of Minerals and Materials Characterization and Engineering, 2010, PP 502-506.

[23] ISO 9692, Welding and Allied Processes -Recommendations for Joint Preparation, 1991

[24] M.J. George, Measurement Of Toughness In The Heat-Affected Zone Of Welded Structural Steels, technical steel research, British Steel Corporation, 1985

[25] Narender Sura , Vijay Mittal, Experimental Study on Effects of Process Parameters on HAZ of Plain Carbon Steel Using GMAW. International Journal of Latest Research in Science and Technology, Volume 4, Issue 2, 2015. PP 167-170

[26] Imaekhai Lawrence, Behavior in Welded Heat Affected Zone (HAZ) of low Alloy steel, Standard Research Journal of Metallurgy and Fabrication Engineering Vol1, August 2014

[27] Jodh Singh, Surinder Singh Bhinder, Effect of Welding Speed on Depth of Penetration During Arc Welding of Mild Steel Plates, IJRMET Vol. 4, Issue 2, 2014.

[28] Sameer S Kulkarni, Study of influence of welding parameters on mild steel, International Advanced Research Journal in Science, Engineering and Technology, Vol. 2, Issue 5, May 2015.

[29] Asibeluo I.S, Emifoniye E, Effect of Arc Welding Current on the Mechanical Properties of A36 Carbon Steel Weld Joints, SSRG International Journal of Mechanical Engineering (SSRG-IJME) – volume 2 Issue 9 ,2015.

[30] Chih-Chun Hsieh, Dong-Yih Lin, Ming-Che Chen and Weite Wu, Microstructure, Recrystallization, and Mechanical Property Evolutions in The Heat-Affected and Fusion Zones of the Dissimilar Stainless Steels, Vol. 48, No. 11, 2008, PP 2898 to 2902,

[31] Peter Mayr, Evolution of Microstructure and Mechanical Properties of The Heat Affected Zone in B-Containing 9% Chromium Steels, Dissertation, Faculty of Mechanical Engineering Graz University of Technology, Austria, 2007.

[32] Zakaria Boumerzoug, Chemseddine Derfouf, Thierry Baudin, Effect of Welding on Microstructure and Mechanical Properties of an Industrial Low Carbon Steel, Scientific Research(SciRP)_Engineering 2, 2010, PP 502-506.

[33] W Pang, N Ahmed, D Dunne, Hardness and Microstructural Gradients in The Heat Affected Zone of Welded Low-Carbon Quenched and Tempered Steels, University of Wollongong Research Online, 2011

[34] Z. Śloderbach, J. Pająk, Determination of Ranges of Components of Heat Affected Zone Including Changes of Structure, Archive metallurgy and materials, Volume 60, Issue 4, 2015.

[35] Ramaswamy, Murali T., Heat Affected Zone Studies of Thermally Cut Structural Steels, Scholar Archive. Paper 130, 1989.

[36] Wan Shaiful Hasrizam Wan Muda, Nurul Syahida Mohd Nasir, Sarizam Mamat and Saifulnizan Jamian, Effect of Welding Heat Input on Microstructure and Mechanical Properties at Coarse Grain Heat Affected Zone of abs Grade a Steel, ARPN Journal of Engineering and Applied Sciences, Vol. 10, No 20, 2015.

Annex 1: Average hardness Across HAZ and parent metal with heat inputs

Sample no.	Average HAZ hardness (HV)	Average parent metal hardness (HV)	Heat input (kJ/mm)
1	208.7	175.7	3.9
2	204.4	169.9	2.9
3	176.7	176.3	4.6
4	207.9	175.7	3.7
5	182.3	176.8	5.3
6	186.4	175.6	4.2
7	204.2	175.8	3.9
8	203.5	171.7	2.9
9	232.8	178.0	4.6
10	211.1	177.9	3.7
11	176.1	174.3	5.3
12	226.1	177.3	4.2
13	200.0	173.3	3.9
14	195.9	171.7	2.9
15	210.8	175.7	4.6
16	205.9	175.9	3.7
17	218.2	177.0	5.3
18	226.1	177.0	4.2

Annex 2: Average hardness across samples tested

Hardness (HV)	Distance from weld center in mm	Sample No.																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	-28	176	158	174	176	174	174	173	172	173	173	174	174	173	172	173	173	174	174
	-26	173	171	173	173	173	173	173	173	172	173	173	173	173	173	172	173	173	173
	-24	169	170	173	169	173	173	169	171	172	170	172	173	169	171	172	170	172	172
	-22	172	169	174	172	174	174	172	169	174	172	174	172	172	169	174	172	174	172
	-20	178	171	176	178	182	176	178	171	176	178	178	176	178	171	176	178	178	176
	-18	181	169	178	181	178	191	181	167	176	181	178	185	179	167	172	181	178	185
	-16	195	174	195	195	195	182	185	174	189	195	169	195	174	174	189	177	195	195
	-14	212	179	178	212	174	168	179	179	196	212	175	185	178	179	196	180	191	185
	-12	204	204	167	204	171	171	204	181	239	204	167	229	202	181	191	204	208	229
	-10	198	198	161	198	171	241	198	196	241	198	165	241	198	196	212	188	215	241
	-8	217	226	168	217	187	176	217	223	238	217	180	238	218	223	238	217	220	238
	-6	223	216	172	223	207	185	223	216	236	223	199	236	219	216	236	223	236	236
	-4	229	218	180	229	222	238	229	217	238	232	222	238	229	217	238	232	238	247
	-2	249	241	233	251	258	268	249	241	268	251	269	263	243	221	258	245	252	255
	0	253	241	254	253	249	267	249	251	268	249	271	261	242	245	259	246	255	258
	2	251	239	241	254	251	271	251	239	265	254	273	262	241	218	261	246	251	255
	4	222	241	189	222	214	251	248	237	237	232	217	258	239	221	241	232	244	249
	6	217	231	176	217	215	205	215	231	245	223	191	240	213	218	242	223	225	240
	8	217	227	178	217	193	193	217	227	246	217	184	246	201	218	224	215	218	246
	10	200	224	165	200	176	178	199	224	245	200	159	245	181	181	206	196	244	245
	12	205	217	159	205	171	168	205	187	237	205	162	220	208	176	187	201	238	220
	14	221	181	202	212	157	171	185	171	205	212	179	181	182	171	176	212	187	181
	16	195	176	199	195	171	199	183	176	192	195	168	176	176	176	178	182	180	176
	18	196	171	181	196	181	176	179	171	181	190	181	178	173	171	181	198	181	178
	20	176	173	179	176	179	179	181	173	179	176	175	176	172	173	176	172	175	173
	22	173	172	183	173	183	172	173	172	183	173	179	182	173	172	172	173	179	182
	24	169	169	179	169	179	173	169	169	179	169	173	176	169	169	179	169	173	176
	26	172	173	174	172	174	174	172	173	174	172	174	174	172	173	174	172	174	174
	28	173	173	172	173	172	172	173	173	172	173	172	172	173	173	172	173	172	172
		5816	5672	5333	5812	5504	5639	5729	5624	6096	5819	5453	6025	5620	5485	5825	5723	5900	6003
Average Hardness HV		**201**	**196**	**184**	**200**	**190**	**194**	**198**	**194**	**210**	**201**	**188**	**208**	**194**	**189**	**201**	**197**	**203**	**207**

Annex 3: Tensile test results

Sample No.	Thickness (mm)	Ultimate tensile load (KN)		Heat input (kJ/mm)
		HAZ	Parent metal	
1	6	38.5	41.9	3.9
2	6	37.8		2.9
3	6	38.3		4.6
4	6	33.6		3.7
5	6	30.6		5.3
6	6	25.5		4.2

Sample No.	Thickness (mm)	Ultimate tensile load (KN)		Heat input (kJ/mm)
		HAZ	Parent metal	
7	8	39.0	40.2	3.9
8	8	38.0		2.9
9	8	38.1		4.6
10	8	33.3		3.7
11	8	31.2		5.3
12	8	28.7		4.2

Sample No.	Thickness (mm)	Ultimate tensile load KN		Heat input (KJ/mm)
		HAZ	Parent metal	
13	10	41.8	42.3	3.9
14	10	41.5		2.9
15	10	37.9		4.6
16	10	32.9		3.7
17	10	32.4		5.3
18	10	31.0		4.2

Annex 4: Impact test result

Sample No.	Thickness (mm)	Impact value (CVN)		Heat input (KJ/mm)
		HAZ	Parent metal	
1	6	183	192	3.9
2	6	184		2.9
3	6	178		4.6
4	6	184		3.7
5	6	168		5.3
6	6	181		4.2

Sample No.	Thickness (mm)	Impact value (CVN)		Heat input (KJ/mm)
		HAZ	Parent metal	
7	8	180	189	3.9
8	8	195		2.9
9	8	175		4.6
10	8	187		3.7
11	8	166		5.3
12	8	180		4.2

Sample No.	Thickness (mm)	Impact value (CVN)		Heat input (KJ/mm)
		HAZ	Parent metal	
13	10	179	189	3.9
14	10	181		2.9
15	10	168		4.6
16	10	181		3.7
17	10	165		5.3
18	10	177		4.2

Annex 5: Average width of heat affected zone

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Thickness (mm)	6	6	6	6	6	6	8	8	8	8	8	8	10	10	10	10	10	10
Average Width of HAZ (mm)	16	14	16	18	16	20	12	14	16	14	14	18	12	14	16	12	14	16

Annex 6: Features of welding machine used for this test

MMA WELDING EQUIPMENT

MMA WELDING

YARD SV 333 / SV 403 / SV 443

YARD power sources are rectifiers for MMA coated electrode welding. They are well suited for both workshop and outdoor working conditions. Easy to use with adjustment using the shunt, they are for professional and intensive applications.

Standards
EN 60974-1
EN 60974-10

Features and product advantages:

- **Input voltage:** bi-tension 230 V - 400 V three-phase.
- **Simple:** power adjustment by shunt.
- **Easy to set:** linear control.
- **Cooling:** forced air cooling fan.
- **Practical:** due to the large diameter wheels and handle.
- **Versatile:** able to weld all types of electrodes (including cellulosics).

1. Switch on/off and primary voltage selection.
2. Current adjustment.
3. Welding current indicator.
4. Welding cables connectors.

TECHNICAL CHARACTERISTICS:

		YARD SV 333	YARD SV 403	YARD SV 443
Three-phase input voltage		230 - 400 V		
Input power		16.9 kVA - 10 kW	22.8 kVA - 13 kW	31.2 kVA - 18 kW
Max input current		43 A - 25 A	57 A- 33 A	78 A - 45 A
Effective input current		25 A - 15.5 A	34 A - 19.5 A	52 A - 30 A
Welding current range		55 - 260 A	50 - 325 A	60 - 400 A
Duty cycle at 40 °C	at 35%	260 A	325 A	400 A (45%)
	at 60%	200 A	250 A	345 A
	at 100%	155 A	190 A	265 A
Connector size		13 mm		
Protection index		IP 21		
Dimensions (mm)		450 x 620 x 890	560 x 730 x 1080	
Weight		83 kg	107 kg	123 kg

Annex 7: Welding joint preparation standard

Welding processes

Joint preparations recommended in this part of ISO 9692 are suitable for welding carried out in accordance with the following processes as specified in Tables 1 to 4; combinations of different processes are possible.

a) (3) gas welding; oxyfuel gas welding;

b) (111) manual metal arc welding (metal arc welding with covered electrode); shielded metal arc welding;

c) (13) gas-shielded metal arc welding; gas metal arc welding includes:

— (131) metal inert gas welding; MIG welding; gas metal arc welding;

— (135) metal active gas welding; MAG welding; gas metal arc welding;

— (136) tubular cored metal arc welding with active gas shield; flux cored arc welding;

— (137) tubular cored metal arc welding with inert gas shield; flux cored arc welding;

d) (141) tungsten inert gas welding; TIG welding; gas tungsten arc welding;

e) (5) beam welding:

— (51) electron beam welding;

— (512) electron beam welding in atmosphere;

— (52) laser welding; laser beam welding.

NOTE The numbers in parentheses refer to the reference number of the welding process specified in ISO 4063.

Finish

The longitudinal edges of the root face should be de-burred and may be chamfered (up to 2 mm).

Type of joint preparation

The recommended types of joint preparation and dimensions are specified in Tables 1 to 4.

Table 1 (*continued*)

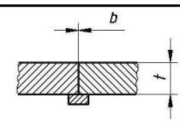
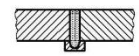
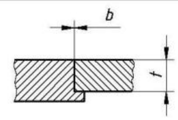
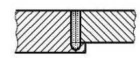
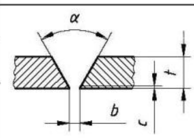
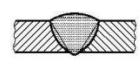
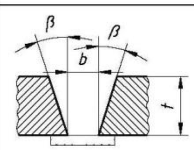
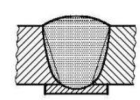
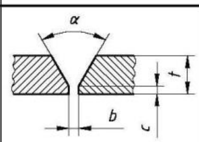
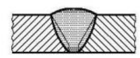
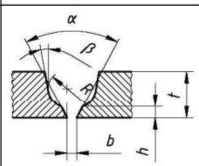
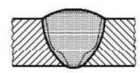
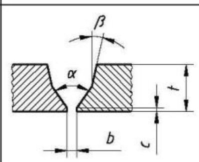
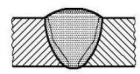
Ref. No.	Material thickness t mm	Type of preparation	Symbol (in accordance with ISO 2553)	Cross-section	Dimensions Angle[a] α, β	Gap[b] b mm	Thickness of root face c mm	Depth of preparation h mm	Recommended welding process (reference number in accordance with ISO 4063)	Weld illustration	Remarks
1.2.3	$\leqslant 100$	Square preparation with backing			—	—	—	—	51		—
1.2.4		Square preparation with centering lip									
1.3	$3 < t \leqslant 10$	Single-V preparation			$40° \leqslant \alpha \leqslant 60°$	$\leqslant 4$	$\leqslant 2$	—	3 111 13 141		Where applicable with backing strip
	$8 < t \leqslant 12$				$6° \leqslant \alpha \leqslant 8°$	–			52[d]		
1.4	> 16	Steep-flanked single-V preparation			$5° \leqslant \beta \leqslant 20°$	$5 \leqslant b \leqslant 15$	—	—	111 13		With backing strip

Table 1 (*continued*)

Ref. No.	Material thickness t mm	Type of preparation	Symbol (in accordance with ISO 2553)	Cross-section	Dimensions Angle[a] α, β	 Gap[b] b mm	 Thickness of root face c mm	 Depth of preparation h mm	Recommended welding process (reference number in accordance with ISO 4063)	Weld illustration	Remarks
1.5	$5 \leqslant t \leqslant 40$	Single-V preparation with broad root face			$\alpha \approx 60°$	$1 \leqslant b \leqslant 4$	$2 \leqslant c \leqslant 4$	—	111 13 141		—
1.6	> 12	Single-U preparation with V root	 e		$60° \leqslant \alpha \leqslant 90°$ $8° \leqslant \beta \leqslant 12°$	$1 \leqslant b \leqslant 3$	—	≈ 4	111 13 141		$6 \leqslant R \leqslant 9$
1.7	> 12	Single-V preparation with V root	 e		$60° \leqslant \alpha \leqslant 90°$ $10° \leqslant \beta \leqslant 15°$	$2 \leqslant b \leqslant 4$	> 2	—	111 13 141		—

Annex 8: Spectrometer test result of test pieces

SPECTRO

Sample Results

Sample Result Name	Type	Measure Date Time	Recalculation Date Time	Origin
10109035 (mild steel)	Unknown	30/12/2017 10:42	30/12/2017 10:44	Measured

Method Name	Check Type	Check Status	Correction Type	Outlier Test Type
Fe-01-M	None	Not Used	None	None

Status
Not Used

Sample Name
10109035 (mild steel)

	C Conc %	Si Conc %	Mn Conc %	P Conc %	S Conc %	Cr Conc %	Mo Conc %	Ni Conc %	Al Conc %	Co Conc %	Cu Conc %	Nb Conc %	Ti Conc %
1	0.026	0.009	0.27	0.023	0.004	0.015	<0.0010	0.008	0.009	<0.002	0.012	<0.004	<0.0010
Rep	***0.026***	***0.009***	***0.27***	***0.023***	***0.004***	***0.015***	<0.0010	***0.008***	***0.009***	<0.002	***0.012***	<0.004	<0.0010

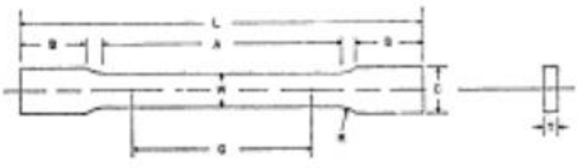
	V Conc %	W Conc %	Pb Conc %	Sn Conc %	Mg Conc %	As Conc %	Zr Conc %	Bi Conc %	Ca Conc %	Ce Conc %	Sb Conc %	Se Conc %	Te Conc %
1	0.0007	0.016	0.008	A 0.13!	<0.0010	<0.002	<0.002	<0.002	0.0003	<0.002	<0.002	<0.001	<0.0010
Rep	***0.0007***	***0.016***	***0.008***	A 0.13!	<0.0010	<0.002	<0.002	<0.002	***0.0003***	<0.002	<0.002	<0.001	<0.0010

	Ta Conc %	B Conc %	Zn Conc %	La Conc %	N Conc %	Fe Conc %
1	0.024	<0.0002	0.002	0.0006	A 0.008!	99.4
Rep	***0.024***	<0.0002	***0.002***	***0.0006***	A 0.008!	***99.4***

Ethiopian Conformity Assess... ARCHI...

Annex 9: Test piece preparation standard for tensile test.

E8/E8M – 09



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gage length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material	
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

NOTE 1—For the 40 mm [1.500 in.] wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. Either a set of nine or more punch marks 25 mm [1 in.] apart, or one or more pairs of punch marks 200 mm [8 in.] apart may be used.

NOTE 2—When elongation measurements of 40 mm [1.500 in.] wide specimens are not required, a minimum length of reduced section (A) of 75 mm [2.25 in.] may be used with all other dimensions similar to those of the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.10, 0.05 or 0.02 mm [0.004, 0.002 or 0.001 in.], respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 1 % larger than the width at the center.

NOTE 4—For each of the three sizes of specimens, narrower widths (W and C) may be used when necessary. In such cases the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used.

NOTE 5—The dimension T is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 40 mm [1.500 in.] wide specimens shall be 5 mm [0.188 in.]. Maximum thickness of 12.5 and 6 mm [0.500 and 0.250 in.] wide specimens shall be 19 and 6 mm [0.750 and 0.250 in.], respectively.

NOTE 6—For the 40 mm [1.500 in.] wide specimen, a 13 mm [0.500 in.] minimum radius at the ends of the reduced section is permitted for steel specimens under 690 MPa [100 000 psi] in tensile strength when a profile cutter is used to machine the reduced section.

NOTE 7—The dimension shown is suggested as a minimum. In determining the minimum length, the grips must not extend in to the transition section between Dimensions A and B, see Note 9.

NOTE 8—To aid in obtaining axial force application during testing of 6-mm [0.250-in.] wide specimens, the overall length should be as large as the material will permit, up to 200 mm [8.00 in.].

NOTE 9—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of 12.5 mm [0.500-in.] wide specimens is over 10 mm [0.375 in.], longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 10—For the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced section within 2.5, 0.25 and 0.13 mm [0.10, 0.01 and 0.005 in.], respectively. However, for referee testing and when required by product specifications, the ends of the 12.5 mm [0.500 in.] wide specimen shall be symmetrical within 0.2 mm [0.01 in.].

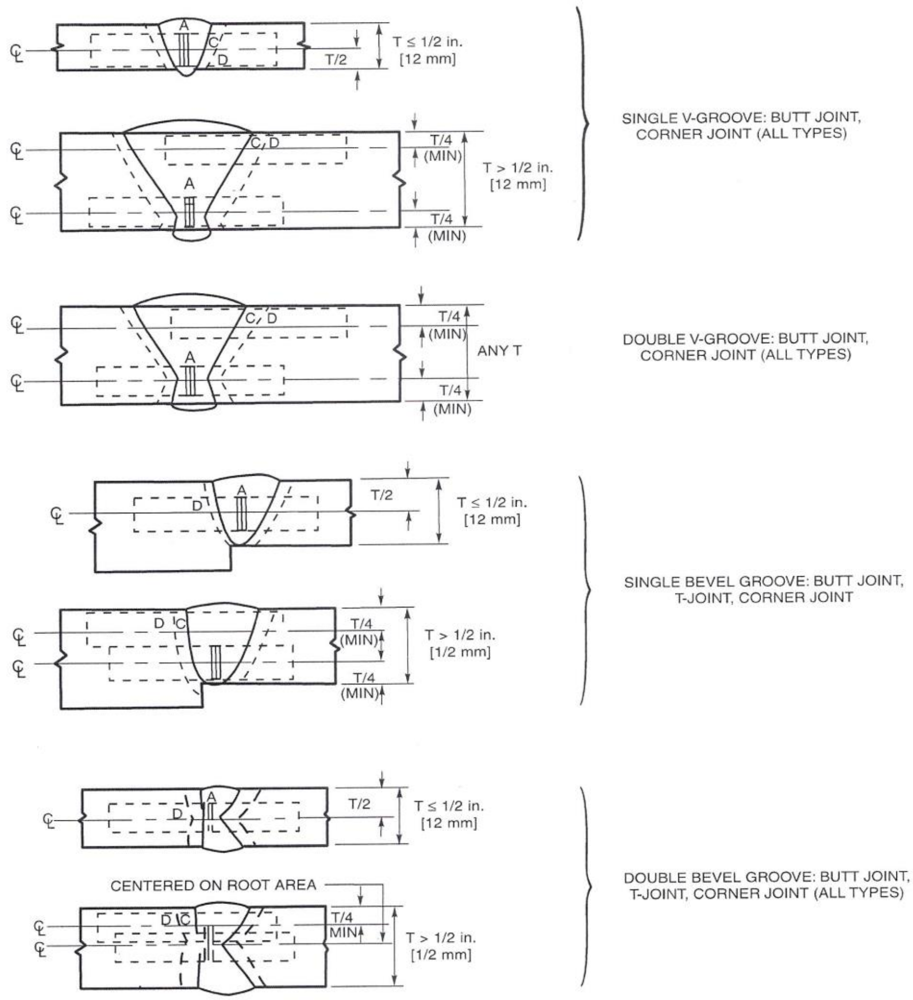
NOTE 11—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 1.25 mm [0.05 in.], and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 0.2 mm [0.01 in.].

NOTE 12—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (a) the above tolerances are used; (b) an adequate number of marks are provided for determination of elongation; and (c) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2 W from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, if the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 1 Rectangular Tension Test Specimens

Annex10: Toughness sample location standard

Menu



A = CENTERLINE OF WELD ON SPECIMEN CENTERLINE
C = HAZ +1 mm FROM FUSION LINE
D = HAZ +5 mm FROM FUSION LINE

Figure III-1—CVN Test Specimen Locations (see III2.1)

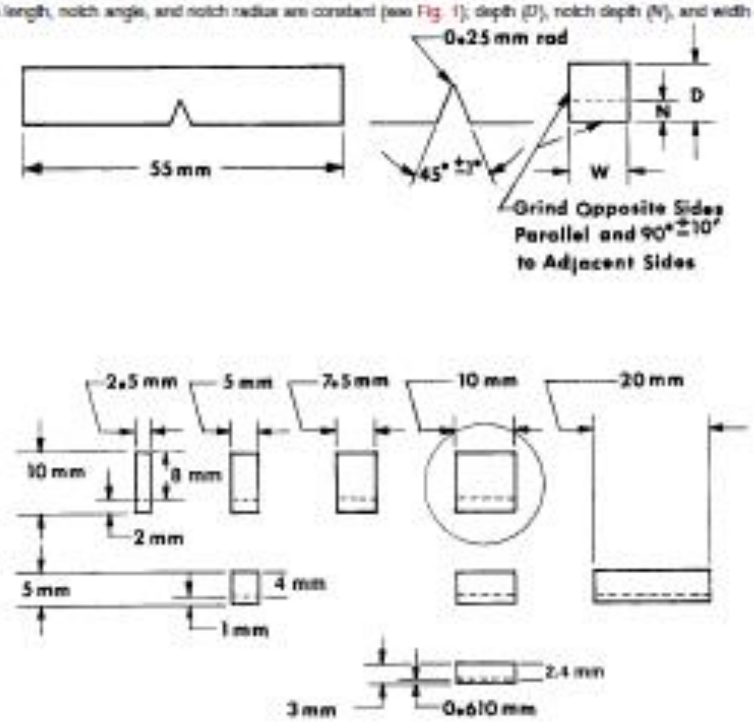
Annex 11: Toughness Sample preparation standard

A3. ADDITIONAL IMPACT TEST SPECIMEN CONFIGURATIONS

A3.1 *Sub-Size Specimen*—When the amount of material available does not permit making the standard impact test specimens shown in Figs. 1 and 2, smaller specimens may be used, but the results obtained on different sizes of specimens cannot be compared directly (X1.3). When Charpy specimens other than the standard are necessary or specified, it is recommended that they be selected from Fig. A3.1.

A3.2 *Supplementary Specimens*—For economy in preparation of test specimens, special specimens of round or rectangular cross section are sometimes used for cantilever beam test. These are shown as Specimens X, Y, and Z in Figs. A3.2 and A3.3. Specimen Z is sometimes called the Philpot specimen, after the name of the original designer. For hard materials, the machining of the flat surface struck by the pendulum is sometimes omitted. Types Y and Z require a different vise from that shown in Fig. A1.3, each half of the vise having a semi-cylindrical recess that closely fits the clamped portion of the specimen. As previously stated, the results cannot be reliably compared with those obtained using specimens of other sizes or shapes.

On sub-size specimens the length, notch angle, and notch radius are constant (see Fig. 1); depth (*D*), notch depth (*N*), and width (*W*) vary as indicated below.



NOTE 1—Circled specimen is the standard specimen (see Fig. 1).
NOTE 2—Permissible variations shall be as follows:

Cross-section dimensions	±1 % or ±0.075 mm, whichever is smaller
Radius of notch	±0.025 mm
Ligament length	±0.025 mm
Finish requirements	2 µm on notched surface and opposite face; 4 µm on other two surfaces

FIG. A3.1 Non-Standard Charpy (Simple-Beam) (Type A) Impact Test Specimens

Annex 12 : Welding certifications of the welder

INTERNATIONAL
INSTITUTE OF WELDING

Having met the Education and Training requirements of IIW Guideline 'International Welding Inspection Personnel' and by examination having satisfied the requirements of the Examination Board of the IIW Authorised National Body

Okelo Fekadu

10th November 1985

is hereby awarded the diploma of

INTERNATIONAL WELDING INSPECTOR

23rd March 2012 ZA/IWI-B00022

TZ Joubert
Chairperson Assessment Committee

J Guild
CEO ANB

SAIW Certification South Africa

SAIW CERTIFICATION

This is to certify that

Okelo Fekadu Roro

EP1037437

Identity Number

has met the requirements of the South African Qualification and Certification Scheme Committee for the Certification of NDT personnel in compliance with ISO 9712 : 2005 to the satisfaction of the Governing Board of SAIW Certification

Ultrasonic Testing	**Butt welds in plate & pipe**
Method	Sector
Two	**2.3/2.4**
Level	Group

This certificate is valid until

12 April 2017

Chairperson, Scheme Committee

12 April 2012

Date of Issue

Certificate Holder

3841

Certificate Number

SAQCC NDT Non-destructive testing

sanas C34

This certificate remains the sole property of SAIW Certification

SAIW
CERTIFICATION

This is to certify that

Okelo Fekadu Roro

EP1037437
Identity Number

has met the requirements of the South African Qualification and Certification Scheme Committee for the Certification of NDT personnel in compliance with ISO 9712 : 2005 to the satisfaction of the Governing Board of SAIW Certification

Radiographic Testing	**X & Gamma Ray Welds – Dense Alloys**
Method	Sector
Two	**2.5/2.6**
Level	Group

This certificate is valid until

12 April 2017

Chairperson, Scheme Committee	**Certificate Holder**
12 April 2012	**3840**
Date of Issue	**Certificate Number**

SAQCC NDT Non-destructive testing

sanas Personnel Certification body C34

This certificate remains the sole property of SAIW Certification

SAIW CERTIFICATION

This is to certify that

Okelo Fekadu Roro

EP1037437

Identity Number

has met the requirements of the South African Qualification and Certification Scheme Committee for the Certification of NDT personnel in compliance with ISO 9712 : 2005 to the satisfaction of the Governing Board of SAIW Certification

Liquid Penetrant Testing	**Multi-sector**
Method	Sector
Two	**2.0**
Level	Group

This certificate is valid until

12 April 2017

Chairperson, Scheme Committee	**Certificate Holder**
12 April 2012	**3839**
Date of Issue	**Certificate Number**

SAQCC NDT Non-destructive testing

sanas Personnel Certification Body C34

This certificate remains the sole property of SAIW Certification

SAIW
CERTIFICATION

This is to certify that

Okelo Fekadu Roro

EP1037437

Identity Number

has met the requirements of the South African Qualification and Certification Scheme Committee for the Certification of NDT personnel in compliance with ISO 9712 : 2005 to the satisfaction of the Governing Board of SAIW Certification

Magnetic Particle Testing	**Multi-sector**
Method	Sector
Two	**2.0**
Level	Group

This certificate is valid until

12 April 2017

Chairperson, Scheme Committee	**Certificate Holder**
12 April 2012	**3838**
Date of Issue	**Certificate Number**

SAQCC NDT
Non-destructive testing

sanas
C34

This certificate remains the sole property of SAIW Certification