EFFECT OF SUBMERGED ARC WELDING ON WELDABILITY AND MECHANICAL PROPERTIES OF IS2062

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BY

BOLEM V K SUSMITHA	**(314126520019)**
JEERI CHAITANYA	**(314126520069)**
ENUKOTI VENKATESH	**(314126520050)**
GORLE HARIKANTH	**(314126520061)**

Under the esteemed guidance of

Sri. M.PRASANTH KUMAR, M.E
ASSISTANT PROFESSOR

DEPARTMENT OF MECHANICAL ENGINEERING
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
(Affiliated to Andhra University)
SANGIVALASA, VISAKHAPATNAM (District) – 531162

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ANIL NEERUKONDA INSTITUTE OF TECHNOGY & SCIENCES

(Affiliated to Andhra University)
Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

PRAGNANAM BRAHMA
ANITS

CERTIFICATE

This is to certify that the Project Report entitled **"OPTIMISATION *OF WELDABILITY CHARACTERSITICS OF IS2062 BY VARYING* INPUT PARAMETERS OF SUBMERGED ARC WELDING"** has been carried out by ***B.SUSHMITHA (314126520019)*** , ***J.CHAITANYA (314126520069), E.VENKATESH (314126520050), G.HARIKANTH (314126520061)*** under the esteemed guidance of Sri. **M.PRASANTH KUMAR**, in partial fulfillment of the requirements for the award of the Degree of Bachelor of Mechanical Engineering by Andhra University, Visakhapatnam.

APPROVED BY	PROJECT GUIDE
(Dr.B.NAGARAJU)	(Sri. M.Prasanth kumar)
Head of the Department	Assistant Professor
Dept. of Mechanical Engineering	Dept. of Mechanical Engineering
ANITS, Sangivalasa	ANITS, Sangivalasa
Visakhapatnam	Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa 531 162 VISAKHAPATNAM Dist A P

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMINER:

Dr. B. Naga Raju
M.Tech,M.E.,Ph.d
Professor & HOD
Dept of Mechanical Engineering
ANITS, Sangivalasa,
Visakhapatnam-531 162.

EXTERNAL EXAMINER:

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BOLEM V K SUSMITHA (314126520019)
JEERI CHAITANYA (314126520069)
ENUKOTI VENKATESH (314126520050)
GORLE HARIKANTH (314126520061)

ABSTRACT

The quality of a weld joint is highly influenced by depth of penetration. Hence, accurate prediction and maximization of depth of penetration is highly essential to ensure a good - quality joint. In this study, the effect of various welding parameters on the weld ability of MS2062 specimens having dimensions 300mm×100mm×16mm welded by Submerged arc welding were investigated. The welding current, arc voltage, welding speed, heat input rate are chosen as welding parameters. The depth of penetrations were measured for each specimen after the welding operation on closed butt joint and the effects of welding speed and heat input rate parameters on depth of penetration, hardness, tensile strength were investigated.

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CHAPTER - I

INTRODUCTION

1.0 The History of Welding

Welding can trace its historic development back to ancient times. The earliest examples come from the Bronze Age. Small gold circular boxes were made by pressure welding lap joints together. It is estimated that these boxes were made more than 2000 years ago. During the Iron Age the Egyptians and people in the eastern Mediterranean area learned to weld pieces of iron together. Many tools were found which were made approximately 1000 B.C.

Edmund Davy of England is credited with the discovery of acetylene in 1836. The production of an arc between two carbon electrodes using a battery is credited to Sir Humphry Davy in 1800. In the mid-nineteenth century, the electric generator was invented and arc lighting became popular. During the late 1800s, gas welding and cutting was developed. Arc welding with the carbon arc and metal arc was developed and resistance welding became a practical joining process.In 1903, a German named Goldschmidt invented thermite welding that was first used to weld railroad rails.

In 1920, automatic welding was introduced. It utilized bare electrode wire operated on direct current and utilized arc voltage as the basis of regulating the feed rate.During the 1920s there was considerable research in shielding the arc and weld area by externally applied gases.

1.1 Introduction of Welding

Welding is an efficient and economical method for joining of metals. Welding has made significant impact on the large number of industries by raising their operational efficiency, productivity and service life of the plant and relevant equipment [1]. Welding is one of the most common fabrication techniques which is extensively used to obtain good quality weld joints for various structural components. The present trend in the fabrication industries is to automate welding processes to obtain high production rate. Welding processes can be automated by establishing the relationship between the process parameters and weld bead geometry to predict and control the weld bead quality [2]. These relationships can be developed by using of experimental design techniques [3]. Submerged arc welding is preferred over other methods of welding because of its high reliability, deep penetration, and smooth finishing and high productivity [4]. Due to high deposition rate, excellent surface appearance, invisible arc and lower welder skill requirement submerged arc welding process is widely used in fabrication of pressure vessel, marine vessel, pipelines and offshore structures [5]. It has also been revealed that slag produced in the process can be reused [6]. So, these qualities have made this welding process as a preferred choice in industries for fabrication.

1.2 Overview of Submerged Arc Welding

Submerged arc welding is an arc welding process in which heat is generated by an arc which is produced between bare consumable electrode wire and the workpiece. The arc and the weld zone are completely covered under a blanket of granular, fusible flux which melts and provides protection to the weld pool from the atmospheric gases.

The molten flux surrounds the arc thus protecting arc from the atmospheric gases. The molten flux flows down continuously and fresh flux melts around the arc. The molten flux reacts with the molten metal forming slag and improves its properties and later floats on the molten/solidifying metal to protect it from atmospheric gas contamination and retards cooling rate.

1.3 Principle of Submerged Arc Welding

Sub Arc welding requires a continuously-fed tubular or consumable solid electrode and may be fully automatic or semi-automatic. The arc is flat and is maintained between the end of a bare wire electrode and the weld. The electrode is constantly fed into the arc and as it is melted, a layer of granular flux provides a protective cover beneath which the welding occurs. The blanket is created as some of the flux becomes molten. Flux physically influences the weld metal as it affects weld bead geometry and load carrying capability [7, 8]. It also affects chemistry of the weld metal by altering its mechanical properties [9, 10] and microstructure of the weld metal [11, 12]. This fusible flux may consist of lime, silica, manganese oxide, calcium fluoride, and other compounds. In a molten or melted state, the flux becomes conductive. This allows it to supply a constant current between the electrode and the welding work. The remainder of the flux is recovered and reused, unless it has become contaminated.

In the automatic version of SAW, the process is performed with a set of rollers driven by a controlled motor to ensure that the wire is fed into the arc at a speed rate that is equivalent to the rate at which the electrode is melted. The arc length remains constant as a result. The SAW process is usually automated; however, there are semi-automated systems available too.

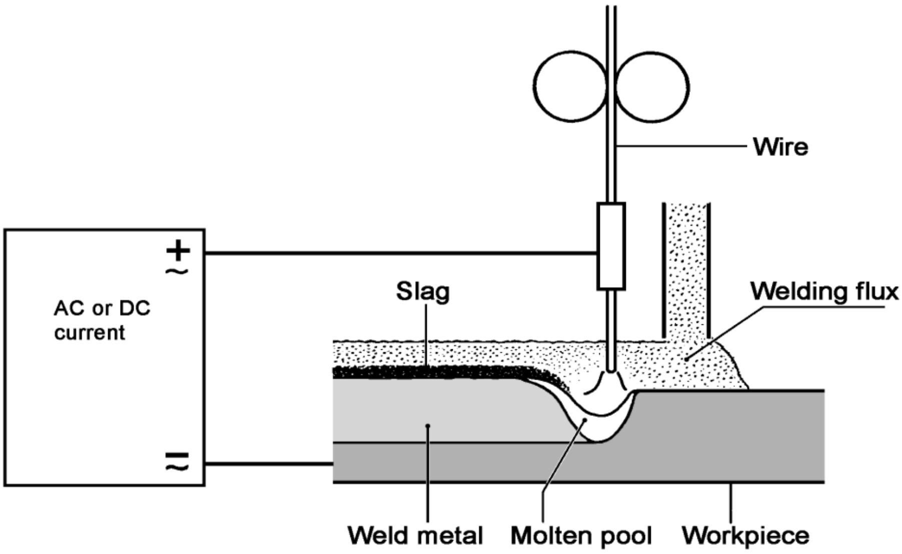

Figure 1.0: Principle of Submerged Arc Welding[13]

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Properly performed Sub Arc welding should consistently result in mechanical properties that are at least equal to that of the base metal. Ductility and impact resistance should be good, and bead appearance should be uniform.

1.4 Equipment for Submerged-Arc Welding

The submerged-arc welding (SAW) process is similar to MIG where the arc is formed between a continuously-fed wire electrode and the workpiece, and the weld is formed by the arc melting the workpiece and the wire. However, in SAW a shielding gas is not required as the layer of flux generates the gases and slag to protect the weld pool and hot weld metal from contamination. Flux plays an additional role in adding alloying elements to the weld pool.

Essential equipment

Essential equipment components for SAW are:

- power source
- SAW head
- flux handling
- protective equipment

As SAW is a high current welding process, the equipment is designed to produce high deposition rates.

1.4.1 Power source

SAW can be operated using either a DC or an AC power source. DC is supplied by a transformer-rectifier and AC is supplied by a transformer. Current for a single wire ranges from as low as 200A (1.6mm diameter wire) to as high as 1000A (6.0mm diameter wire). In practice, most welding is carried out on thick plate where a single wire (4.0mm diameter) is normally used over a more limited range of 600 to 900A, with a twin wire system operating between 800 and 1200A.

In DC operation, the electrode is normally connected to the positive terminal. Electrode negative (DCEN) polarity can be used to increase deposition rate but depth of penetration is reduced by between 20 and 25%. For this reason, DCEN is used for surfacing applications where parent metal dilution is important. The DC power source has a 'constant voltage' output characteristic which produces a self-regulating arc. For a given diameter of wire, welding current is controlled by wire feed speed and arc length is determined by voltage setting.

AC power sources usually have a constant-current output characteristic and are therefore not self-regulating. The arc with this type of power source is controlled by sensing the arc voltage and using the signal to control wire feed speed. In practice, for a given welding current level, arc length is determined by wire burnoff rate, i.e. the balance between the welding current setting and wire feed speed which is under feedback control.

Square wave AC square wave power sources have a constant voltage output current characteristic. Advantages are easier arc ignition and constant wire feed speed control.

1.4.2 *Welding gun*

SAW can be carried out using both manual and mechanised techniques. Mechanised welding, which can exploit the potential for extremely high deposition rates, accounts for the majority of applications.

1.4.2. (a).Manual welding

For manual welding, the welding gun is similar to a MIG gun, with the flux which is fed concentrically around the electrode, replacing the shielding gas. Flux is fed by air pressure through the handle of the gun or from a small hopper mounted on the gun. The equipment is relatively portable and, as the operator guides the gun along the joint, little manipulative skill is required. However, because the operator has limited control over the welding operation (apart from adjusting travel speed to maintain the bead profile) it is best used for short runs and simple filling operations.

As SAW is often used for welding large components, the gun, wire feeder and flux delivery feed can be mounted on a rail, tractor or boom manipulator. Single wire welding is mostly practiced using DCEP even though AC will produce a higher deposition rate for the same welding current. AC is used to overcome problems with arc blow, caused by residual magnetism in the work piece, jigging or welding machine.

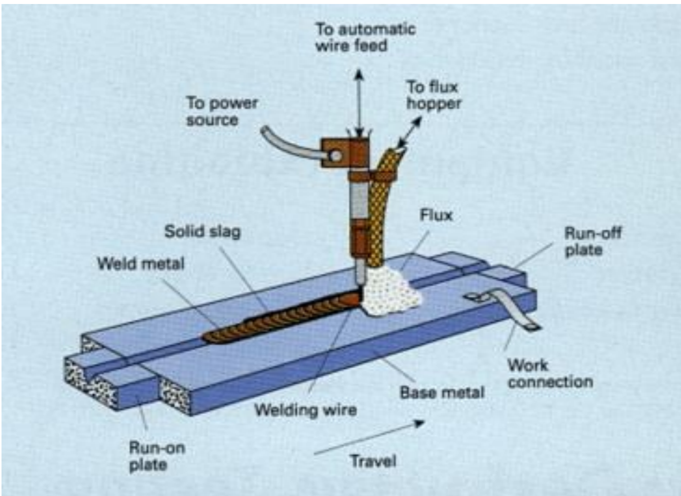


Figure1.1: *Mechanized welding - single wire*

Mechanized welding - twin wire

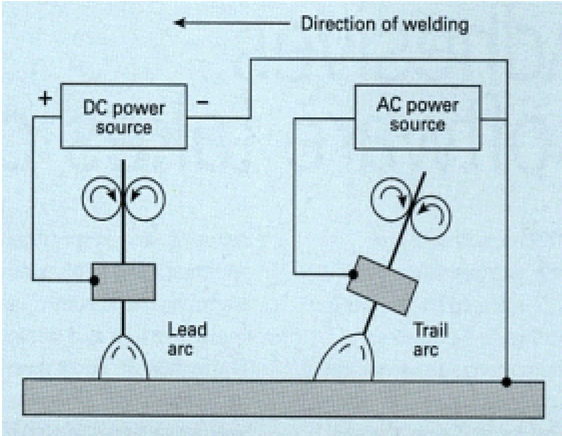


Figure 1.2: *Tandem arc connections*

SAW can be operated with more than one wire. Although up to five wires are used for high deposition rates, e.g. in pipe mills, the most common multi-wire systems have two wires in a tandem arrangement. The leading wire is run on DCEP to produce deep penetration. The trailing wire is operated on AC which spreads the weld pool, which is ideal for filling the joint. AC also minimizes: interaction between the arcs, and the risk of lack of fusion defects and porosity through the deflection of the arcs (arc blow). The wires are normally spaced 20mm apart so that the second wire feeds into the rear of the weld pool.

1.4.3 Wire stick out, or electrode extension

The distance the wire protrudes from the end of the contact tip is an important control parameter in SAW. As the current flowing between the contact tip and the arc will preheat the wire, wire burn off rate will increase with increase in wire stick out. For example, the deposition rate for a 4mm diameter wire at a welding current of 700A can be increased from approximately 9 kg/hr at the normal 32mm stick out, to 14 kg/hr at a stick out length of 178mm. In practice, because of the reduction in penetration and greater risk of arc wander, a long stick out is normally only used in cladding and surfacing applications where there is greater emphasis on deposition rate and control of penetration, rather than accurate positioning of the wire.

For most applications, electrode stickout is set so that the contact tube is slightly proud of the flux layer. The depth of flux is normally just sufficient to cover the arc whose light can be seen through the flux.

Table.1.0: Recommended and maximum stick-out lengths

Wire diameter (mm)	**Current range (Amp)**	**Wire stickout**	
		Normal (mm)	**Maximum (mm)**
0.8	100 to 200	12	-
1.2	150 to 300	20	-
1.6	200 to 500	20	-
2.0	250 to 600	25	63
3.2	350 to 800	30	76
4.0	400 to 900	32	128
4.75	450 to 1000	35	165

1.4.4 Gun angle

In manual welding, the gun is operated with a trailing angle, i.e. with the gun at an angle of 45 degrees (backwards) from the vertical. In single wire mechanised welding operations, the gun is perpendicular to the workpiece. However, in twin wire operations the leading gun is normal to the workpiece, with the trailing gun angled slightly forwards between an angle of 60 and 80 degrees. This reduces disturbance of the weld pool and produces a smooth weld bead profile.

1.4.5 Flux handling

Flux should be stored in a humidity-controlled store. While flux from a newly-opened package is ready for immediate use, flux which has been opened and held in a store should first be dried according to manufacturer's instructions. In small welding systems, flux is usually held in a small hopper above the welding gun.

It is fed automatically (by gravity or mechanised feed) ahead of the arc. In larger installations the flux is stored in large hoppers and is fed with compressed air. Unused flux is collected using a vacuum hose and returned to the hopper.

1.4.6 Protective equipment

Unlike other arc welding processes, SAW is a clean process which produces minimum fume and spatter when welding steels (Some noxious emissions can be produced when welding special materials). For normal applications, general workshop extraction should be adequate.

Protective equipment such as a head shield and a leather apron are not necessary. Normal protective equipment (goggles, heavy gloves and protective shoes) are required for ancillary operations such as slag removal by chipping or grinding. Special precautions should be taken when handling flux - a dust respirator and gloves are needed when loading the storage hoppers.

1.5 Joint Preparation

Joint preparation depends on plate thickness; type of joint e.g. circumferential or longitudinal and to some extent on the standards to which the structure is being made. Plates of up to 14mm thick can be butt welded without preparation with a gap not exceeding 1mm or 10% of the plate thickness, whichever is the greater. Thicker plates need preparation if full penetration is to be obtained.

A welder using stick electrodes can adjust his technique to cope with varying joint gaps and root faces or varying dimensions.[14]Not so an automatic welding head. If conditions are set up for a root gap of 0.5mm and this increases to 2 or 3mm, burn through will occur unless an efficient backing strip is used. In such circumstances a hand welded root run using MIG or MMA is advisable. All plate edges must be completely clean and free from rust, oil, mill scale, paint, etc. If impurities are present and are melted into the weld, porosity and cracking can easily occur.

Time spent in minimizing such defects by careful joint preparation and thorough inspection prior to welding is time well spent since cutting out weld defects and re welding is expensive and time consuming.

1.6 Welding Parameters

Selection of the correct welding conditions for the plate thickness and joint preparation to be welded is very important if satisfactory joints free from defects such as cracking, porosity and undercut are to be obtained.

The process variables, which have to be considered, are:

a. Electrode polarity
b. Welding current
c. Electrode diameter
d. Arc voltage
e. Welding speed
f. Electrode extension
g. Electrode angle
h. Flux depth

These are the variables that determine bead size, bead shape, and depth of penetration and in some circumstances metallurgical effects such as incidence of cracking, porosity and weld metal composition.

1.6.1. Electrode polarity

The deepest penetration is obtained with DC reverse polarity (DC electrode positive, DCEP) which also gives the best surface appearance, bead shape and resistance to porosity. Direct current straight polarity (DC electrode negative, DCEN) gives faster burn off (about 35%) and shallower penetration since the maximum heat is developed at the tip of the electrode instead of at the surface of the plate. For this reason DC electrode negative polarity is often used when welding steels of limited weldability and when surfacing/cladding since, in both cases, penetration into the parent material must be kept as low as possible. The flux/wire consumption ratio is less with electrode negative polarity than with electrode positive polarity, so that alloying from the flux is reduced.

With DC polarity the maximum current used is 1000 amperes due to arc blow problems. In changing from positive to negative polarity some increase in arc voltage may be necessary to obtain a comparable bead shape.

Alternating current gives a result about half way between DC electrode positive and DC electrode negative and usually gives a flatter, wider bead. It can be used on multihead systems and is particularly useful when arc blow is a problem. It is often used in tandem arc systems where a DC positive electrode is used as the leading electrode and an AC electrode as the trail.

1.6.2 Welding current

Increasing the wire feed speed increases the welding current so that the deposition rate increases as the welding current increases. The wire feed speed is the most influential control of fusion and penetration. The current density controls the depth of penetration - the higher the current density the greater the penetration. For a given flux, arc stability will be lost below a minimum threshold current density so that if the current for a given electrode diameter is too low arc stability is lost and a rugged, irregular bead is obtained. Too high a current density also leads to instability because the electrode overheats and undercutting may also occur.

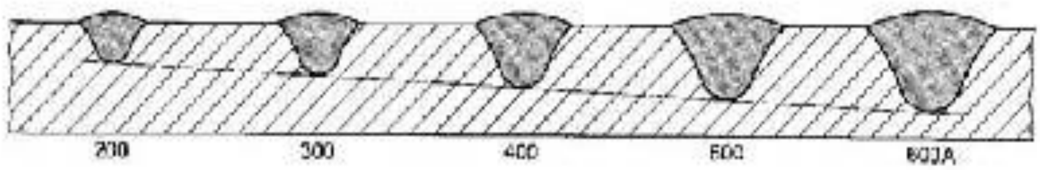


Figure 1.3: Variation of depth of penetration with welding speed

1.6.3. Electrode Diameter

For given current, changing the electrode diameter will change the current density. Therefore a larger diameter electrode will reduce penetration and the likelihood of burn through, but at the same time arc striking is more difficult and arc stability is reduced.

1.6.4. Arc voltage

The arc voltage controls the arc length, flux consumption and weld metal properties. Increase in arc voltage increases the arc length which results in wider bead width [15]. As increasing the arc voltage increases the arc length so more heat is available to melt the metal and flux due to which more alloying elements enter the weld metal.

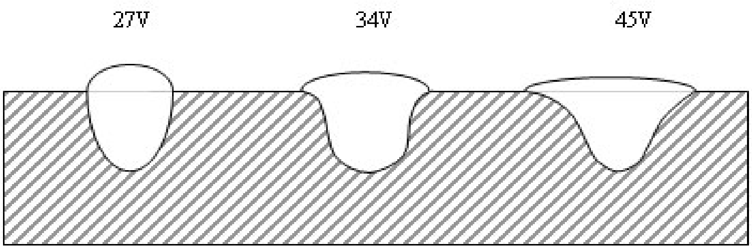


Figure 1.4: Effect of arc voltage on weld bead

Thus arc voltage affects the weld metal composition. Flux consumption is also increased as more flux is melted. Murugun et al. [16] observed that voltage has no significant effect on penetration, reinforcement decreases but bead width increases with increases in voltage. For a particular electrode diameter and extension irrespective of the electrode positive or negative polarity there is increases in bead width with increase in voltage [17].

1.6.5. Welding speed

Welding speed or travel speed controls depth of penetration. Faster speeds reduce penetration and bead width, increase the likelihood of porosity and, if taken to the extreme, produce undercutting and irregular beads. At high welding speeds the arc voltage should be kept fairly low otherwise arc blow is likely to occur. If the welding speed is too slow burn through can occur. A combination of high arc voltage and slow welding speed can produce a mushroom shaped weld bead with solidification cracks at the bead sides.

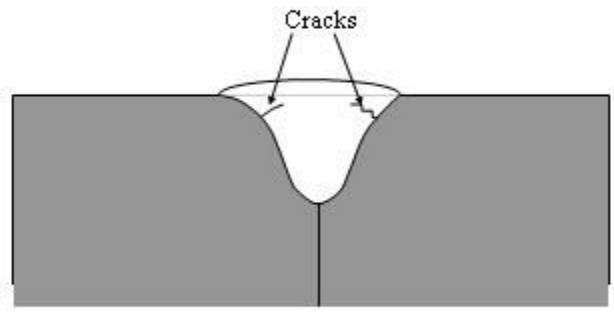


Figure 1.5: Crack formation

1.6.6 Electrode extension

Also known as electrode stick out and alters the tip to work distance. Electrode extension governs the amount of resistance heating which occurs in the electrode. If the extension is short the heating effect is small and penetration is deep. Increasing the extension increases the temperature of the electrode, which decreases the penetration, but deposition rates are increased. Increased extension is therefore useful in cladding and surface applications, but steps have to be taken to guide the electrode, otherwise it wanders.

For normal welding the electrode extension should be 25 - 30mm for mild steel and less, about 20 - 25mm, for stainless steel. This is because the electrical sensitivity of stainless wire is appreciably greater than that of mild steel wire.

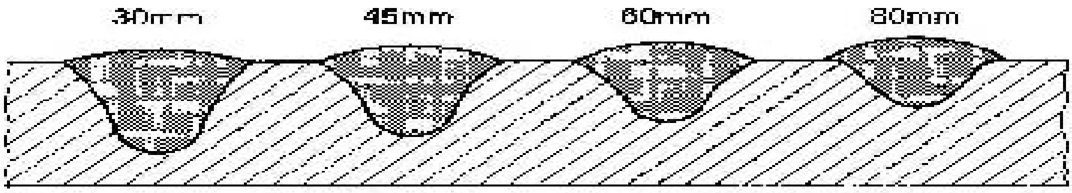


Figure 1.6: Variation of depth of penetration with electrode extension

1.6.7 Electrode angle

Since the angle between the electrode and the plate determines the point of application and direction of the arc force it has a profound effect on both penetration and undercut. The first figure shows the effect on horizontal/vertical fillet welds and the second figure compares the effect obtained with a vertical arc with those obtained with leading and trailing arcs. The effect on undercutting can be particularly marked.

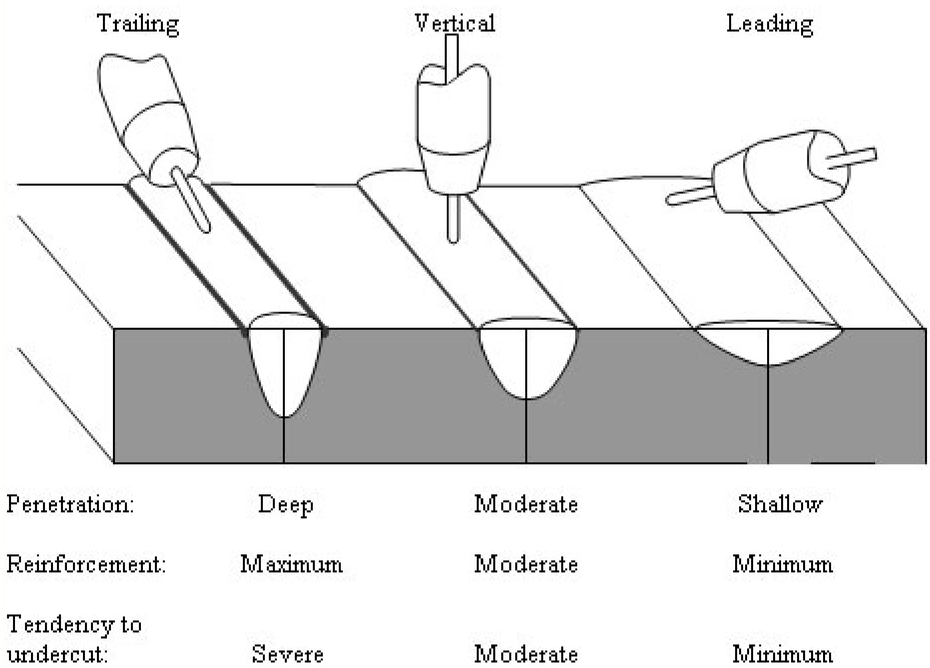


Figure 1.7: Effect of electrode angle on butt welds

1.6.8 Flux depth

The depth of the flux, or flux burden, is often ignored and the powder heaped around the wire until the arc is completely covered. If optimum results are to be obtained the flux depth should be just sufficient to cover the arc, although the point where the electrode enters the flux bed light reflected from the arc should be just visible. Too shallow a flux bed gives flash-through and can cause porosity because of inadequate metallurgical protection of the molten metal. Too deep a flux bed gives a poor bead appearance and can lead to spillage on circumferential welds.[18] On deep preparations in thick plate it is particularly important to avoid excessive flux depth otherwise the weld bead shape and slag removal can be unsatisfactory.

1.7 Process variants

The submerged arc process is somewhat unusual in that the welding consumables, unlike the other fluxed processes of MMA or FCAW, comprise two components, the wire and the flux, that may be supplied separately.

Since both the wire and the flux will have an effect on the weld metal composition, and hence on the mechanical properties, the welding engineer is faced with choosing the appropriate wire/flux combination for the application.

1.7.1 Wire

SAW is normally operated with a single wire on either AC or DC current. Common variants are:

- twin wire
- multiple wire (tandem or triple)
- single wire with hot or cold wire addition
- metal powder addition
- tubular wire

All contribute to improved productivity through a marked increase in weld metal deposition rates and/or travel speeds. A narrow gap process variant is also established, which utilizes a two or three bead per layer deposition technique.

1.7.2 Flux

Fluxes used in SAW are granular fusible minerals containing oxides of manganese, silicon, titanium, aluminum, calcium, zirconium, magnesium and other compounds such as calcium fluoride. The flux is specially formulated to be compatible with a given electrode wire type so that the combination of flux and wire yields desired mechanical properties. All fluxes react with the weld pool to produce the weld metal chemical composition and mechanical properties. It is common practice to refer to fluxes as 'active' if they add manganese and silicon to the weld, the amount of manganese and silicon added is influenced by the arc voltage and the welding current level.

1.8 Submerged Arc Flux

Granular flux used in welding is a type of granular insulative material that is made up of numerous small particles. In Submerged Arc Welding (SAW), the granular flux provides a blanket over the weld, which protects against sparks and spatter. In SAW, the granular flux is frequently the means for achieving high deposition rates. The flux is also instrumental in producing the type of quality weld that is common in this particular welding process.

1.8.1 Functions of Flux in Sub Arc Welding

The effect of gravity on the flux feeding into the weld area and the molten weld pool limits the versatility of Submerged Arc Welding. This process must be performed in the flat and horizontal fillet positions only, except in special cases. These special cases include vertical and horizontal welds using special equipment, such as belts or shoes, to hold the flux in position.

The granular flux used in SAW serves several functions. In addition to providing a protective cover over the weld, the flux shields and cleans the molten puddle. The flux also affects the chemical composition of the weld metal, the weld bead shape, and the mechanical properties of the weld.

Another function of granular flux is to act as a barrier that holds the heat in and concentrates the heat into the weld area to promote deep penetration.

1.8.2 Types of Granular Fluxes

The methods used to manufacture fluxes determine the flux types. There are fused fluxes, bonded fluxes, agglomerated fluxes, and mechanically mixed fluxes.[19] When manufacturing *fused fluxes,* raw materials are melted into a liquid state with a high temperature electric furnace. The material is then cooled and crushed or ground into the desired particle size.

When making *bonded fluxes,* the ingredients are dry mixed, then glued together with a liquid binder. This binder may be a liquid such as sodium silicate. After the particles are bonded, they are baked and then sifted through a sieve to attain flux particles of the desired size.

Agglomerated fluxes are manufactured much the same way that bonded fluxes are made. However, instead of a liquid binder, a ceramic binder is used. A higher drying temperature is used, too. (The higher drying temperature limits the use of deoxidizers and alloy elements.)

Fluxes that are *mechanically mixed* are combinations of two or more bonded or agglomerated fluxes. Although mechanically mixed fluxes make it possible to create special mixtures for more sensitive welds, these fluxes may separate during storage, use, and recovery of flux.

Fused Fluxes versus Bonded Fluxes

Among the various types of fluxes use in Submerged Arc Welding are the fused flux and the bonded flux. Each of these fluxes offers some advantages and some disadvantages.

1.8.3 Fused Fluxes

When making fused fluxes, the raw materials are dry mixed together, and then they are fused or melted into a liquid state by using a high temperature furnace. After fusion is complete, the fluxes are cooled. This may be accomplished by using a stream of water or with big chill blocks.

Once the fluxes are cooled, they are crushed or ground into particles. A variety of particle sizes are made to ensure optimal performance for different applications.

Advantages of fused fluxes include:

- The non-hygroscopic flux particles do not absorb moisture and, therefore, any surface moisture can be eliminated merely by drying the particles at a low temperature oven setting of 300 degrees F.
- Low temperature drying of condensation on the fused flux particles provides better protection against hydrogen cracking.
- Flux particles create welds that are chemically consistent.
- Recycling of fused flux particles through the flux recovery systems can be achieved without losing sizing or composition.

A disadvantage of fused fluxes is that the high temperature used during the manufacture process makes it difficult to add alloys and deoxidizers.

1.8.4 Bonded Fluxes

The manufacture of bonded fluxes involves combining the dry ingredients, then using a liquid binder such as sodium silicate or potassium silicate to glue the ingredients together. After the bonded mix is made into pellets, the pellets are baked at a low oven temperature. Once the drying of the pellets is complete, the pellets are broken up by using a sieve to attain the desired particle size. The particles are then packaged for shipping.

Advantages of bonded fluxes include:

- Deoxidizers are present in bonded fluxes, protecting against rust and mill scale. These deoxidizers also help to prevent welds from becoming porous.
- Alloys can be added to bonded fluxes. Alloy elements may improve chemical and mechanical properties of the flux.
- Bonded fluxes allow for a thicker flux layer when welding.
- Bonded fluxes can be identified by color.
- Bonded fluxes typically provide better peeling properties than fused fluxes.

There are at least two disadvantages of using bonded fluxes. These are:

- They absorb moisture.
- They can change in composition due to segregation or loss of fine particle size.

1.8.5 Welding wire

The welding wire is generally of a composition that matches that of the parent metal and wires are available for the welding of carbon and low and high alloy steels, stainless steels, nickel and copper/nickel alloys. In addition, submerged arc welding may be used for surfacing with corrosion or wear resistant coatings using both wires and flat strips. The wires may be solid or metal cored. Strips may be rolled or sintered.

Welding wires vary from 1.2mm ('thin' wire or twin wire submerged arc) to 6.4mm in diameter and are capable of carrying welding currents ranging from 150 to 1600amps. The wires for ferritic steels are generally copper coated to increase contact tip life, improve electrical conductivity and extend the shelf life. Stainless steel and nickel alloy wires are bright drawn and uncoated. The wire is supplied on reels weighing 10 to 50kg and can also be obtained in large pay-off packs weighing up to 500kg. The strip used for surfacing is supplied in 15 to 240mm widths but the thickness is a standard 0.5mm. As with the wire, strip is available in a range of coil weights.

Whilst the wire is relatively simple and is designed to match the parent metal composition and/or mechanical properties, the flux is far more complex.

BS EN ISO 14171:2010 is the specification for Welding consumables:
Solid wire electrodes, tubular cored electrodes and electrode/flux combinations for submerged arc welding of non alloy and fine grain steels. This standard replaces BS EN 756:2004.

The specification covers the classification of the wire chemical composition and the wire/flux combination. It also specifies the mechanical properties of all weld metal deposits in the as-welded condition.
This standard is a combined specification providing for classification utilizing a system based upon the yield strength and the average impact energy for weld metal of 47 J, or utilizing a system based upon the tensile strength and the average impact energy for weld metal of 27 J.
The classification is composed of:

- A reference to the standard 'ISO 14171'

- A symbol 'A' if the classification is based on yield strength and average impact energy is 47J or 'B' if the classification is based on tensile strength average impact energy is 27J.

And of five parts, plus a sixth supplementary part:

Examples of designations:

The designation for an electrode/flux combination for submerged arc welding for multi-run technique depositing a weld metal with minimum yield strength of 460 MPa (46) and minimum average impact energy of 47 J at -30°C (3) produced with an aluminate-basic flux (AB) and a wire S2 would be: ISO 14171-A-S 46 3 AB S2

1.9 Variations of the Submerged Arc Welding Process

The submerged arc welding process may be varied in a number of ways to give it more capabilities. These include, but are not limited to, varying the number of wires and power sources, adding iron powder to the flux, and using a strip electrode for surfacing.

1.9.1 Multi-wire systems offer advantages, because the use of more electrodes can improve deposition rates and travel speeds. The utilization of more than one electrode in submerged arc welding may be accomplished with either a single power source or separate power sources for each wire.

The use of multiple power sources with two or more electrodes allows for the utilization of different polarities on the electrodes. Also, with separate power sources for two electrodes, alternating current may be used on one, while direct current is used on the other electrode. Typically, when three wires are used in the tandem position (one electrode is placed in front of the other), alternating current is used. The electrodes are connected to three-phase power systems, which are used for making high-speed longitudinal seams on large pipes and fabricated beams.

1.9.2 Adding iron powder to the flux increases deposition rates of submerged arc welding, but it does not decrease the properties of the weld metal.

1.9.3 The utilization of a strip electrode for surfacing may be done to save money. This particular welding system uses the strip electrode and flux to make a corrosion-resistant overlay on a less expensive base material such as stainless steel. During this procedure, a wide, uniform bead is produced that has minimum penetration. The uniform bead is necessary to provide a smooth overall surface. The strip welding system is often used for overlaying the inside of vessels. The flux that is used in strip surfacing is made specifically for that purpose.

1.10 Advantages and Disadvantages of Submerged Arc Welding

Some of the ***advantages*** of submerged arc welding include:

- High deposition rates (over 100 lb/h (45 kg/h) have been reported).
- High operating factors in mechanized applications.
- Deep weld penetration.
- Sound welds are readily made (with good process design and control).
- High speed welding of thin sheet steels up to 5 m/min (16 ft/min) is possible.
- Minimal welding fume or arc light is emitted.
- Practically no edge preparation is necessary.
- The process is suitable for both indoor and outdoor works.
- Low distortion
- Welds produced are sound, uniform, ductile, and corrosion resistant and have good impact value.
- Single pass welds can be made in thick plates with normal equipment.
- The arc is always covered under a blanket of flux, thus there is no chance of spatter of weld.
- 50% to 90% of the flux is recoverable.
-

Disadvantages

- Limited to ferrous (steel or stainless steels) and some nickel based alloys.
- Normally limited to the 1F, 1G, and 2F positions.
- Normally limited to long straight seams or rotated pipes or vessels.
- Requires relatively troublesome flux handling systems.
- Flux and slag residue can present a health & safety concern.
- Requires inter-pass and post weld slag removal.

1.11 Applications

SAW is ideally suited for longitudinal and circumferential butt and fillet welds. However, because of high fluidity of the weld pool, molten slag and loose flux layer, welding is generally carried out on butt joints in the flat position and fillet joints in both the flat and horizontal-vertical positions. For circumferential joints, the workpiece is rotated under a fixed welding head with welding taking place in the flat position. Depending on material thickness, either single-pass, two-pass or multipass weld procedures can be carried out. There is virtually no restriction on the material thickness, provided a suitable joint preparation is adopted. Most commonly welded materials are carbon-manganese steels, low alloy steels and stainless steels, although the process is capable of welding some non-ferrous materials with judicious choice of electrode filler wire and flux combinations.

CHAPTER - II

LITERATURE REVIEW

2.1 INTRODUCTION

Before going with our project a brief study on papers related to welding is done. Many authors gave different ideas related to their works on the analysis of the submerged arc welding. The details of different papers are presented in this review.

- RAVINDER PAL SINGH, R.K.GARG, D.K.SHUKLA, "Parametric Effect on Mechanical Properties in Submerged arc welding process –A review"International Journal of Engineering Science and Technology (IJEST), ISSN : 0975-5462 Vol. 4 No.02 February 2012.

Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be assessed in terms of weld bead geometry, mechanical properties and distortion. Higher quality and cost effective welds can be achieved by understanding the weld metal properties and the influence of welding parameters. A comprehensive review of parameters of submerged arc welding and their effect on weld quality have been reported in this paper.

- K. Lakshminarayanan, V. Balasubramanian,K. Elangovan "Effect of welding processes on tensile properties of AA6061 aluminum alloy joints" International journal on Advanced Manufacturing Technology (2009) 40:286–296Springer-Verlag London Limited 2007.

The present investigation is aimed at to study theeffect of welding processes such as GTAW, GMAW and FSW on mechanical properties of AA6061 aluminium alloy. In the above work, tensile properties, micro hardness, microstructure and fracture surface morphology of the GMAW, GTAW and FSW joints have been evaluated, and the results are compared.

- S. P. Tewari, Ankur Gupta, JyotiPrakash, “Effect of welding parameters on the weldability of material” , S. P. Tewari et. al. / International Journal of Engineering Science and Technology, Vol. 2(4), 2010, 512-516.

In the above study, the effect of various welding parameters on the weldability of Mild Steel specimens having dimensions 50mm× 40mm× 6 mm welded by metal arc welding were investigated. The welding current, arcvoltage, welding speed, heat input rate are chosen as welding parameters. The depth of penetrations weremeasured for each specimen after the welding operation on closed butt joint and the effects of welding speedand heat input rate parameters on depth of penetration were investigated.

- J. Amanie1, I. N. A. Oguocha and S. Yannacopoulos “Effect of submerged arc welding parameterson microstructure of SA516 steel weld metal”Canadian Institute of Mining, Metallurgy and PetroleumPublished by Maney on behalf of the InstituteDOI 10.1179/000844311X13117643274794.

The influence of submerged arc welding (SAW) process parameters on the microstructure ofSA516 grade 70 steel weld metal (WM) was investigated in the above paper. The morphologies and volume fractions of the various ferrites in the WM were studied using optical microscopy and the morphologies and chemical compositions ofthe WM inclusions were examined using scanning electron microscopy and energy dispersive Xrayspectrometry. The results showed that the WM grain structure coarsened but the grain widthof prior austenite grains decreased with increasing heat input.

- R Sudhakaran, V Vel-Murugan and PS Sivasakthivel,“Effect of Process Parameters on Depth of Penetration inGas Tungsten Arc Welded (GTAW) 202 Grade StainlessSteel Plates Using Response Surface Methodology” TJER 2012, Vol. 9, No. 1, 64-79.

The quality of a welded joint is directly influenced by the welding input parameters. Inadequate weld bead dimensions such as shallow depth of penetration may contribute to failure of a welded structure since penetration determines the stress carrying capacity of a welded joint. In this study, the regression model was used to establish a relationship between welding input parameters and depth of penetration for gas tungsten arc welding of 202 grade stainless steel plates.

From the above works, it has been observed that much work is not reported so far to investigate the effect of depth of penetration in SAW on the mechanical properties of the weld joint. Hence an attempt was made to correlate the mechanical properties and depth of penetration with the help of their microstructures.

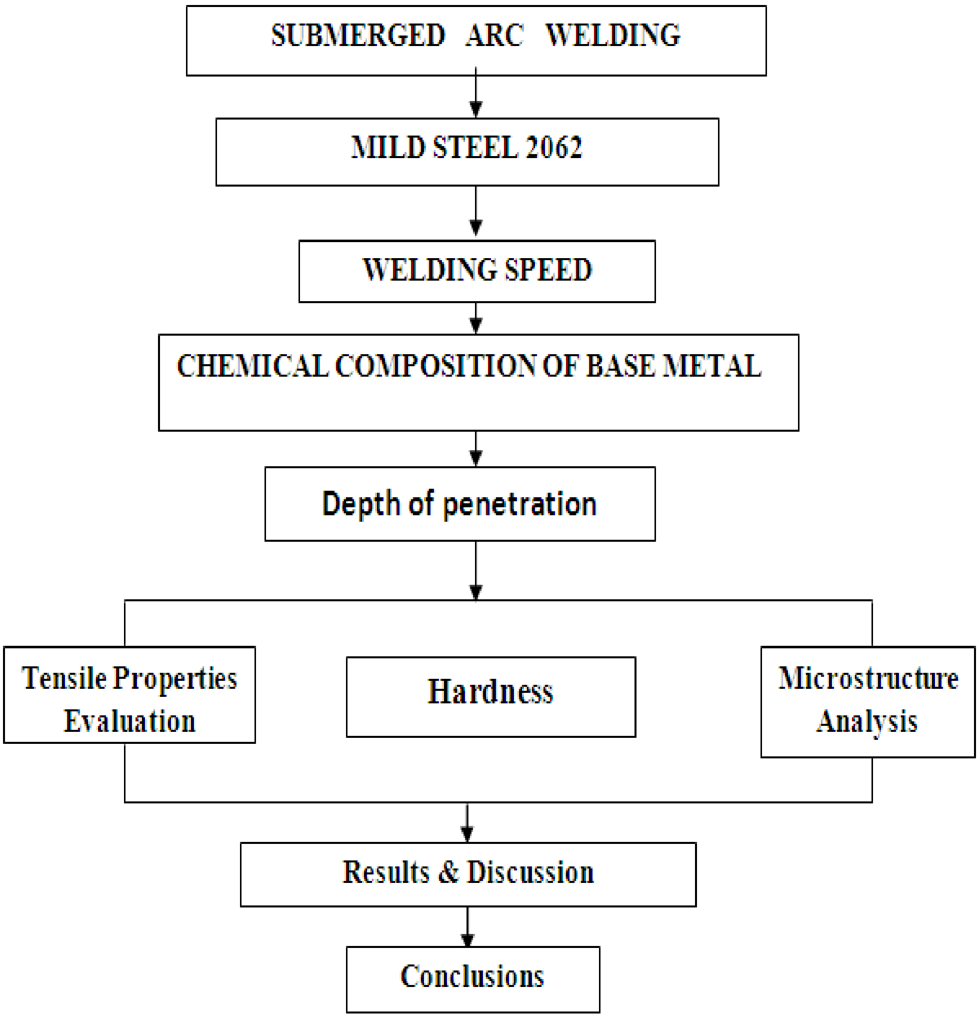
CHAPTER - III

EXPERIMENTAL DETAILS

3.0 BASE METAL

MS 2062 is taken as a base metal, which is a low carbon steel. And it is known as for "Steel for general structural purposes". The main applications are of pressure vessels, bridge beams, massive water pipes, thin sheet shells. As in above mentioned applications generally submerged arc welding is used hence it is taken as the base metal. The low carbon content allows excellent weldability with all processes usually no preheat inter-pass or post-heat necessary.

3.1 EXPERIMENTATION PLAN



3.2 CHEMICAL COMPOSITION

The base metal taken is tested under a chemical composition tester and the obtained chemical composition of MS 2062 is as follow:

Table 3.0: Chemical composition of the base metal

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Aluminum	Iron
0.18	0.79	0.017	0.010	0.18	0.026	Balance

Figure 3.0: Chemical composition tester

3.3 Weld joint preparation

MS-2062 sheets of 16mm thickness are chosen for welding. First the sheets were cut into 150mm x 100mm x 16mm size using power saw and cleaned. Copper sinks are fixed to fixtures to minimize the distortion and extreme care has to be taken for proper butting of sheets. The following assembly techniques are done in order to minimize the distortion.

- Tack welding
- Back-to-back assembly
- Stiffening

Figure 3.1: Assembly techniques

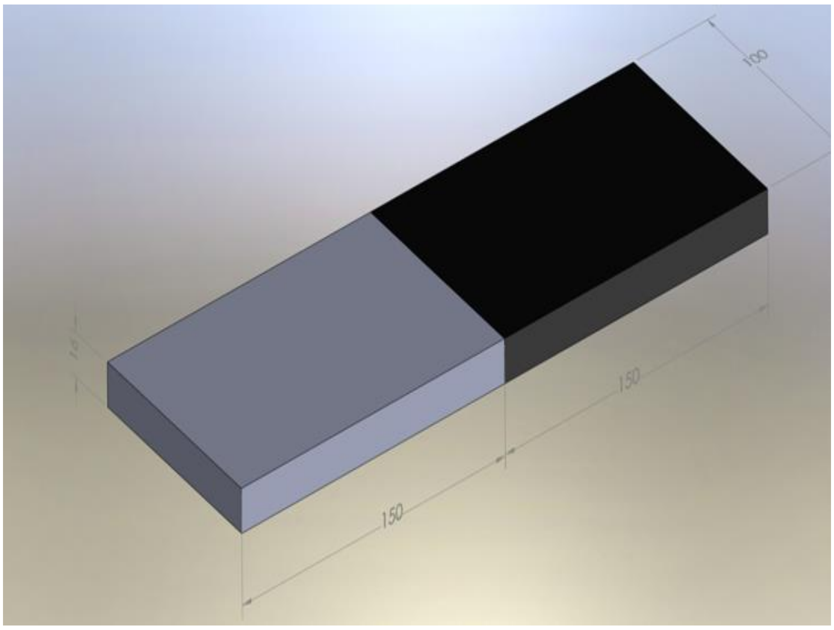


Figure 3.2: Dimensions of welded joint

3.4 Experimental conditions

Welding was carried out on submerged arc welding Machine at Uma constructions, Autonagar Visakhapatnam.

IS2062 sheets of 150 x 100 x 16 mm are welded autogenously with closed butt joint. Submerged arc welding (SAW) is carried out on these specimens using automated welding machine with consumable electrode E2062, 4mm dia.Granulated flux powder is used to submerge the arc. The welding has been carried out under the welding conditions presented in table 3.2.There are many influential process parameters which affect the weld quality of SAW process like welding speed, wire fed speed, welding current, welding voltage, etc. From the earlier works it is observed that welding speed is one of the major parameters that effect the weld quality characteristics. Here welding current, welding voltage, wire fed rate are taken as constant process parameters and welding speed is considered as variable process parameter.

Details about experimental setup are shown in Figure-11 and Welding conditions in Table-3.

Figure 3.3: Experimental setup of SAW

Table 3.1: Welding conditions

Electrode	E2062
Electrode diameter	4mm
Flux powder	Granulated
Nozzle to plate distance	1mm
Torch position	Vertical
Operation type	Automatic

Table-3.2: Important weld parameters

Serial No	Input Factor	Units	Value
1	Welding Voltage	Volts	600
2	Welding Current	Amperes	32
3	Welding Speed	mm/min	Variable
4	Wire fed rate	mm/min	25

3.5 Preparation of test specimens

Every welded specimen of size 300 x 100 x 16 mm which is welded at constant speed is cut into 3 pieces of size 300 x 30 x 16 mm. The test specimen for analysis of different mechanical properties like tensile strength and hardness were prepared as per ASTM standard and its description is given below. Specimens are also prepared for metallography.

3.5.1 Specimen for tensile strength test

A tensile test specimen as per ASTM E-8 standard is prepared for this purpose is based on the following equation.

$$L_0 = 5.65(A_0)^{1/2}$$

Where, L_0 = Gauge length

A_0 = Cross sectional area

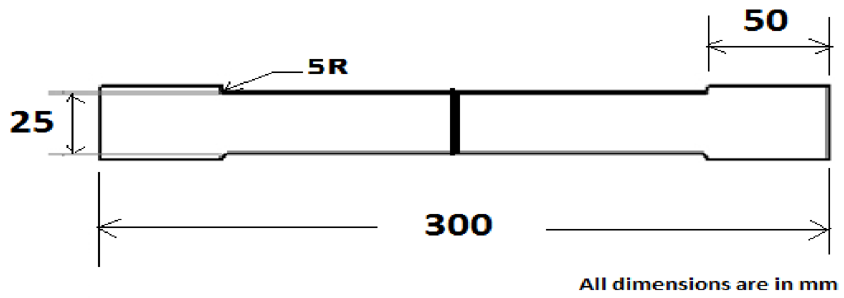


Figure 3.4: Tensile test specimen

Dimensions of specimen for tensile test

Width - 25 mm

Thickness - 16 mm

Gauge length - 100 mm

Grip distance - 50 mm

3.5.2 Specimen preparation for microstructure analysis

Specimen preparation is necessary for to study its microstructure, because the metallurgical microscope makes use of the principle of reflection of light to obtain the final image of the metal structure.

Satisfactory metallographic results can be obtained only, when the specimen has been carefully prepared. Even the most costly microscope cannot reveal the metal structure if the specimen has been poorly prepared.

A properly prepared metal specimen

- Is flat
- Does not contain scratches,
- Is nicely polished, and
- Is suitably etched.

Steps involved.

Procedure for preparing the specimen for micro examination is as follows

1. Selection of specimen

When investigating the properties of a metal or alloy, it is essential that specimen should be selected from that area of the alloy plate or casting which can be taken as representative of the whole mass.

2. Cutting of the specimen

After selecting particular area in the whole mass, the specimen may be removed with the help of a saw.

3. Obtaining flat specimen surface

It is necessary to obtain a reasonably flat specimen surface on the specimen. This is achieved by using fairly coarse file or machining or grinding, by using a motor driven emery belt.

4. Intermediate and fine grinding

Intermediate and fine grinding is carried out using emery papers of progressively finer grade The emery papers should be of very good quality in respect of uniformity of particle size Four grades of abrasives used are:220grit, 320grit,400grit an 600grit; the 320grit has particle sizes as about 33 microns and 600grit that of 17 microns.

The specimen is first ground on 220grit paper, so that scratches are produced roughly at right angle to those initially existing on the specimen and produced through preliminary grinding or coarse filing operation. Having removed the primary grinding marks, the specimen is washed free of No.220.

Grinding is then continued on the No.320 paper, again turning the specimen through 90^0 and polishing until the previous scratch marks are removed.

The process is repeated with the No.400 and No.600 papers.

Grinding with the No.220, No.320, etc., papers could be done in the following ways

(a) The specimen may be hand rubbed against abrasive paper, which is laid over a flat surface such as a piece of glass plate.

(b) The abrasive paper may be mounted on the surface of a flat, horizontally rotating wheel and the specimen held against it.

In either case surface of the abrasive paper shall be lubricated with water so as to provide flushing action to carry away the particles cut from the surface.

5. Fine polishing

The polishing compound used is alumina (Al_2O_3) powder placed on a cloth covered rotating wheel. Distilled water is used as lubricant.

Fine polishing removes the fine scratches and very thin distorted layer remaining from the rough polishing stage.

6. Etching

Necessity

Even after fine polishing, the granular structure in a specimen usually cannot be seen under the microscope, because grain boundaries in a metal have a thickness of the order of a few atom diameters at best, and the resolving power of a microscope is much too low to reveal their presence.

In order to make the grain boundaries visible, after fine polishing the metal specimens are usually etched.

Etching imparts unlike appearances to the metal constituents and thus makes metal structure apparent under the microscope.

Method

Before etching, the polished specimen is thoroughly washed in running water. Then etching is done either by

(a) Immersing the polished surface in etching reagent or by

(b) Rubbing the polished surface gently with a cotton swab wetted with the Etching Reagent.

After etching, the specimen is again washed thoroughly and dried.

Now the specimen can be studied under the microscope.

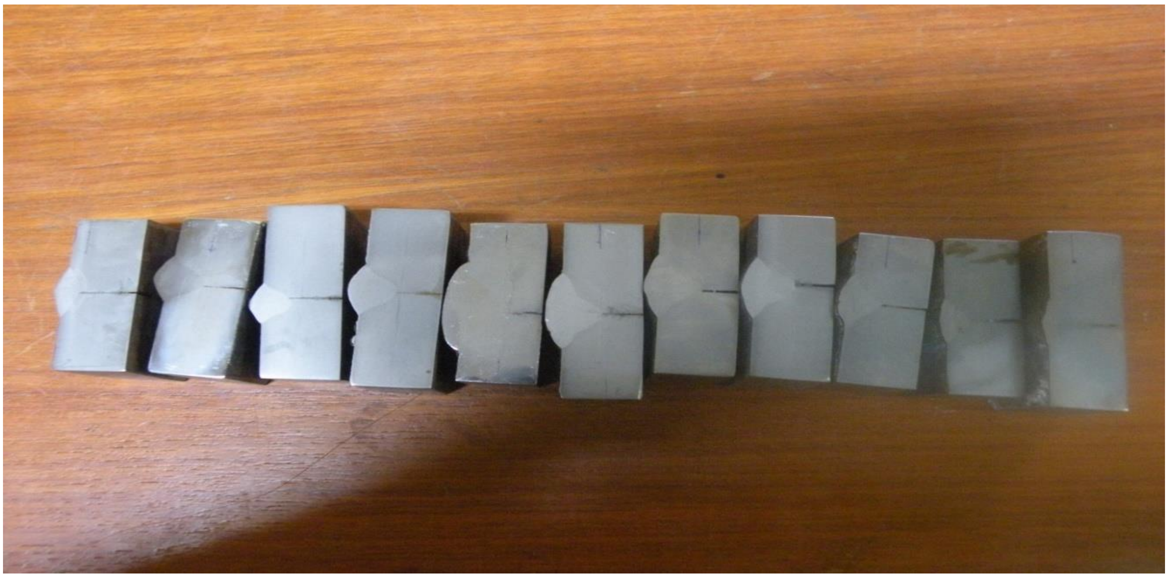


Figure 3.5: Specimens for metallography

Metallurgical microscope

Metallurgical microscope consists of:

(a) Arm

It is fixed on the base of the microscope and it supports all the parts of the microscope.

(b) Body tube

It has objective lens at one end and eye piece lens on other end. It can be up and down using coarse and fine adjustments to vary the distance between the specimen on the table and the objective lens. This helps in rough and fine focusing of the specimen. There is an inclined plane glass reflector in the tube which reflects the light from the light source to illuminate the specimen.

(c) Objective lens

It forms the enlarged image of the specimen at eye piece.

(d) Eye piece

It is a small lens for issuing the specimen.

(e) Base

It is the lowest portion of the microscope which supports all other parts.

(f) Multistage table

It is located between the base and objective. It holds the specimen to be viewed.

Working

The prepared specimen is placed on multistage table. The light is switched on and the adjustment of lenses is made by coarse and fine adjustment knobs. A clear image of the structure of the specimen is obtained by adjusting the distance between the objective and specimen using adjusting knobs. The image of the specimen must be properly magnified so that microstructure of the specimen is clearly visible. The microstructure so obtained is then compared with the standard photo micro graphs of the inlet of which the specimen is made. Certain microscopes are also provided with cameras to photograph the microstructure.[20]

3.6 Hardness test

Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. Although hardness testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties. Hardness testing is widely used for material evaluation due to its simplicity and low cost relative to direct measurement of many properties.

This method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load *F0* usually 150kg. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration. When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

In present experimental work Rockwell hardness was measured on the welded area. For each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case.

Figure 3.6: Rockwell hardness tester

3.7 Tensile test

The tensile strength is measured by tensile test. This involves the preparation of a test specimen as per ASTM standard as shown in fig.4 and this test specimen is based on following relation.

$$L_0 = 5.65(A_0)^{1/2} \quad \text{----------} \ (1)$$

Where, L_0 = Gauge length

A_0 = Cross sectional area

Here the important parameter are the gauge length L0 and the cross sectional area A0 then a uniformly increasing load is applied on the specimen. As the load increases the specimen initially gets elastically elongated. On further elongation, the specimen starts necking at some points when the material goes beyond the elastic range. The reduced width of specimen would further be reduced under the force of the load and finally develops fractures when the test is completed It can be observed that there is a limit up to which the applied stress is directly proportional to the induced strain, the end of this linear portion is the yield point of the material above which the material starts plastically deforming and when the force applied load goes beyond the limit that can borne by the material, the specimen breaks. The stress at elastic limit is called yield strength. The maximum stress reached in a material before the fracture is termed as the ultimate tensile strength.

Figure 3.7: Tensile testing machine

CHAPTER-IV

RESULTS & DISCUSSIONS

This study deals with the results and discussions of the experimental findings of welded joints prepared at constant current, constant voltage, different welding speeds and welding technique (Down hand welding) [21]. The specimens prepared under different welding speeds, heat input rates with constant current and voltages are having different effects.

4.0 The Effect of Welding Speed on Depth of Penetration

Weld bead penetration is the maximum distance between the top surface of the base plate and depth to which the fusion has taken place. Penetration determines the load carrying capacity of a welded structure. It is observed that the penetration is influenced by welding current, polarity, arc travel speed, electrode stick-out, and physical properties of the flux. Penetration decreases with the increase in welding speed because the time during which the arc force is allowed to penetrate into the materials surface decreases. However, reducing the welding speed can have the opposite effect, i.e. a reduction in penetration, as the arc is prevented from transferring thermal energy to the parent metal by the excessive size of the weld pool. Having finished the welding processes, in order to measure the depth of penetration, welds were cut perpendicular to the direction of welding on power hacksaw. Then with the help of measuring instrument, depth of penetration of welded specimens was measured [22] as shown in table 4.0.

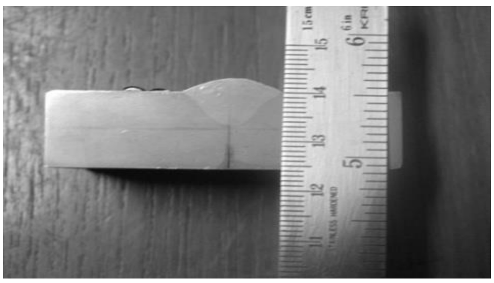


Fig.4.0. Depth of penetration measurement

The variations in the penetration are analyzed with the help of graph (Fig.4.1) which is plotted between welding speed and penetration. Voltage (32v) and current (600A) are taken constant and welding speed is varied during the welding of specimens. The depth of penetration increases with increasing welding speed up to 375mm/min which was optimum value to obtain maximum penetration, because it begins to decrease linearly after this point. Increasing the speed of travel and maintaining constant arc voltage and current increases penetration until an optimum speed is reached at which penetration is maximum. Increasing the speed beyond this optimum results in decreased penetration. So it can be concluded from experimental analysis that for the mild steel welded specimen having dimension 300mm×100mm×16mm, optimum weldability can be achieved by considering the welding parameters as welding speed 375mm/min with current 600 Amp, arc voltage 32 V and electrode(E 2062) diameter 4mm.

Table-4.0: Comparison of weld quality characteristics

S.No.	Welding voltage (V)	Welding current (A)	Welding speed(v) (mm/min)	Heat input rate (J/mm)	Penetration (mm)	Hardness (HR_B)	Ultimate tensile Strength (N/mm2)
1	32	600	200	5760	7.5	78	63.93
2	32	600	275	4189	8.0	78	70.66
3	32	600	375	3072	8.2	79	73.56
4	32	600	450	2560	7.64	82	67.90
5	32	600	525	2194.3	6.6	82	63.48
6	32	600	600	1920	6.5	84	60.7
7	32	600	625	1843.2	5.7	85	58.68
8	32	600	675	1706.7	5.4	87	57.78
9	32	600	775	1486.5	5.0	89	56.66

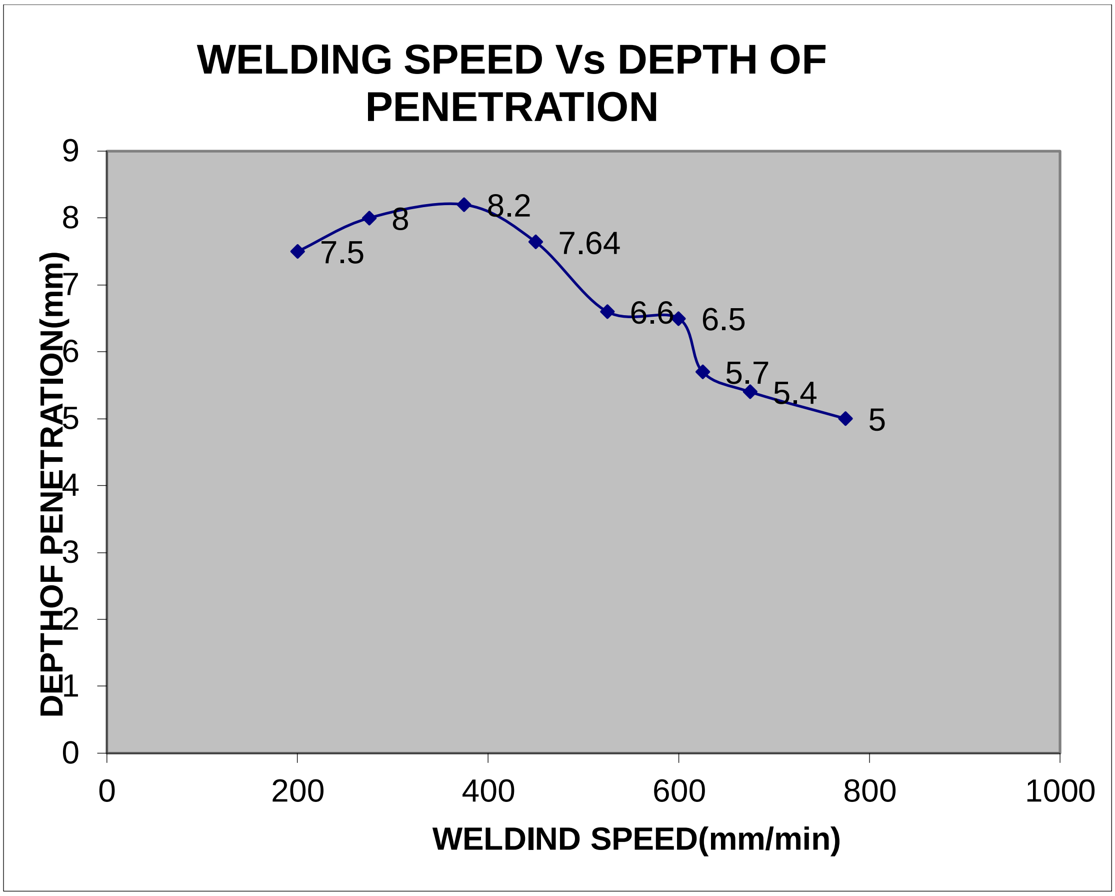


Fig.4.1. Depth of Penetration Vs Welding Speed

4.1 The Effect of Heat Input Rate on Depth of Penetration

Speed of welding is defined as the rate of travel of the electrode along the seam or the rate of travel of the work under the electrode along the seam.

The variations in the penetration are analyzed with the help of graph (Fig.4.2) which is plotted between Heat input rate and penetration. From the analysis, it is evident that there occurs maximum depth of penetration occurs at heat input rate of 3072 J/mm. Greater the depth of penetration, better is the weldability. So, Optimum weld ability can be obtained with heat input rate as 3072 J/mm.

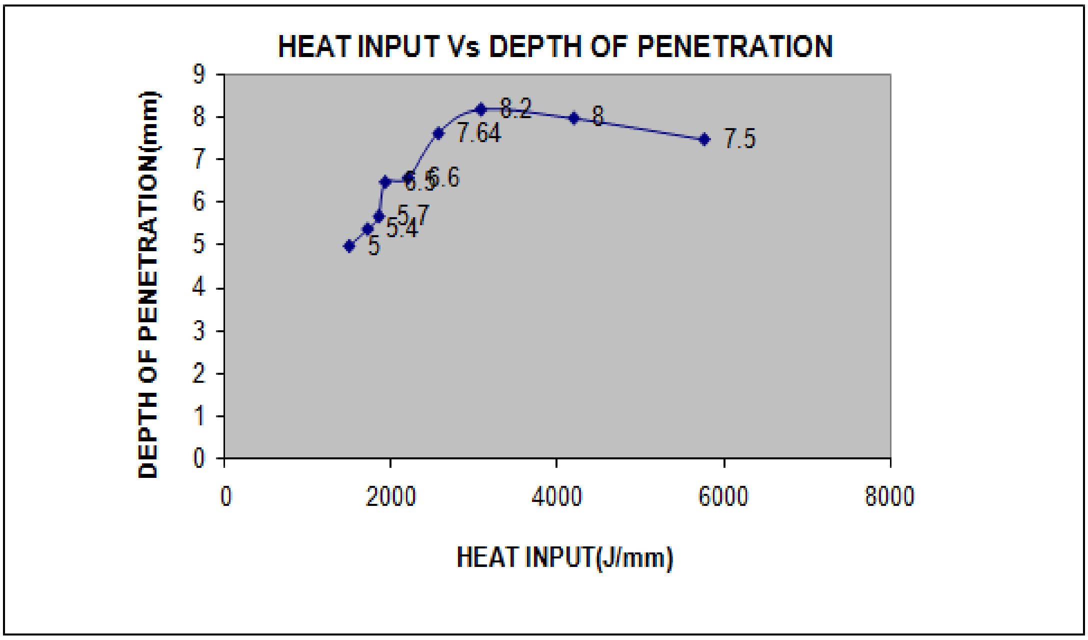


Fig.4.2. Depth of Penetration Vs Heat input rate

4.2 Calculation of Heat input rate

Heat input rate or arc energy = V×I×60 /v joules per mm

Where:

V is arc voltage in volts,

I is welding current in ampere,

v is speed of welding in mm/min. [23]

4.3 Weld pool geometry

From the figures 4.3, 4.4 it is noticed that at welding speed of 100mm/min least penetration and unnecessarily heavy bead width is observed and at the welding speed of 900mm/min there is improper fusion of the base metal. At the welding speed of around 375mm/min optimum weld pool geometry parameters are obtained. The variation of weld pool geometry parameters are presented in figures 4.3 and 4.4.

Figure-4.3: Weld obtained at very high speed.

Figure-4.4: Weld obtained at very low speed

4.4 Hardness and Tensile Strength

It is observed that the hardness values of the welded zone increases with welding speed [24]. Properties of steel depend on the microstructure. As shown in Fig.4.5 the light colored region of the microstructure is the ferrite and the dark colored regions are the pearlite. Decrease in the size of grains and decrease in the amount of pearlite improves the strength, ductility and toughness of the steel.

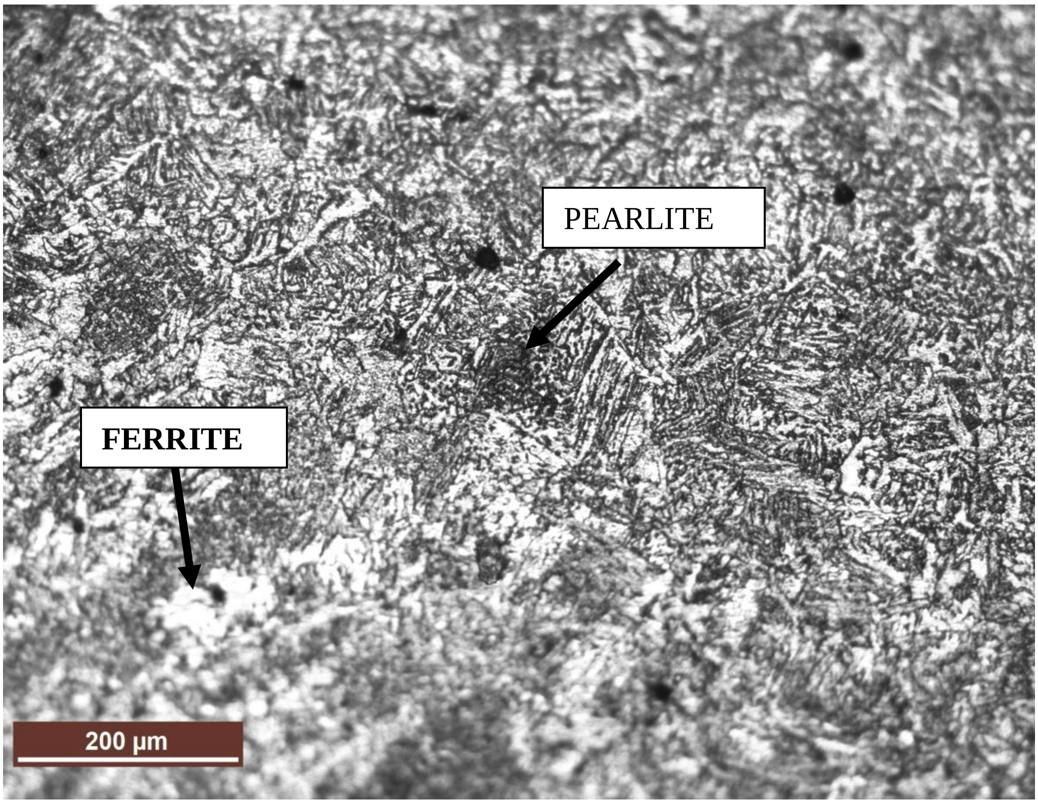


Figure 4.5: Microstructure of welded specimen at HAZ

Figure 4.5 shows that ferrite and pearlite structures are formed and traces of acicular ferrite can also be found in the heat affected zone. The light coloured region of mild steel is the ferrite. Grain boundaries between ferrite grains can be seen quite clearly. Dark regions are called Pearlite.

4.4.1 Ferrite

Ferrite, also known as α-ferrite (α-Fe) or alpha iron is a materials science term for pure iron, with a body-centered cubic crystal structure. It is this crystalline structure which gives steel and cast iron their magnetic properties, and is the classic example of a ferromagnetic material.

It has strength of 280 N/mm^2[citation needed] and a hardness of approximately 80 Brinell.

Mild steel (carbon steel with up to about 0.2 wt% C) consist mostly of ferrite, with increasing amounts of pearlite (a fine lamellar structure of ferrite and cementite) as the carbon content is increased. Since bainite and pearlite each have ferrite as a component, any iron-carbon alloy will contain some amount of ferrite if it is allowed to reach equilibrium at room temperature.[25] The exact amount of ferrite will depend on the cooling processes the iron-carbon alloy undergoes as it cools from liquid state.

Only a very small amount of carbon can be dissolved in ferrite; the maximum solubility is about 0.02 wt% at 723 °C (1,333 °F) and 0.005% carbon at 0 °C (32 °F).This is because carbon dissolves in iron interstitially, with the carbon atoms being about twice the diameter of the interstitial "holes", so that each carbon atom is surrounded by a strong local strain field.

4.4.2 Pearlite

Pearlite is often said to be a two-phased, lamellar (or layered) structure composed of alternating layers of alpha-ferrite (88 wt%) and cementite (12 wt%) that occurs in some steels and cast irons. In fact, the lamellar appearance is misleading since the individual lamellae within a colony are connected in three dimensions; a single colony is therefore an interpenetrating bicrystal of ferrite and cementite. In an iron-carbon alloy, during slow cooling pearlite forms by a eutectoid reaction as austenite cools below 727 °C (1,341 °F) (the eutectoid temperature). Pearlite is a common microstructure occurring in many grades of steels.

The eutectoid composition of austenite is approximately 0.77% carbon; steel with less carbon content will contain a corresponding proportion of relatively pure ferrite crystallites that do not participate in the eutectoid reaction and cannot transform into pearlite. Likewise steels with higher carbon contents will form cementite before reaching the eutectoid point. The proportion of ferrite and cementite forming above the eutectoid point can be calculated from the iron/iron—carbide equilibrium phase diagram using the lever rule.

Steels with pearlite (eutectoid composition) or near-pearlite microstructure (near-eutectoid composition) can be drawn into wires. Such wires, often bundled into ropes, are commercially used as piano wires, ropes for suspension bridges, and as steel cord for tire reinforcement. High degrees of wire drawing (logarithmic strain above 3) leads to pearlite wires with yield strengths of several Giga Pascal's. It makes pearlite one of the strongest structural bulk materials on earth.

Pearlite was first identified by Henry Clifton Sorby and initially named sorbite; however the similarity of microstructure to nacre and especially the optical effect caused by the scale of the structure made the alternative name more popular.

Bainite is a similar structure with lamellae much smaller than the wavelength of visible light and thus lacks this pearlescent appearance. It is prepared by more rapid cooling. Unlike pearlite, whose formation involves the diffusion of all atoms, bainite grows by a displacive transformation mechanism.

4.4.3 Acicular ferrite

Acicular ferrite is a microstructure of ferrite that is characterized by needle shaped crystallites or grains when viewed in two dimensions. The grains, actually three dimensional in shape, have a thin lenticular shape. This microstructure is advantageous over other microstructures because of its chaotic ordering, which increases toughness.

Acicular ferrite is formed in the interior of the original austenitic grains by direct nucleation from the inclusions, resulting in randomly oriented short ferrite needles with a 'basket weave' appearance. This interlocking nature, together with its fine grain size (0.5 to 5 um with aspect ratio from 3:1 to 10:1), provides maximum resistance to crack propagation by cleavage. Acicular ferrite is also characterized by high angle boundaries between the ferrite grains. This further reduces the chance of cleavage, because these boundaries impede crack propagation. It is reported that nucleation of various ferrite morphologies is aided by nonmetallic inclusion; in particular oxygen-rich inclusions of a certain type and size are associated with the intragranular formation of acicular ferrite. Acicular ferrite is a fine Widmanstätten constituent, which is nucleated by an optimum intragranular dispersion of oxide/sulfide/silicate particles.

Composition control of weld metal is often performed to maximize the volume fraction of acicular ferrite due to the toughness it imparts. Higher alloy contents generally delay transformation, during continuous cooling transformation will then take place at lower temperatures and lead to higher hardness.

4.5 Photo macrographs of HAZ in welded specimens

The below figures shows the microstructures at the heat affected zones at various welding speeds.

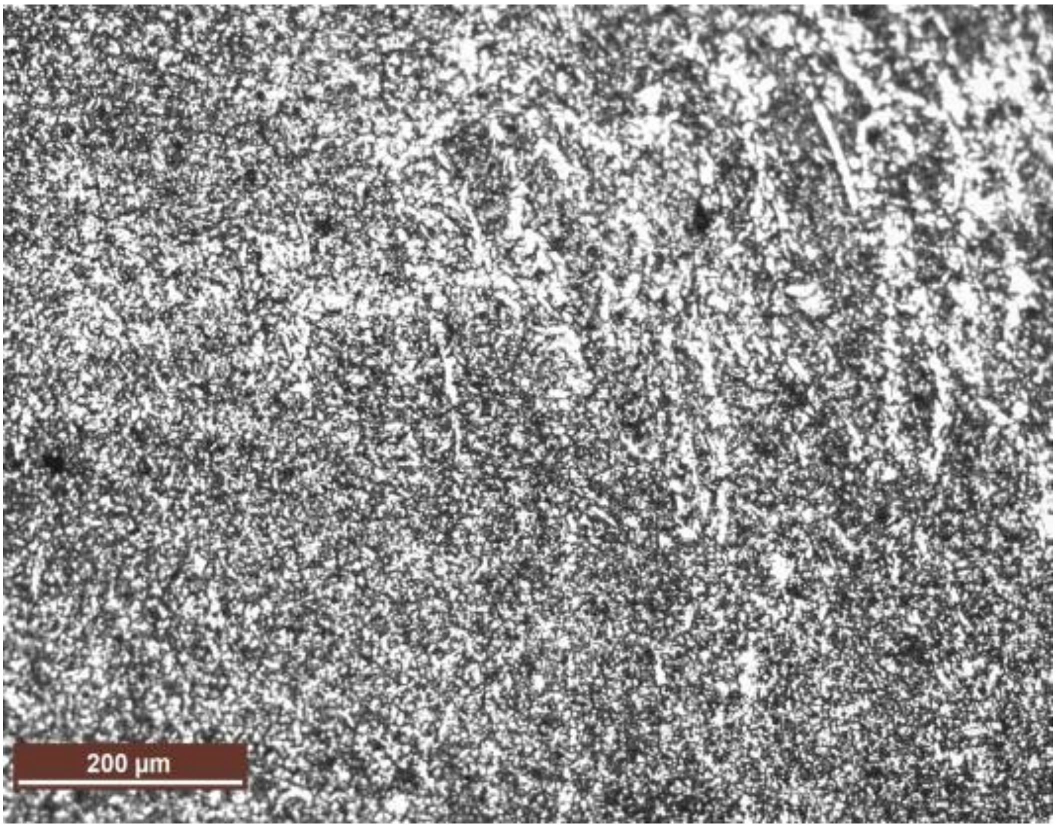


Figure 4.6: Microstructure of HAZ at 200mm/s

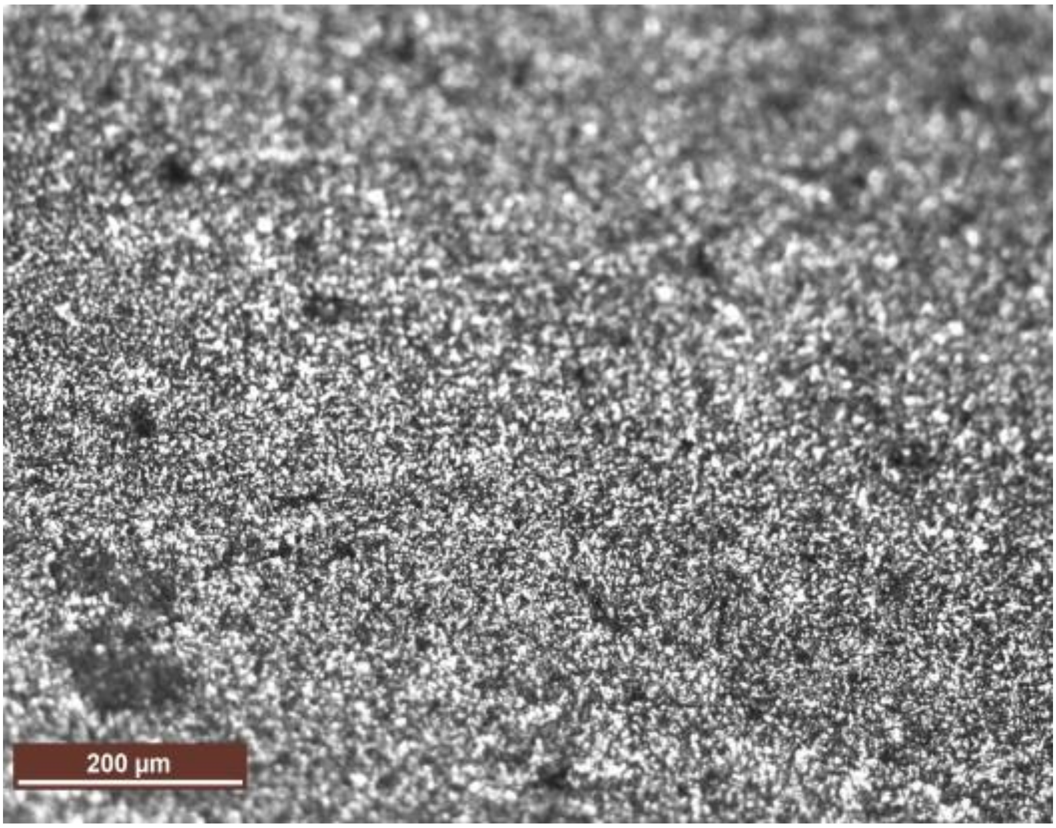


Figure 4.7: Microstructure of HAZ at 275mm/s

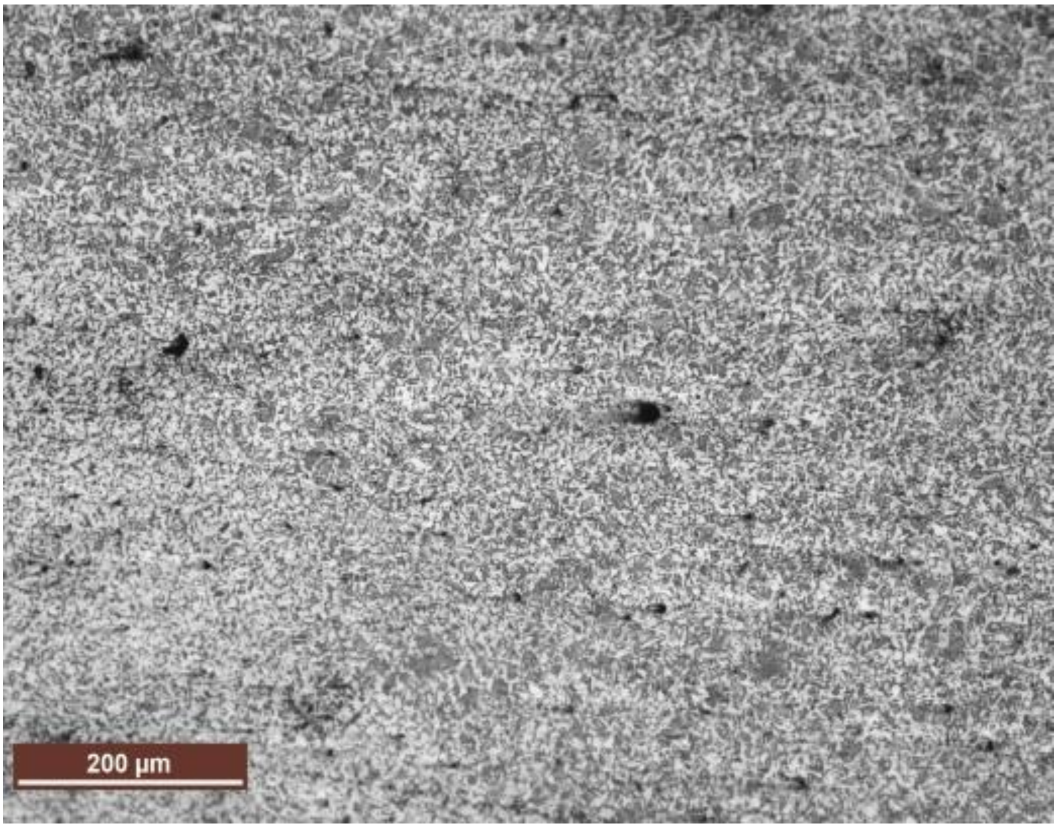


Figure 4.8: Microstructure of HAZ at 375mm/s

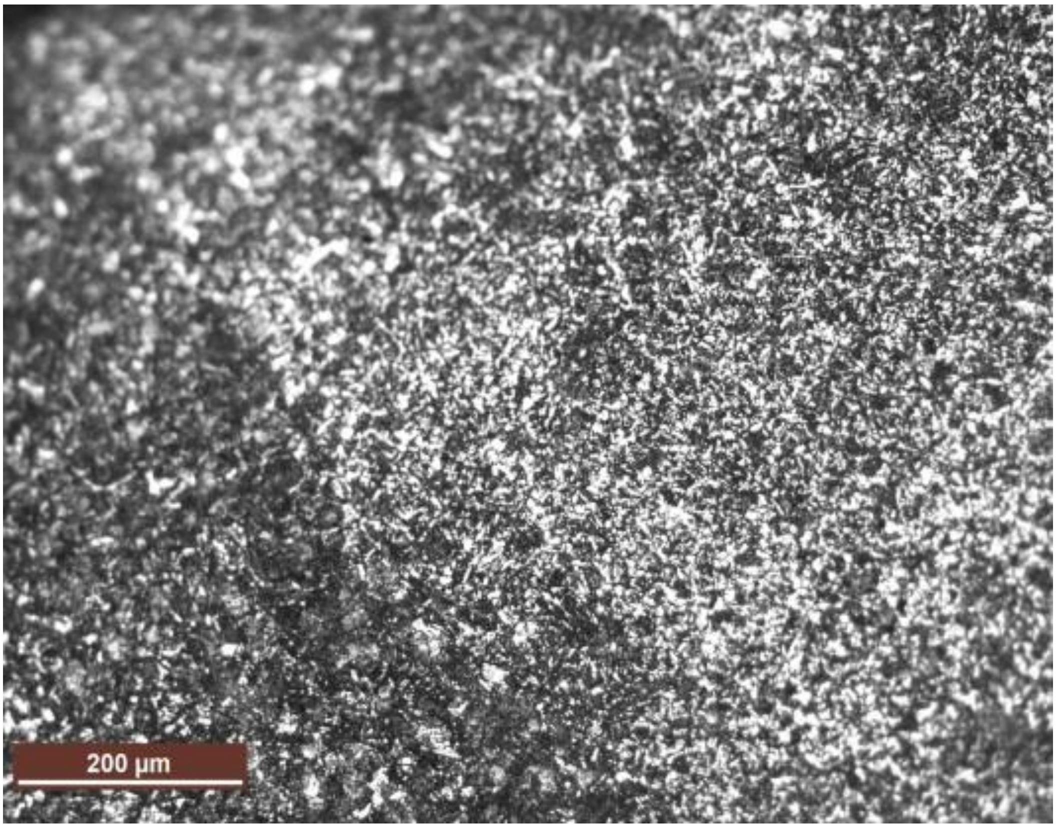


Figure 4.9: Microstructure of HAZ at 450mm/s

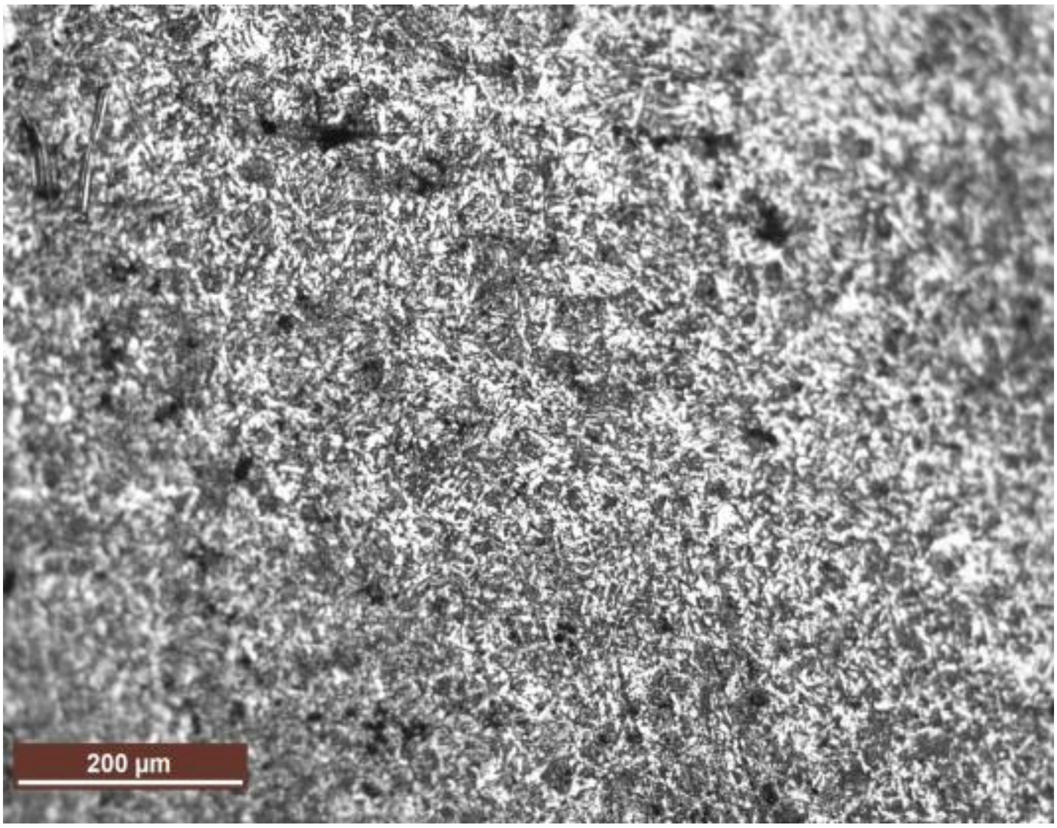


Figure 4.10: Microstructure of HAZ at 525mm/s

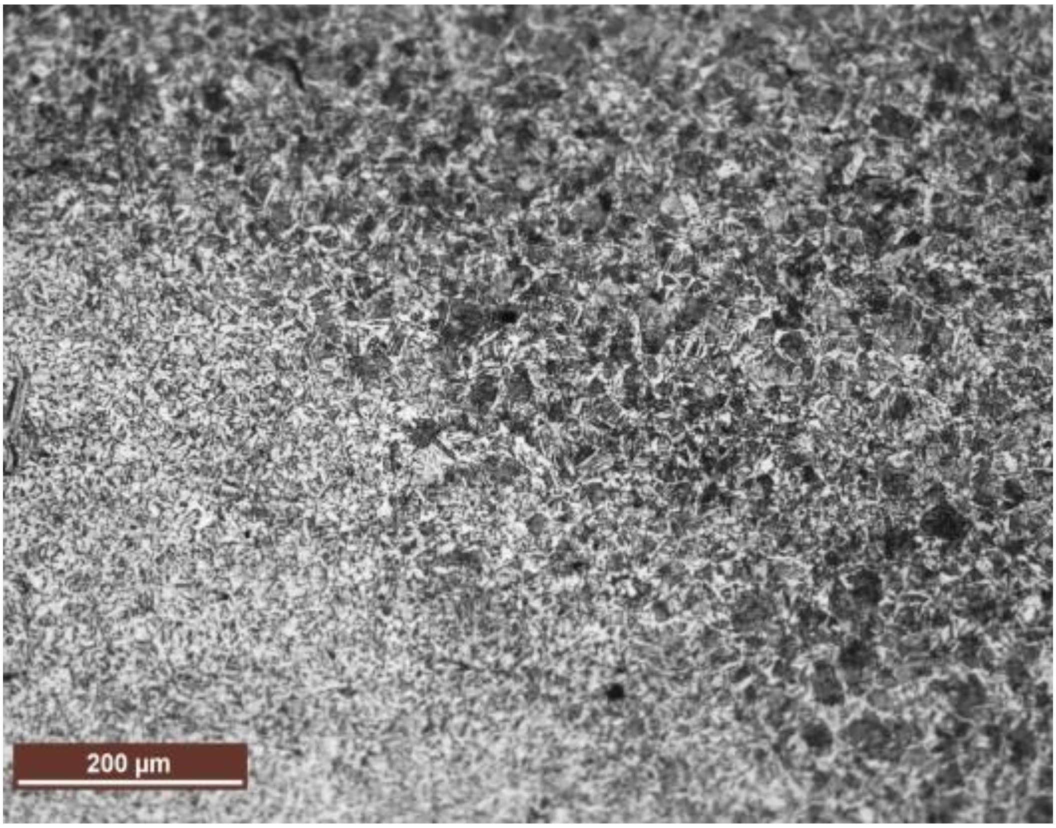


Figure 4.11: Microstructure of HAZ at 600mm/s

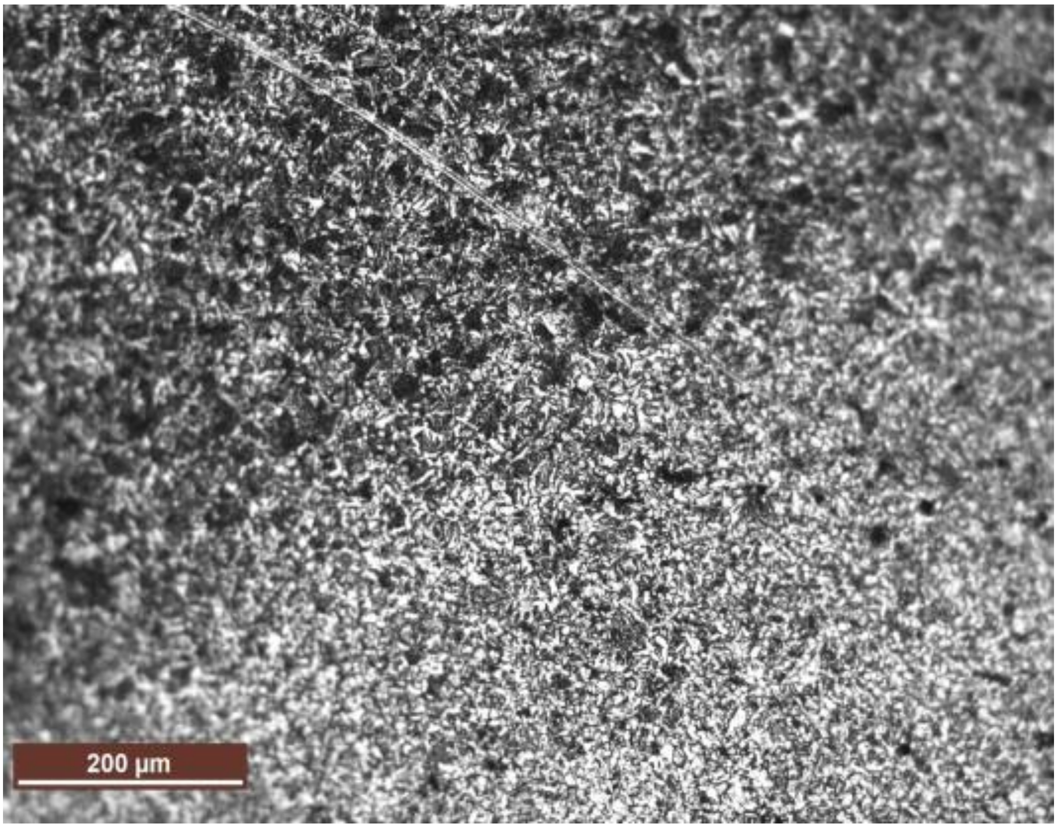


Figure 4.12: Microstructure of HAZ at 625mm/s

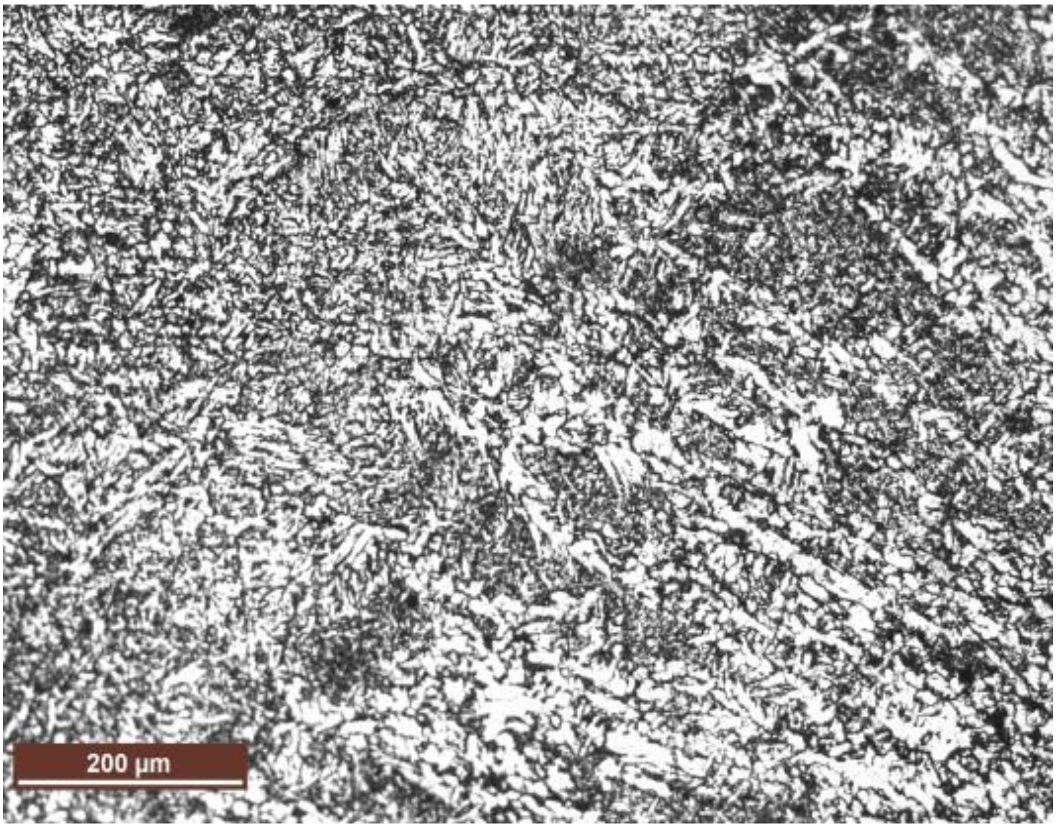


Figure 4.13: Microstructure of HAZ at 675mm/s

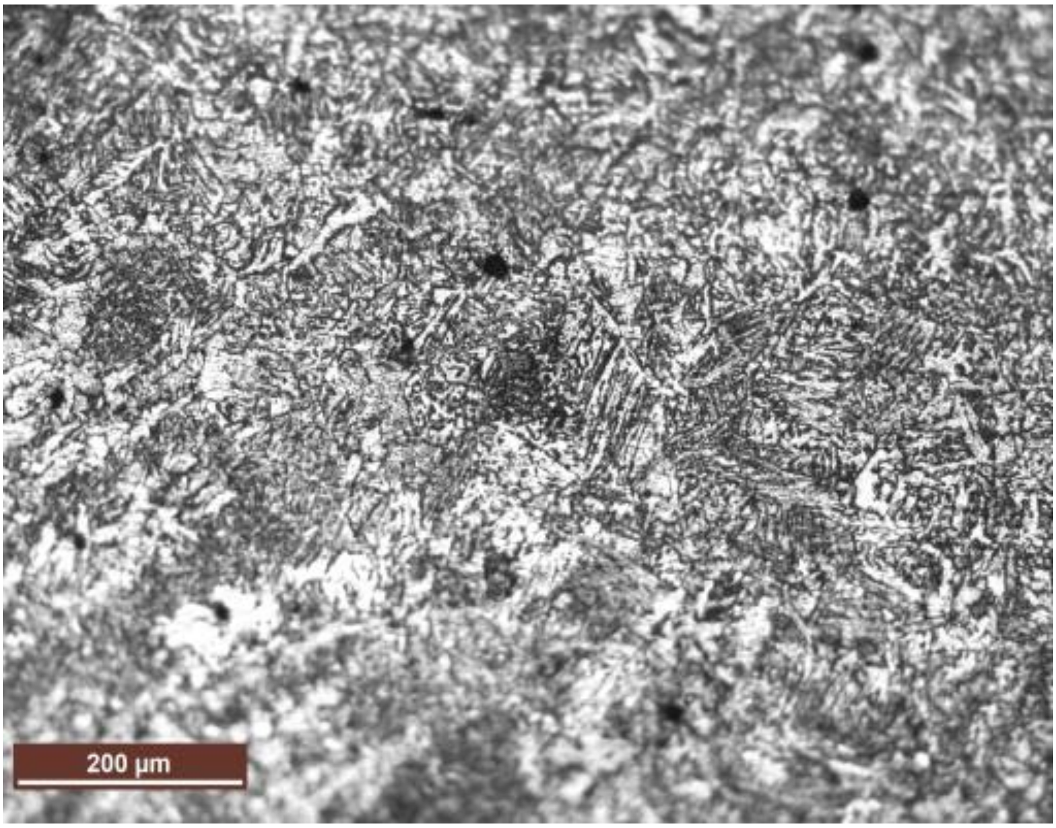


Figure 4.14: Microstructure of HAZ at 775mm/s

Microstructures of the welded specimens at different welding speeds related with tensile strengths are as shown below.

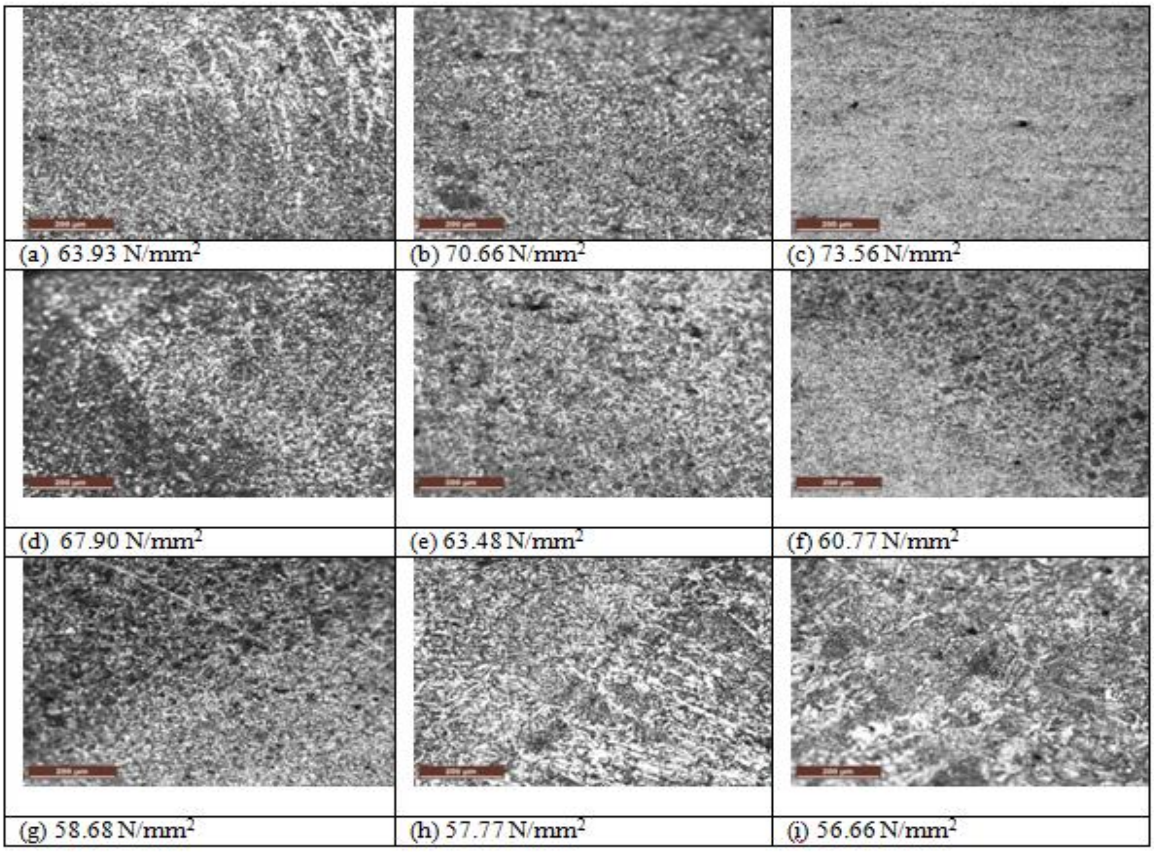


Fig.4.15. Metallographic examination of welded specimens at different welding speeds

CHAPTER - V

CONCLUSIONS

Optimum parameters for the weldability of Mild steel specimen:

- When the welding speed was taken as a variable parameter, the deepest penetration i.e. 8.2mm was obtained in 375mm/min.

- Maximum depth of penetration was obtained when heat input rate was 3072 J/mm.

Hence it can be concluded that increasing the speed of travel and maintaining constant arc voltage and current will increase penetration until an optimum speed is reached at which penetration will be maximum. Increasing the speed beyond this optimum value will result in decreasing penetration.

- It is observed that, decrease in the size of grains and decrease in the amount of pearlite improves the strength of the steel.

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