A Thesis
On

DEVELOPMENT OF SUBMERGED ARC WELDING FLUXES FOR WELDING OF API 5L X65 STEELS

Submitted in partial fulfilment of the requirement for the award of degree

MASTER OF ENGINEERING
IN
CAD/CAM & ROBOTICS

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CERTIFICATE

This is to certify that the work done in this thesis report entitled "**DEVELOPMENT OF SUBMERGED ARC WELDING FLUXES FOR WELDING OF API 5L X65 STEELS**" submitted in partial fulfilment of requirement for the award of the **Master of Engineering Degree in CAD/CAM & ROBOTICS** in the Mechanical Engineering Department Thapar University, Patiala, is an authentic record of work carried out by me under the guidance of Mr. Kishore Khanna, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala.

The matter embodied in this report has not been submitted in part or fully to any other university or institute for the award of any degree.

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ABSTRACT

The present work is an attempt to study the effect of flux on the tensile strength, Impact strength, micro hardness, and microstructure of high strength low alloy steel welds made by the submerged arc welding. The parent metal, heat affected zone and weld metal regions of each weldment have been examined. The effect of different kind of fluxes by keeping the welding parameters like welding current, welding voltage and welding speed constant has been evaluated for the different high strength low alloy weld joints. The microstructure evolution in these weld joints has also been studied and attempt has been made to correlate the observation. Further it has also been found out the best suited fluxes for welding of pressure vessel steels as per requirement. Mechanical and fracture properties of the steel have also been investigated.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

During the earlier times several attempts were made to mechanize the arc welding process. Developing a continuous coated electrode as an extension of the manual metal-arc welding electrode was ruled out for some reasons. Since the coating is non-conducting, arranging electrical contact with the electrode is not practicable. The coating is likely to peel off when the electrode is coiled, and the coating is also likely to get crushed when fed through the feed rolls. In one of the methods attempted, the work piece was painted with a thin slag flux, while feeding of the bare wire and arc travel were mechanized. Many methods were tried out to provide flux coating in mechanized welding, but all efforts led to failure. The idea of placing a thick layer of dry granular flux on the joint ahead of the carbon electrode was conceived and successfully developed in the U.S.A. and later applied to the welding of penstocks and water conduits in California. Submerged-arc welding was the next logical step and the process became a commercial success both in the U.S.A. and the U.S.S.R. by the middle and late 1930's.

1.2 The Submerged Arc Welding Process

The modern submerged arc welding (SAW) is an arc welding process, in which one or more arcs formed between one or more bare wire electrodes and the work piece provides the heat for coalescence. The flux is supplied through a funnel located ahead of the filler wire which is fed continuously. The flux exercises a shielding function. During welding, part of it is converted into a readily removable slag. In fully-automatic welding, the flux is fed mechanically to the joint ahead of the arc, the wire is fed automatically to the welding head, the arc length is automatically controlled and the traverse of the arc or the work piece is also mechanized. Flux feed may be by gravity flow, through a nozzle concentric with the electrode from a small hopper a top the gun, or it may be through a concentric nozzle connected to an air-pressurized flux tank. Flux may also be applied in advance of the welding operation or ahead of the arc from a hopper run along the joint.

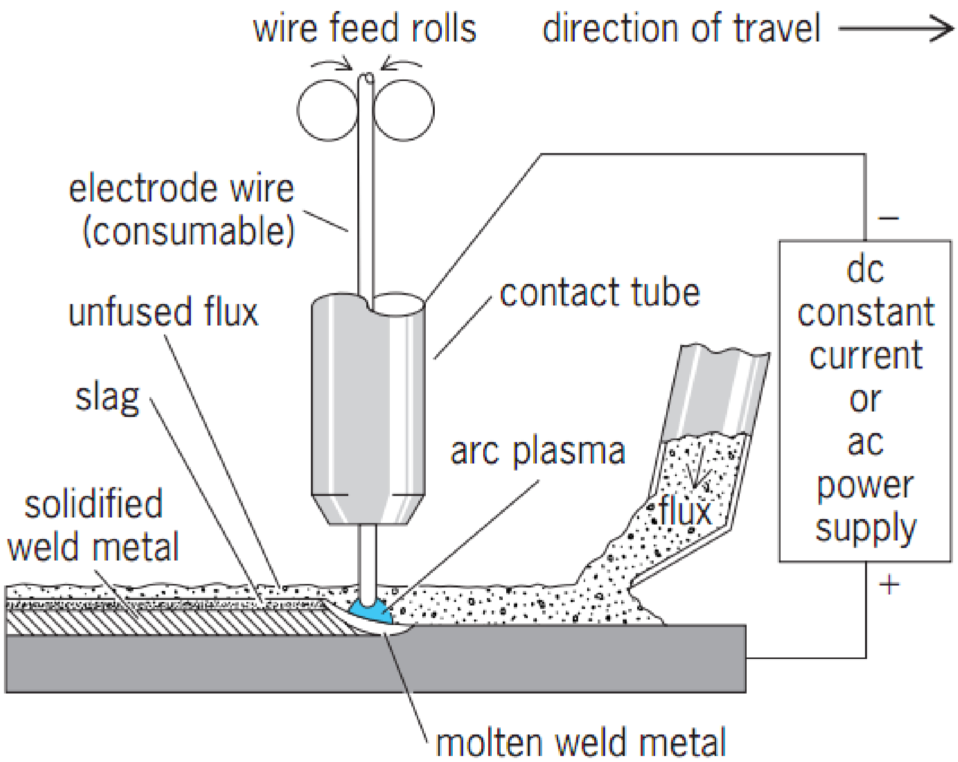


Figure 1.1: Mechanism of Submerged Arc Welding [18]

During welding, the intense heat of the arc simultaneously melts the tip of the bare wire electrode and part of the flux as shown in Figure 1.1. The electrode tip and the welding zones are always surrounded and protected by molten flux, while all of them are covered by the top layer of unfused flux. As the arc progresses along the joint, the molten metal settles down while the lighter molten flux rises from the puddle in the form of slag. The weld metal, having a-higher melting point, solidifies first while the slag above it takes some more time to solidify. The solidified slag continues to protect the weld metal while it is still hot, and is capable of reacting with atmospheric oxygen and nitrogen. The submerged arc welding process can provide higher deposition rates and faster travel speeds, and the process is known to produce a very smooth bead with good penetration and excellent fusion. And as with other welding processes, it lends itself to creative applications. R Quintana [17] observed a peculiarity of the submerged arc welding process is that, where the electric arc meets the slag covered welding area; both the welding pool and the welding cord of the same material are protected. This limits oxidation of the alloyed metal elements, with relatively small losses of fluxes agglomerated with vitreous, ceramic and pseudo ceramic matrices, which are molten at 1,350 ^{0}C and not very volatile in the electric arc conditions. In addition, during this process 95-98% of the wire-electrode and a high percentage of the alloyed load is deposited, and almost the entire matrix (>96 %) contributes to slag formation. One of the more important characteristics of SAW is the high utilization of the energy of the electric arc, since there are no losses due to radiation or projection. The calorific yield has been determined as between 80 and 90 %.

1.3 Applications of SAW

Applications cover pressure vessels, pipe line, storage tanks, heavy structural's, ships, railway wagons and coaches, surfacing and build-up work.

1.4 Basic Equipment

The typical set up for submerged arc welding equipment is shown in Figure 1.2, it essentially consists of:

- A wire feeder to drive the electrode to the work through the contact tube of a Welding gun or welding head
- A welding power source to supply electric current to the electrode at the contact Tube
- A means of traversing the weld joint

Typical welding outfits:

a) Power source

b) Wire feeder

c) Torch with flux hopper.

(a) Power source: It is a DC welding rectifier giving maximum welding current of 600 amps 60% duty cycle and 500 amps at 100% duty cycle. It has constant potential characteristics, giving a constant arc, voltage, while the current is determined by the wire- feed rate. The rectifier has a drip-proof casing with the following built-in components: transformer, silicon rectifier, and reactance coil, and fan, safety device against ventilation failure, control transformer and welding contactor.

(b) Wire feeder: The wire feeder for submerged arc welding is shown in Figure 1.3, with an arrow pointing towards it. It consists of a DC wire drive motor, reduction Gearbox, four- roll drive mechanism and a wire spool holder. Wire-feed rate is continuously variable in the range of 0.5-2.5 m/min.

(c) Torch with flux hopper: Welding torch with flux hopper has been shown in figure 1.4. It is a self-contained unit with bent torch head; it has a long hose, flux hopper which can take up to kilograms of flux, and a suitable coupler for connection to the wire feeder. The flux is fed around the electrode from a cylindrical tunnel along with the electrode.

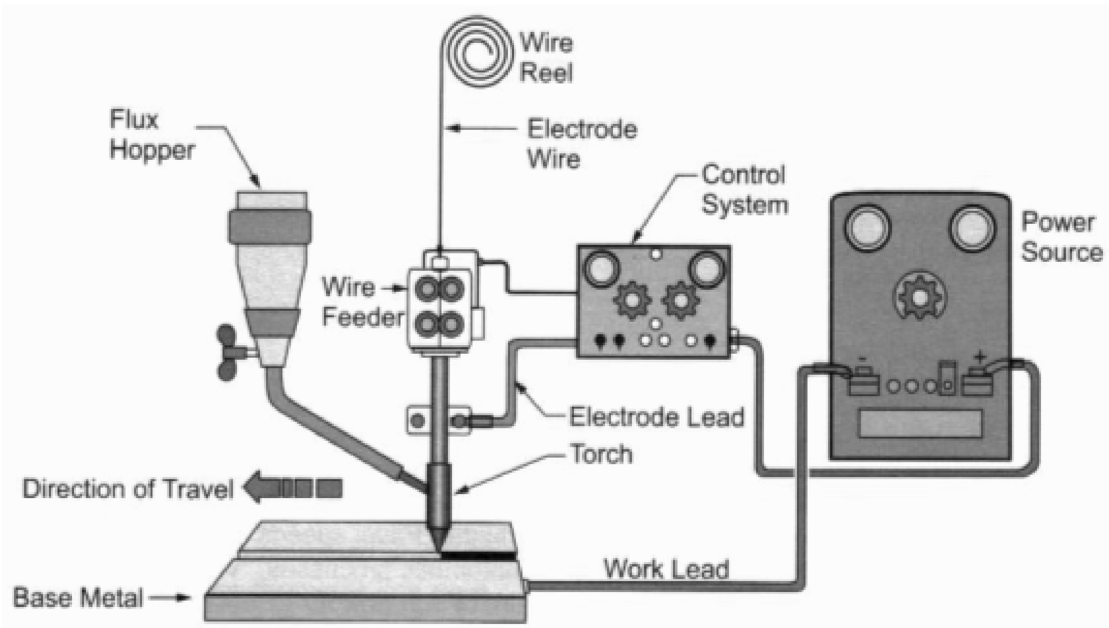


Figure 1.2: Equipment set-ups for Single Wire Submerged Arc Welding [18]

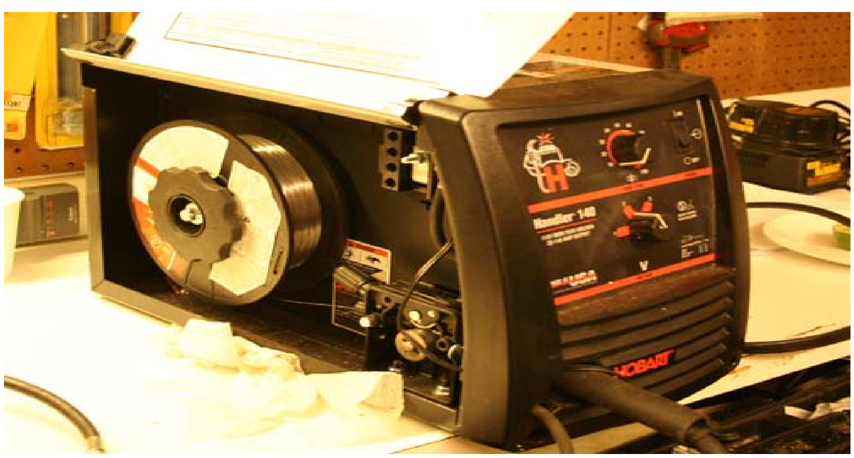


Figure 1.3: Wire feeder of a Semi-Automatic SAW unit [18]

1.5 Basicity Index

Basicity index is used to approximately measure the flux oxidation capacity, and the same principles were applied to the welding technology. Consequently, it has been general practice to use the basicity index to characterize a welding flux with regard to its physical and chemical properties. In practice, weld metal mechanical properties and weld metal oxygen content are related to the welding fluxes by means of the basicity index, which is usually defined as the following:

$$Basicity\ index = \frac{\sum Basic\ oxides}{\sum Acidic\ oxides}$$

B.I. = $CaO + CaF_2 + MgO + 0.5(MnO + FeO) / SiO_2 + 0.5(Al_2O_3 + TiO_2)$

It is the most widely used basicity index formula and is recognized by the International Institute of Welding (IIW). It is often referred to as Tuliani's expression, in which flux component contents are expressed in weight percent. Using the above expression, when the basicity index is less than 1.0, the flux is regarded as acidic, between 1.0 and 1.2, as neutral, and a flux with a B.I. greater than 1.2, as basic.

1.5.1 Types of fluxes

SAW flux basically performs the same functions as the coating of a manual electrode. Additionally, it must satisfy certain special conditions demanded by the nature of the process. The flux protects the molten pool and the arc against atmospheric oxygen and nitrogen by creating an envelope of molten slag. The slag also cleanses the weld metal (i.e. deoxidizes it and removes impurities such as sulphur) modifies its chemical composition and controls the profile of the weld bead. The molten slag also provides favourable conditions for very high current densities, which together with the insulating properties of the flux; concentrate intense heat into a relatively small welding zone. This result in a deeply penetrating arc, which makes narrower and shallower welding grooves practicable, thus reducing the amount of weld metal, required to comp1ete the joint. It also results in higher welding speeds. The properties of the flux enable submerged arc weld-to be made over a wide range of welding currents, voltage and speeds, each of which can be controlled independently of the other. Thus one can obtain welded joints of desired shape, chemistry and mechanical and metallurgical properties by using an appropriate welding procedure. Nowadays, two main types of submerged arc fluxes are available, depending on the method of manufacture i.e. fused and agglomerated. Sintered fluxes have been produced in some countries but their properties and welding characteristics have been rarely reported in the literature.

1.5.2 Fused fluxes

Typical ingredients are quartz, manganese ore or slag, dolomite, potassium feldspar and clay. These minerals are ground and mixed in a definite proportion and melted. Melting is carried out in a magnesia or fireclay crucible if heating is by gas or in a graphite crucible if electricity is used. Electric melting is started by heating with an arc between the electrode and crucible and continued by resistance heating with the electrode submerged in the molten flux, which is an electrical conductor. After fusion, the melt is solidified rapidly by quenching into water or pouring into cell steel chills to produce small fragments of flux. These are dried and crushed to the required size; sieved, sized and packed in bags or drums.

Fused Flux Features:

- ✓ Non-hygroscopic
- ✓ Fully Reacted
- ✓ Chemically homogenous
- ✓ Contain no metallic deoxidizers
- ✓ Glass-like appearance, high grain strength

Fused Flux Benefits:

- ➢ Particles are non-hygroscopic and do not absorb moisture, therefore only a low Temperature (300°F/150°C) drying cycle is required to remove surface Moisture/condensation, providing increased protection against hydrogen cracking.

- ➢ Provide smooth, stable performance even welding currents (up to 2,000 amps).

- ➢ Flux particles are chemically consistent welds Fused fluxes are less susceptible to particle breakdown due to flux recycling, reducing the creation of fine dust particles.

1.5.3 Agglomerated fluxes

In these fluxes chemical bounding takes place between particles due to formation of electrovalent or covalent bounds. Temperature involved in preparation of these fluxes is lower than that used for producing fused fluxes. For producing an agglomerated flux, finely powdered ingredients are mixed and ground dry in a mixer. The mix is steadily moistened by spraying with a solution of alkaline silicate and the mixing is continued. The mixer blades are suitably designed to assist agglomeration. The silicate solution initially fills the spaces between the pores of the particles. When subsequently dried, the water evaporates, leaving the binder as bridges between particles. After baking, the flux is graded to a specified granule size by sieving, and packed in water-proof containers.

Bonded flux properties:

✓ It Contain metallic deoxidizers.

✓ It May contain alloying agent.

✓ Flat, low gloss or dry particle appearance

✓ Every flux particle has a unique chemistry.

1.5.4 Sintered fluxes

They are produced by grinding the dry charge together, pressing into small balls, and heating to 1,000-1,100°C (just below melting point) in gas-fired furnaces. The solid mass produced then has the characteristics of a fused flux. It is crushed to the desired fineness, sieved, sized and packed in suitable containers.

1.5.5 Flux Storage

To prevent contamination of weld by hydrogen, the flux must be kept dry and free from oils and other hydrocarbons. If flux becomes damp, it must be redried. Excessive levels of hydrogen in some steels can cause porosity. In hardable steels, even small amount of hydrocarbon can cause underline cracking. Commercially available dryers are the best method of drying flux. Do not dry fluxes by using direct flame this may fuse the flux together; at the same time, the flame produces water that might condense on the flux.

1.6 Welding Parameters

In SAW, the weld deposit quality is determined by the type of flux, grade of wire and the

Following parameters:

1.6.1 Welding Current

It controls the melting rate of the electrode and thereby the weld deposition rate. It also controls the depth of penetration and thereby the extent of dilution of the weld metal by the base metal. Too high a current causes excessive weld reinforcement which is wasteful, and burn-through in the case of thinner plates or in badly fitted joints, which are not provided with proper backing. Excessive current also produces a high narrow bead and undercut. Excessively low current gives an unstable arc, inadequate penetration and overlapping SAW equipment is usually usually provided with an ammeter to monitor and control the welding current.

1.6.2 Arc-Voltage

Arc voltage is also called welding voltage. It is the electrical potential difference between the electrode wire tip and the surface of the molten weld puddle. It is shown by the voltmeter provided on the equipment. It has less affects on the electrode melting rate, but it indicate the profile and surface appearance of the weld bead. When arc voltage increases, the weld bead becomes wider and flatter, and the penetration decreases.

The effects of changing the voltage are as :

1) Rise voltage:

a) Produces a flatter and wider bead.

b) Rise in flux consumption.

c) Increases resistance to porosity caused by rust or scale.

d) Increases pickup of alloy from the flux: this can be used to

2) Reducing the voltage produces a stiffer arc needed for getting penetration in a deep groove and to resist arc blow on high-speed work.

3) An excessively less voltage produces a high, narrow bead with poor slag removal.

1.6.3 Speed of Arc Travel

For a given combination of welding current and voltage, increase in the welding speed or the speed of arc travel results in less penetration, less weld reinforcement and less heat input per unit length of weld. Excessively high travel speeds decrease fusion between the weld deposit and the parent metal, and increase tendencies for undercut, arc blow, porosity and irregular bead shape. As the travel speed is decreased, penetration and weld reinforcement increase. But too slow a speed results in poor penetration, because under this condition, the weld puddle is directly under the electrode tip and the force of the arc is cushioned by the weld puddle. Excessively slow speeds also produce a convex bead shape, which results in an uneven weld bead with slag inclusions.

1.6.4 Size of Electrode

As in the case of SAW, the electrode size is selected according to the plate thickness and the desired size of weld. With increase in electrode size, welding current can be increased so as to get higher deposition rates, deeper penetration and increased weld size. At a given welding current, changing over to a larger electrode results in a wider, less penetrating bead. Hence in joints with poor fit-up, a larger electrode is preferred to a smaller one for bridging the root gap. For a given electrode size, a high current density (i.e. welding current in amps divided by the cross-section of the wire, expressed in amps/ mm^2) results in a strong, penetrating arc, while a lower current density gives a soft arc which is less penetrating.

1.6.5 Electrode Stick-Out

It is also termed electrode extension. It refers to the length of the electrode, between the end of contact tube and the arc, which is subject to resistance heating (also called 1^2R heating) at the high current densities used in the process. The longer the stick-out, the greater the amount of heating and higher the deposition rate. Increased electrode stick-out reduces to some extent the energy supplied to the arc, resulting in lower arc voltage and a different bead shape. Hence when the electrode stick-out is increased to obtain higher deposition rate, the voltage setting on the equipment must be increased to maintain correct arc length. Deposition rates can be increased by as much as 25-50% by increasing electrode stick-out, but the technique is little used in industry. This may be due to the following factors:

(a) Insulated guide is needed to direct the hot wire to the weld pool.

(b) Penetration is reduced by about 10%.

(c) Excessive overheating of the wire leads to electrode pulsation, arc instability and stubbing

Also termed arc energy, it is calculated by using the formula:

$$HIR = \frac{V \times I \times 60}{S \times 100}$$

HIR=heat input rate in kilojoules per mm (kJ/mm)

V = arc voltage

I = welding current

S = arc travel speed in mm/ min.

For a given joint thickness, the higher the heat input rate, the lower is the cooling rate of the weld metal and heat affected zone (HAZ) of the parent metal, and vice versa. Heat input rate has an important bearing on the weld metal microstructure and the final microstructure of the HAZ.

1.7 Advantages of SAW

The growth in the use of SAW has been due to its major advantages, as follows:

- Minimum operator protection required
- Highest deposition rate. This rate is nearly two times the rate of flux Cored arc welding and four times the SMAW. No process other than the electro slag welding can come close to

this deposition rate.

- High quality welds-many codes permit saw to be used on structural iron, pressure vessels, cryogenic cylinders, and many other critical applications.

1.8 Disadvantages of SAW

As with other processes, the submerged arc processes have several disadvantages:

- Restricted to flat position and horizontal fillets
- Welding parameters need careful control
- Mechanical guidance is necessary. Even with good guidance systems, positioning Problems can develop if the wire does not have a large and uniform cast (or little band) and a negligible (twist). Significant variations in cast or large helix will cause an arc to wander.

1.9 Pressure vessels

Thick-walled cylindrical steel vessel enclosing the reactor core in a nuclear power plant. The vessel is made of special fine-grained low alloy ferritic steel, well suited for welding and with a high toughness while showing low porosity under neutron irradiation. The inside is lined with austenitic steel cladding to protect against corrosion. For example for a 1,300 MWe pressurized water reactor, the pressure vessel is about 12 m high, the inner diameter is 5 m, and the wall of the cylindrical shell is about 250 mm thick. The overall weight amounts to approx. 530 t without internals. The vessel is designed for a pressure of 17.5 MPa (175 bar) and a temperature of 350°C.

1.9.1 Material used in manufacture of Pressure vessels

The properties of carbon and low alloy steels currently used in the USA for commercial power pressure vessel construction are examined in reference to higher strength-higher alloy steels having potential for advanced reactor service. Emphasis is placed upon the characteristics of selected vessel steels which are critical to the intended service function and the influence of fabrication and the service environment in changing important mechanical properties. Recent developments for assessing these properties

Figure 1.4: Pressure vessel shipping [18]

After simulated nuclear service are reviewed along with techniques for minimizing the effects of radiation. The review places much emphasis upon improved properties for steels which show strong potential for future nuclear structural application. Engineering considerations are cited only to highlight the descriptive review of pressure vessel steels, current and future, and their capacity for meeting the critical functions required of a primary containment vessel.

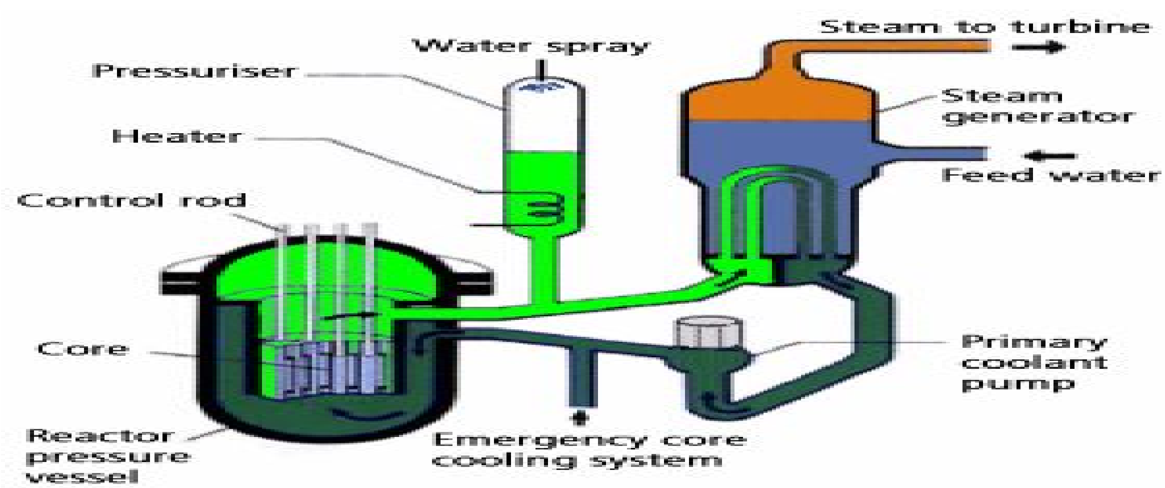


Figure 1.5: Pressure vessel in power plant [18]

Figure 1.6: Pressure vessel manufacturing [18]

The main steel grades following: 1Cr0.5Mo2.25, Cr1Mo1.25, Cr0.5Mo1.25

1.9.2 Welding Issues on Pressure vessel

Many experiments have been carried out to assess flux effects on PV steels. The interpretation of available data is not straightforward due to a large variety of experimental conditions (ranges of flux, chemical composition, etc.). The salient conclusions from previous research are:

- ✓ Greater sensitivity to weld cracking during fabrication
- ✓ Susceptible to re-heat cracking
- ✓ Intermediate stress relief (ISR) mandatory for highly stressed-pressure retaining welds
- ✓ Greater control required on preheats and inter-pass temperatures
- ✓ Welding consumables suppliers are limited globally
- ✓ Very low toughness of “as welded” welds deposit.

✓ Field-weld repairs are much more difficult to carry out, due to heating steps necessary in the welding process.

1.9.3 Welding carbon alloy steels

Not all carbon or low alloy steels for pressure vessel use are considered weldable. Those materials considered to be of weldable quality have been assigned a P−Number. These assignments are found in both Section II and Section IX of the ASME Code. The P-No is a designation by ASME Boiler and Pressure Vessel Code to categorize the chemical composition and weldability of metals used in the fabrication of pressure retaining items. In my study I consider the ferrite steel API 5L X65 for welding purpose.

CHAPTER 2 LITERATURE REVIEW

2.1 Review of Literature

A lot of work has been done in the area of submerged arc welding. Here is some of the work done by various Researchers. A lot of work has been done in this field with the change in flux compositions we can improve the weld chemical properties resulting in strengthening of weld.

Chang-Shung[1], The thermodynamic and kinetic parameters controlling the chemical composition of weld deposits produced during flux shield arc welding have been studied. the primary process studied was submerged arc welding using fused neutral fluxes although several bounded neutral fluxes were also tested .a statistical analysis of the effect of the SAW operating parameters on the manganese, silicon and oxygen recovery has been performed. The results indicate that vide variations' in the weld metal chemistry may occur depending upon the choice of operating parameters

Samit Sharma [2], In this project, steel plates of the type, ASTM A5 16-Grade 70, were welded using submerged arc welding. Three point bend specimens were made of the weldments which were then notched at different positions relative to the weld interface. These specimens were fatigue pre-cracked and fractured according to plane strain fracture toughness standard ASTM E-399-90 on an MTS 8 10 servo-hydraulic system. The study found that in weldment the base metal has a pearlite structure, followed by a coarse grained structure consist of acicular ferrite, bainite and a network of cementite in the heat effected zone, while the weld metal had a large proportion of coarse grain boundary with side plate ferrite,fine acicular ferrite and probably bainite.

D.Carrouge et al. [3], Studied the effect of the presence of non-equilibrium d-ferrite on the impact properties of a supermartesitic stainless steel. To generate homogeneous d-ferrite containing microstructures the material was, in the first part of the present study, subjected to a series of high temperature furnance heat treatments. Three microstructures possessing variable ferrite content and different grain sizes were generated. Charpy impact results indicate that the presence of 14% d-ferrite in a martensitic matrix of 60 mm prior austenite grain size raises the ductile to brittle transition temperature by about 50 degree compared with a fully martensitic microstructure of 80 mm. For a similar grain size, reducing the amount of d-ferrite from 14% to

2% restored the tempered parent material. Testing of the simulated HAZ indicated that toughness was not significantly affected by the presence of d-ferrite.

Zoran Sterjovski [4], Longitudinal and circumferential welds in transportable pressure vessels were produced by submerged-arc welding using a single vee preparation and multiple weld runs. This thesis reports on the weld procedure, micro structural evaluation and various mechanical properties (bend, yield strength, tensile strength, elongation, fatigue, impact toughness, CTOD fracture toughness and hardness) for steel weldments. The parent metal, heat affected zone and weld metal regions of each weldment were examined, and then exposed to temperatures and times in the PWHT range. Although there was no apparent change in microstructure at an optical level and little change in hardness for up to four post weld heat treatments, there was a marked decrease in hardness of the parent metal for more extensive heat treatments For all test plates, results are also presented for Charpy V-notch impact tests in the parent metal, HAZ and weld metal region, and CTOD fracture toughness tests in the PM region. The effect of exposure to multiple PWHT cycles on these properties is discussed.

B. Tanguy et al. [5], The Study was devoted to the ductile–brittle transition behaviour of a French A508 Cl3 (16MND5) steel. Due to its importance for the safety assessment of PWR vessels, a full characterization of this steel with Charpy V-notch test in this range of temperature was undertaken. The aim of this study is to provide a wide experimental database and micro structural observations to supply, calibrate and validate models used in a local approach methodology. Mechanical and fracture properties of the steel have been investigated over a wide range of temperatures and strain rates. Effects of impact velocity on ductile–brittle transition curve, on ductile tearing and on notch temperature rise are presented and discussed. A detailed study of ductile crack initiation and growth in

Charpy specimens were also carried out. From fractographic investigations of the micro voids nucleation around carbide second phase particles, a plastic strain threshold for nucleation is determined for this material. A508 Cl3 steels undergo a transition in fracture toughness properties with temperature, due to a change in fracture mode from micro voids coalescence to cleavage fracture. A systematic investigation on the nature and the position of cleavage triggering sites and on any change in the ductile to brittle transition (DBT) range has been carried out. This leads to the conclusion that Manganese sulphide inclusions do not play an increasing role with increasing test temperature as recently mentioned in other studies on A508 Cl3 steel with higher sulphur content. In a companion paper [1], the numerical simulation of the Charpy test in the ductile–brittle transition range using fully coupled local approach to fracture is presented.

S.K. Nath et al. [6], Fracture toughness of medium carbon steel has been determined by round notched tensile specimen. Two notch diameters (5.6mm and 4.2mm) and three notch angles namely 45º, 60º and 75º have been used to observe the effect of notch diameter and notch angle on fracture toughness of the steel. By heat treatment the microstructure of the steel is also varied and its effect on the fracture toughness is also observed. It has been found that the fine grained structure improves the fracture toughness.

Ljubica Milovic et al. [7], The study was devoted for determination of parameters of the fatigue crack for constituents of welded joints produced of high strength low alloyed steel Nionikral-70(yield strength 700 Mpa).Results have shown that the position of notch and crack initiation affect the values of the stress intensity range of fatigue threshold and parameter in the Paris equation

F.H. Lang et al. [8], Maraging steels are iron-nickel alloys designed to combine high strength with good fracture toughness. The properties are achieved through the age-hardening of low carbon martensite that forms when the steels are cooled from the austenitizing temperatures. The martensite forms when the steels are cooled from the austenitizing temperatures. The martensite forms independently of cooling rate and is relatively soft, but when it is aged at approximately 900 ºF it hardens considerably through the precipitation of intermetallic compounds. From the weld ability point of view, the most important feature of maraging steels is the fact that they are relatively soft after cooling from the austenitizing temperatures.

Honeycomb [9], Stated that the ductile fracture, in the form of void coalescence, initiates at fine second phase particles (most likely carbides in the present case). The mechanism involves the nucleation, growth and linking of voids in the plastic zone ahead of the crack tip, thus propagating the fracture. It was appearing that the voids are smaller in diameter when there is no exposure to PWHT. Hence it can be deduced that very fine, dispersed second phase carbide particles exist throughout the matrix. As the second phase carbide particles coarsen, the voids increase in diameter and spacing and facilitate crack growth. When the second phase carbide particles reach a certain size by a growth-coalescence mechanism their ability to initiate voids was impaired .resulting in quasi-cleavage, a more brittle mode of cracking, at lower impact energy. The precipitation of new carbides such as MoC may also occur and coarsen with increased number of PWHT cycles. The effect of cumulative PWHT cycles on the Charpy fracture surface of the 11 mm fast and slow cooled PM samples was not as clear as 20 mm BIS80PV because all surfaces show quasi-cleavage fracture. In the fractograph of the 11 mm sample without PWHT, a quasi-cleavage brittle type fracture surface was evident. The reason for this difference could lie in subtle differences in chemical composition and the nature of the banding and segregation in the two different thicknesses of the same steel.

Hiroshige et al. [10], A highly corrosion-resistant stainless steel, NSSC260A, for application to chemical cargo tankers and welding consumables for the steel were developed. The stainless steel and welding consumables were designed to exhibit good resistance to corrosion by sulphuric acid, crude phosphoric acid and salt water. The developed welding consumables, flux-cored wire NITTETSU FC-317LNCU for CO_2 welding and NITTETSU BF-317LNCU (flux)NITTETSU Y-316C (solid wire) for submerged arc welding, proved that it is possible to attain weld joints that satisfy required corrosion resistance and mechanical properties, and their actual use for construction of chemical cargo tankers began in June 2004.

Jagannathan et al. [11], An experimental program was carried out to interpret the effect of submerged arc flux compositions on the charpy toughness and fracture behaviours of typical pressure vessel steel weldments. Three different fluxes with varying basicity namely linde grade 80, linde grade 0091 and oerlikon OP76-were selected for the program. The steel weldments used were C-Mn-Si, 2-1/4 Cr/1 Mo, and A543 class 1. It has been found that silicon rich inclusions are harmful to toughness and that grade 80 welds with the presence of high amounts of these inclusion results in lower toughness compared to that grade 80 welds with the presence of high amounts of these inclusions results in lower toughness compared to grade 0091 or OP76. Of the three fluxes, OP76 develops a much clear weld with very few silicon –rich inclusions, resulting extremely tough weld. Characterization of toughness at different positions of the weld shows sensitivity of the toughness tests on the weld metal to impact test position.

J. Jang et al. [12], Bead-on-plate welds were produced using twenty four fused reagent grade submerged arc welding fluxes, selected from three flux systems, SiO_2-MnO-FeO, MnO-CaF_2 and SiO_2-CaO-CaF_2. The welds were processed using AISI 1010 steel coupons, and a Lincoln L-50 AWS type A5.17) welding wire with a constant heat input of 3.0 kJ mm. The three flux systems were selected because of their different oxygen potentials and their ability to produce welds with a wide oxygen range (70 to 1400 ppm). Qualitative and quantitative metallographic and chemical analysis was performed on the welds. Inclusion morphology and volume fraction are observed to be affected by flux composition Inclusions of 1µm in size and greater are associated with grain boundary and blocky proeutectoid ferrites, while inclusions 0.64µm and smaller are linked with the presence of acicular ferrite.

Kane et al. [13], they summarized the development and qualification of an appropriate welding consumable for a demanding cryogenic magnet application. It begins with a review of the research conducted on cryogenic fracture toughness of wrought and welded austenitic stainless steels.

This research showed that certain elements of the composition have a powerful effect upon the steel's fracture toughness at 4 K. In particular, the higher oxygen content in the weld manifests itself as inclusions, which have a severe detrimental effect upon the fracture toughness. This one factor accounts for most of the difference in toughness between wrought and weld materials of similar composition, and is a function of the weld process.

Also, welds enriched with manganese and nickel has demonstrated improved fracture toughness. These discoveries were combined in the development of a nitrogen- and manganese-modified, high-nickel stainless- steel alloy. It produced gas metal arc welds with superior cryogenic mechanical properties (yield strength near 900 MPa at 4 K and a Charpy V-notch impact energy near 140 J at 76 K) when the procedures were modified to reduce the oxygen content.

Mitra et al. [14], Explained that during submerged arc welding, as in other flux shielded welding processes, chemical reactions takes place between the molten flux and the metal. This reaction between the slag and the metal results in compositional changes affecting the structure and the properties of the weldment. Thus, in order to control the mechanical properties of the weldment and match them with those of the work piece, it is necessary to estimate the extent of interaction between the metal and the slag. This need is more acute now since major improvements in steel making technology have improved base metal properties and have resulted in the creation of entirely new classes of steel, such as High Strength Low alloy (HSLA) steels for use in ship building, pipelines, pressure vessels etc. thus far, there is no general method for determining weld metal composition.

N.D. Pandey et al.[15], studied the influence of submerged arc welding(SAW) parameters and flux basicity index on the weld chemistry and transfer of elements manganese, silicon, carbon and sulphur has been investigated, five fluxes and different values of the welding parameters being used for study. The welds were produced as a bead on a mild-steel plate. The weld metal composition showed, in general, gain of silicon and loss of carbon, manganese and sulphur elements. The results show that welding current and voltage have an appreciable influence on element transfer as well as on weld composition. On the other hand, except for weld-metal silicon, the basicity index of the fluxes has only a minor influence. Weldments properties such as strength, toughness and solidification cracking behaviour are affected by chemical composition.

P. Ambroza et al. [16], Carried out the experiment using WC-8%Co powder spread on low carbon structural steel surface and then melted by arc under the flux, containing graphite powder. The test results showed that by using for overlaying welding under flux WC-8%Co powder, it is possible to obtain layers with large amount of carbide phase (about 90%); formation of carbides was influenced by both amount of WC-8%Co powder spread over the structural steel surface, and amount of graphite powder, mixed with flux. Electric arc between welding wire and base metal resulted, due to high temperature, melting of WC carbide in powder and formation of Fe_3W_3C carbide during cooling, because the iron into welding bath came from both melted welding wire and structural steel surface. The microstructure was obtained in which carbides are bounded by the matrix, having alloyed steel composition. The matrix is composed of martensite, Troostite and retained austenite. Amount of these phases depends on the amount of alloying elements (W, Co, Mn and Si), and amount of carbon, as well as heat treatment.

R.Quintana et al. [17], said that to obtain metal coatings with complex chemical compositions and phases, as well as differing mechanical properties, the Submerged Arc Welding (SAW) process is often used, employing a great variety of types of agglomerate fluxes. All agglomerate fluxes consist of two fundamental parts: the matrix and the alloyed load. The ratio of matrix to the alloyed load can vary greatly.. The two constituents of the flux aggregate, by various processes, with the help of agglomerating agents. Agglomeration by granulation (palletizing) using liquid sodium and/or potassium glass is the most common and widely used for these types of fluxes, despite their hygroscopic character. One of the most significant profitability characteristics of an agglomerate flux is the efficiency of the transfer of the chemical element of the alloyed load of the flux to the deposited metal by particular wire-flux systems and welding regimens. The aim of this study was to evaluate the capacity of various agglomerate fluxes to transfer to the welding bath the elements Cr, Mn and C from alloy loads formed with different ratios of FeCr, FeMn and graphite. To do this, a vitreous matrix was synthesized and melted in an electric arc furnace, using a formulation of the minerals, and alloyed loads were formed with different ratios of the components established using a McLean Anderson experimental design.

CHAPTER 3 PROBLEM FORMULATION

Basically not much literature is available regard to studies on welding of pressure vessel steels vis. vis. strength and metallurgical considerations during welding applications. The welding and joining of pressure vessel steels is a complicated phenomenon and involves structural integrity test and structural health monitoring issues.

The application of these steels has been limited by the availability of suitable filler metals. As the weld metal strength increases, the probability of hydrogen-assisted cracking also increases. For more improvement in welding we have to minimize the effects of diffusible hydrogen and develop tough microstructures. The current research proposes to study the effects of welding flux on tensile strength, toughness, micro hardness, microstructure of work piece.

Fluxes for welding are commercially available but these are patented. In the present work fluxes are to be developed for joining of API 5L X65 steel.

The objective of the present work is to investigate the uses of submerged arc welding fluxes of pressure vessel steels and to find out the effect of process parameters on structural integrity of these welds. The aim of the present work would also be to generate relevant data for structural integrity assessment of welds.

CHAPTER 4 EXPERIMENTATION

Submerged arc welding is a best method to weld a plate. Any change in the parameter of submerged arc welding affects the properties of welding. So, in this experiment by changing the flux (basicity index) and keeping all other parameter constant and find out the result that what is the effect of basicity index on tensile strength, toughness, micro hardness, microstructure etc. The high strength low alloy steel (API 5L X65) plate used as a work material and the dimension 18 x 150 x 250 mm. The experiments have been conducted on Submerged Arc Welding Machine i.e. Tornado Saw M-800 transformer and FD 10-200T welding tractor available at Central Workshop, Thapar University, Patiala. For 3.2 mm diameter the value of Current 300-400 ampere, Voltage 25-30 volt so, firstly by using these we make bead on plate by taking different current and voltage reading. Then we find out that 300ampere current, 29 volt voltage is best suitable for welding.

Table 4.1: Test Matrix

Exp. No	Welding Flux	Current (A)	Voltage (V)	Travelling Speed (m/h)
1	1	300	29	25
2	2	300	29	25
3	3	300	29	25
4	4	300	29	25
5	5	300	29	25

4.1 Method of preparation of flux

(a) Agglomerated fluxes to be used in the study would be prepared by varying the

Ingredients CaO, MgO, CaF_2 and Al_2O_3 as per formulations based on statistical

Mixture design

(b) The flux ingredients CaO, Al_2O_3, CaF_2, MgO, SiO_2, TiO_2 and MnO would be mixed Properly to form homogeneous powder mixture and then mixed with a binder sodium silicate solution within a container to form an agglomerated mass.

(c) Then agglomerated mass is dried at room temperature for 24 hours.

(d) After drying it would be taken in a stainless steel container and heated in a furnace at a temperature of 500°C for 1h duration to remove moisture and other volatile matter.

(e) Thereafter it would be taken from the furnace and cooled in air. The size classification of the agglomerated mass will be done by sieve shaker. After size classification of fluxes were kept in air tight polythene bags.

Table 4.2: Basicity Index

Flux	1	2	3	4	5
Basicity Index	3.7	1.1	2.5	3.0	2.4

The solution of sodium silicate (20% weight of flux) binder was added to the dry mixed powder and it was mixed for 10 min. Sodium silicate was added for better arc stability. The mixture flux were dried in air for 24 h and then baked in the pit furnace at approximate 700°C for nearly 3 h. After cooling, this flux were crushed and sieved. After sieving, fluxes were kept in air-tight bags. By using this method we make 5 different kind of flux.

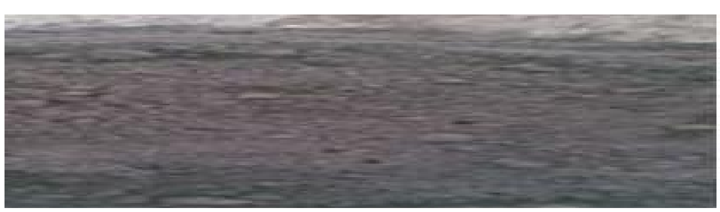


Fig 4.1: Compounds mix with Binder

Fig 4.2: Test sieve (8 BS, 10 ASTM, 2 mm IS, 2057 microns

Fig 4.3: Fluxes after sieved

4.2 Chemical composition of base metal and electrode

The composition of base metal and welding electrode was finding out by using spectroscope.

Table 4.3: Chemical Composition of base metal (HSLA Steel type: API 5L X65)

Specification	Grade	C % Max	Mn % Max	P % Max	S % Max
API 5L	X65	0.28	1.40	0.03	0.03

EH 14 –AWS grade EH-14 (E- Electrode H- High Manganese Content from 1.7 to 2.2% Max, 14×10^{-2} - Carbon Content) Source: Product Catalogue, Ador Fontech Ltd. Diameter of Wire: 3.2 mm

Table 4.4: Chemical Composition of electrode (Welding Wire)

Specification	**AWS Grade**	**C %**	**Mn %**	**Si %**	**S %**	**P %**	**Cu%**
EH 14	EH 14	0.10/0.20	1.7/2.2	0.1	0.03	0.03	0.35

4.3 Method of preparation of steel plate specimen

We have 10 plates of dimension 18x150x250 mm. These plates chamfer on 250 mm side so, that we can make V joint at 60 degree angle when joining two plates then tacking on back side of plates using manual arc welding so that, keeping these plate on level.

After tacking, put specimen on base plate of SAW machine clamp the specimen with base plate using clampers then by putting 5 different kind of flux one by one in hopper welding was done in V grooves of 10 plates.

Fig 4.4: Making chamfer on corner of plate

Fig 4.5: Joint of plates after welding

Now cut the specimen in required dimension for tensile test, impact test, Micro hardness,

Micro structure analysis, SEM and Chemical composition.

4.4 Tensile Test

Ratio of the maximum load a material can support without fracture when being stretched to the original area of a cross section of the material. When stresses less than the tensile strength are removed, a material completely or partially returns to its original size and shape. As the stress approaches that of the tensile strength, a material that has begun to flow forms a narrow, constricted region that is easily fractured. Tensile strengths are measured in units of force per unit area. Welded specimen made from base metal and fined the tensile strength and stress-strain curves. The testing would be carried on computerized Universal Testing Machine (UTM) as shown in fig 4.6

Fig 4.6: Computerised Universal Testing Machine

4.5 Impact Test

The ability of a metal to rapidly distribute within itself both the stress and strain caused by a suddenly applied load or the ability of a material to withstand shock loading is toughness. It is the exact Opposite of "brittleness" which carries the implication of sudden failure. A brittle material has little resistance to failure once the elastic limit has been reached.

According to standard shown in fig 4.7, we make 20 specimens shown in fig 4.8, 5 from each plate of dimension 10x10x55 mm for charpy test and test them on machine as shown fig 4.9.

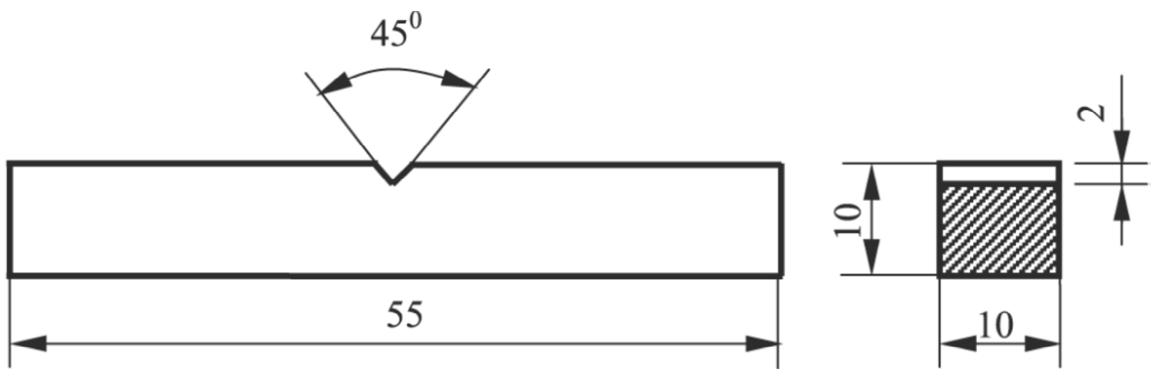


Fig 4.7: Standard Charpy test specimen

Fig 4.8: Charpy test specimen

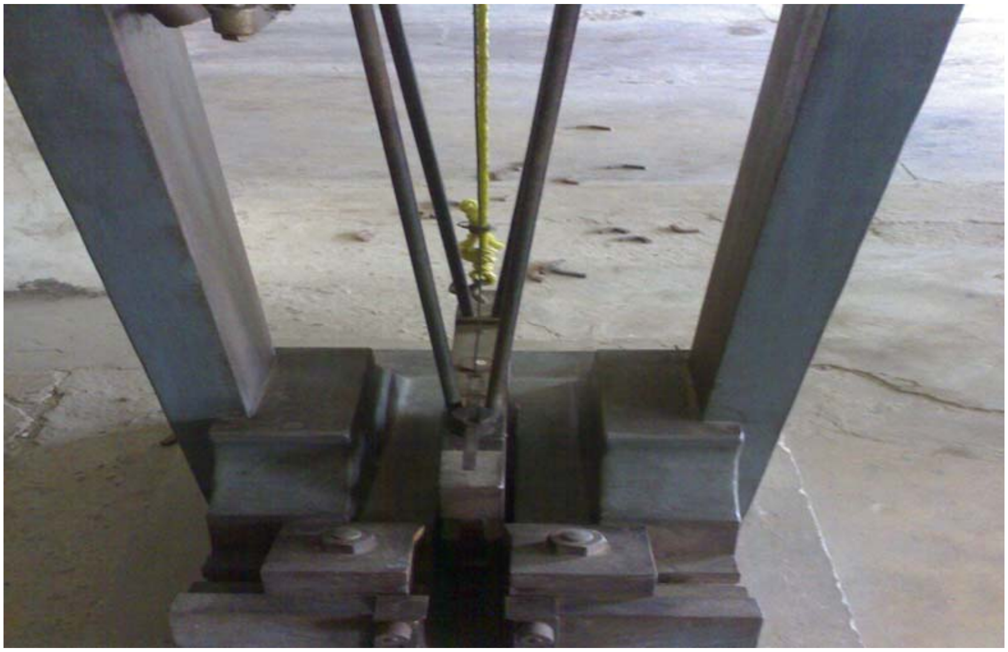


Fig 4.9: Charpy testing machine

4.6 Microstructure

A microscope is an instrument to see objects too small for the naked eye. The science of investigating small objects using such an instrument is called microscopy. Microscopic means invisible to the eye unless aided by a microscope. There are many types of microscopes, the most common and first to be invented is the optical microscope which uses light to image the sample. In this test the specimen after cutting rugged with ambry paper of size no. 100, 200, 400, 600, 800, 1000 then put under microscope as shown in fig 4.11 and see the structure of specimen shown in fig. 4.13 and the different zone of welding shown in fig 4.13

Fig 4.10: Microscope

Fig 4.11: Polishing machine

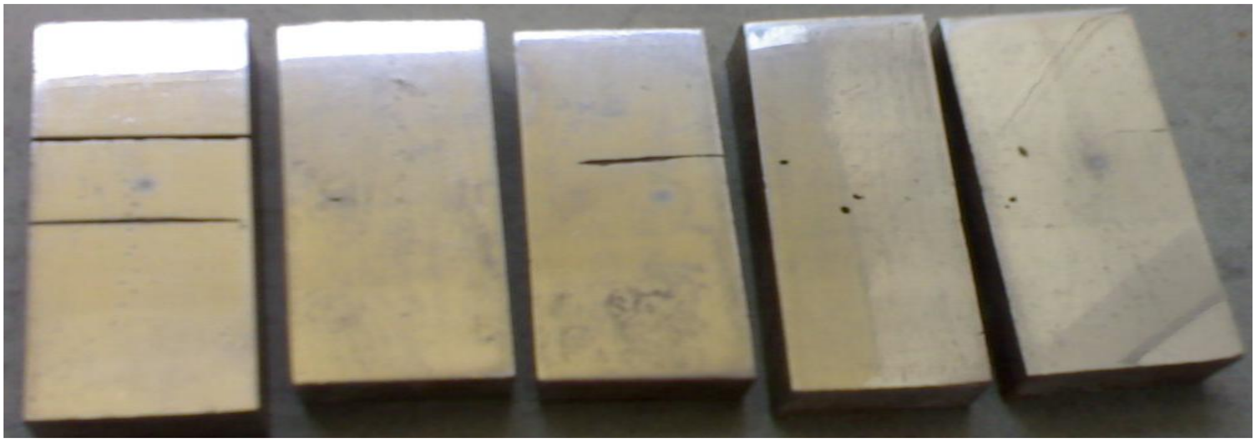


Fig 4.12: Specimens for microscope testing

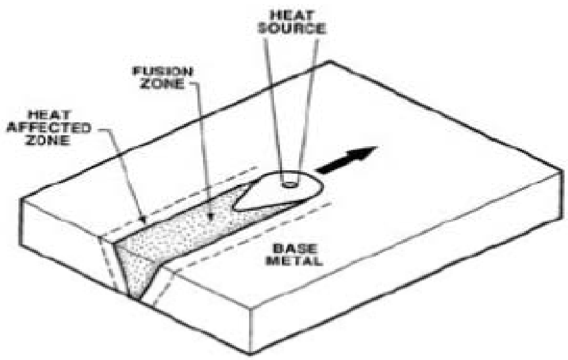


Fig 4.13: Specimens showing different zone of welding

4.7 Micro Hardness Test

Micro hardness testing shown in fig 4.14 is used for measuring the hardness of a material on a microscopic scale. A precision diamond indenter is impressed into the material at loads from a few grams to 1 kilogram and we have taken load of 500gm. The impression length, measured microscopically, and the test load are used to calculate a hardness value. The hardness values obtained are useful indicators of a material's properties.

The indentations are typically made using either a square-based pyramid indenter (Vickers hardness scale) or an elongated, rhombohedral-shaped indenter (Knoop hardness scale). The tester applies the selected test load using dead weights. The length of the hardness impressions are precisely measured with a light microscope using either a filar- eyepiece or a video image and computer software. A hardness number is then calculated using the test load, the impression length, and a shape factor for the indenter type used for the test and the test specimen shown in fig 4.15.

Fig 4.14: Micro Hardness test machine

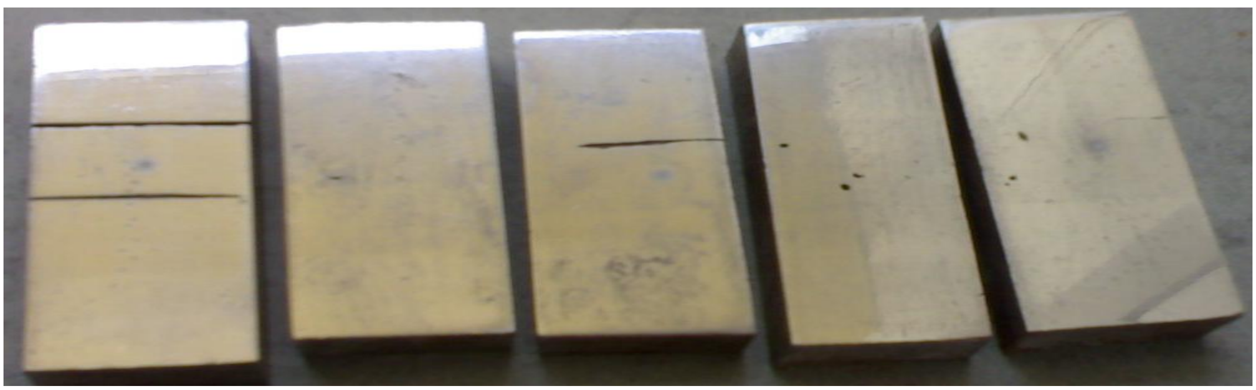


Fig 4.15: Micro Hardness test specimen

4.8 Chemical composition of weld metal

The composition of base metal and welding electrode was finding out by using atomic absorption spectroscope.This machine is connected with computer.when we insert the specimen in machine then computer software gives us the actual values of the composition.

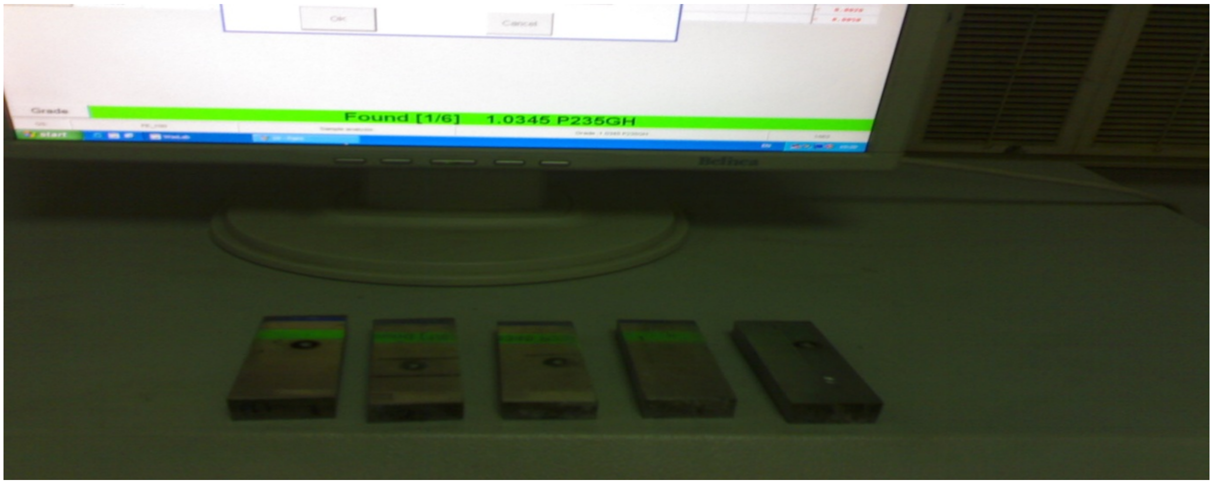


Fig 4.16: Atomic Absorption Spectrometer

4.9 Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) is an important tool for micro structural analysis. The micro structural characteristic of the sample correlate the effect of different processing condition with properties and behaviour of materials that involves their micro structural changes. The SEM provides information relating to topographical features, morphology, phase distribution, compositional differences, crystal orientation and presence of defects and their location. The strength of SEM lies in its inherent versatility due to the multiple signals generated, simple image formation process, wide magnification range and excellent depth of field. Structural analyses were carried out to see the morphological features of grain formation. The experiments have been conducted on Scanning Electron Microscope as shown in fig 4.20 i.e. JEOL JSM-6510 LV available at R & D Centre, Thapar University, Patiala.

Fig 4.17: Scanning Electron Microscope machine

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Tensile Test

Table 5.1: Ultimate Tensile Load Reading:

Flux No.	Basicity Index	Peak load (K. Newton)	Peak displacement(mm.)
1.	3.7	62.64	16.31
2.	1.1	72.63	18.46
3.	2.5	64.68	19.05
4.	3.0	52.06	15.84
5.	2.4	71.90	21.40

Table 5.2: Ultimate Tensile Stress Reading:

Flux No.	Basicity Index	Peak stress (K. Newton/sq.mm)	Peak strain(mm)
1.	3.7	0.51	0.44
2.	1.1	0.59	0.40
3.	2.5	0.52	0.26
4.	3.0	0.42	0.24
5.	2.4	0.58	0.37

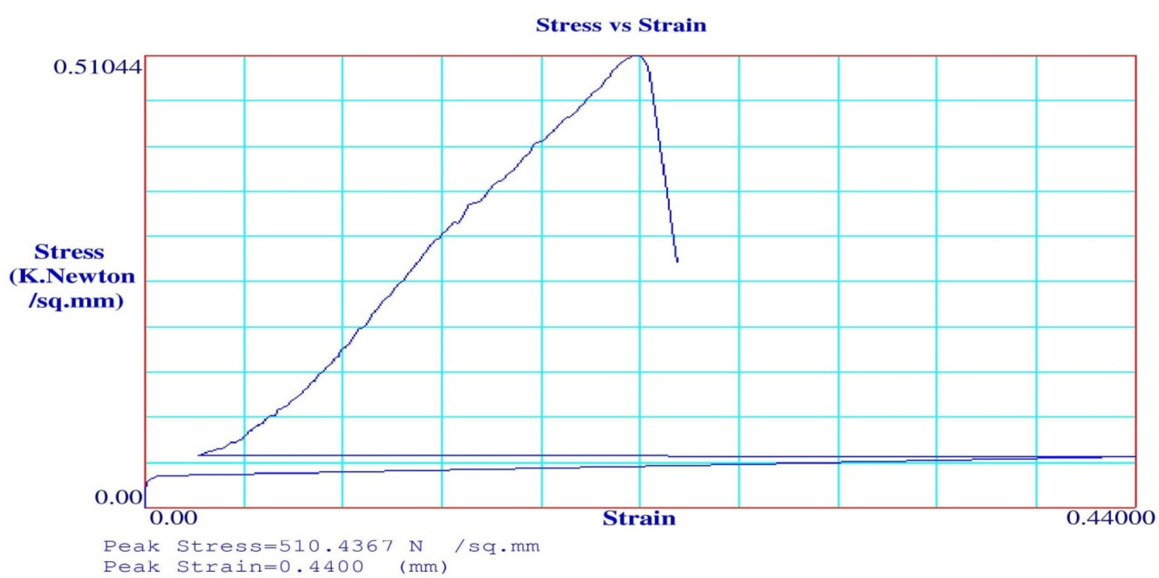


Fig 5.1: stress vs. strain curve for specimen which weld from flux1

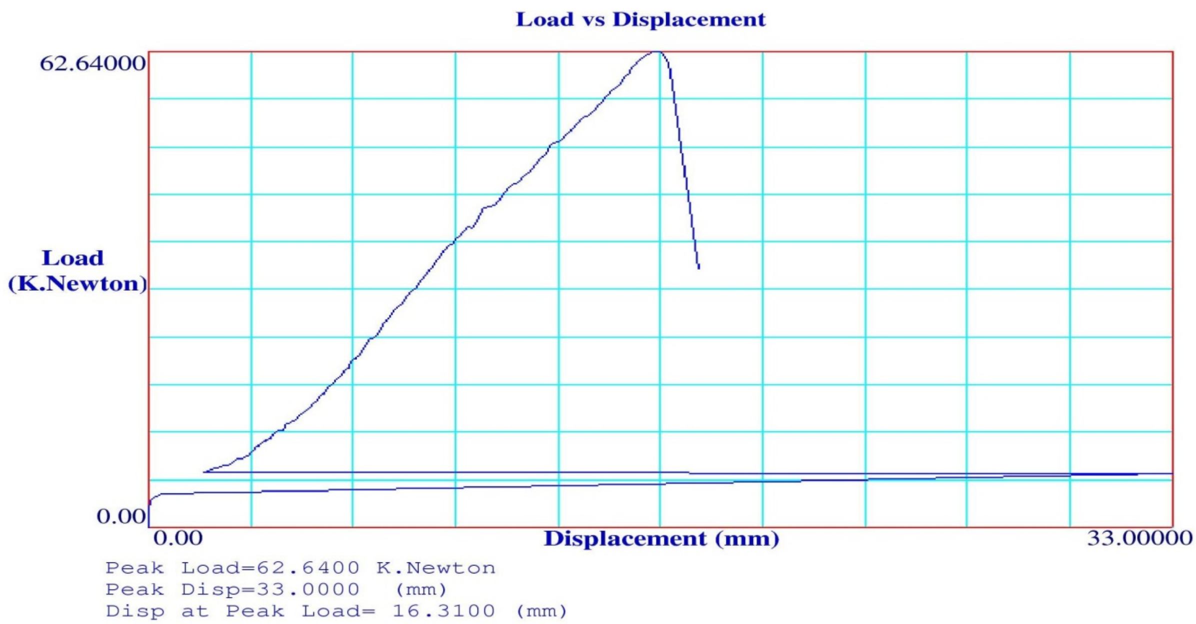


Fig 5.2: Load vs. displacement curve for specimen which weld from flux1

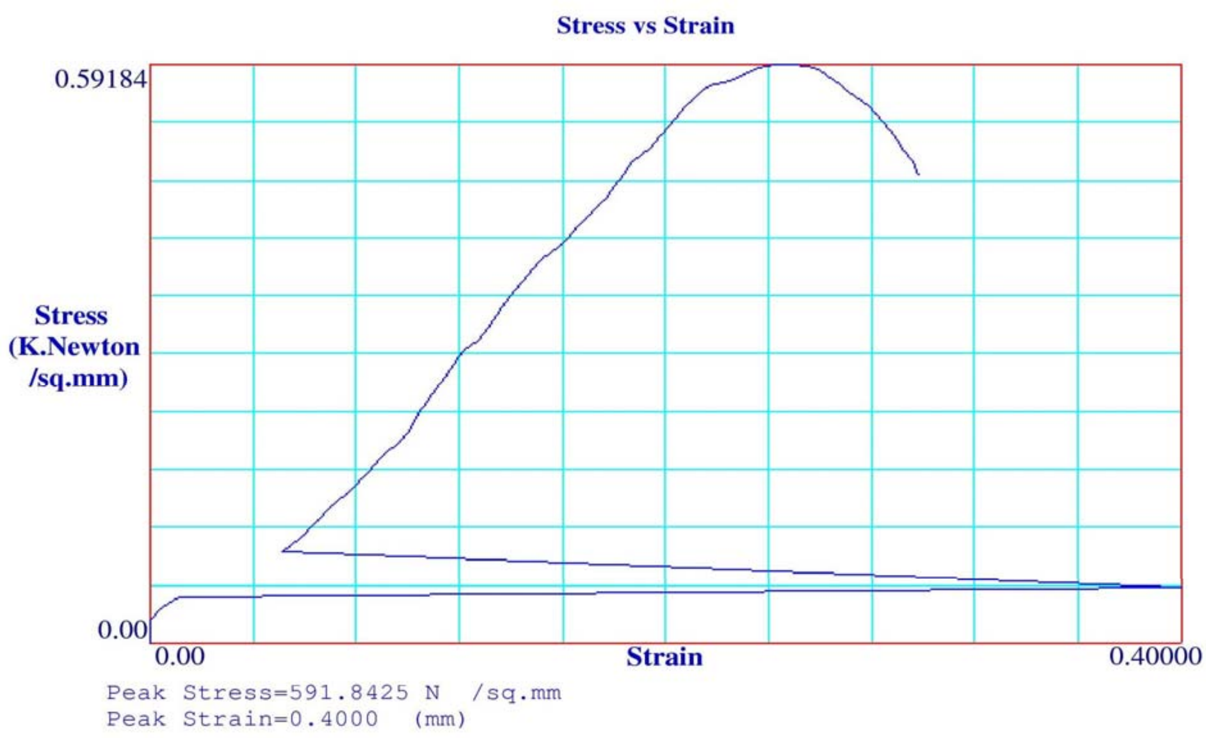


Fig 5.3: stress vs. strain curve for specimen which weld from flux2

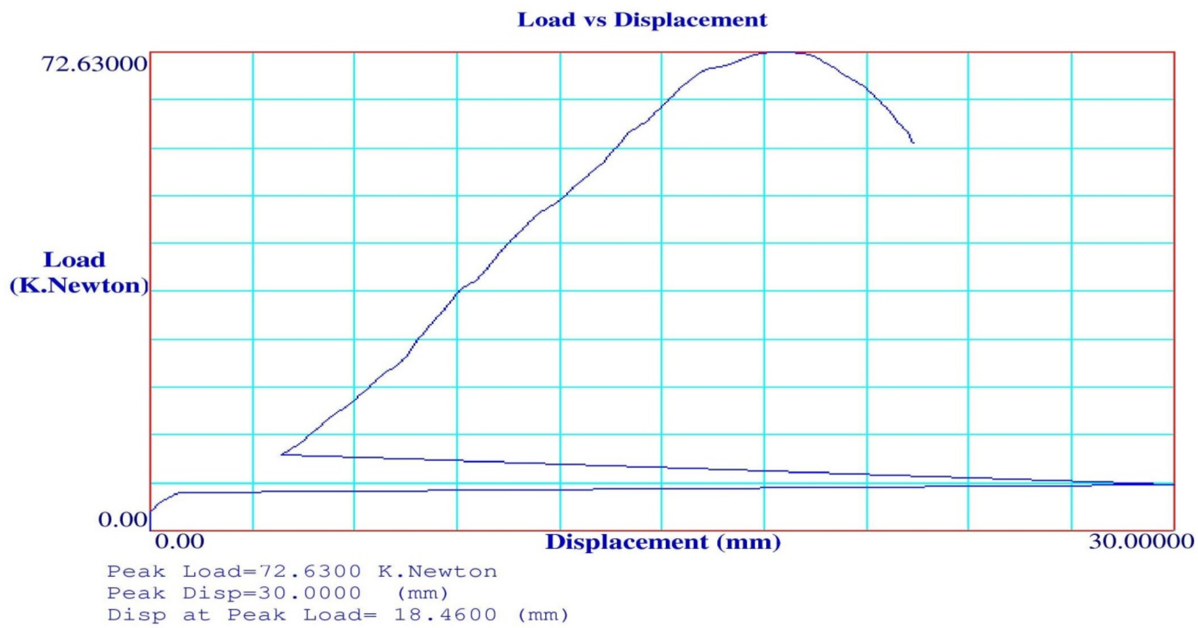


Fig 5.4: Load vs. displacement curve for specimen which weld from flux 2

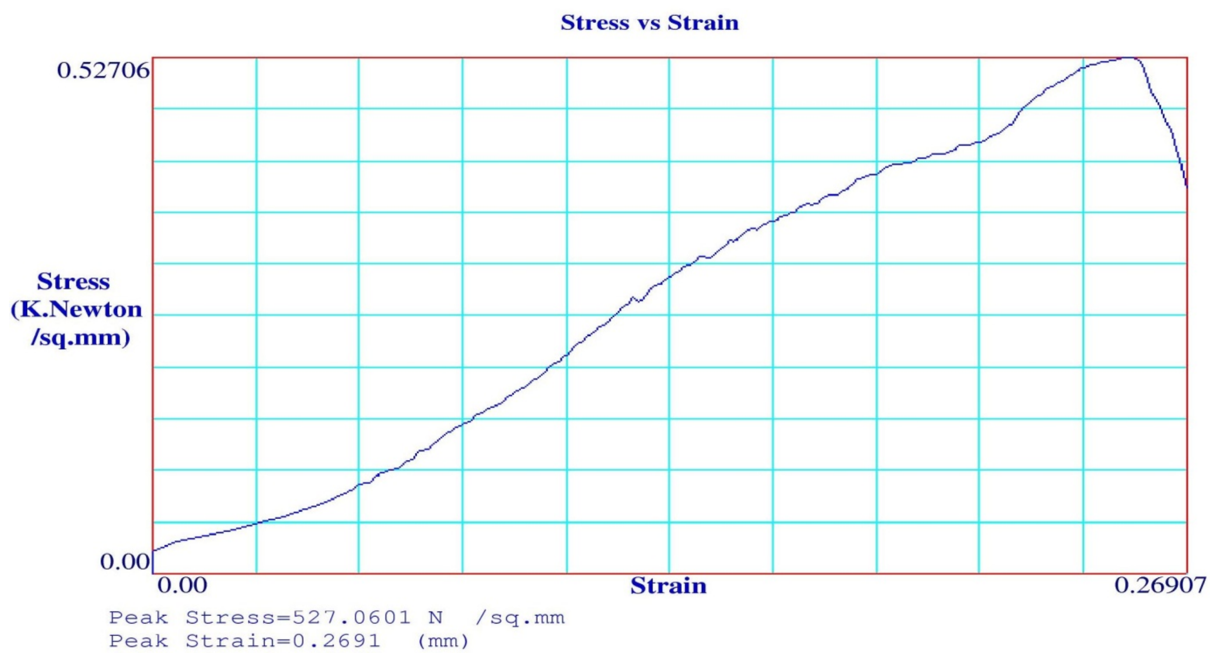


Fig 5.5: stress vs. strain curve for specimen which weld from flux 3

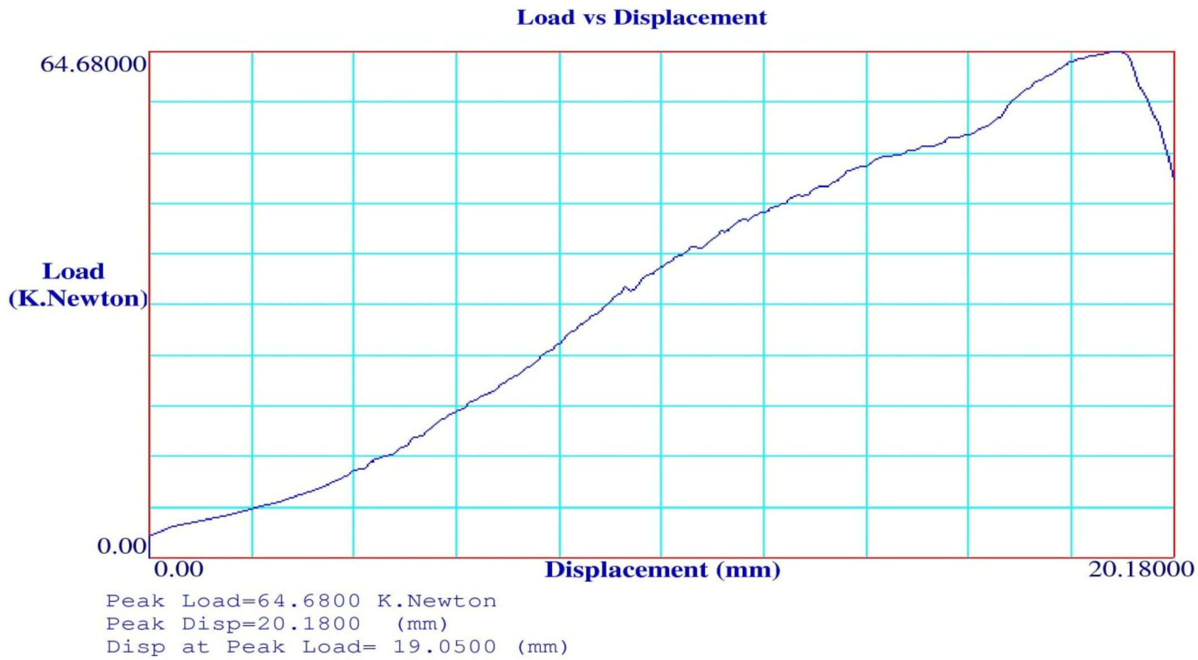


Fig 5.6: Load vs. displacement curve for specimen which weld from flux 3

Fig 5.7: stress vs. strain curve for specimen which weld from flux 4

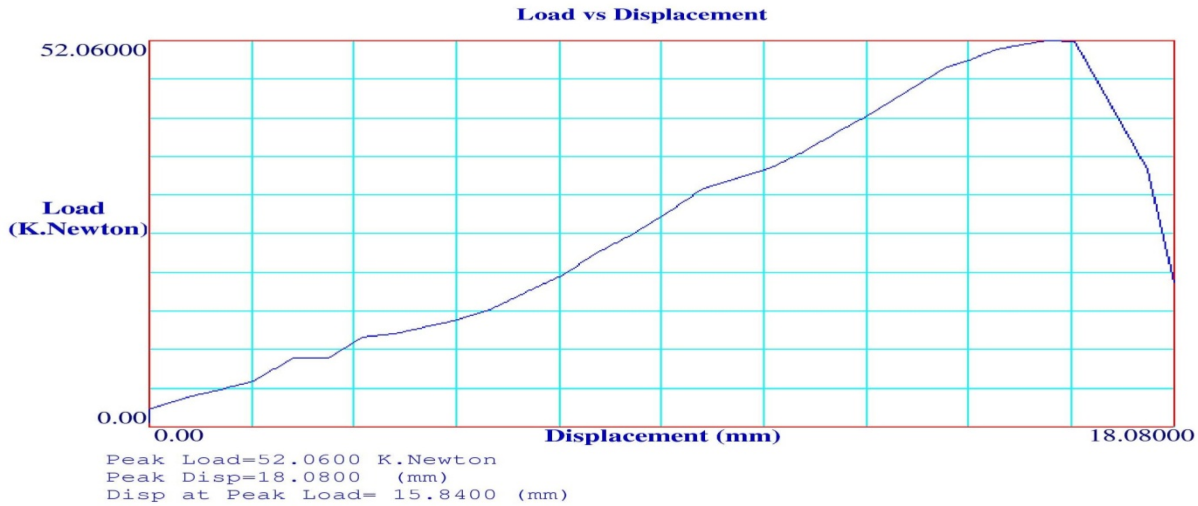


Fig 5.8: Load vs. displacement curve for specimen which weld from flux 4

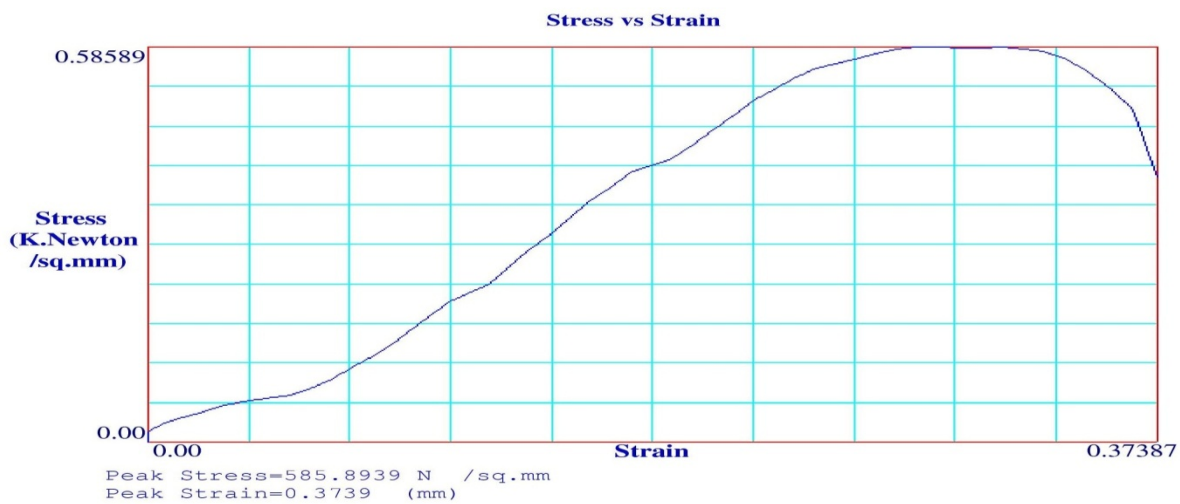


Fig 5.9: stress vs. strain curve for specimen which weld from flux5

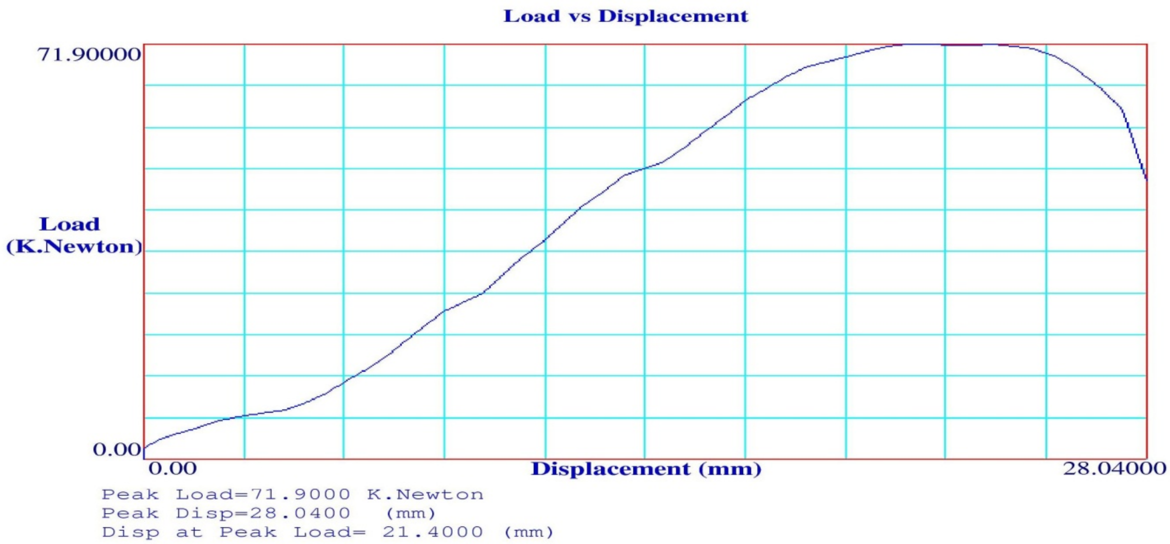


Fig 5.10: Load vs. displacement curve for specimen which weld from flux5

Discussion of tensile test

It is clear from fig 5.3 and 5.4 that the maximum tensile load and maximum stress comes from flux 2. So, it is concluded that flux 2 enhanced tensile load and stress value. For welding of materials in which we require more tensile stress flux 2 should be used. So flux 2 is best suited for welding of API 5L X65 steel welds.

5.2 Impact Toughness Test

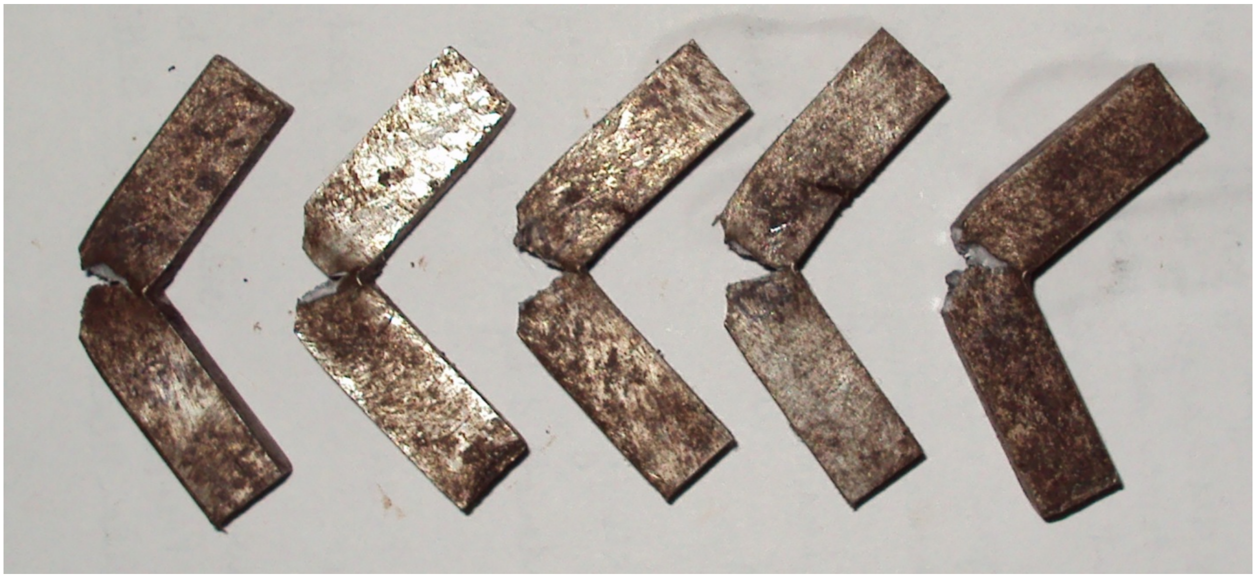


Fig 5.11: Specimen after impact test

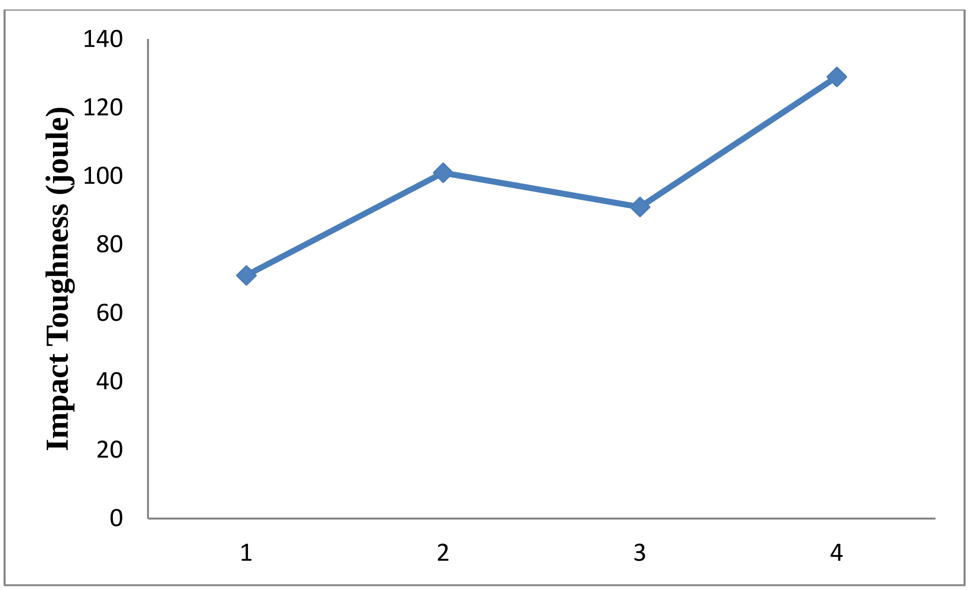


Fig 5.12: Impact Toughness of specimen which weld from welding of flux 1

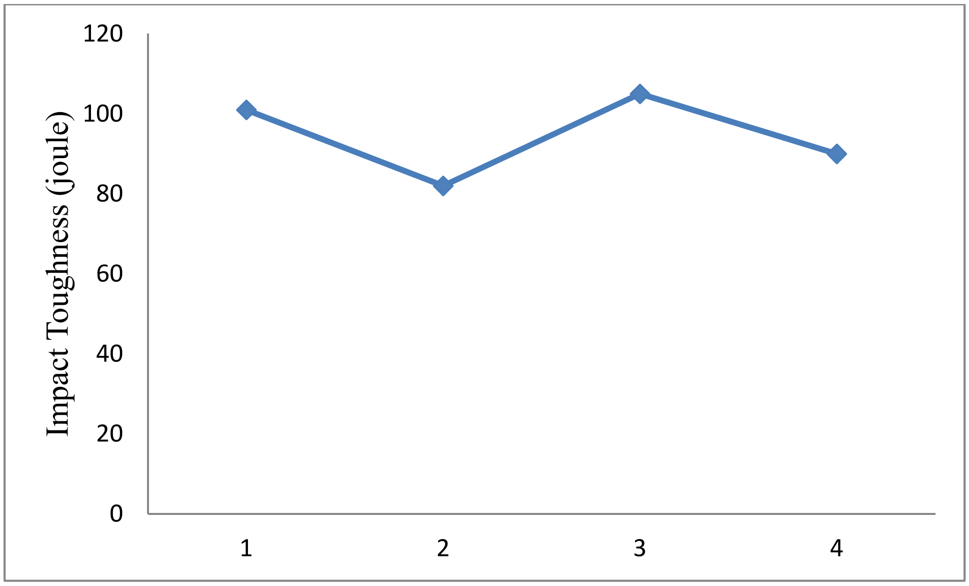


Fig 5.13: Impact Toughness of specimen which weld from welding of flux 2

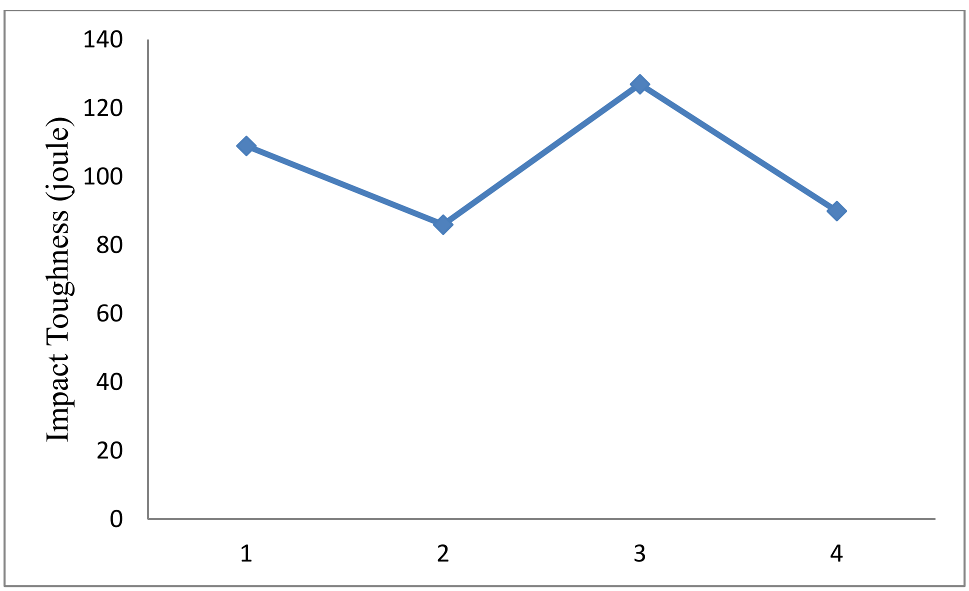


Fig 5.14: Impact Toughness of specimen which weld from welding of flux 3

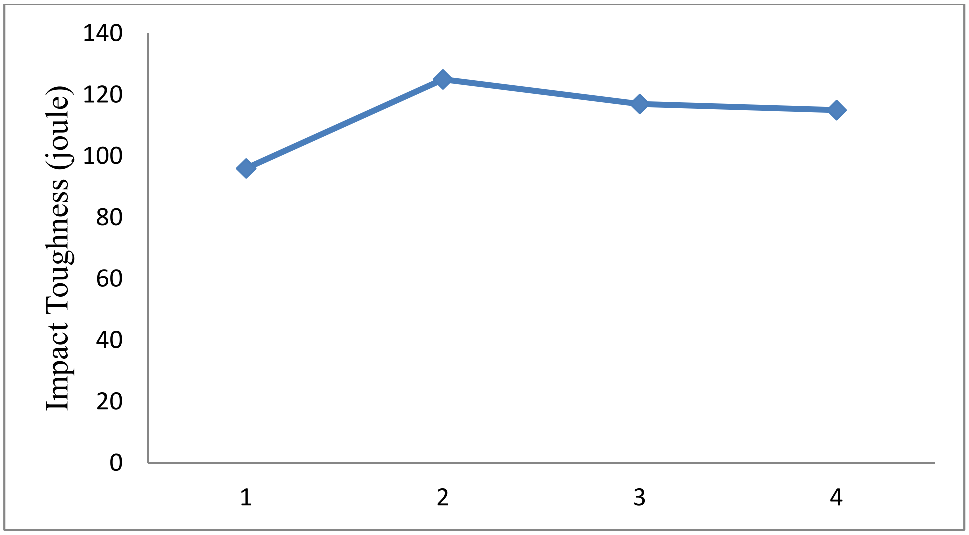


Fig 5.15: Impact Toughness of specimen which weld from welding of flux 4

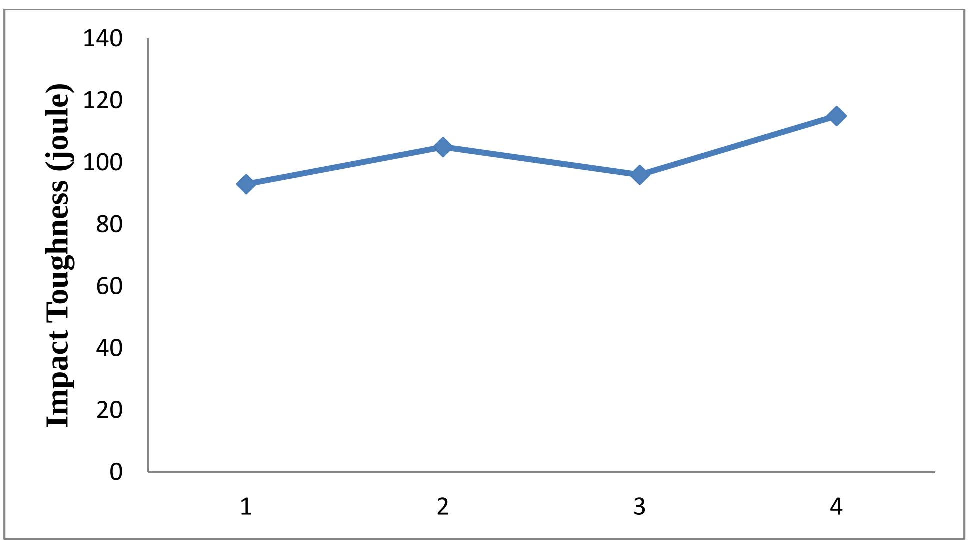


Fig 5.16: Impact Toughness of specimen which weld from welding of flux 5

Discussion of Impact Toughness

It is clear from fig 5.12 that the maximum toughness is observed from flux 1. It is concluded that at room temperature flux 1 enhances toughness value. So flux 1 is best suited when we want maximum toughness in API 5L X65 steel weld.

5.3 Micro hardness Test

Micro hardness of different weld made from different types of flux shown in fig 5.17

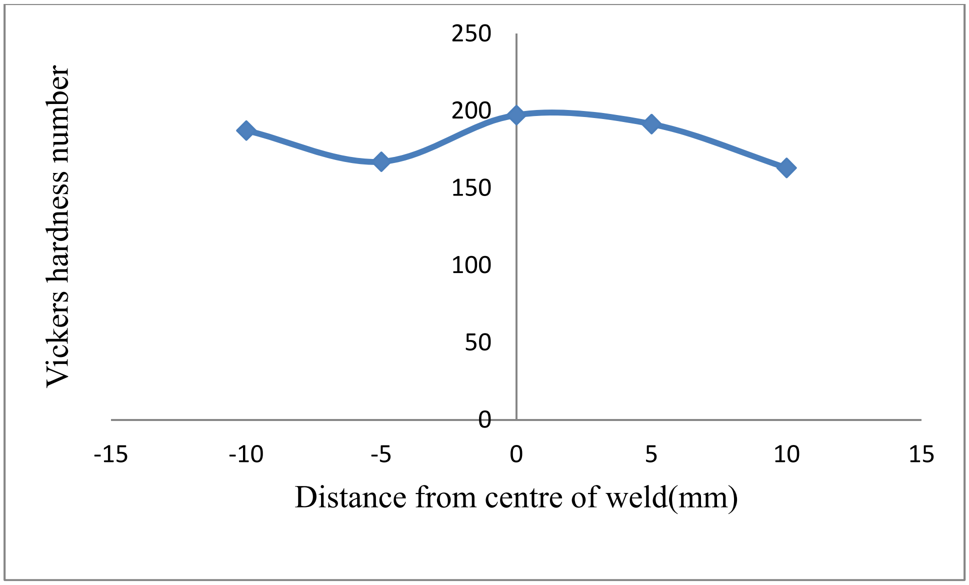


Fig 5.17 (a): Micro hardness of specimen which weld from welding of flux 1

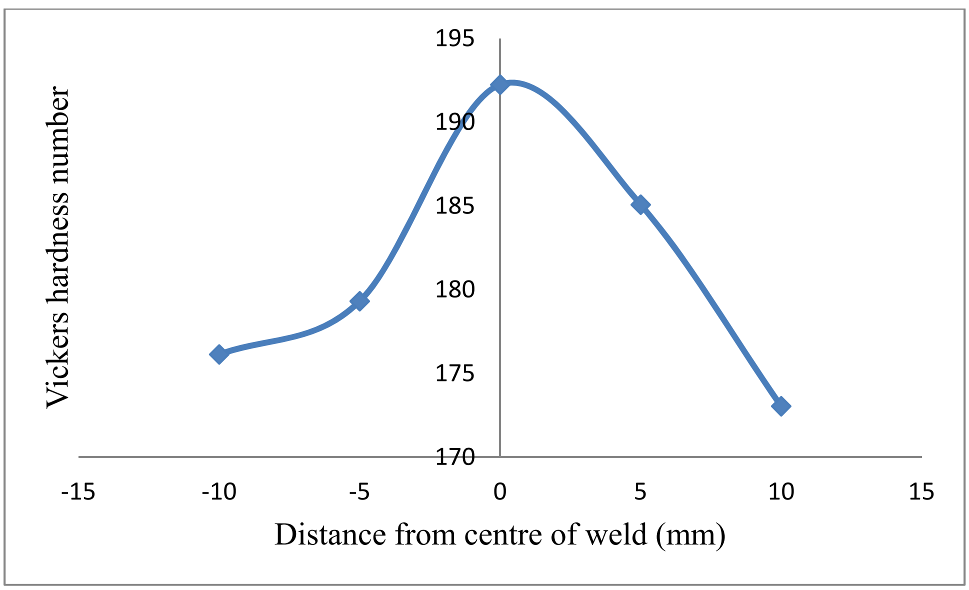


Fig 5.17 (b): Micro hardness of specimen which weld from welding of flux 2

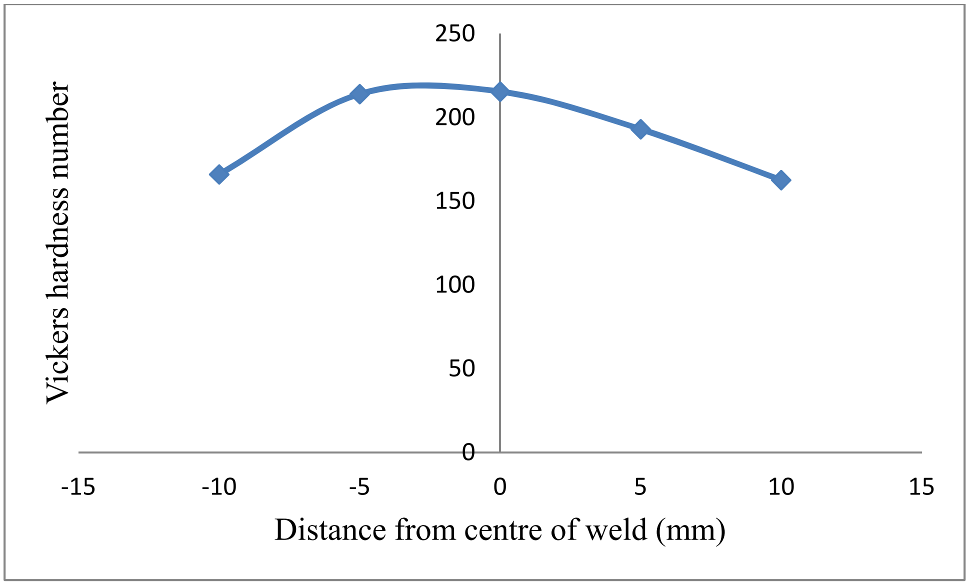


Fig 5.17 (c): Micro hardness of specimen which weld from welding of flux 3

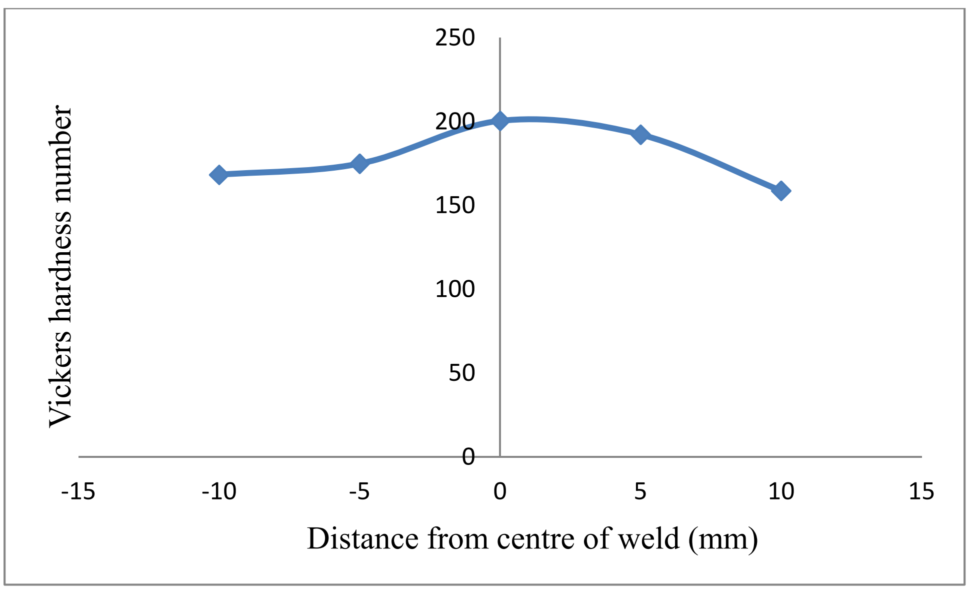


Fig 5.17 (d): Micro hardness of specimen which weld from welding of flux 4

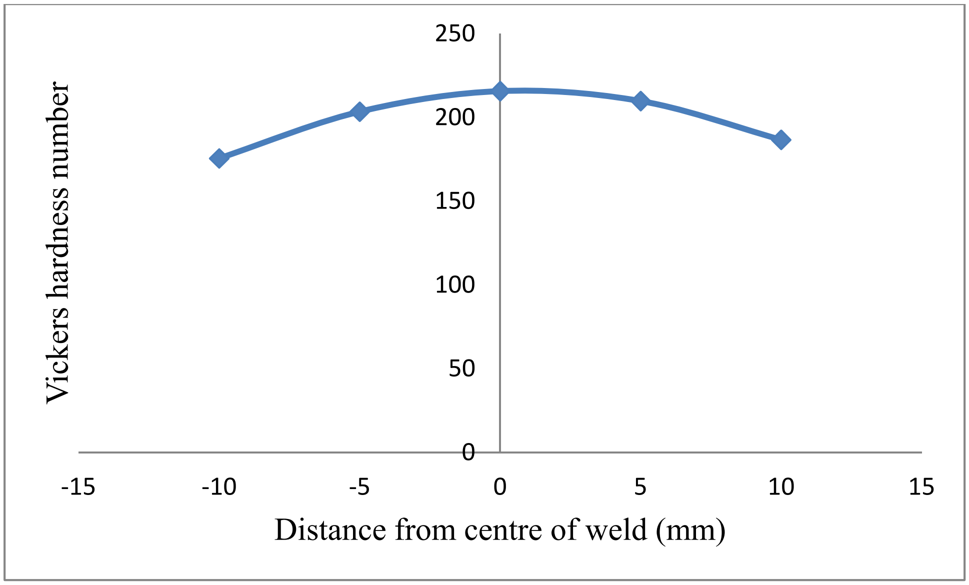


Fig 5.17 (e): Micro hardness of specimen which weld from welding of flux 5

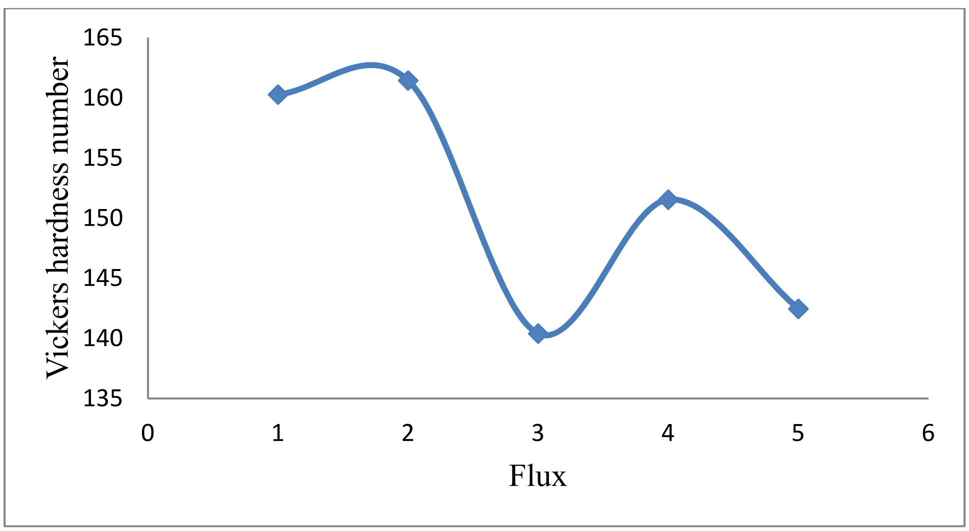


Fig 5.17 (f): Micro hardness of welding specimen at HAZ by using different 5 flux

Discussion of Micro hardness

It is clear from fig 5.17(c) and 5.1(e) that the max. Micro hardness in weld centre is observed from flux 3 and 5. It is clear from fig 5.17(f) that the max. Micro hardness in HAZ is observed from flux 2. So flux 3 and 5 have better hardness values. So these two fluxes are best suited when we weld the API 5L X65 steel.

5.4 Chemical composition of weld metal

The specimen after composition of weld shown in fig 5.18

Fig 5.18: Specimen after checking composition

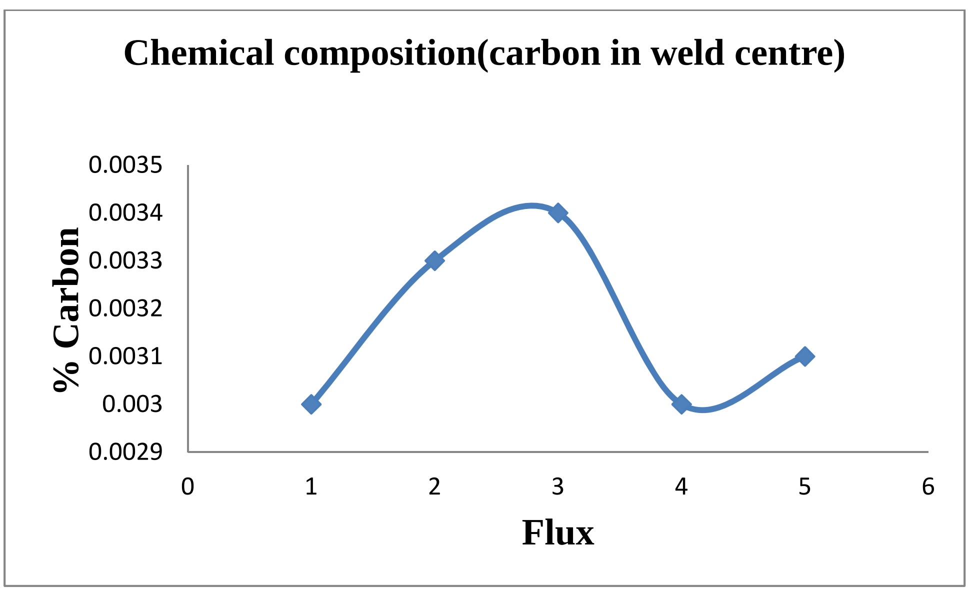


Fig 5.18(a): %age composition of carbon in weld centre

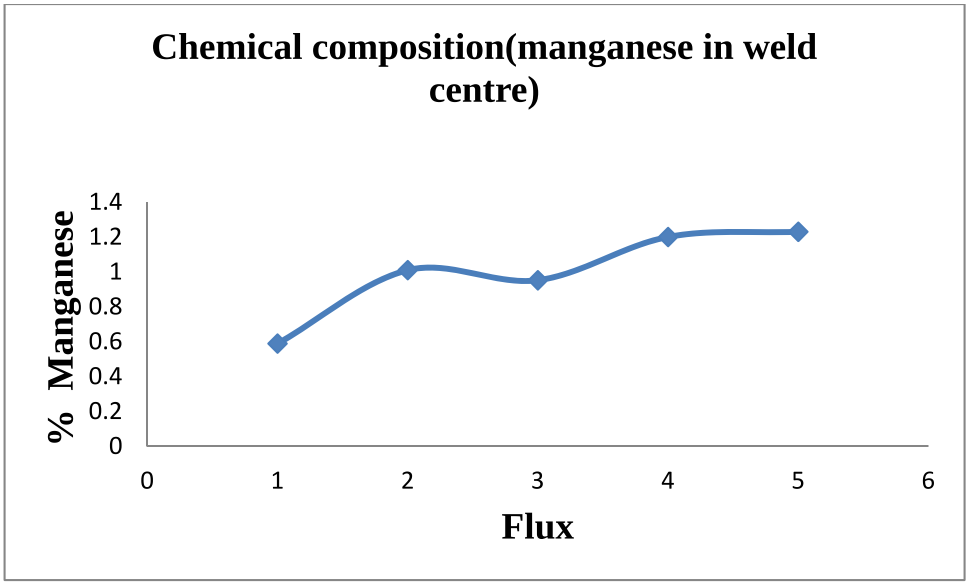


Fig 5.18(b): %age composition of manganese in weld centre

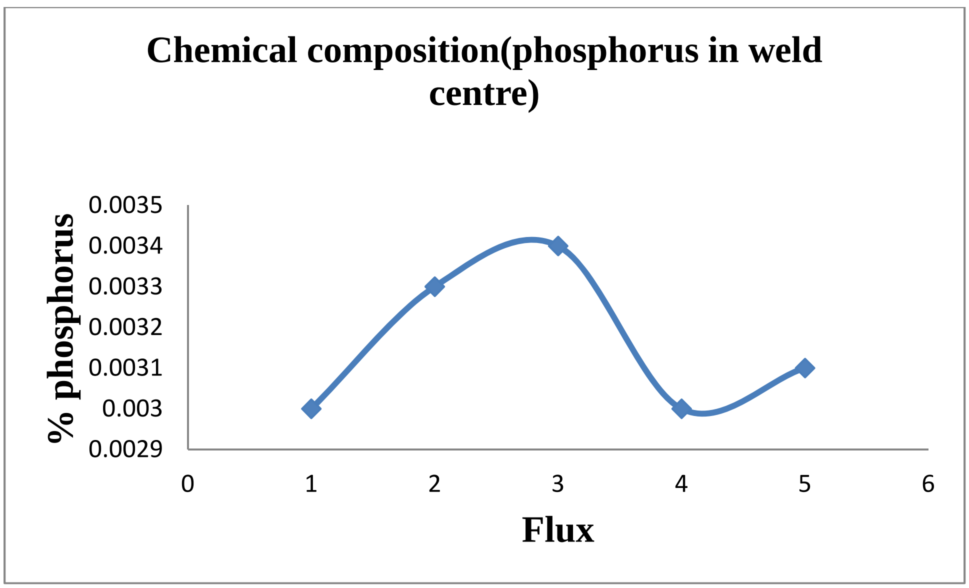


Fig 5.18(c)*:* %age composition of phosphorus in weld centre

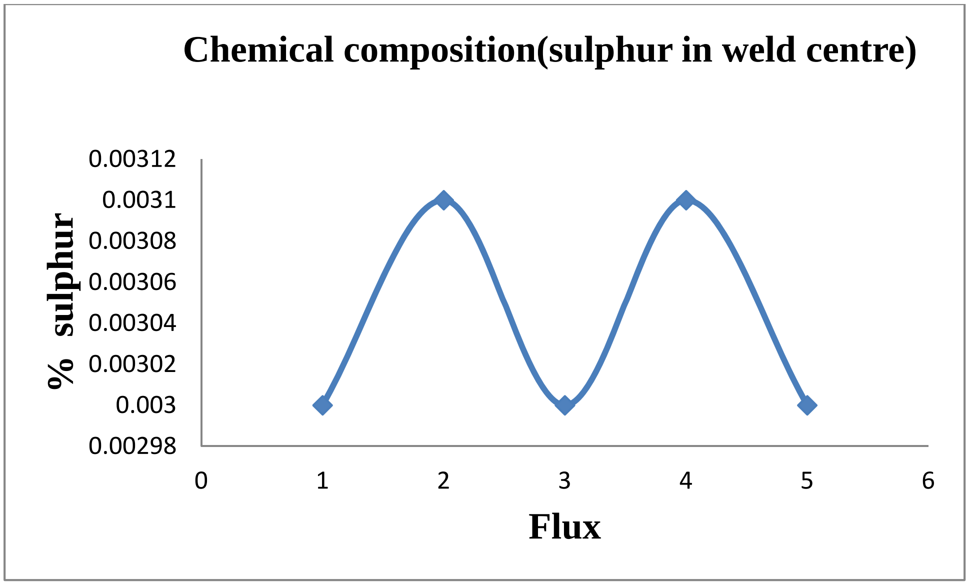


Fig 5.18 (d): %age composition of sulphur in weld centre

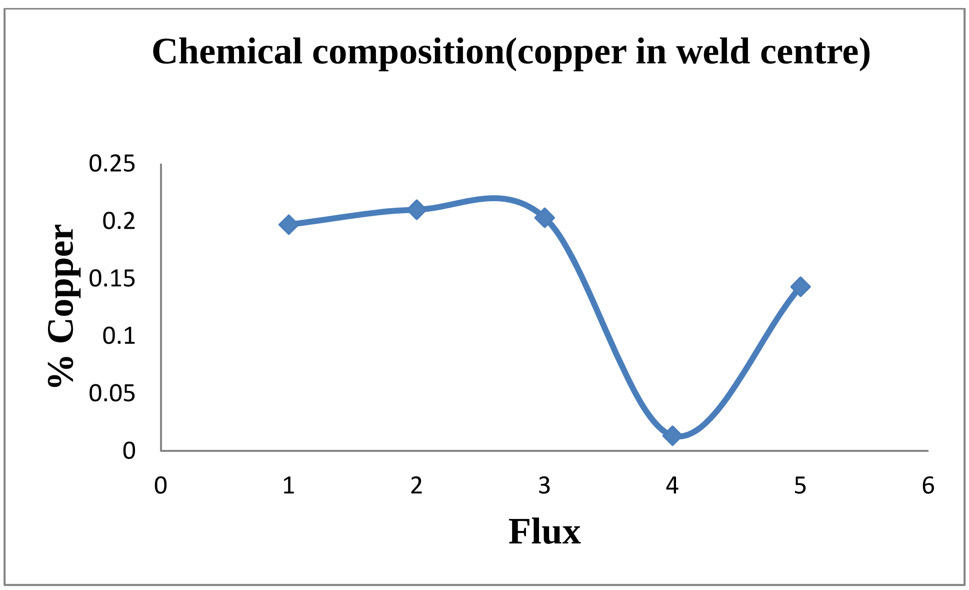


Fig 5.18(e): %age composition of copper in weld centre

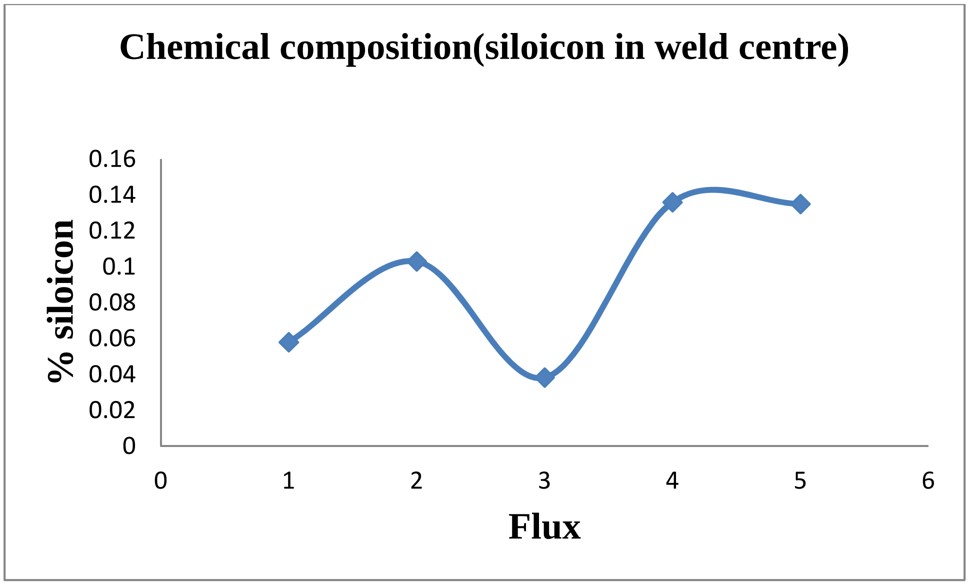


Fig 5.18(f): %age composition of silicon in weld centre

Table 5.3 Percentage change in chemical composition

Flux	Carbon	Carbon in electrode	% change in Carbon	Manganese	Manganese in electrode	% change in Manganese
1	0.0057	0.2	89	0.589	1.7	65
2	0.0125	0.2	93	1.01	1.7	40
3	0.0143	0.2	90	0.952	1.7	44
4	0.0233	0.2	88	1.20	1.7	29
5	0.0707	0.2	64	1.23	1.7	27

Flux	Phosphorus	Phosphorus in Electrode	% change in Phosphorus	Sulphur	Sulphur in Electrode	% change in Sulphur
1	0.0030	0.03	90	0.0030	0.03	90
2	0.0033	0.03	89	0.0031	0.03	89
3	0.0034	0.03	88	0.0030	0.03	90
4	0.0030	0.03	90	0.0031	0.03	89
5	0.0031	0.03	89	0.0030	0.03	90

Flux	Copper	Copper in electrode	% change in Copper	Silica	Silica in Electrode	% change in Silica
1	0.197	0.35	39	0.0580	0.1	34
2	0.210	0.35	35	0.103	0.1	-3
3	0.203	0.35	31	0.0383	0.1	51
4	0.0134	0.35	79	0.136	0.1	-36
5	0.143	0.35	49	0.135	0.1	-35

Percentage change in composition:

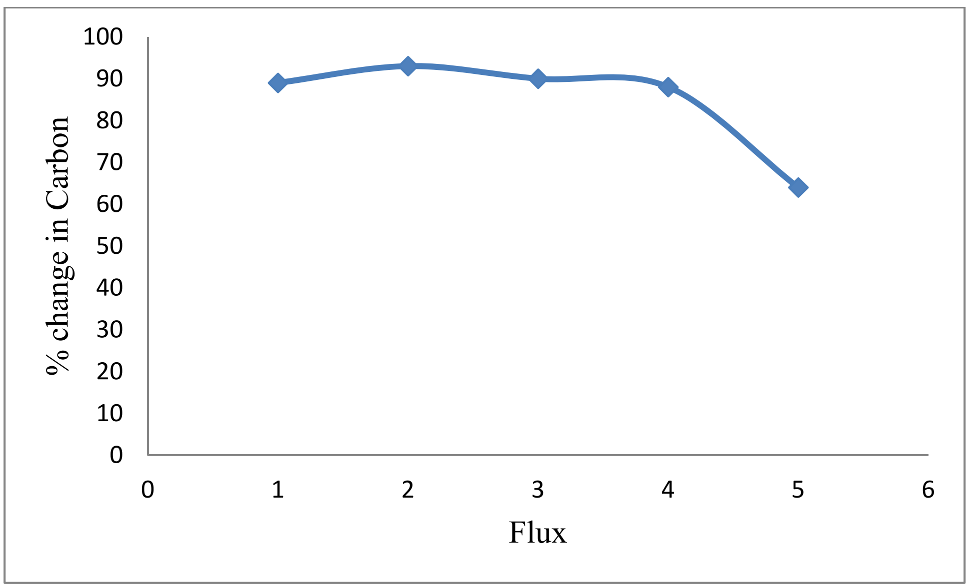


Fig 5.19 (a): Percentage change in composition of carbon in weld centre

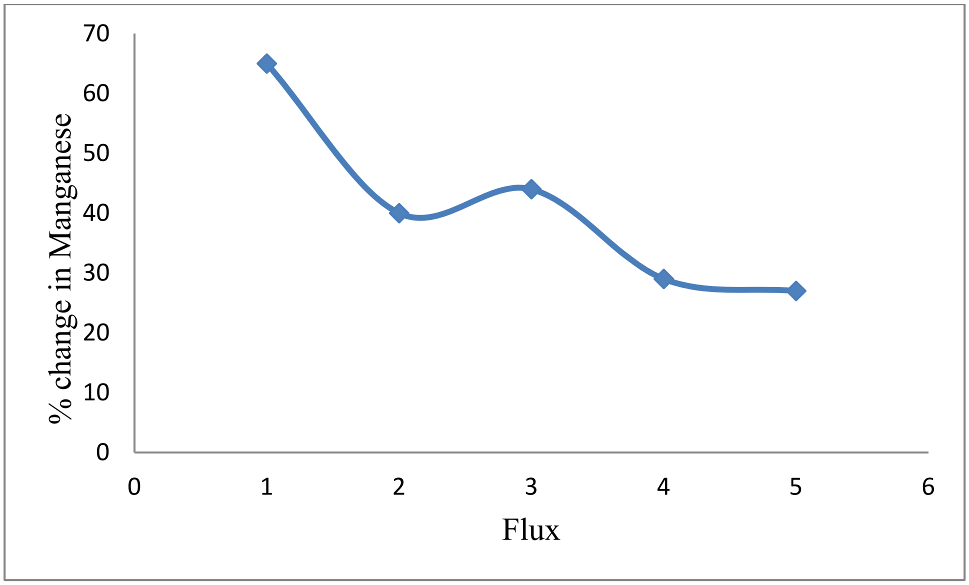


Fig 5.19 (b): Percentage change in composition of manganese in weld centre

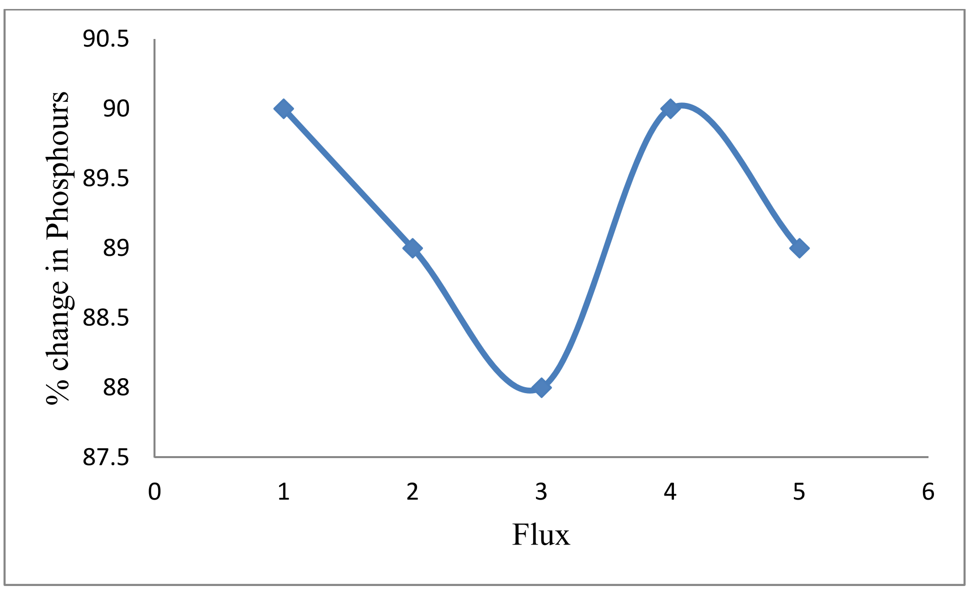


Fig 5.19 (c): Percentage change in composition of phosphorus in weld centre

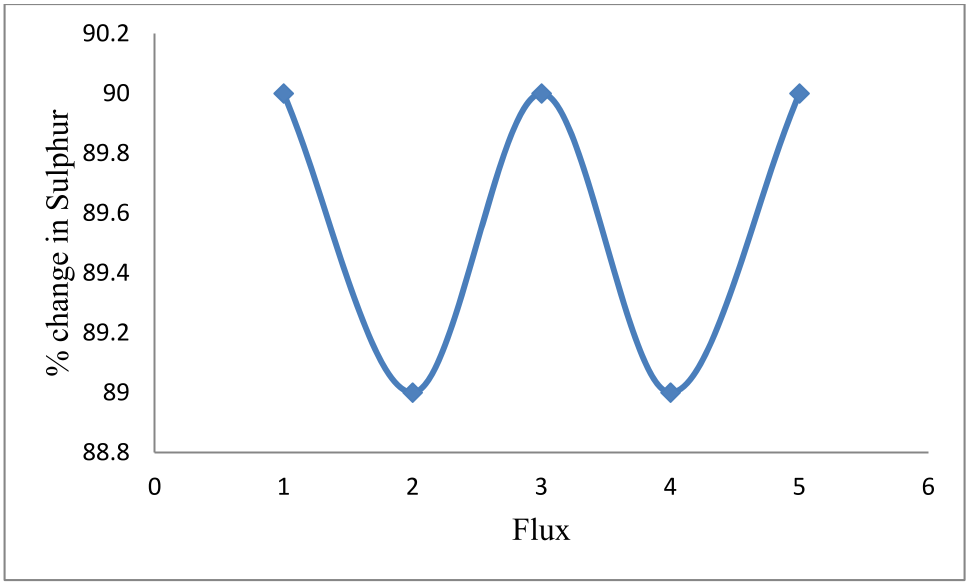


Fig 5.19 (d): Percentage change in composition of sulphur in weld centre

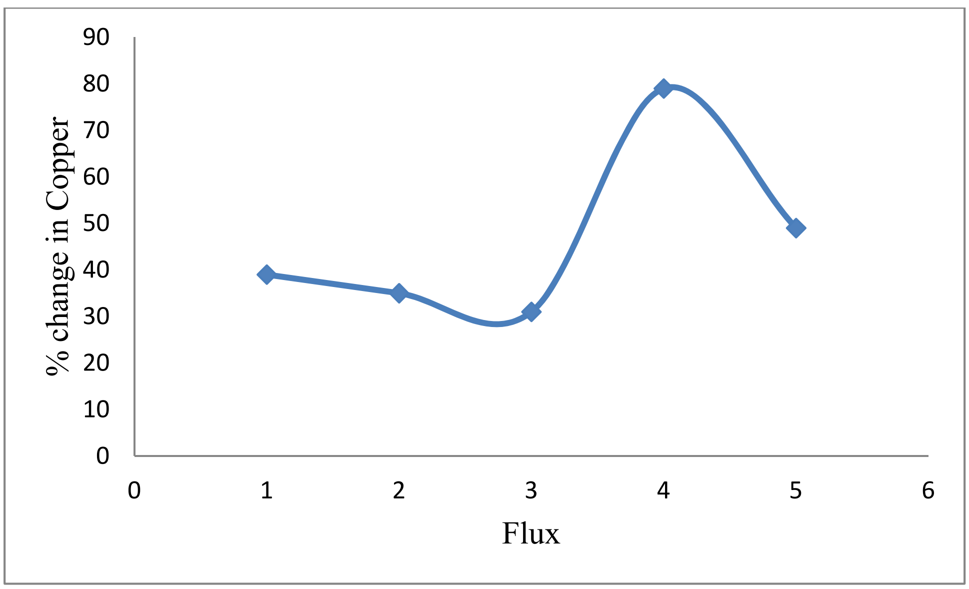


Fig 5.19(e): Percentage change in composition of copper in weld centre

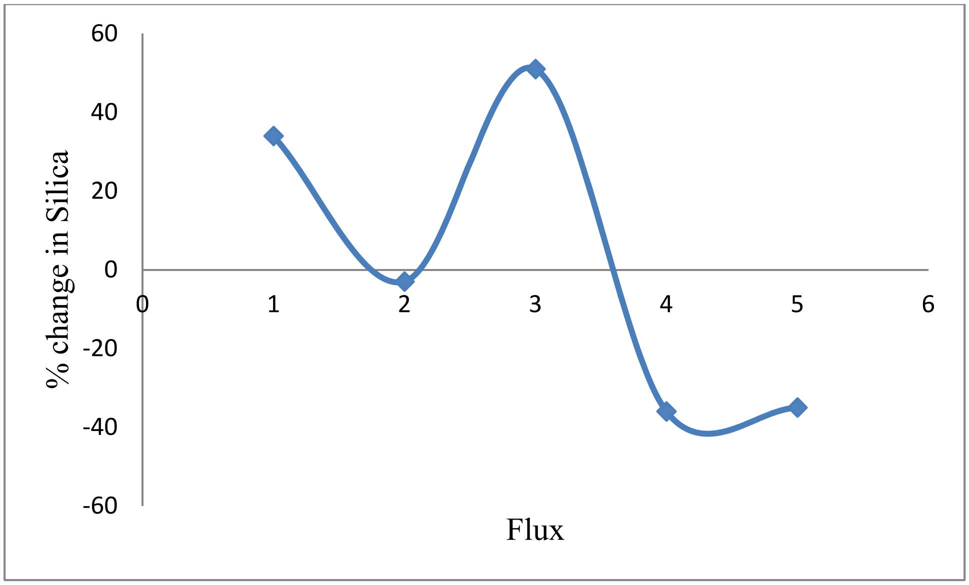


Fig 5.19 (f): Percentage change in composition of silica in weld centre

Discussion of Chemical composition

It is clear from fig 5.19 that percentage change in carbon, manganese contents are increasing in weld region but the copper contents are decreasing. So, it is concluded that some compounds of flux goes to the weld region. Low carbon and high manganese contents are typical for the WM. The carbon content is minimised to avoid weld ability problems and manganese is used to counterbalance the loss in tensile properties associated with the low carbon content in the WM. Copper can detrimental to surface quality. Copper is beneficial to atmospheric corrosion resistance but in small amounts. Manganese is beneficial to surface quality; it also contributes to strength and hardness. Manganese affects the harden ability of steels significantly Phosphorus increase strength and hardness but decreases' ductility and notch impact toughness of weld region in steels. Silicon acts as a deoxidizer in weld region. Percentage of sulphur indicates good machinbility of weld region.

5.5 Microstructure

The different types of microstructure shown in below figure 5.20

Weld zone

Heat affected zone

Base material

Fig 5.20 (a): Microscopic structure of sample which is made from using of flux 1 at x50

Weld zone

Heat affected zone

Base material

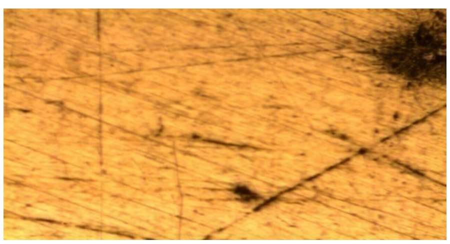
Fig 5.20 (b): Microscopic structure of sample which is made from using of flux 2 at x50

Weld zone

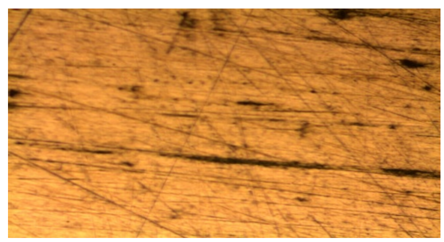
Heat affected zone

Base material

Fig 5.20(c): Microscopic structure of sample which is made from using of flux 3 at x50



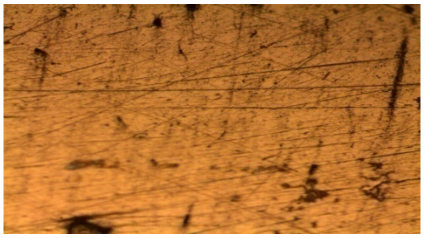
Weld zone



Heat affected zone

Base material

Fig 5.20(d): Microscopic structure of sample which is made from using of flux 4 at x50



Weld zone

Heat affected zone

Base material

Fig 5.20 (e): Microscopic structure of sample which is made from using of flux 5 at x50

Discussion of Microstructure

The microstructure of HSLA base at magnifications of 50X is shown in Figure 5.20. The micrographs of the figures reveal the presence of typical ferrite (more bright)-pearlite (less bright) microstructure.

Therefore it can be said that the distribution of the microstructure in the weld consists of three distinctly different micro structural regions, such as the dendritic region at interface, reheat refined coarse grain region and reheat refined fine grain region. It have some amount of fine pearlite with pro-eutectoid ferrite at the grain boundary. The fine grain reheat refined region HSLA HAZ has been found to primarily consist of ferrite and pearlite.

5.6 Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) of different test piece shown in fig

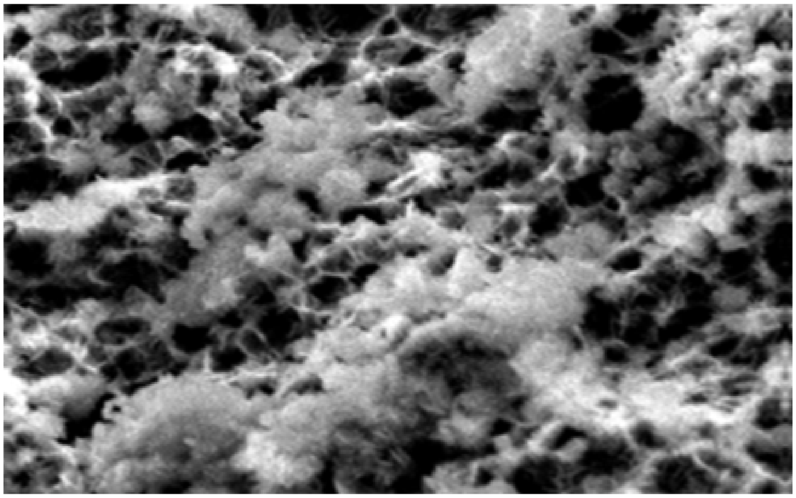


Fig 5.21: SEM measurement at x1000 magnification for specimen after breakage of tensile test which weld from by using welding flux (i)

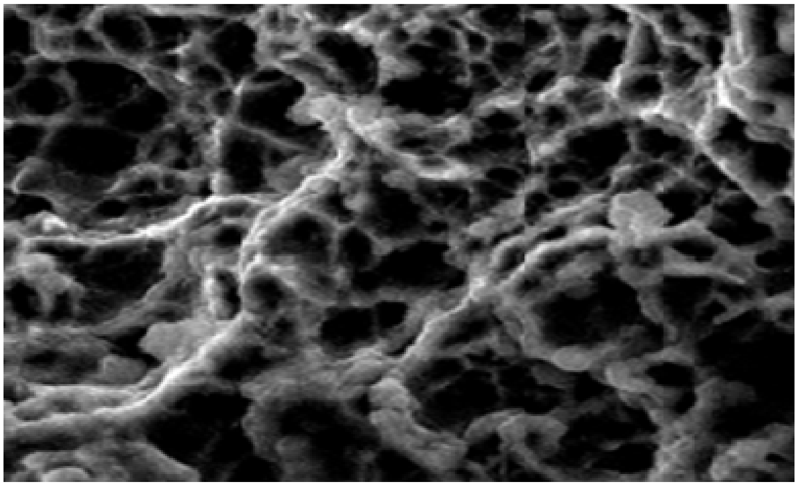


Fig 5.22: SEM measurement at x1000 magnification for specimen after breakage of tensile test which weld from by using welding flux (ii)

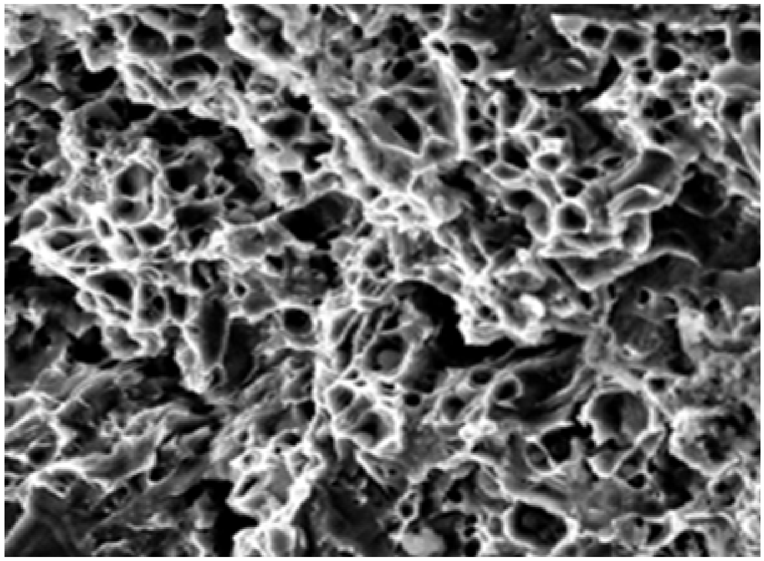


Fig 5.23: SEM measurement at x1000 magnification for specimen after breakage of tensile test which weld from by using welding flux (iii)

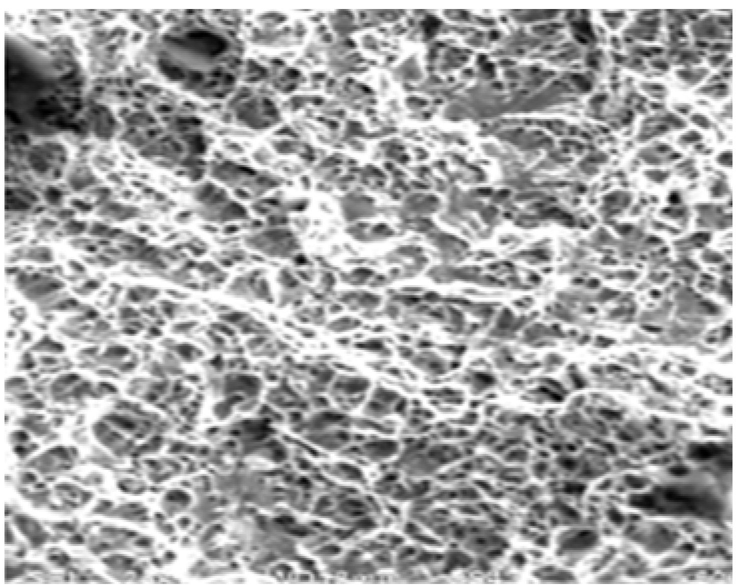
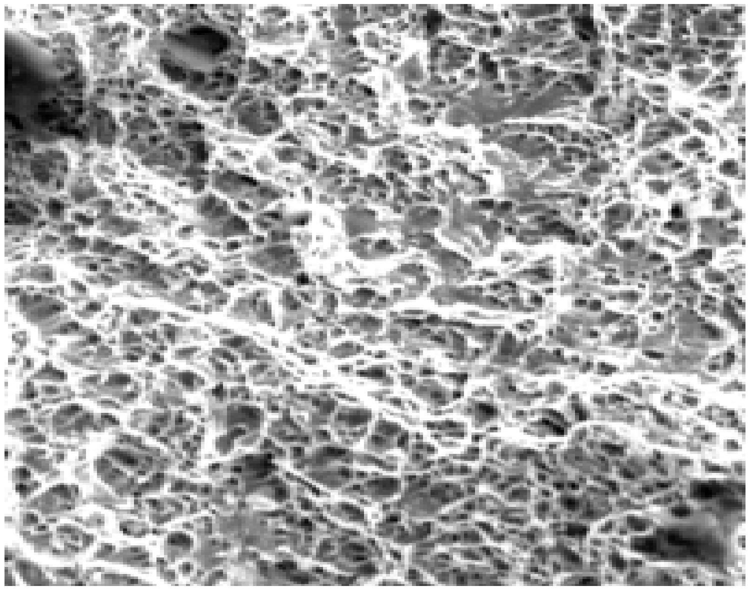


Fig 5.24: SEM measurement at x1000 magnification for specimen after breakage of tensile test which weld from by using welding flux (iv)



(v)

Fig 5.25: SEM measurement at x1000 magnification for specimen after breakage of tensile test which weld from by using welding (v)

Discussion of Microstructure

As we can see from fig 5.23,5.24, 5.25 that at room temperature in tensile specimen there are dimples present in the matrix in the SEM so, it is ductile fracture and there is cleavage present in fig 5.25 which indicates brittle fracture.

CHAPTER 6 CONCLUSION & FUTURE SCOPE

The present work has been carried out to study the effects of flux on the welding characteristics in the submerged arc welding by keeping other welding parameters constant like current, voltage and welding speed. The following is the summary of the work carried out:

1) Preparation of fluxes for submerged arc welding of high strength low alloy steel.
2) The Ultimate Tensile Strength values were also satisfactory for weld joints.
3) The Impact toughness value at room temperature increase with increase in basicity index
4) Microstructure evaluation of the welded joints.
5) Highest micro hardness values are formed at the weld joint regions for welded specimens.

Further work can be done in following directions:

1) Different fluxes can be made for different material.
2) CaF_2 can be replaced any other compound suitable for welding.
3) Fatigue and corrosion properties can be measured and correlated with different
4) There are lot of parameters (Current, voltage, welding speed, diameter of electrode) which can be varied individually to see their individual effects and combining these parameters to see their combine effect.

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