A Thesis

On

DEVELOPMENT OF FLUXES FOR SUBMERGED ARC WELDING OF HIGH STRENGTH LOW ALLOY STEEL

Submitted in the partial fulfillment of requirement for

the award of degree

MASTER OF ENGINEERING

In

PRODUCTION AND INDUSTRIAL ENGINEERING

By

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July-2010

Dedicated To My Loving

Grand Parents

CERTIFICATE

This is to certify that the work done in this thesis report titled **"DEVELOPMENT OF FLUXES FOR SUBMERGED ARC WELDING OF HIGH STRENGTH LOW ALLOY STEEL"** submitted in partial fulfilment of requirement for the award of the **Master of Engineering Degree in Production and Industrial Engineering** in the Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of work carried out by me under the guidance of **Dr. V. P. Agrawal**, Visiting Professor, Mechanical Engineering Department, Thapar University, Patiala.

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

(Rupesh Kaushik)

This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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ACKNOWLEDGEMENT

I am highly grateful to the authorities of Thapar University, Patiala for providing this opportunity to carry out the thesis work.

I express my deep gratitude and respects to my guide **Dr. V. P. Agrawal** *for his keen interest and valuable guidance, strong motivation and constant encouragement during the course of the work. I thank him for his great patience, constructive criticism and myriad useful suggestions apart from invaluable guidance to me.*

I would like to express a deep sense of gratitude and thank profusely ***Dr. Rahul Chhibber*** *for their sincere & invaluable guidance, suggestions and attitude for his encouragement and execution of thesis work.*

I thank our head of departement ***Dr. S. K. Mahapatra****, whose excelent leadership and administration made this research project very covenient in term of required stuff and nice working condition. I am extermely thakful to member of distinguished faculty.*

The non teaching staff ***Mr. Surender Singh, Mr. Rath, Mr. Surender Suri, Mr. Rajender, Mr. A. S. Cheema, Mr. Trilok Singh, Mr. Kuldeep, Mr. Manoj, Mr. Purushotam, Mr. Narender, Mr. Sukhbir*** *deserve special thanks for there help during this period of this work.*

I am also thankful to other faculty members and all the workshop staff of Mechanical Department, Thapar University, Patiala for their l support.

Some friends were never too busy to give me a hand whenever they were needed. No word acknowledge the support I received from ***Yogesh Kumar Singla, Rajesh Kumar, Lalit Kumar, Lalit Upadhyay, Shailove Kumar, Gurpreet Singh, Gurmail Singh Malhi, Gopal Krishan dixit, Sanjeev Kumar, Narinder singh, Gourav Singla*** *for their valorous help and co-operation.*

Last but not the least, I would like to thank my ***grand father, parents, uncle, aunty, sister, brothers*** *for always being there when I needed them most and for their moral support that kept my spirit up during the endeavor.*

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ABSTRACT

The present work is an attempt to study the effect of flux (basicity index) on the tensile strength, Impact strength, micohardness, microstructure, of high strength low alloy weld made during the submerged arc welding. 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 been studied and attempt has been made to corelate the macroscopic observation with microscopic observation.

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ABBREVATION

SAW	-	Submerged Arc Welding
HAZ	-	Heat Affected Zone
DC	-	Direct Current
AC	-	Alternating Current
XRD	-	X-ray Diffraction
SEM	-	Scanning Electron Microscope

Chapter 1 Introduction

1.1 Welding

The process of joining together two pieces of metal so that bonding accompanied by appreciable interatomic penetration takes place at their original boundary surfaces. The boundaries more or less disappear at the weld, and integrating crystals develop across them. Welding is carried out by the use of heat or pressure or both and with or without added metal. There are many types of welding including Metal Arc, Submerged Arc, Resistance Butt, Flash, Spot, Seam and Projection.

1.2 History of submerged arc welding

One of the most significant welding processes invented and widely employed throughout the world is Submerged Arc welding. Submerged Arc was not the first automatic welding process. Patents dating in the early 1920's describe automatic welding processes. It is an elaborate devise for automatic welding with a continuous bare wire feed from a reel to the weld zone. The unique feature defined in this patent is the use of oscillation of the wire in the joint to be welded. However, as with a number of other machine patents of the era, it was used with an open arc in air. Other references note the welds from this simple process contained porosity and were not suitable for many applications.

One stated that even with an improved version of the open arc in air process, a manual weld made with covered electrode (SMAW) would be used inside a vessel to prevent leaks. Other automatic processes of the time used coated rods where the coating was slit as the weld progressed to allow current to be transferred at a fixed point from the work [1].

1.3 Submerged arc welding

Fig 1.1 Submerged arc welding machine

SAW machine used for the experiments is shown in the above fig 1.1. The main parts of the machine are control box panel, electrode wire, wire spool and flux hopper. The welding current, welding voltage and welding speed can be regulated, displayed and preset on the panel of the tractor for the convenience of the operator. The function of inch wire feeding and withdrawing makes it convenient for the welder to preset the operating position of the welding wire. Control is provided on the machine for the movement of the tractor on the platform. The movement can be manual or can be automatic. There is also welding head site adjustment function it make the gun move vertically and horizontally. Main technical parameters of the tractor are given below.

Table 1.1: Technical Parameters of Welding Machine

Travel speed	20-600 m/h
Wire feeding rate	0.5 m/min - 2.5 m/min
Wire diameter	2.4 mm -5 mm
Rated current value	800 amp
Rated voltage	110 volts

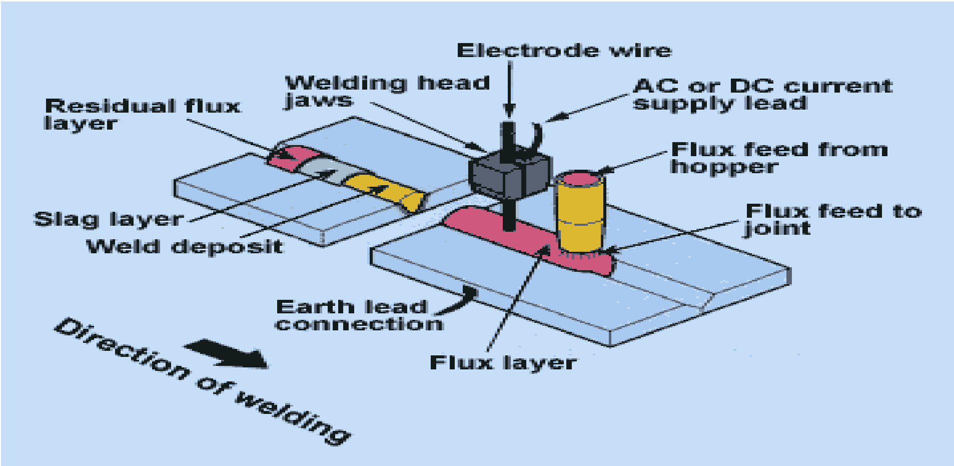


Fig 1.2 Submerged arc welding process

Source: www.twi.co.uk

Submerged arc welding (SAW) is a common arc welding process shown in fig 1.2. It requires a continuously fed consumable solid electrode. The molten weld and the arc zone are protected from atmospheric contamination by being “submerged” under a blanket of granular fusible flux. When molten, the flux becomes conductive, and provides a current path between the electrode and the work. The thick layer of flux completely covers the molten metal thus preventing spatter and sparks as well as suppressing the intense ultraviolet radiation and fumes. SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are available.

The submerged arc process is somewhat unusual in that the welding consumables, unlike the other fluxed processes of MMA (Manual metal arc welding), 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.

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 [1].

1.4 Basic equipment

The submerged-arc welding (SAW) process in which 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. The equipment components required for submerged arc welding are shown by figure1.3.

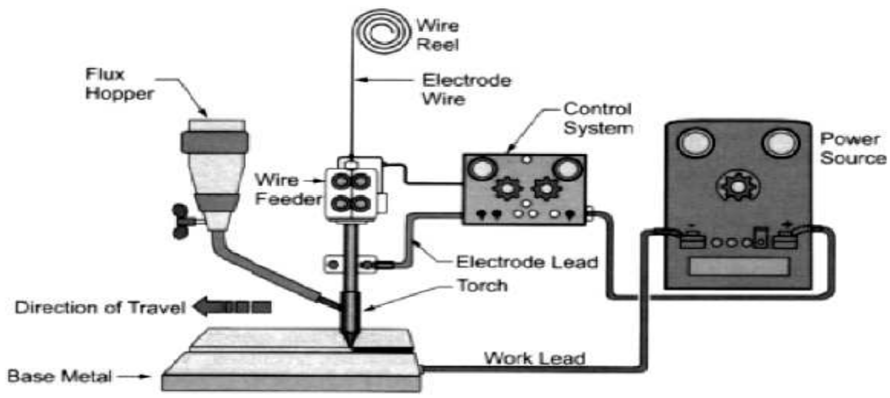


Fig 1.3 Equipment set up for single wire submerged arc welding

Source: www.weldguru.com

Essential equipment components for SAW are:

- power source
- SAW head (welding gun)
- 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.

In DC operation, the electrode is normally connected to the positive terminal. Electrode negative (Direct current electrode negative) 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.

1.4.2 Welding gun

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. Wire stickout, 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 burnoff rate will increase with increase in wire stickout.

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 stickout, to 14 kg/hr at a stickout length of 178mm. Because of the reduction in penetration and greater risk of arc wander, a long stickout 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.

1.4.3 Flux handling

Flux should be stored in unopened packages under dry conditions. Open packages 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.

1.4.4 Protective equipment

Unlike other arc welding processes, SAW is a clean process which produces minimum fume and spatter when welding steels. 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].

1.5 Effect of welding parameter on welding

The submerged arc welding process can provide higher deposition rates and faster travel speeds, and produce a very smooth bead with good penetration and excellent fusion which mainly depends upon Welding current, Arc-Voltage, Speed of Arc Travel, Flux etc.

1.5.1 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 provided with an ammeter to monitor and control the welding current.

1.5.2 Arc-Voltage

Arc voltage, also called welding voltage, means the electrical potential difference between the electrode wire tip and the surface of the molten weld puddle. It is indicated by the voltmeter provided on the equipment. It hardly affects the electrode melting rate, but it determines the profile and surface appearance of the weld bead. The effects of changing voltage are explained as follows:

Increasing voltage:

a) Produces a flatter and wider bead.

b) Increases 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 advantage to raise the alloy content of the weld when welding is performed with alloy or hard surfacing fluxes. If excessive, it can reduce ductility and increase crack sensitivity, particularly in the making of multiple-pass welds.

- Produces poor slag removal in groove welds.
- In multiple-pass welds, increases the normal alloy pickup from the flux.
- Produces a concave fillet weld that may be subject to cracking
- Increases undercut on fillet welds.

Lowering the voltage produces a stiffer arc needed for getting penetration in a deep groove and to resist arc blow on high-speed work. An excessively low voltage produces a high, narrow bead with poor slag removal.

1.5.3 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 lesser penetration, lesser weld reinforcement and lower 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.

1.5.4 Flux

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 favorable conditions for very high current densities, which together with the insulating properties of the flux; concentrate intense heat into a relatively small welding zone.

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 [1] [2].

1.6 Advantages of SAW

- High deposition rates (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.
- Distortion is much less.
- Welds produced are sound, uniform, ductile, 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.

1.7 Limitations of SAW

- Limited to ferrous (steel or stainless steels) and some nickel based alloys.
- 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.

1.8 Application of SAW

1. Large girders for modern long span bridges
2. Massive beams needed for tall buildings

3. Electric Power Generation:
    a. Penstocks to transport water from dams through water turbines
    b. Steam boilers, piping, turbines
    c. Nuclear vessels
    d. Wind turbine towers, transmission towers
4. Petrochemical vessels and piping
5. Chemical processing vessels
6. Ships and submarines
7. Railroad cars and locomotives
8. Large presses and machine bases
9. Natural gas and oil pipelines
10. Offshore drill rigs
11. Large diameter water pipe
12. Many other heavy plate structures
13. Thinner material products such as water heaters and propane tanks
14. Hard facing for steel mills, earthmoving equipment, mining, etc.

1.9 Flux

Flux is a chemical cleaning agent which facilitates welding by removing oxidation from the metals to be joined. Common fluxes are: ammonium chloride, rosin, hydrochloric acid, zinc chloride, borax. Different fluxes, based on sodium chloride, potassium chloride, sodium fluoride, are used.

In high-temperature metal joining processes (welding, brazing and soldering), the primary purpose of flux is to prevent oxidation of the base and filler materials. Tin-lead solder attaches very well to copper, but poorly to the various oxides of copper, which form quickly at soldering temperatures. Flux is a substance which is nearly inert at room temperature, but which becomes strongly reducing at elevated temperatures, preventing the formation of metal oxides. Flux shown in fig 1.4

Fig 1.4 flux

Source: www.diytrade.com

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

The functions of the flux are:

- to assist arc striking and stability
- to form a slag that will protect and shape the weld bead
- to form a gas shield to protect the molten filler metal being projected across the arc gap
- to react with the weld pool to provide clean high quality weld metal with the desired properties
- to deoxidise the weld pool
- provide deoxidants

The most convenient method of classifying, however, is by reference to the 'basicity index' (BI) of the flux. The index is calculated by dividing the sum of the percentages of the basic constituents by the sum of the acid constituents. Calcium, magnesium, sodium, potassium and manganese oxides, calcium carbonate and calcium fluoride are the basic constituents of a flux; silica and alumina the acid constituents. The basicity of a flux has a major effect on the weld metal properties, most importantly the notch toughness. As a general rule the higher the basicity the higher the notch toughness.

The flux is termed acidic or basic depending on the value of BI. One of the major differences between basic and acidic fluxes is their ability to rid the molten metal of residual sulphur and phosphorus.

Neutral fluxes are designed to have little or no effect on the chemical analysis of the weld metal and therefore on the mechanical properties. They contain low silica, calcium silicate and alumina and do not add significant amounts of silicon and manganese to the weld.

The acid fluxes contain substantial amounts of silica, silicates in the form of calcium or manganese silicate and manganese oxide. These fluxes react with the weld pool and will raise both silicon and manganese content of the weld together with high oxygen content. The result of this is that the toughness of the weld is poor but the fluxes will tolerate rusty surfaces, will detach easily and give a good weld appearance. They are especially useful for single pass high speed welding such as fillet welding of web to flange girder joints.

The basic fluxes fill much the same role in submerged arc welding as basic coatings do in manual metal arc welding. They have low silica content and are composed of varying amounts of calcium carbonate and/or fluoride, alumina, calcium, manganese and magnesium oxides.

This combination of compounds gives clean, low sulphur, low oxygen weld metal with good to excellent notch toughness. The transfer of silicon and manganese into the weld metal is also limited. Such fluxes are preferred for the welding of high quality structural steels, pressure vessels, pipe work and offshore structures where either good high or low temperature properties are required.

The fused fluxes are acid, neutral or slightly basic and are manufactured by mixing the constituents together, melting them in an electric furnace and crushing the solidified slag that is produced to give a flux with a glassy appearance.

These fluxes are homogeneous, resistant to moisture pick-up and mechanically strong so that they do not break down but maintain the required particle size. The high temperatures required by the melting operation mean that some constituents, particularly the de-oxidants present in the highly basic fluxes, decompose and are lost. This limits the range of applications of these fluxes to general structural work where sub-zero service temperatures will not be encountered.

The BI as adopted by International Institute of Welding is given in terms of the weight percentage of various oxides and fluorides constitutes.

- BI= CaF_2 +CaO+R_2O+0.5(MnO+FeO)/SiO_2+0.5(Al_2O_3+TiO2+ZrO_2)

Where RO represents alkaline earth oxides and R2O the alkali oxides.

The flux is termed acidic or basic depending on the value of BI. One of the major differences between basic and acidic fluxes is their ability to rid the molten metal of residual sulphur and phosphorus.

There are four levels of BI for standardization of flux give as follow:

- Fluxes having basicity index less than 1 are incapable of controlling the sulphur content of the weld metal effectively. In short BI <1=Acidic.
- Fluxes having basicity index (BI) between 1and 1.5 are capable of controlling the sulphur effectively but not oxygen in the weld metal. In short $1<BI<1.5$=Neutral.
- Fluxes having basicity index (BI) between 1.5 and 2.5 are capable of controlling the Sulphur and oxygen content effectively and lowering the transition temperature by controlling Si content in the weld metal to a certain extent. In short $1.5<BI<2.5$=Basic.
- Fluxes having basicity index (BI) above 2.5 are capable of lowering the charpy V notch transition temperature down to -40C or even below by controlling the composition and microstructure of weld metal suitably. In short $BI>2.5$=High Basic [3].

1.10 Different flux compounds and their function

- Fluxing agents: Silica, CaO_3, and Fluorspar.
- Slag formers: Rutile , Titania, potassium titanate, Absestos, Alumina, Silica floor, iron oxide, Fluorspar etc.
- Arc stabilizers: potassium, Silicate, potassium oxalate, Zirconium carbonate, Lithium carbonate, Titania etc.
- Gas forming material: Cellulose, Wood Floor, Lime Stone.
- Slipping agents (for easy extrusion): Glycerine, China Clay, Talc, Mica etc.
- Binding agent: Sodium Silicate, Dextrin, potassium Silicate, Sugar.

- Deoxidizers and alloying elements: Ferrosilicon, Ferro-chromium etc.

1.11 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 favorable 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.

1.11.1 Fused fluxes

Typical ingredients are quartz, manganese ore or slag, dolomite, potassium felspar 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.

1.11.2 Agglomerated 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.

Agglomerated *Flux Features:*

• Contain metallic deoxidizers

• May contain alloying agents

• Flat, low gloss, or dry particle appearance

• Each flux particle has a unique chemistry.

Agglomerated Flux Benefits:

• Presence of deoxidizers provides good performance over rust and mill scale and helps prevent weld porosity.

• Usually provides better peeling properties than fused fluxes.

• Alloying elements can be added to provide improved chemical and mechanical properties.

• Usually exhibit lower flux consumption than a fused flux welded at the same current and voltage [3, 4].

1.12 High-strength low-alloy steel

High-strength low-alloy (HSLA) steel is a type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. HSLA steels vary from other steels in that they aren't made to meet a specific chemical composition, but rather to specific mechanical properties. They have carbon content between 0.05–0.25percentage to retain formability and weldability. Other alloying elements include up to 2.0 percentage manganese and small quantities of copper, nickel, niobium, nitrogen, vanadium, chromium, molybdenum, titanium, calcium, rare earth elements, or zirconium.

Copper, titanium, vanadium, and niobium are added for strengthening purposes. These elements are intended to alter the microstructure of carbon steels, which is usually a ferrite-pearlite aggregate, to produce a very fine dispersion of alloy carbides in an almost pure ferrite matrix. This eliminates the toughness-reducing effect of a pearlitic volume fraction, yet maintains and increases the material's strength by refining the grain size, which in the case of ferrite increases yield strength.

The yield strengths vary between 250–590 megapascals. Due to their higher strength and toughness HSLA steels usually require 25 to 30% more power to form, as compared to carbon steels.

Copper, silicon, nickel, chromium, and phosphorus are added to increase corrosion resistance. Zirconium, calcium, and rare earth elements are added for sulfide-inclusion shape control which increases formability. These are needed because most HSLA steels have directionally sensitive properties. Formability and impact strength can vary significantly when tested longitudinally and transversely to the grain.

HSLA steels are also more resistant to rust than most carbon steels, due to their lack of pearlite – the fine layers of ferrite.

1.13 HSLA Steel properties

High-strength low-alloy (HSLA) steels provide increased strength-to-weight ratios over conventional low-carbon steels for only a modest price premium. Because HSLA alloys are stronger, they can be used in thinner sections, making them particularly attractive for transportation-equipment components where weight reduction is important. HSLA steels are available in all standard wrought forms - sheet, strip, plate, structural shapes, bar-size shapes, and special shapes.

Typically, HSLA steels are low-carbon steels with up to 1.5% manganese, strengthened by small additions of elements, such as columbium, copper, vanadium or titanium and sometimes by special rolling and cooling techniques. Improved-formability HSLA steels contain additions such as zirconium, calcium, or rare-earth elements for sulfide-inclusion shape control.

HSLA steels can have thinner cross sections than equivalent parts made from low-carbon steel, corrosion of HSLA steel can significantly reduce strength by decreasing the load-bearing cross section. While additions of elements such as copper, silicon, nickel, chromium, and phosphorus can improve atmospheric corrosion resistance of these alloys, they also increase cost. Galvanizing, zinc-rich coatings, and other rust-preventive finishes can help protect HSLA-steel parts from corrosion.

Improved-formability HSLA steels were developed primarily for the automotive industry to replace low-carbon steel parts with thinner cross-section parts for reduced weight without sacrificing strength and dent resistance.

Forming, drilling, sawing, and other machining operations on HSLA steels usually require 25 to 30% more power than do structural carbon steels. They are used to handle large amounts of stress or a good strength-to-weight ratio. HSLA steels are usually 20 to 30% lighter than carbon steel with the same strength. HSLA steels usually have densities of around 7800 kg/m^3.

HSLA alloys have directionally sensitive properties. For some grades, formability and impact strength vary significantly depending on whether the material is tested longitudinally or transversely to the rolled direction. For example, bends parallel to the longitudinal direction are more apt to cause cracking around the outside, tension-bearing surface of the bend. This effect is more pronounced in thick sheets. This directional characteristic is substantially reduced in HSLA steels that have been treated for sulphide shape control.

1.14 Application of HSLA

Improved-formability HSLA steels were developed primarily for the automotive industry to replace low-carbon steel parts with thinner cross-section parts for reduced weight without sacrificing strength and dent resistance. Typical passenger-car applications include door-intrusion beams, chassis members, reinforcing and mounting brackets, steering and suspension parts, bumpers, and wheels.

Trucks, construction equipment, off-highway vehicles, mining equipment, and other heavy-duty vehicles use HSLA sheets or plates for chassis components, buckets, grader blades, and structural members outside the body. For these applications, sheets or light-gage plates are specified. Structural forms (alloys from the family of 45,000 to 50,000-psi minimum yield strength HSLA steels) are specified in applications such as offshore oil and gas rigs, single-pole power-transmission towers, railroad cars, and ship construction [5].

[6] Serdar Karaoglua et al. (2008), observed process parameters has great influence on the quality of a welded connection. Mathematical modeling can be utilized in the optimization and control procedure of parameters. Rather than the well-known effects of main process parameters, this study focuses on the sensitivity analysis of parameters and fine tuning requirements of the parameters for optimum weld bead geometry. Changeable process parameters such as welding current, welding voltage and welding speed are used as design variables. The objective function is formed using width, height and penetration of the weld bead. Experimental part of the study is based on three level factorial designs of three process parameters.

In order to investigate the effects of input (process) parameters on output parameters, which determine the weld bead geometry, a mathematical model is constructed by using multiple curvilinear regression analysis. After carrying out a sensitivity analysis using developed empirical equations, relative effects of input parameters on output parameters are obtained. Effects of all three design parameters on the bead width and bead height show that even small changes in these parameters play an important role in the quality of welding operation. The results also reveal that the penetration is almost non-sensitive to the variations in voltage and speed.

[7] Kook-soo Bang et al. (2008), said that submerged arc welding was performed using metal-cored wires and fluxes with different compositions. The effects of wire/flux combination on the chemical composition, tensile strength, and impact toughness of the weld metal were investigated and interpreted in terms of element transfer between the slag and the weld metal, i.e., quantity. Both carbon and manganese show negative quantity in most combinations, indicating the transfer of the elements from the weld metal to the slag during welding.

The amount of transfer, however, is different depending on the flux composition. More basic fluxes yield less negative C and Mn through the reduction of oxygen content in the weld metal and presumably higher Mn activity in the slag, respectively. The transfer of silicon, however, is influenced by Al2O3, TiO2 and ZrO2 contents in the flux. Si becomes less negative and reaches a positive value of 0.044 as the oxides contents increase. This is because Al, Ti, and Zr could replace Si in the SiO2 network, leaving more Si free to transfer from the slag to the weld metal.

[8] Keshav Prasad et al. (2006), investigate the influence of the submerged arc welding (SAW) process parameters (welding current and welding speed) on the microstructure, hardness, and toughness of HSLA steel weld joints. Attempts have also been made to analyze the results on the basis of the heat input. The SAW process was used for the welding of 16 mm thick HSLA steel plates. The weld joints were prepared using comparatively high heat input (3.0 to 6.3 KJ/mm) by varying welding current (500–700 A) and welding speed (200–300 mm/min).

Results showed that the increase in heat input coarsens the grain structure both in the weld metal and heat affected zone (HAZ). The hardness has been found to vary from the weld centre line to base metal and peak hardness was found in the HAZ. The hardness of the weld metal was largely uniform. The hardness reduced with the increase in welding current and reduction in welding speed (increasing heat input) while the toughness showed mixed trend. The increase in welding current from 500 A to 600 A at a given welding speed (200 mm/min or 300 mm/min) increased toughness and further increase in welding current up to 700 A lowered the toughness.

[9] R Quintana et al. (2003), developed 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 fluxes1. All agglomerate fluxes consist of two fundamental parts: the matrix and the alloyed load. The two constituents of the flux aggregate, by various processes, with the help of agglomerating agents. Agglomeration by granulation (pelletising) using liquid sodium or potassium glass is the most common and widely used for these types of fluxes.

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 elements of the alloyed load can constitute up to 85% of the production cost of the flux. One of the most widely used and economic alloy systems for fluxes used to refinish pieces subject to wear due to abrasion and light impact, and for metal to metal wear, is the system constituted by FeCr, FeMn and graphite. The chemical activity and structural characteristics of the matrix of the agglomerate flux influence the efficacy of the transfer of the chemical elements alloyed to the metal deposited during SAW.

In chemical terms, the SAW process can be considered a very heterogeneous reaction, which develops in different states and ranges of temperature and concentration, the reacting components of which are wire–electrode, flux and base material. The final product of this reaction is an alloy (welding cord), with a specific chemical composition, microstructure and mechanical properties, which can be modified according to technological parameters, with slag and gases.

[10] P. Kanjilal et al. (2005), had shown rotatable designs based on statistical experiments for mixtures have been developed to predict the combined effect of flux mixture and welding parameters on submerged arc weld metal chemical composition and mechanical properties. Bead-on-plate weld deposits on low carbon steel plates were made at different flux composition and welding parameter combinations.

The results show that flux mixture related variables based on individual flux ingredients and welding parameters have individual as well as interaction effects on responses, viz. weld metal chemical composition and mechanical properties. In general, two factor interaction effect are higher than the individual effect of mixture related variables. Amongst welding parameters, polarity is found to be important for all responses under study.

[11] J. Tuseka et al. (2003), studied multiple-wire submerged-arc welding and cladding with metal-powder addition. Three different ways of supplying the metal powder to the welding area are described and shown schematically. It was found that the use of metal powder will increase the deposition rate and the welding-arc efficiency and reduce the shielding-flux consumption. A suitable device permits submerged-arc welding and cladding with metal-powder addition. The process is primarily meant for the cladding of worn surfaces or the production of surfaces with certain characteristics (corrosion or wear resistance). By using the metal-powder addition it is possible to alloy a weld or a cladding with optional chemical elements.

[12] R. S. Chandel et al. (1998), suggested that conventional submerged arc welding (SAW) process has a very high deposition rate, there has been continued effort in further improving that rate. Consequently, many variants of SAW multiple wire, strip electrodes etc., are now available and widely used for specific applications.

With the use of proper parameters and SAW variant, it is now possible to achieve deposition rates in excess of 50 kg/hr. The increase in deposition rate in most cases is, however, achieved by increasing welding current and hence the heat input, which tends to impair joint toughness. The mechanical properties, particularly the toughness of high heat input welds, are known to be inferior due to grain coarsening in the heat-affected zone (HAZ) and segregation and large columnar grains in the weld metal. Thus, the increase in deposition rate by increasing heat input is at the expense of mechanical properties. This factor is becoming more and more important due to the emergence of high-strength materials such as high strength low alloys (HSLA).

Many researchers have shown that by adding the powder in SAW, a better use of heat can be made; thus, for a given heat input, the number of passes required to a joint can be reduced and, therefore, the total energy supplied to the joint can be reduced. Alternatively, the same bead size or deposition rate can be achieved by lowering heat input per pass. Welds made with lower heat input experience higher cooling rates, and thermal gradients are steeper; hence, the width of the HAZ is also less.

Additionally, the time spent above the peak temperature is reduced; the combined effect of this results in a narrow HAZ that cools faster and has smaller grain growth. Weld metals produced under faster cooling rates are also superior in mechanical properties. Thus, the process of powder addition has potential not only for producing welds that are cost effective but metallurgically superior, too, and they may become attractive for welding HSLA. In light of this, a study was carried out to evaluate the effect of the addition of metal powder on the mechanical properties of SAW metal made in steel.

[13] Saurav Datta et al. (2006), said that quality has now become an important issue in today's manufacturing world. Whenever a product is capable of conforming to desirable characteristics that suit its area of application, it is termed as high quality.

Therefore, every manufacturing process has to be designed in such a way that the outcome would result in a high quality product. The selection of the manufacturing conditions to yield the highest desirability can be determined through process optimization. Therefore, there exists an increasing need to search for the optimal conditions. In the present work, we aim to evaluate an optimal parameter combination to obtain acceptable quality characteristics of bead geometry in submerged arc bead-on-plate weldment on mild steel plates.

The SAW process has been designed to consume fused flux, in the mixture of fresh flux. Thus, the work tries to utilize the concept of 'waste to wealth'. Apart from process optimization, the work has been initiated to develop mathematical models to show different bead geometry parameters, as a function of process variables. Hence, optimization has been performed to determine the maximum amount of slag–flux mixture that can be used without sacrificing any negative effect on bead geometry, compared to the conventional SAW process, which consumes fresh flux only. Experiments have been conducted using welding current, slag-mix percentage and flux basicity index as process parameters, varied at four different levels.

Using four 3 full factorial designs, without replication, we have carried out welding on mild steel plates to obtain bead-on plate welds. After measuring bead width, depth of penetration and reinforcement; based on simple assumptions on the shape of bead geometry, we calculated other relevant bead geometry parameters: percentage dilution, weld penetration shape factor, weld reinforcement form factor, area of penetration, area of reinforcement and total bead cross sectional area.

[14] Ana Ma. et al. (2003), discussed chemical and structural characterization of fluxes for submerged-arc welding was conducted. Three flux formulations were prepared using mineral oxides for agglomerating and sintering processes. A commercial agglomerated and sintered flux was used for comparison. The four fluxes were analyzed chemically by atomic absorption and X-ray diffraction to determinate the quantity and type of oxides formed, as well as the change in oxidation number after the sintering process at 950 ^{oC} of the initial compounds. Differential thermal analysis was carried out from 1000 to 1350 ^{oC} in order to determine the temperatures for phase transformations and melting of the different compounds formed in the sintering process.

This kind of flux characterization enables us to quantify the ions that might be present in the plasma arc during the submerged welding process due to the fluxes. This analysis also make possible the prediction of reactions in the weld pool.

[15] Behcet Gulenc et al. (2003), said that submerged arc welding process is commonly used due to its easy applicability, high current density and its ability to deposit a large amount of weld metal using more than one wire at the same time, especially in restoration of worn parts, which is of great importance to manufacturers. In this study, worn parts were welded using the submerged arc welding process.

Various wires and fluxes were used for this purpose. These welded parts were subjected to wear tests under different loads, and changes in the hardness and microstructures were examined. The results showed that the hardest weld metal showed the highest wear resistance, while the least hard weld metal showed the least wear resistance. The weld hardness and wear resistance obtained were found to be dependent on the chemical composition of the weld wire and flux.

[16] N. A. Mcpherson et al. (1998), produced Butt welds using the submerged arc welding (SAW) process to join a carbon steel plate of normal shipbuilding grade to an austenitic stainless steel plate. Variables used in this work were the position of the consumable wire in the weld preparation and the ferrite number of the consumable wire. Abnormally high hardnesses were measured in some regions of the welds.

These were related to the central position of the consumable wire in the weld preparation. Undesirably low ferrite numbers were related to the ferrite number of the consumable wire and also to the central position of the consumable wire in the weld preparation. The position of the consumable wire in the weld preparation controlled the relative dilution from the parent plates, and when the dilution from the 316LN steel was increased by off-setting the wire to that side of the weld preparation, the high hardness regions were no longer found. Similar optical microstructures were found to have significantly different hardnesses, which were related to the dilution effects, which were also related to the wire position within the weld preparation.

[17] Vera Lu et al. (2001), carried out Post weld heat treatment (PWHT) is frequently applied to steel pressure vessels, following the requirements of the ASME code, which establishes the parameters of the PWHT based on the thickness and chemical composition of the welded section. This work shows the results of an analysis undertaken on a sample of ASTM A537 C1 steel subjected to qualifying welding procedure tests including PWHT. The results obtained showed that this PWHT practice promoted a reduction in the mechanical properties of the base metal and the heat-affected zone (HAZ).

[18] Shan-Ping Lua et al. (2004), studied wear resistant Fe–Mn–Cr–Mo–V alloy cladding was deposited on SM45C substrate by automatic submerged arc welding using stoody 105 alloy wire. Microstructure and surface hardness of the cladding were investigated and measured on samples prepared under different welding conditions. The results showed that the retained austenite in the cladding increases with the increased welding current and reduced travel speed. The wear behavior of the clad was studied using ball-on-disk tribometer. Wear mechanism was analyzed based on the analysis of the worn surfaces both the clad and ball by scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS). The scanning electron microscopic examination of the worn surface shows that a layer of oxide film forms on the worn surface. Oxidation wear mechanism controls the wear process.

[19] I.C. Kuo et al. (2008), discussed two types of martensitic stainless steel strips, PFB-132 and PFB-131S, were deposited on SS41 carbon steel substrate by a three-pass submerged arc cladding process. The effects of post-weld heat treatment (PWHT) on thermal fatigue resistance and hardness were evaluated by thermal fatigue and hardness testing, respectively. The weld metal microstructure was investigated by utilizing optical microscopy, scanning electron microscopy (SEM).

Results showed that, by increasing the PWHT temperature, hardness decreased but there was a simultaneous improvement in weldment thermal fatigue resistance. During tempering, carbide, such as (Fe, Cr)23C6, precipitated in the weld metals and molybdenum appeared to promote (Fe, Cr, Mo)23C6 formation. The precipitates of (Fe, Cr, Mo)23C6 revealed a face-centered cubic (FCC) structure with fine grains distributed in the microstructure, thereby effectively increasing thermal fatigue resistance.

[20] Abilio Manuel et al. (2007), introduced normalized fine grain carbon low alloy steel, P355NL1, intended for service in welded pressure vessels, where notch toughness is of high importance, has been investigated. Applications with this steel usually require the intensive use of welds. One of the most common welding processes that are used in the manufacturing of pressure vessels is the submerged arc welding. This welding process is often automated in order to perform the main seam welds of the body of the vessels.

The influence of the automated submerged arc welding, in the mechanical performance, is investigated. The low and high cycle fatigue and crack propagation behaviors are compared between the base and welded materials. Several series of small and smooth specimens as well as cracked specimens made of base, welded and heat affected materials, respectively, were fatigue tested. Strain, stress and energy based relations for fatigue life assessment, until crack initiation, are evaluated based on experimental results and compared between the base and welded materials. Finally, the fatigue crack propagation behaviors are compared between the base, welded and heat affected materials.

[21] Saurav Datta et al. (2009), discussed optimization problem of submerged arc welding. The target was to search an optimal process environment, capable of producing desired bead geometry parameters of the weldment. Four correlated features of bead geometry: depth of penetration, reinforcement, bead width, and percentage dilution has been selected in the study. The process environment has been assumed consisting of variables like voltage, wire feed rate, traverse speed.

Multiple correlated responses have been converted into independent quality indices called principal components. Principal component analysis (PCA) has been adapted to covert multiple objectives of the optimization problem into a single objective function. This single objective function has been denoted as composite principal component. Taguchi's robust optimization technique has been applied to determine the optimal setting, which can maximize the composite principal component. Result of this aforesaid optimization technique has been compared to that of grey- Taguchi technique; another approach which is widely used for solving multicriteria optimization problems. A confirmatory test showed satisfactory result.

[22] Saurav Datta et al. (2007), investigated Taguchi philosophy has been applied for obtaining optimal parametric combinations to achieve desired weld bead geometry and dimensions related to the heataffected zone (HAZ), such as HAZ width in the present case, in submerged arc welding. The philosophy and methodology proposed by Dr. Genichi Taguchi can be used for continuous improvement in products that are produced by submerged arc welding. This approach highlights the causes of poor quality, which can be eliminated by selfadjustment among the values of the process variables if they tend to change during the process.

Depending on functional requirements of the welded joint, an acceptable weldment should confirm maximum penetration, minimum reinforcement, minimum bead width, minimum HAZ width, minimum bead volume, etc. to suit its area of application. Hence, there exists an increasing demand to evaluate an optimal parameter setting that would fetch the desired yield. This could be achieved by optimization of welding variables. Based on Taguchi's approach, the present study has been aimed at integrating statistical techniques into the engineering process.

Taguchi's L9 (3**3) orthogonal array design has been adopted and experiments have been accordingly conducted with three different levels of conventional process parameters using welding current and flux basicity index to obtain bead-onplate weld on mild steel plates. Features of bead geometry and HAZ in terms of bead width, reinforcement, depth of penetration and HAZ width have been measured for each experimental run. The slag, generated during welding, has been consumed in further runs by mixing it with fresh unmelted flux. The percentage of slag in the mixture of fused flux (slag) and fresh flux has been defined as slagmix percentage. Welding has been performed by using varying slagmix percentage, treated as another process variable, in order to obtain the optimum amount of slag-mix that can be used without any alarming adverse effect on features of bead geometry and HAZ. This would lead to 'waste to wealth'.

[23] Nassour et al. (2001), had shown creep behavior of two austenitic stainless-steel weld metals was investigated. Two AISI 316L stainless steel base plates were welded together using the submerged arc-welding process. Creep tests were carried out on the welds at constant load, over a stress range of 100 to 400 MPa, and in the temperature range of 600 to 700 ^{oC}.

The results showed that AISI 347 weld metal presented a higher creep resistance with lower values of the minimum strain rate, and, consequently, it exhibited a longer life before rupture than AISI 316L weld metal. However, this weld metal showed a lower ductility value than AISI 316L welds metal. The weld-metal microstructure survey, performed before and after the creep testing, has shown different amounts of delta ferrite, which was strongly dependent on time, temperature, and stress level.

[24] H.S. Moon et al. (2002), investigated significant portion of the total manufacturing time for a pipe fabrication process is spent on the welding following the primary machining and fit-up processes. To achieve a reliable weld bead appearance, automatic seam tracking and adaptive control to fill the groove are urgently required. For seam tracking in the welding processes, vision sensors have been successfully applied.

However, the adaptive filling control for a multitorch system for the appropriate welded area has not yet been implemented in the area of submerged arc welding (SAW). This describes several advances in sensor and process control techniques for applications in SAW which combine to give a fully automatic system capable of controlling and adapting the overall welding process. This technology has been used in longitudinal and spiral pipe mills and in pressure vessel production.

[25] BY E. Baune et al. (2000), investigated performed using a set of five experimental FCAW electrodes, an improved version of the basicity index formula is developed. This new methodology is described in two papers, titled Part 1: Solidified Slag Composition of a FCAW Consumable as a Basicity Indicator and

Part 2: Verification of the Flux/Slag Analysis Methodology for Weld Metal Oxygen Control. To accomplish this purpose, the partition of the various elements contained in the formulation of one FCAW electrode is studied and modeled in Part 1. Correspondingly, the composition of the solidified slag is predicted for this particular electrode. To verify the model, the prediction of the slag chemical composition is compared with experimental measurements. Good accordance is found, which shows the model is applicable. A new way of defining the basicity of a FCAW consumable based on the chemical composition of the slag is derived. In Part 2, comparison of this innovative methodology with formula is achieved, as well as with other means reported in the literature for expressing the flux/slag basicity. The newly defined basicity index is found to offer superior correlation with the weld metal oxygen content, demonstrating the validity of the assumptions made in the present investigation.

[26] Saurav Datta et al. (2006), carried out application of the Taguchi method in combination with grey relational analysis has been applied for solving multiple criteria (objective) optimization problem in submerged arc welding (SAW). A grey relational grade evaluated with grey relational analysis has been adopted to reveal an optimal parameter combination in order to obtain acceptable features of weld quality characteristics in submerged arc bead-on-plate welding. The idea of slag utilization, in subsequent runs, after mixing it with fresh unmelted flux, has been introduced. The parentage of slag in the mixture of fresh flux and fused flux (slag) has been denoted as slag-mix percentage.

Apart from two conventional process parameters: welding current and flux basicity index, the study aimed at using varying percentages of slag-mix, treated as another process variable, to show the extent of acceptability of using slagmix in conventional SAW processes, without sacrificing any characteristic features of weld bead geometry and HAZ, within the experimental domain. The quality characteristics associated with bead geometry and HAZ were bead width, reinforcement, depth of penetration and HAZ width.

Predicted results have been verified with confirmatory experiments, showing good agreement. This proves the utility of the proposed method for quality improvement in SAW process and provides the maximum (optimum) amount of slag-mix that can be consumed in the SAW process without any negative effect on characteristic features of the quality of the weldment in terms of bead geometry.

[27] Vinod Kumar et al. (2009), Submerged arc welding contributes to approximately 10% of the total welding. Approximately 10% -15% of the flux gets converted into very fine particles termed as flux dust before and after welding, due to transportation and handling. If welding is performed without removing these very fine particles from the flux, the gases generated during welding are not able to escape, thus it may result into surface pitting (pocking) and even porosity. On the other hand, if these fine particles are removed by sieving, the cost of welding will be increased significantly. And if this flux dust is dumped/ thrown, will create the pollution. Therefore to reduce the cost of welding and pollution, in the present work attempts have been made to develop the acidic and basic agglomerated fluxes by utilizing wasted flux dust. The investigation of the present study showed chemical composition and mechanical properties of the all weld metal prepared from the developed fluxes and the parent fluxes to be in the same range. The welded joints were also found to be radiographically sound. Therefore the developed fluxes prepared from the waste flux dust can be used without any compromise in mechanical properties and quality of the welded joint. It will reduce the cost of welding and pollution.

Chapter 3 Problem Formulation

High strength low alloy steel is preferred materials for Trucks, construction equipment, off-highway vehicles, mining equipment, and other heavy-duty vehicles use HSLA sheets or plates for chassis components, buckets, grader blades, and structural members outside the body. For these applications, sheets or light-gage plates are specified. Structural forms are specified in applications such as offshore oil and gas rigs, single-pole power-transmission towers, railroad cars, and ship construction.

The application of high strength low alloy (HSLA) steels has been limited by the availability of suitable filler metals. Specifically, as the weld metal strength increases, the susceptibility to hydrogen-assisted cracking increases. To take full advantage of the developments in HSLA steel base metals, weld flux which minimize the effects of diffusible hydrogen and develop tough microstructures must be developed. The current research proposes to study the effects of welding flux on tensile strength, toughness, microhardness, microstucture of work piece.

The welding fluxes for these steels are commercially available but the flux compositions are patented and are not widely reported in literature. In the present work flux is to be developed for joining of HSLA steel.

The aim of the experiment is to study the effects of flux on tensile strength, toughness, microstructure and microhardness. The mechanical testing of the weld metal had to be carried out to determine, and co-relate the properties of weld metal with strength, hardness and dilution variations, under the influence of different fluxes.

Chapter 4 Experimentation

As we seen that any change in the parameter of submerged arc welding affect 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, microhardness, microstructure etc. The high strength low alloy steel (FE-540) plate used as a work material and the dimension 16 x 100 x 200 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 4 mm diameter the value of Current 300-600ampere, Voltage 26-36 volt so, firstly by using these we make bead on plate by taking differet current and voltage reading. Then we find out that 300ampere current, 34 volt voltage and 425ampere, 36 volt voltage is best suitable for welding.

Table 4.1: Test Matrix

	Run 1				Run 2			
Exp. No	Welding Flux	Current (A)	Voltage (V)	Travelling Speed (m/h)	Welding Flux	Current (A)	Voltage (V)	Travelling Speed (m/h)
1	1	300	34	28	1	425	36	27
2	2	300	34	28	2	425	36	27
3	3	300	34	28	3	425	36	27
4	4	300	34	28	4	425	36	27
5	5	300	34	28	5	425	36	27
6	6	300	34	28	6	425	36	27
7	7	300	34	28	7	425	36	27
8	8	300	34	28	8	425	36	27

4.1 Method of preperation flux

For the manufacturing of flux for SAW, 7 compound required CaF_2, CaO, R_2O, MnO, SiO_2, Al_2O_3, TiO_2 by mixing these element in weight percentage we can get different fluxes (basicity index). From literature review we find that the main effect on welding comes from SiO_2, CaF_2 and CaO. So, by keeping constant weight percentage of all other coumpounds we changing the weight percentage of SiO_2, CaF_2 and CaO we manufacture 8 different kind of flux and see the effect of these fluxes on welding properties.

$$B.I.= CaF_2 + CaO + R_2O + 0.5(MnO+FeO)/SiO_2 + 0.5(Al_2O_3+TiO_2+ZrO_2)$$

So, by taking proper weight %age of the compounds we find out the basicity index

Table 4.2: Basicity Index

Flux	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Basicity Index	0.763116	1.240064	1.399046	1.458967	1.875994	2.370821	2.674772	3.586626

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 8 different kind of flux.

Fig 4.1: Compounds mix with Binder

Fig 4.2: Mixture in furnace

Fig 4.3: Test sieve (8 BS, 10 ASTM, 2 mm IS, 2057 microns)

Fig 4.4: 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

C	Si	Mn	P	S	Cu	Nb	Ti
0.18	0.26	1.43	0.02	0.01	0.09	0.07	0.008

Table 4.4: Chemical Composition of electrode

C	Mn	P	S	Cu	Nb	B
0.05	0.1	0.01	0.02	0.09	0.004	0.07

4.3 Method of preparation of steel plate specimen

We have 16 plates of dimension 16x100x200 mm. These plates chamfer on 200 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.

Fig 4.5: Making chamfer on corner of plate

Fig 4.6: Chamfer on plate

Fig 4.7: Tacking on back side of plates

After tacking, put specimen on base plate of SAW machine clamp the specimen with base plate using clampers then by putting 8 different kind of flux one by one in hopper welding was done in V grooves of 8 plates.

Fig 4.8: Submerged arc welding of plates

Fig 4.9: Joint of plates after welding

Fig 4.10: Welding on plates

Now cut the specimen in required dimension for Tensile test, Toughness, Micro hardness, Microstructure, SEM and Chemical composition.

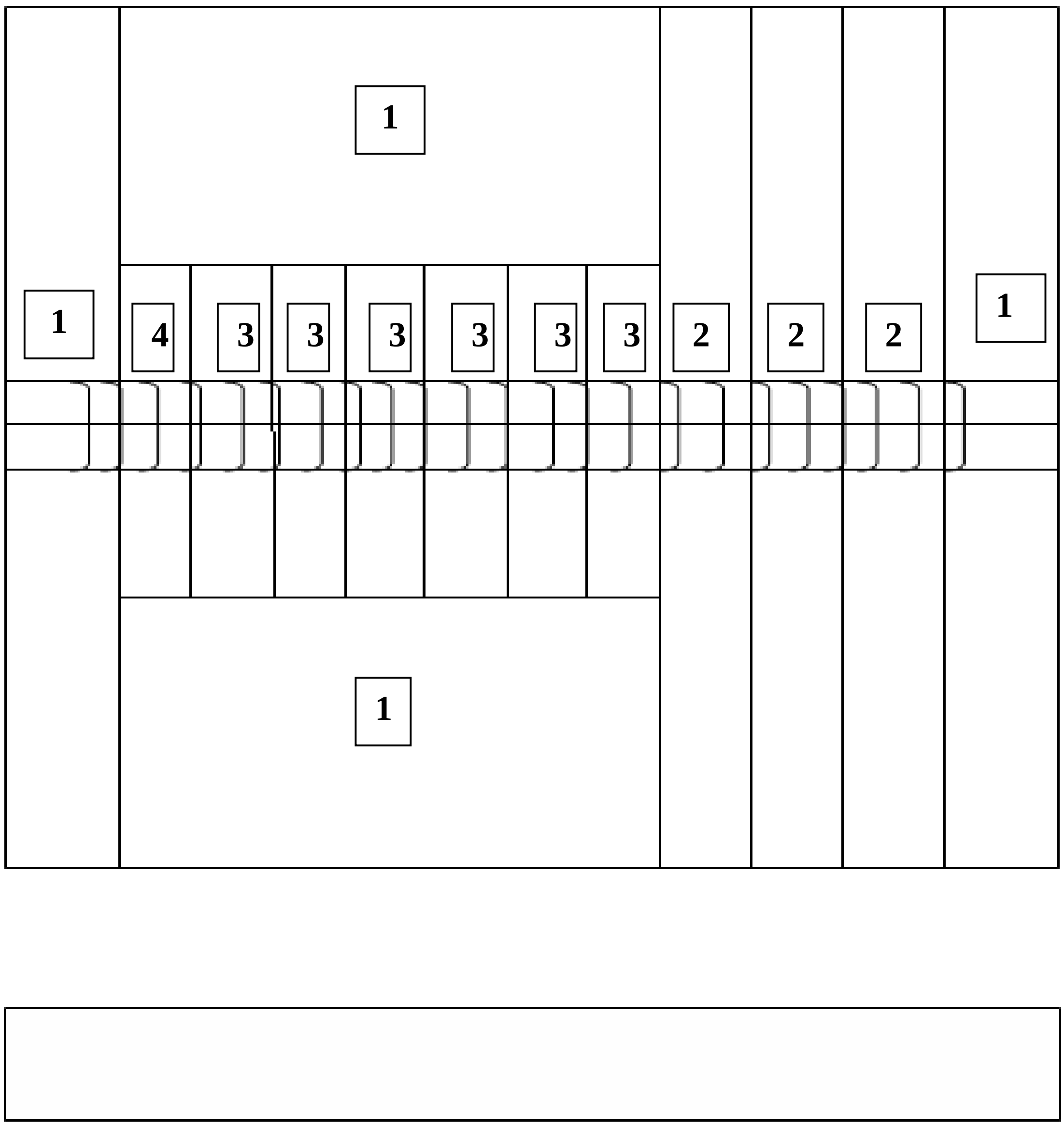


Fig 4.11: Cutting of plates after welding

In fig 4.11 which is cutting of plates after welding notation (1) represent waste material, (2) represent tensile test piece, (3) represent toughness test piece, (4) represent microstructure, microhardness and composition test piece.

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 computerised Universal Testing Machine (UTM) as shown in fig 5.1 available at Technology Education & Research Integrated Institution (TERII), Kurukshetra and the tensile test specimen are shown in fig 4.12 and tensile test specimen shown in fig 4.13.

Fig 4.12: Computerised Universal Testing Machine

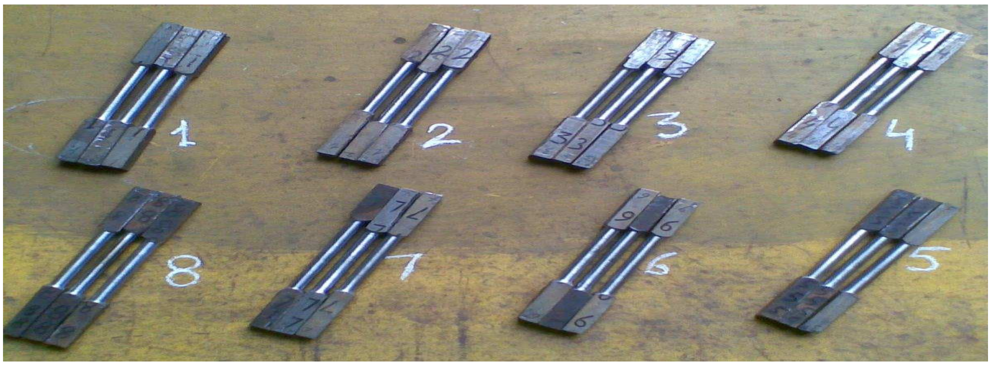


Fig 4.13: Tensile test specimen

4.5 Impact Toughness 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. 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 4.14, We make 48 specimens shown in fig 4.15, 6 from each plae of dimension 10x10x55 mm for charpy test and test them on machine as shown fig 4.16 at different temperatures by using liquid nitrogen shown in fig 4.17 i.e. room temp., -10, -30, -40, -45, -50 ^{o}C.

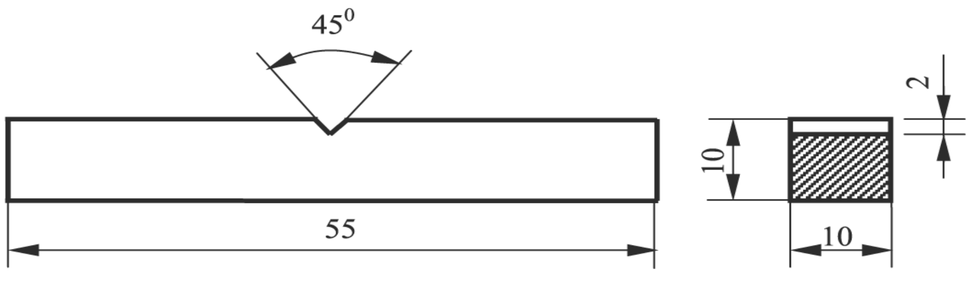


Fig 4.14: Standard Charpy test specicmen

Fig 4.15: Charpy test specicmen

Fig 4.16: Charpy toughness test machine

Fig 4.17: Apparatus for Liquid Nitrogen

4.6 Microstucture

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 4.18 and see the structure of specimen shown in fig. 4.19 and the different zone of welding shown in fig 4.20.

Fig 4.18: Microscope test machine

Fig 4.19: Specimens for microscope testing

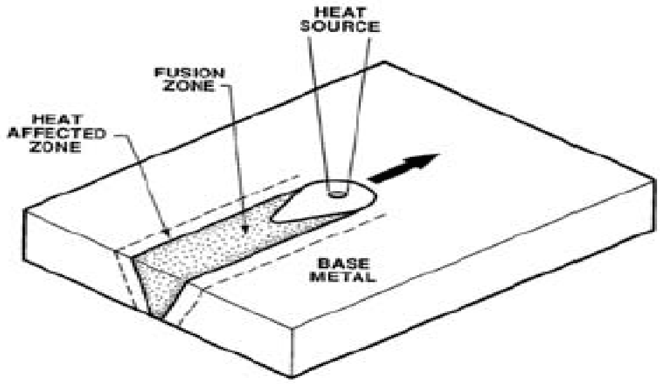


Fig 4.20: Specimens showing different zone of welding

4.7 Micohardness Test

Microhardness testing shown in fig 4.21 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 4.22.

Fig 4.21: Micohardness test machine

Fig 4.22: Micohardness test specimen

4.8 Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) is an important tool for microstructural analysis. The microstructural characteristic of the sample correlate the effect of different processing condition with properties and behaviour of materials that involves their microstructural 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 4.22 i.e. JEOL JSM-6510 LV available at R & D Centre, Thapar University, Patiala.

Fig 4.23: Scanning Electron Microscope machine

4.9 X-Ray diffraction

X-ray diffraction techniques are a family of non-destructive analytical techniques which reveal information about the crystallographic structure, chemical composition, and physical properties of materials and thin films. This technique is based on observing the scattered intensity of an X-ray beam hitting a sample as a function of incident and scattered angle, polarization, wavelength or energy.

Figure 4.24: XRD machine

4.10 Chemical composition of weld metal

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

Fig 4.25: Atomic Absorption Spectrometer

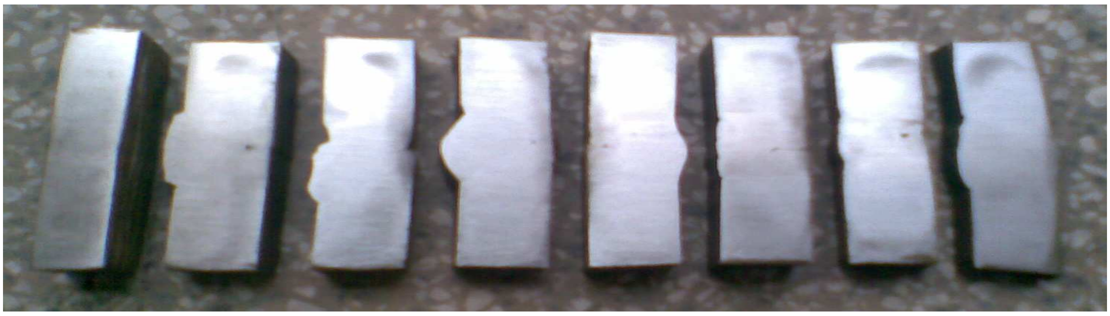


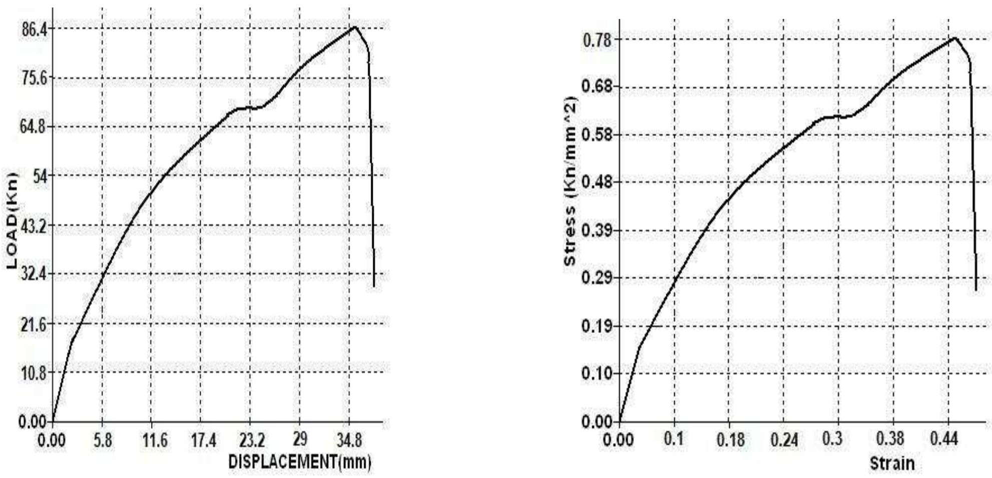
Fig 4.25: Specimen for composition

Chapter 5 Results and Discussion

5.1 Tensile Test

Tensile specimen after tensile test shown in fig 5.1

Fig 5.1: Specimen after tensile test



Peak Load = 86.4 k.newton
Peak Displacement = 37.8 mm

Peak Stress = 0.78 k.newton
Peak Strain = 0.48 mm

Fig 5.2: Load vs displacement and stress vs strain curve for specimen which is made from base metal

Table 5.1: Load & stress Reading of base metal:

Base Material	Peak load (K. Newton)	Peak stress (K. Newton/mm^2)
	86.4	0.78

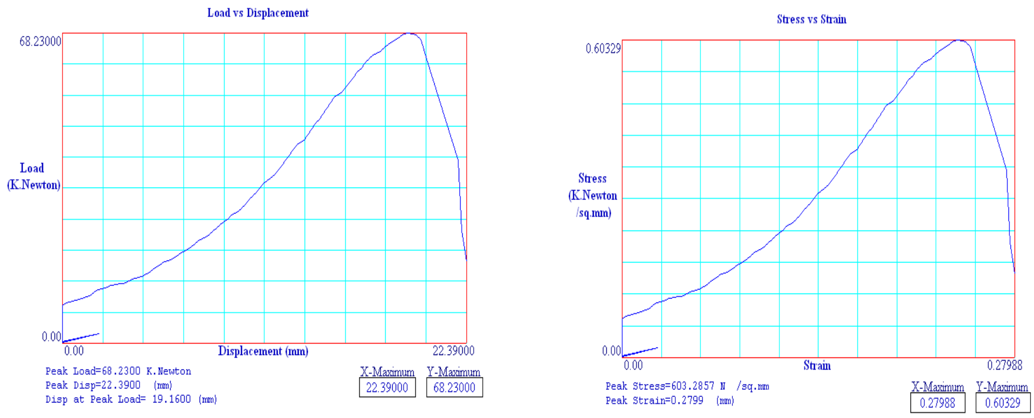
Table 5.2: Ultimate Tensile Load Reading:

Flux No.	Basicity Index	Reading 1 (K. Newton)	Reading 2 (K. Newton)	Reading 3 (K. Newton)	Average (K. Newton)
1.	0.76	68.23	58.04	52.38	59.55
2.	1.24	71.30	68.11	74.85	71.42
3.	1.39	71.46	*	*	71.46
4.	1.45	72.59	68.29	83.20	74.69
5.	1.87	68.14	70.14	71.48	69.92
6.	2.37	73.39	82.02	77.05	77.48
7.	2.67	74.64	66.03	60.86	67.17
8.	3.58	70.64	75.77	72.81	73.07

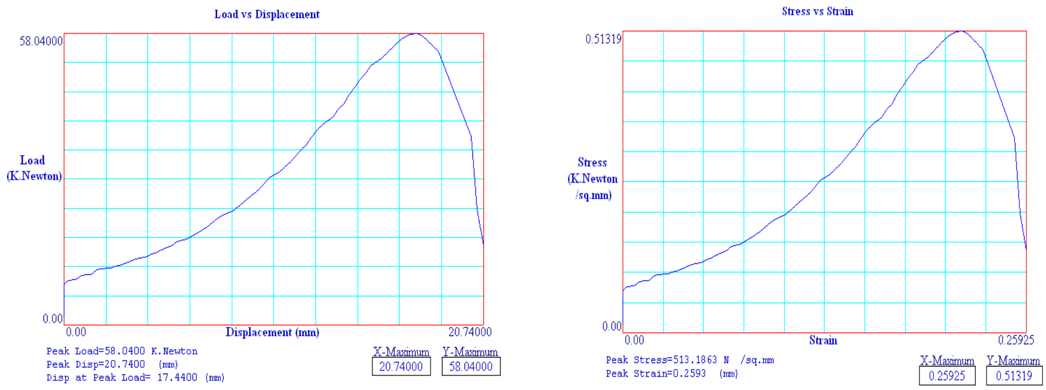
Table 5.3: Ultimate Tensile Stress Reading:

Flux No.	Basicity Index	Reading 1 (K. N./mm^2)	Reading 2 (K. N./mm^2)	Reading 3 (K. N./mm^2)	Average (K. N./mm^2)
1.	0.76	0.60	0.51	0.46	0.52
2.	1.24	0.63	0.60	0.66	0.63
3.	1.39	0.63	*	*	0.63
4.	1.45	0.64	0.60	0.73	0.65
5.	1.87	0.60	0.62	0.63	0.61
6.	2.37	0.64	0.72	0.68	0.68
7.	2.67	0.65	0.58	0.53	0.58
8.	3.58	0.62	0.66	0.64	0.64

*indicates non availablity of experimental values due to power problem



(i)



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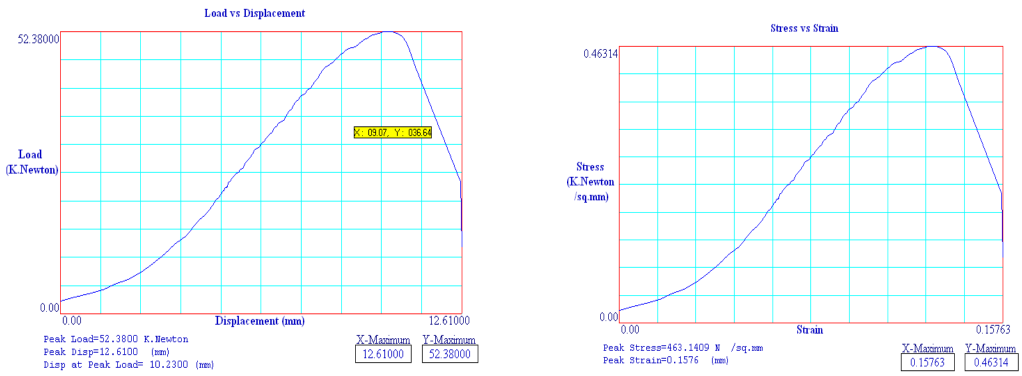
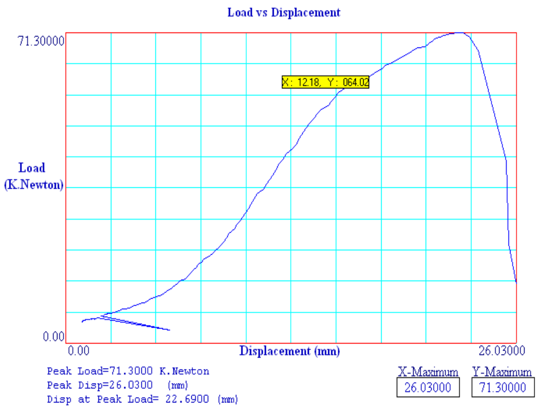


(iii)

Fig 5.3 (a): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 1



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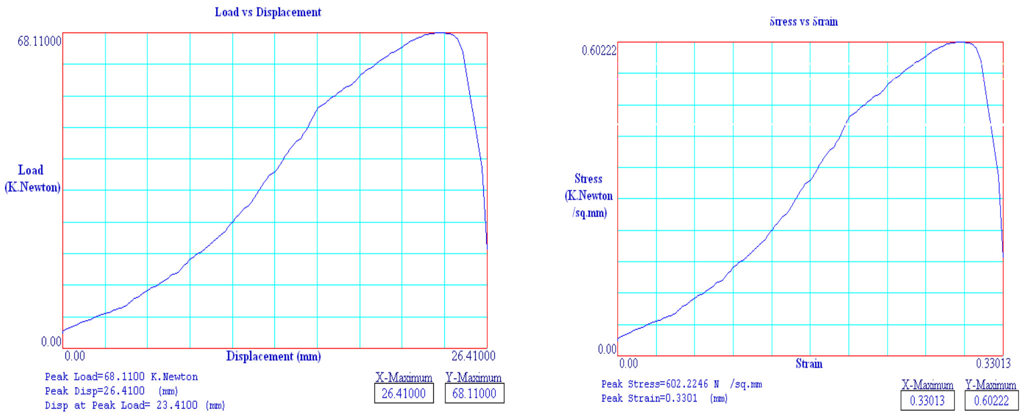

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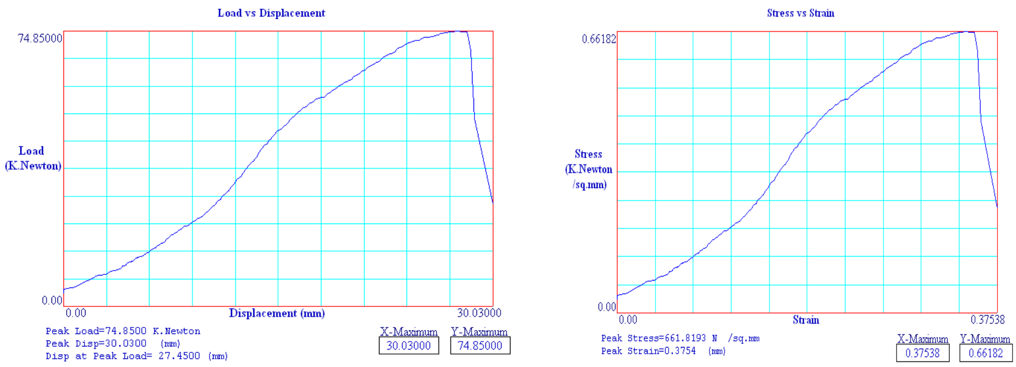
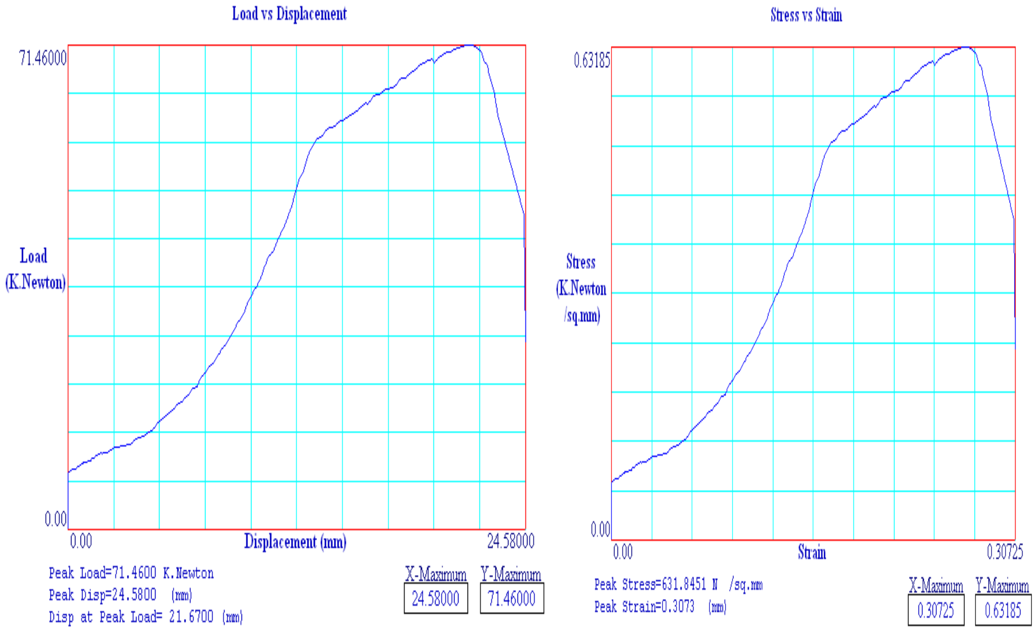


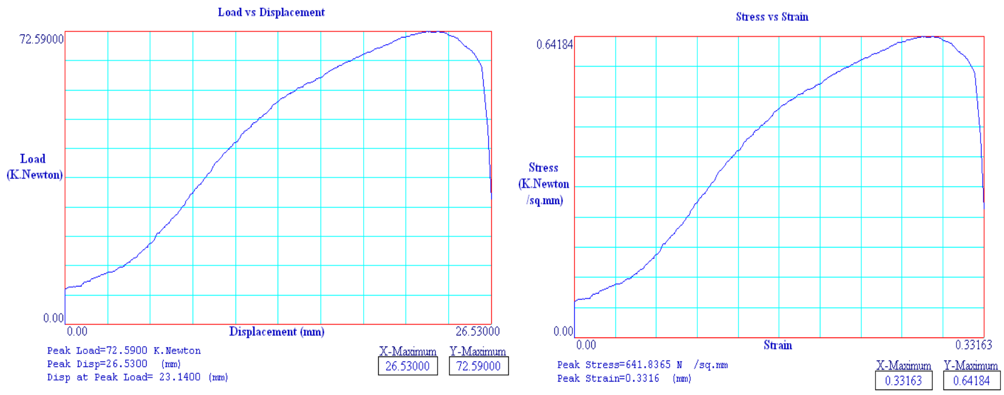
(iii)

Fig 5.3 (b): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 2



(i)

Fig 5.3 (c): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 3



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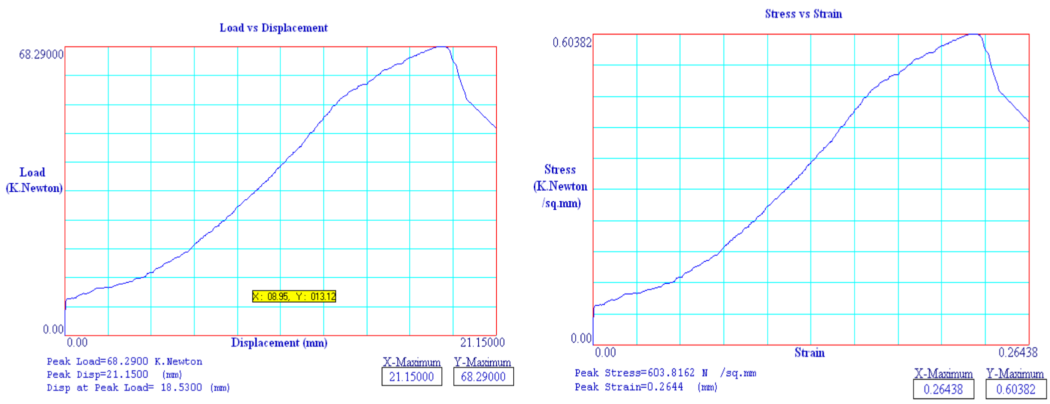

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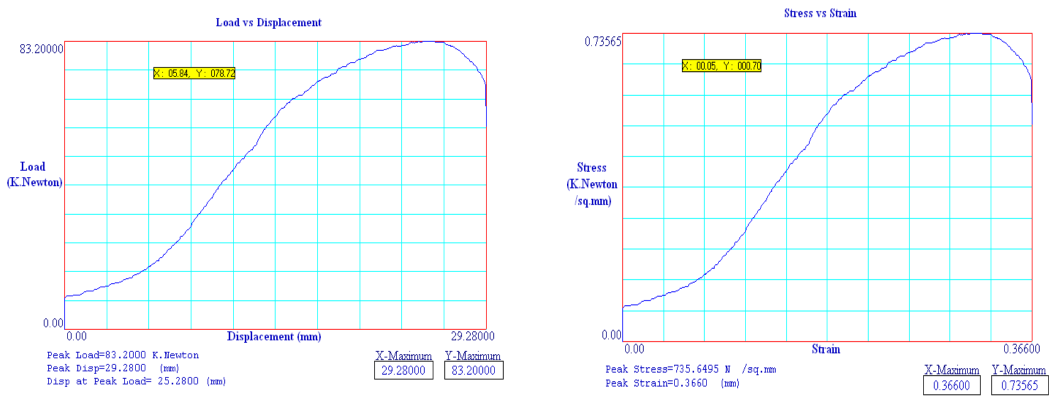
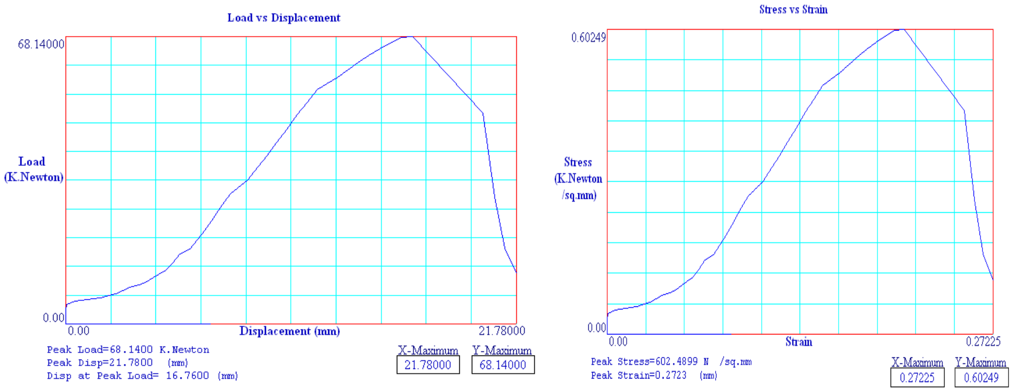
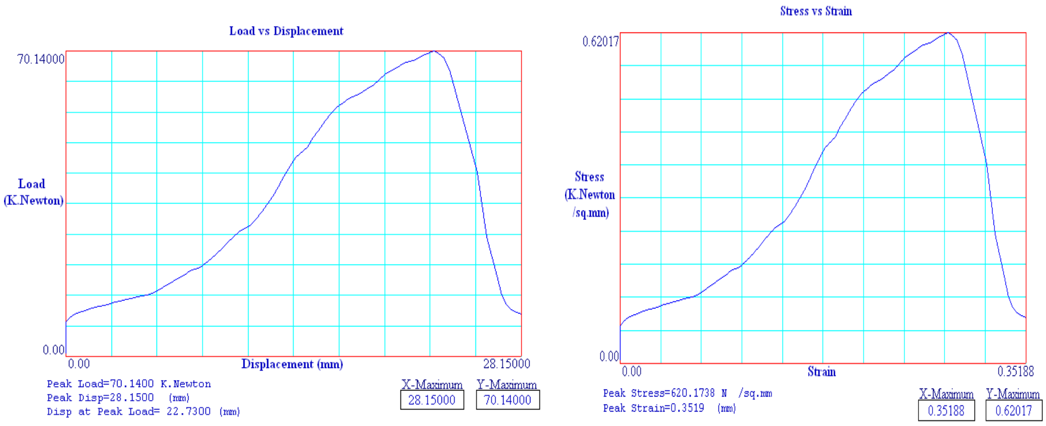


(iii)

Fig 5.3 (d): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 4



(i)



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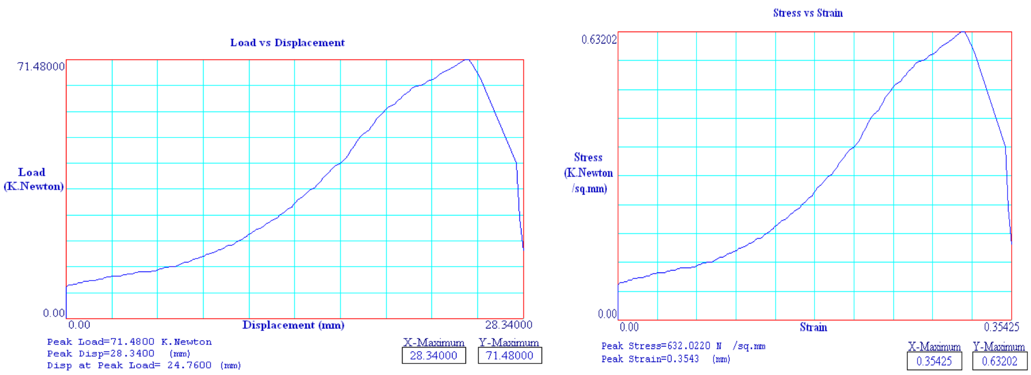
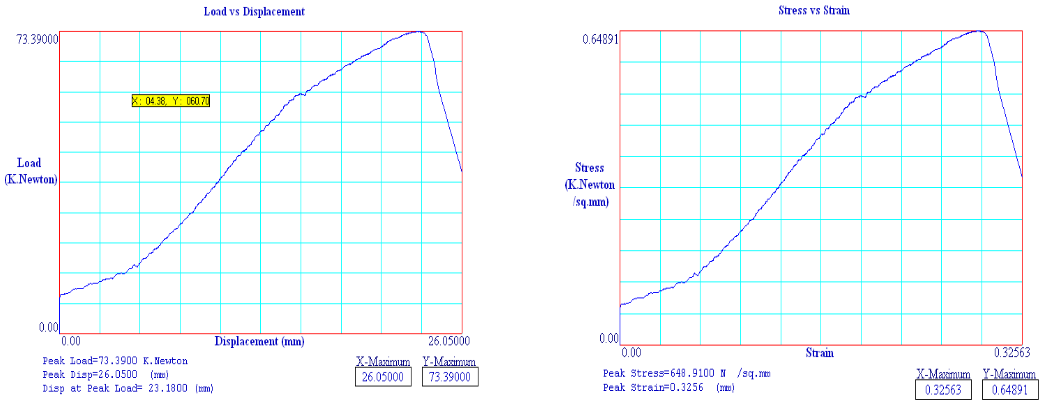


(iii)

Fig 5.3 (e): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 5



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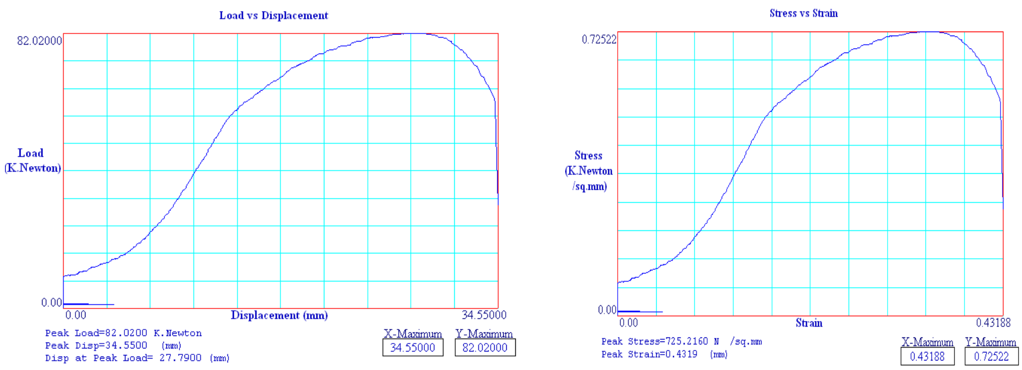

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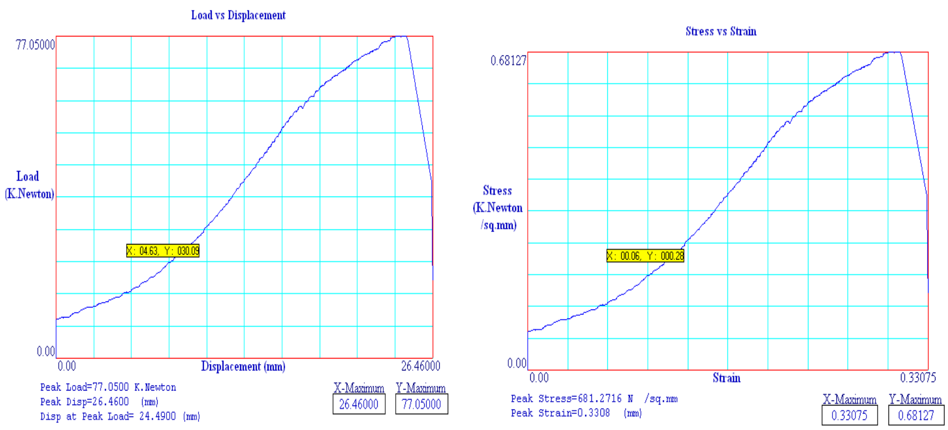
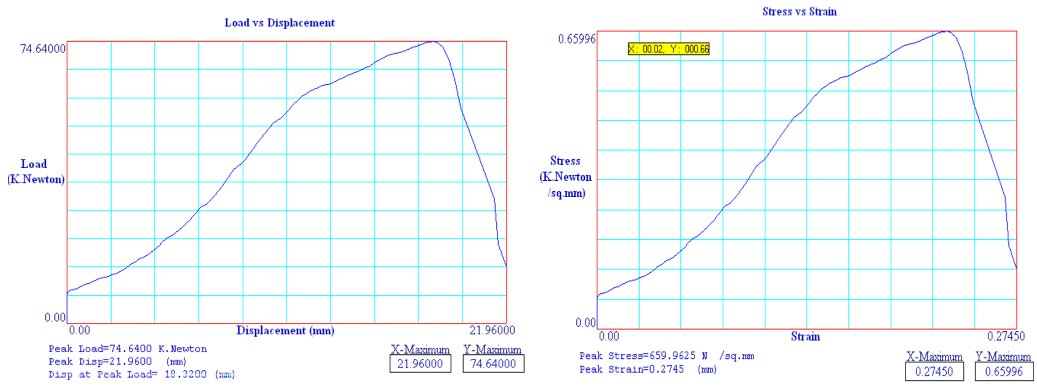


(iii)

Fig 5.3 (f): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 6



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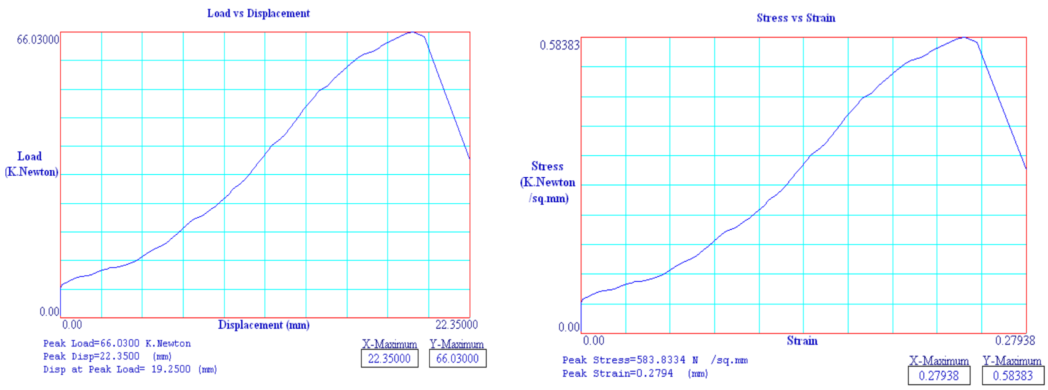

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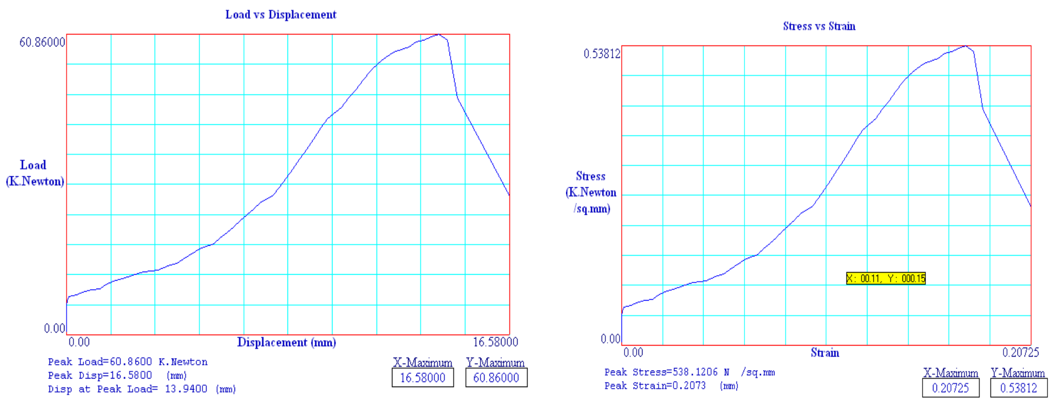
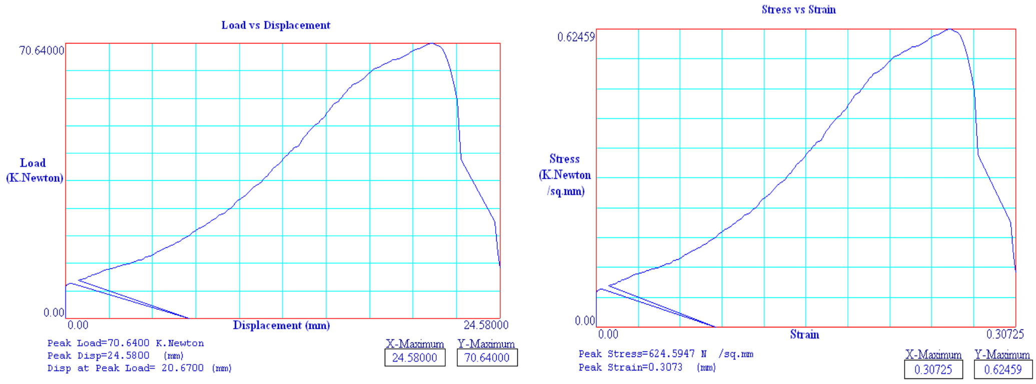


(iii)

Fig 5.3 (g): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 7



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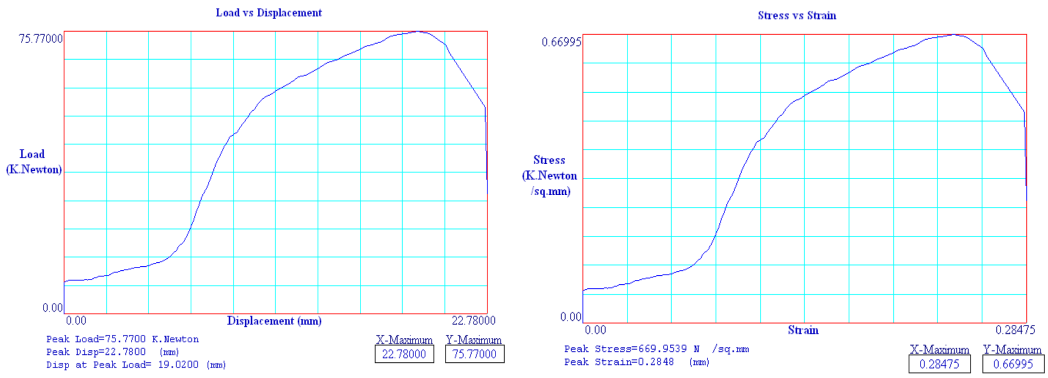

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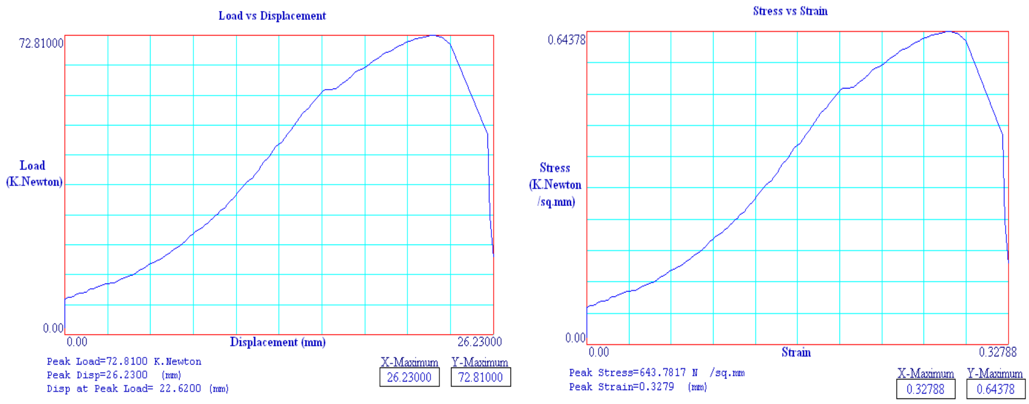


(iii)

Fig 5.3 (h): Load vs displacement and stress vs strain curve for specimen which weld from welding of flux 8

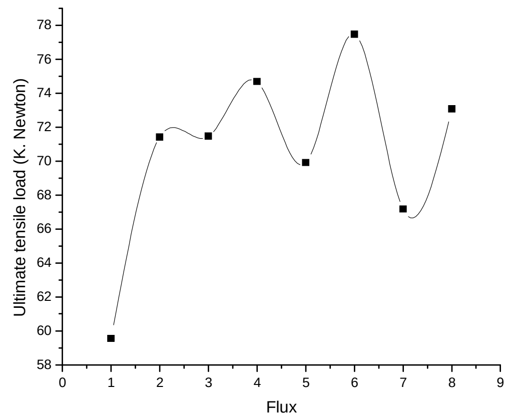


Fig 5.4: Ultimate tensile Load vs flux for specimens which weld from weling of 8 type of flux

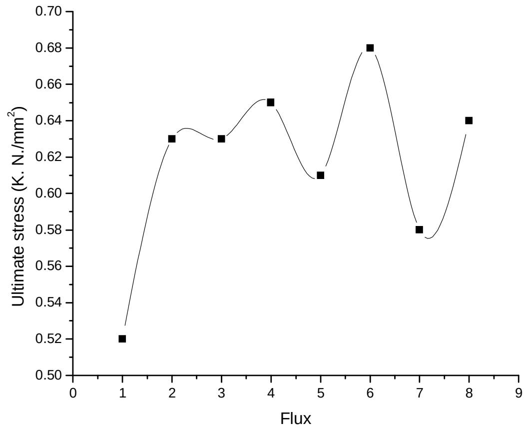


Fig 5.5: Ultimate stress vs flux for specimens which weld from weling of 8 type of flux

Discussion of tensile test

It is clear from fig 5.4 and fig 5.5 that the maximum tensile load and maximum stress comes from flux 6. So, it is concluded that flux 6 enhanced tensile load and stress value. For welding of materials in which we require more tensile stress flux 6 used.

5.2 Impact Toughness Test

Specimen after impact test shown in fig 5.6

Fig 5.6: Specimen after impact toughness test

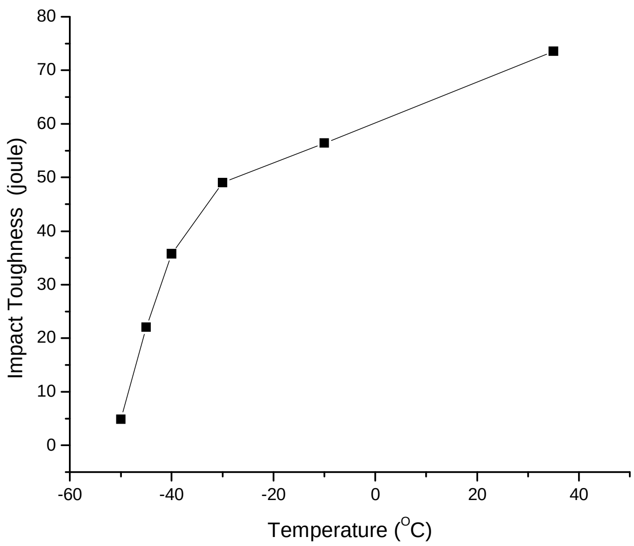


Fig 5.7 (a): Impact Toughness of specimen which weld from welding of flux 1

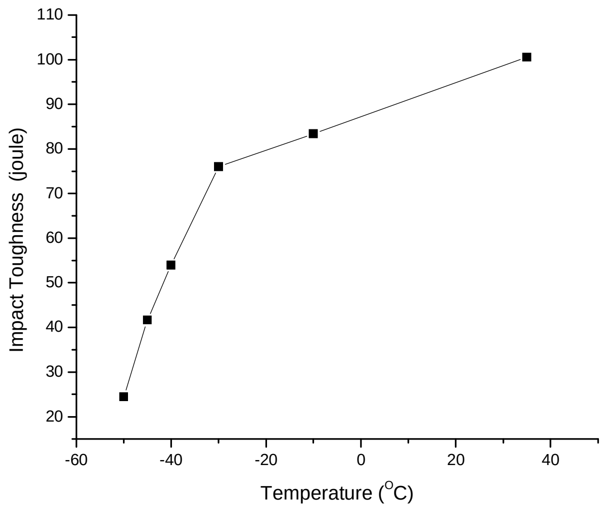


Fig 5.7 (b): Impact Toughness of specimen which weld from welding of flux 2

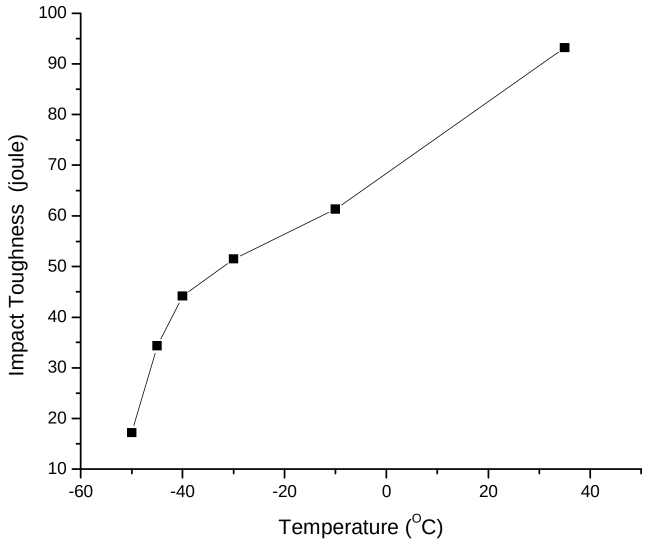


Fig 5.7 (c): Impact Toughness of specimen which weld from welding of flux 3

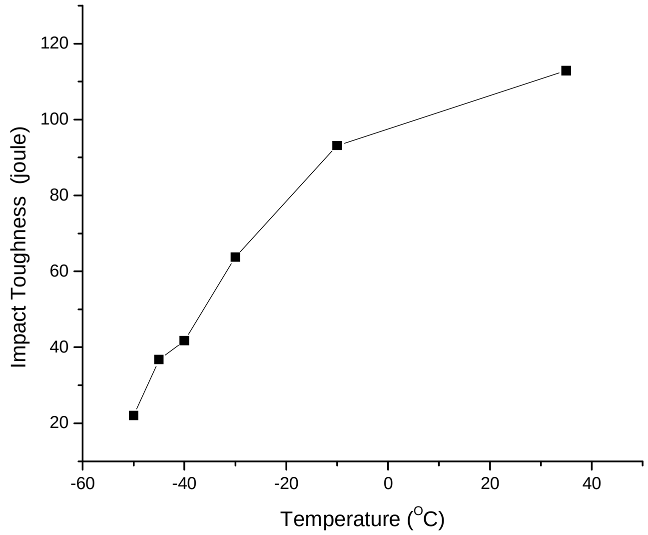


Fig 5.7 (d): Impact Toughness of specimen which weld from welding of flux 4

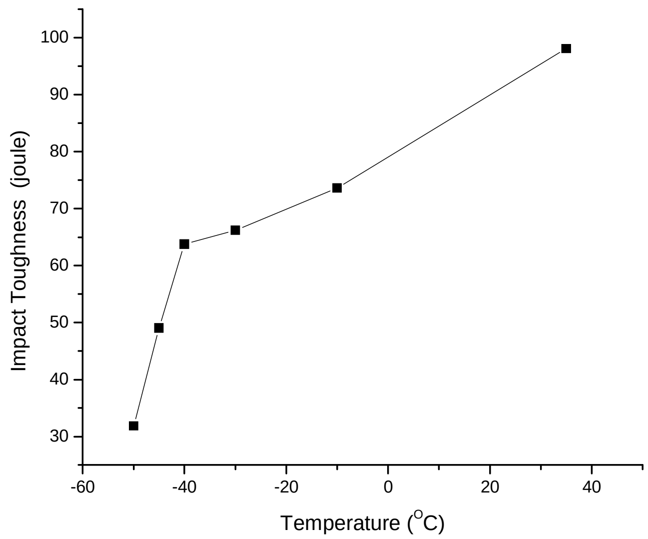


Fig 5.7 (e): Impact Toughness of specimen which weld from welding of flux 5

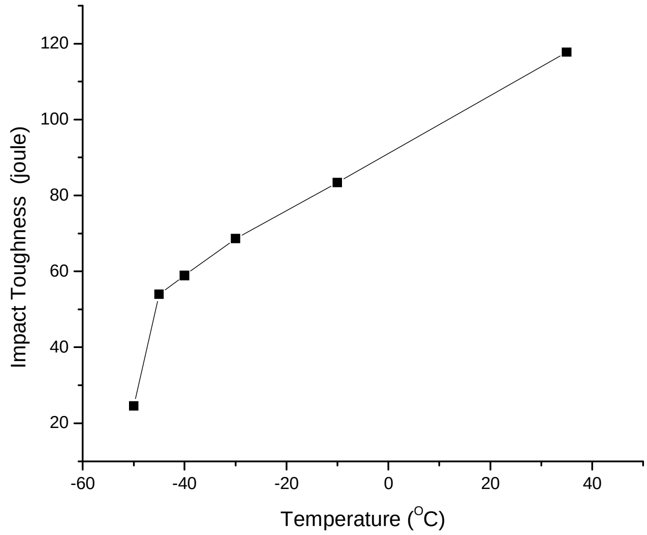


Fig 5.7 (f): Impact Toughness of specimen which weld from welding of flux 6

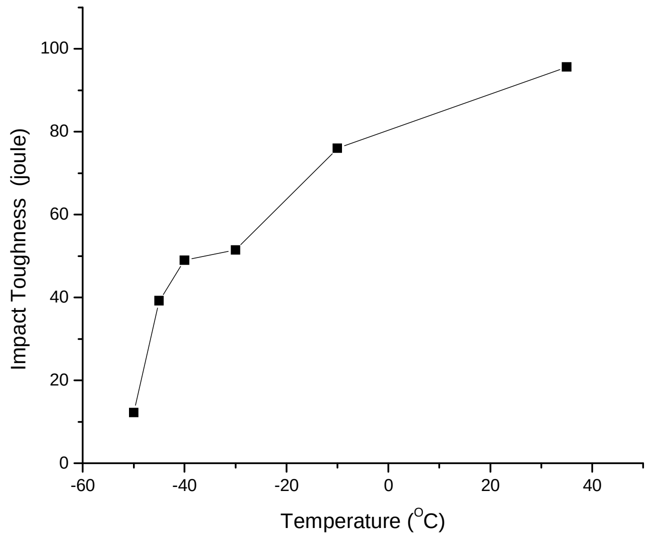


Fig 5.7 (g): Impact Toughness of specimen which weld from welding of flux 7

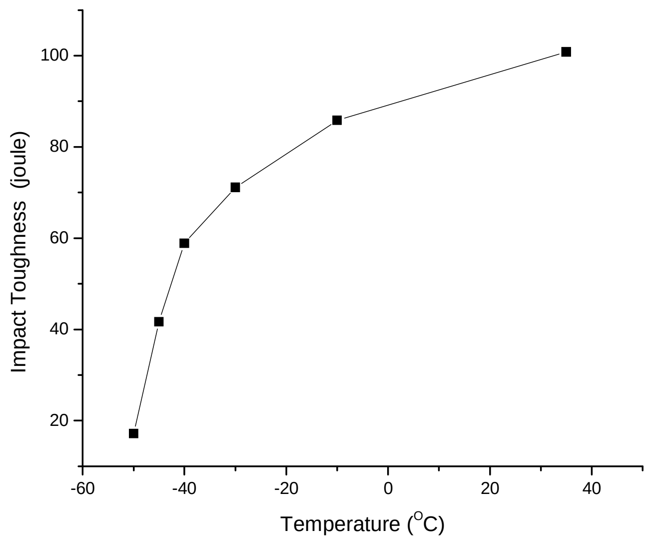


Fig 5.7 (h): Impact Toughness of specimen which weld from welding of flux 8

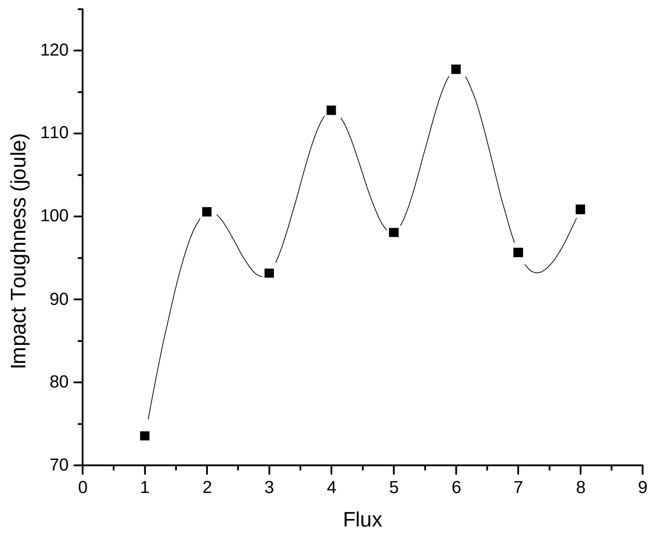


Fig 5.8: Impact Toughness vs flux at room temperature for specimens which weld from welding of different flux

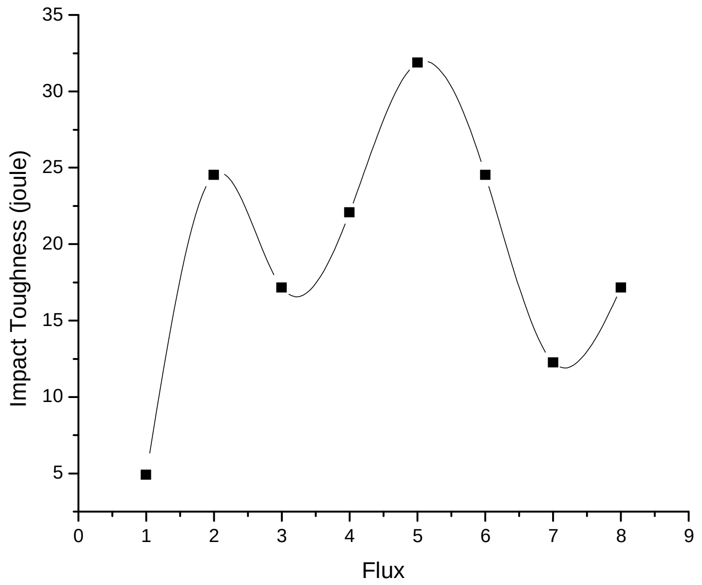


Fig 5.9: Impact Toughness vs flux at -50^{0}C temperature for specimens which weld from welding of different flux

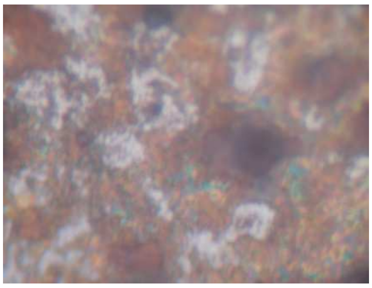
Discussion of Impact Toughness

It is clear from fig 5.8 that the maximum toughness is observed from flux 6. It is concluded that at room temperature flux 6 enhances toughness value.

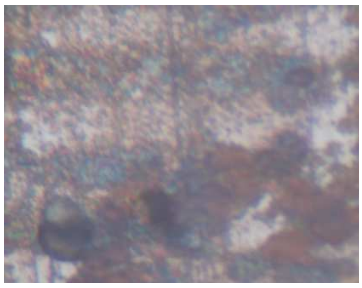
It is clear from fig 5.9 that the maxmium toughness is observed from flux 5. It is concluded that at -50^{0}C temperature flux 5 enhances toughness value.

5.3 Microstucture

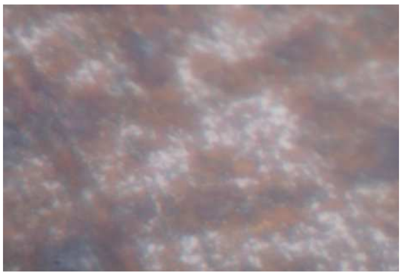
The different types of microstucture shown in below figure 5.10



Weld zone

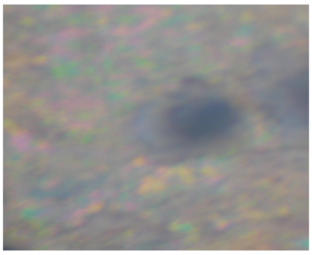
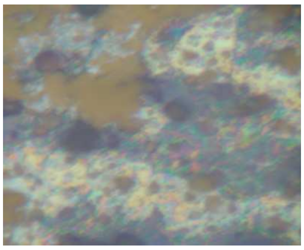


Heat affected zone

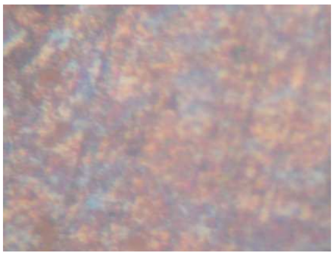


Base material

Fig 5.10 (a): Microscopic structure of sample which is made from using of flux 1 at x400 magnification

Weld zone Heat affected zone



Base material

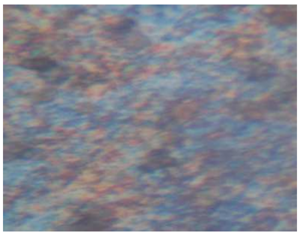
Fig 5.10 (b): Microscopic structure of sample which is made from using of flux 2 at x400 magnification

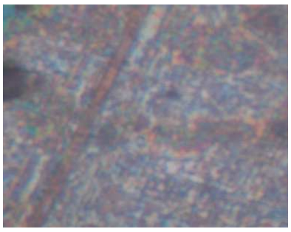
 

Weld zone Heat affected zone

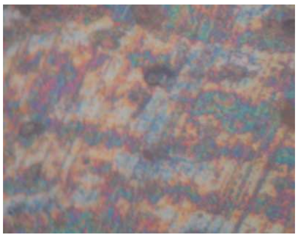
Base material

Fig 5.10 (c): Microscopic structure of sample which is made from using of flux 3 at x400 magnification



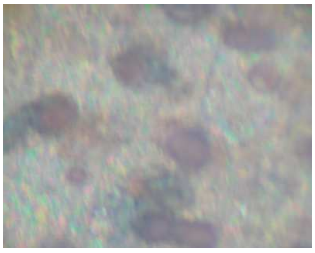


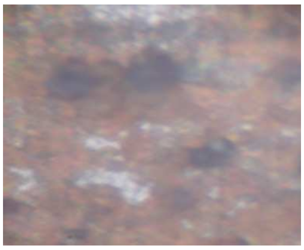
Weld zone Heat affected zone



Base material

Fig 5.10 (d): Microscopic structure of sample which is made from using of flux 4 at x400 magnification

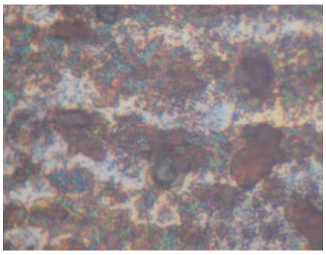
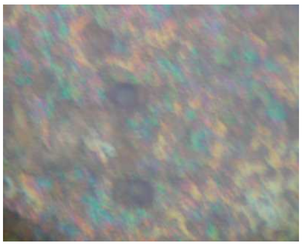




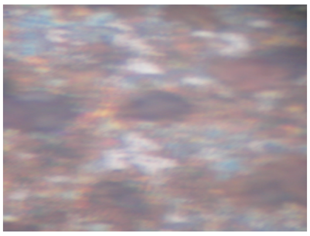
Weld zone Heat affected zone

Base material

Fig 5.10 (e): Microscopic structure of sample which is made from using of flux 5 at x400 magnification

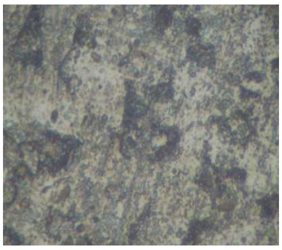
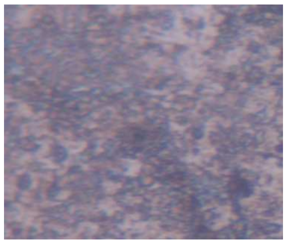



Weld zone   Heat affected zone

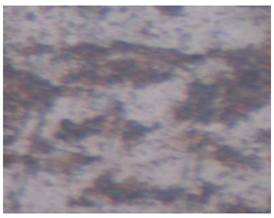


Base material

Fig 5.10 (f): Microscopic structure of sample which is made from using of flux 6 at x400 magnification

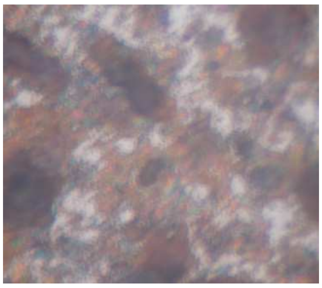
Weld zone   Heat affected zone



Base material

Fig 5.10 (g): Microscopic structure of sample which is made from using of flux 7 at x400 magnification

Weld zone



Heat affected zone

Base material

Fig 5.10 (h): Microscopic structure of sample which is made from using of flux 8 at x400 magnification

Discussion of Microstructure

The microstructure of HSLA base at magnifications of 400X is shown in Figure 5.10. The micro-graph of the figures reveal the presence of typical ferrite (bright)-pearlite (dark) microstructure. The density of flow lines i.e. banding and the morphology of ferrite and pearlite has been found to vary in samples. The microstructure of HSLA base at magnifications of 400X is shown in Figure 5.10.

Weld Metal Two microstructural regions featured by cast dendrite and reheat refined grains as shown in fig 5.10 in the weld region. The reheat refined region closed to the dendritic boundary develops comparatively coarser grain than the size observed in the reheat refined region away from the dendritic boundary of the weld interface. Therefore it can be said that the distribution of the microstructure in the weld consists of three distinctly different microstructural regions, such as the dendritic region at interface, reheat refined coarse grain region and reheat refined fine grain region. The microstructures of the different interface regions of weld metal as revealed in the weld are typically shown in the micrographs presented in Figures 5.10. The distribution of the three different microstructural regions has been found to be similar in all the welds.

The morphologies of the dendritic region at interface, coarse grain reheat refined region in HSLA, HAZ. The studies on these three regions of the welds have been typically shown in all Figures. The micrographs depict that the dendritic region is possibly having lower bainite in combination of some amount of fine pearlite with pro-eutectoid ferrite at the grain boundary shown in fig 5.10. The coarse grain reheat refined region primarily contains pearlite and a mixture of acicular and chunky ferrite in fig 5.10 whereas, the fine grain reheat refined region HSLA HAZ has been found to primarily consists of ferrite and pearlite. The variation in coarseness of the morphology of different welds, as revealed in the weld joints, inherently occurs at different locations of different welds depending upon randomness and heterogeneity in distribution of weld thermal cycle. Thus, it may be concluded that the morphology of the weld prepared varies within a broad range of coarseness as typically marked in the micrographs presented in the Figure 5.10.

5.4 Microhardness Test

Microhardness of different weld made from different types of flux shown in fig 5.11.

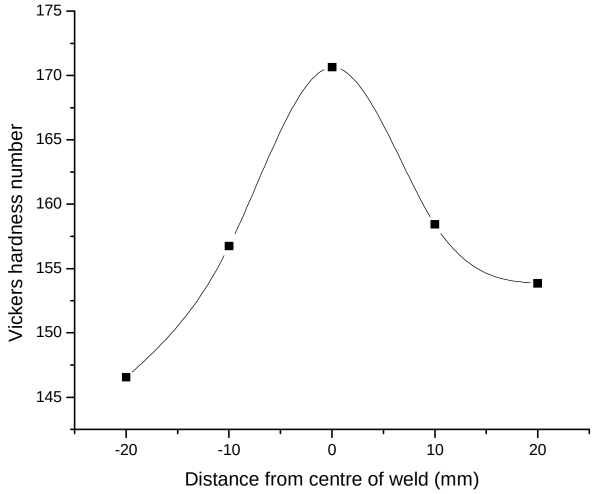


Fig 5.11 (a): Microhardness of specimen which weld from welding of flux 1

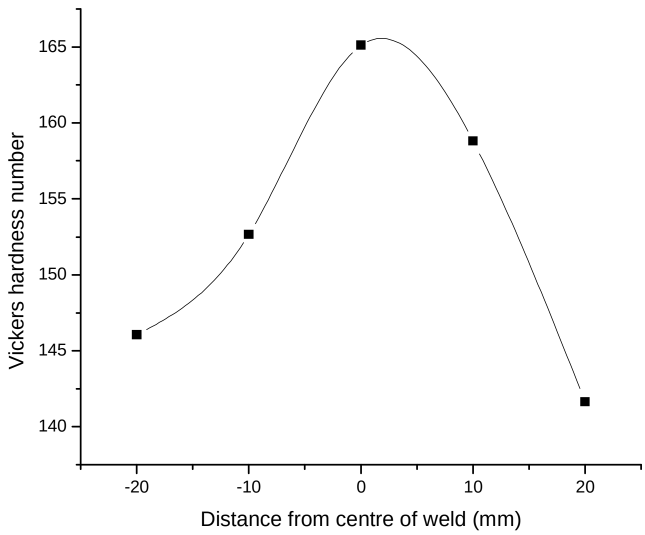


Fig 5.11 (b): Microhardness of specimen which weld from welding of flux 2

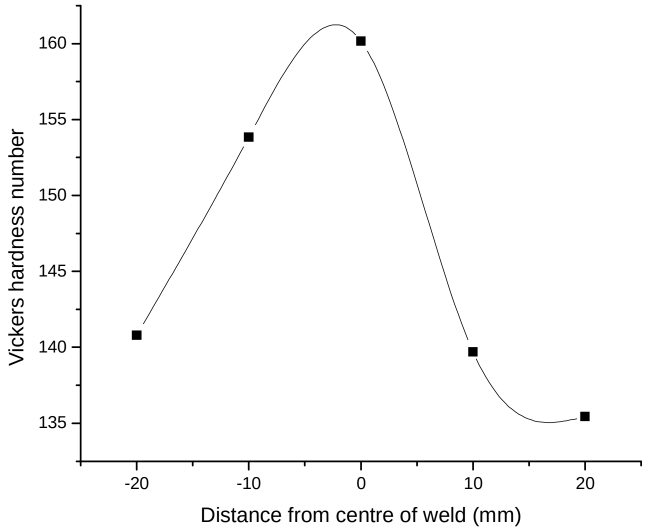


Fig 5.11 (c): Microhardness of specimen which weld from welding of flux 3

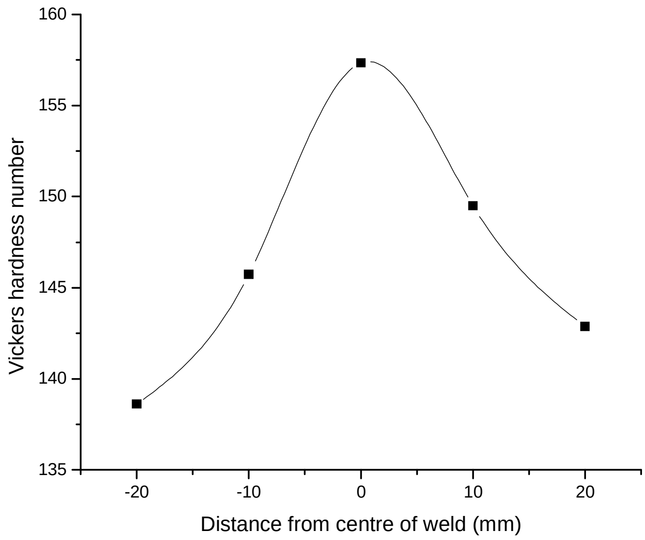


Fig 5.11 (d): Microhardness of specimen which weld from welding of flux 4

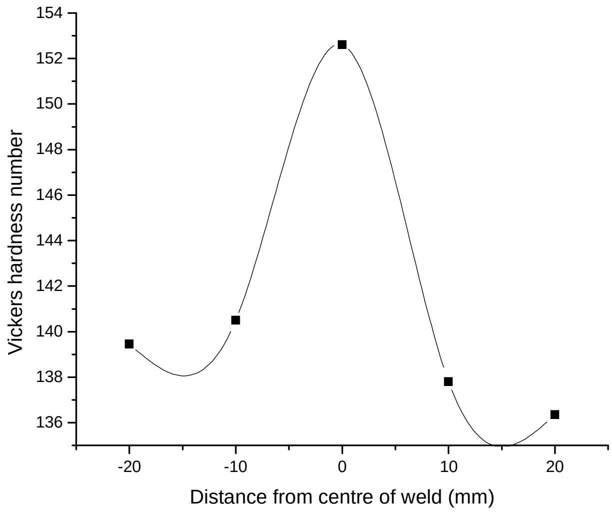


Fig 5.11 (e): Microhardness of specimen which weld from welding of flux 5

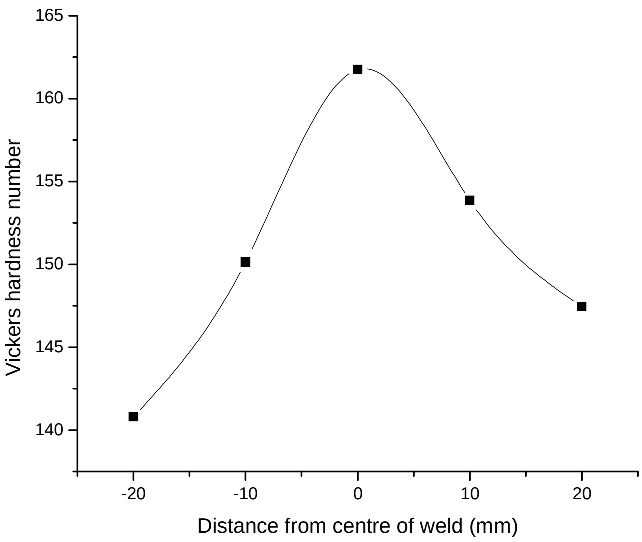


Fig 5.11 (f): Microhardness of specimen which weld from welding of flux 6

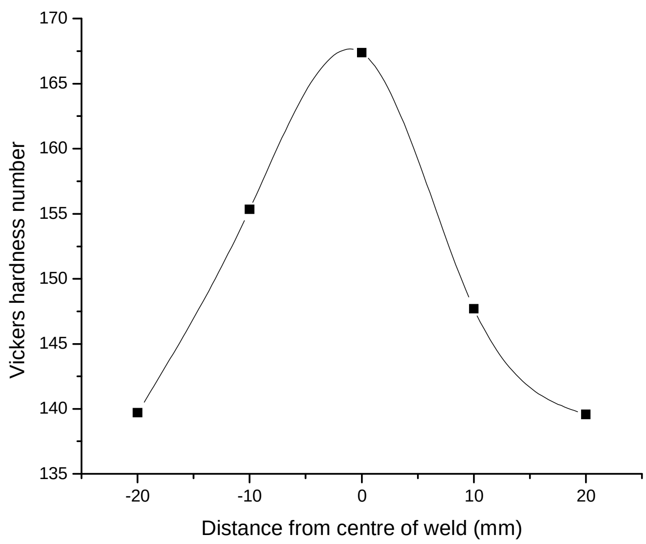


Fig 5.11 (g): Microhardness of specimen which weld from welding of flux 7

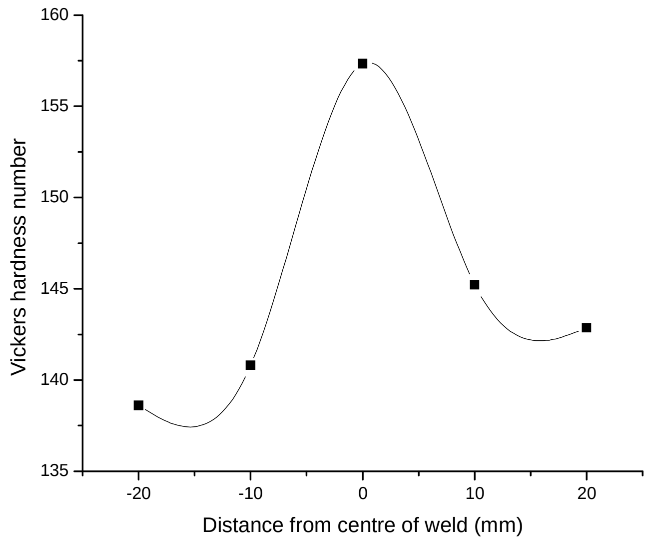


Fig 5.11 (h): Microhardness of specimen which weld from welding of flux 8

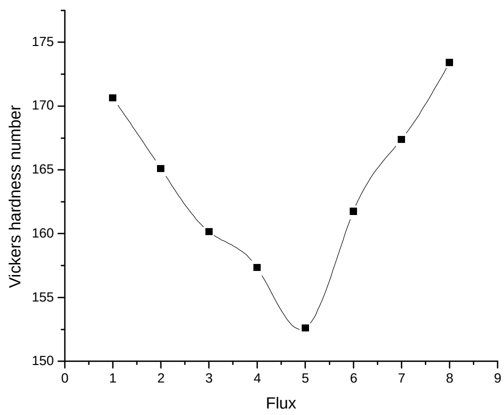


Fig 5.12: Microhardness of welding specimen at centre of weld by using different 8 flux

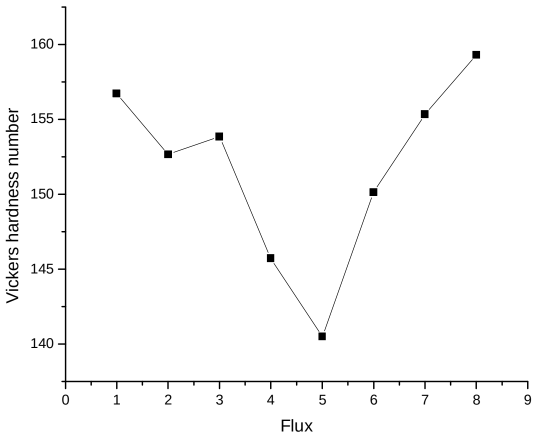


Fig 5.13: Microhardness of welding specimen at HAZ by using different 8 flux

Discussion of Microhardness

It is clear from fig 5.12 that the max. microhardness (vickers hardness number) in weld centre is observed from flux 8.

It is clear from fig 5.13 that the max. microhardness (vickers hardness number) in HAZ is observed from flux 8.

5.5 Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) of different test piece shown in fig 5.14, 5.15.

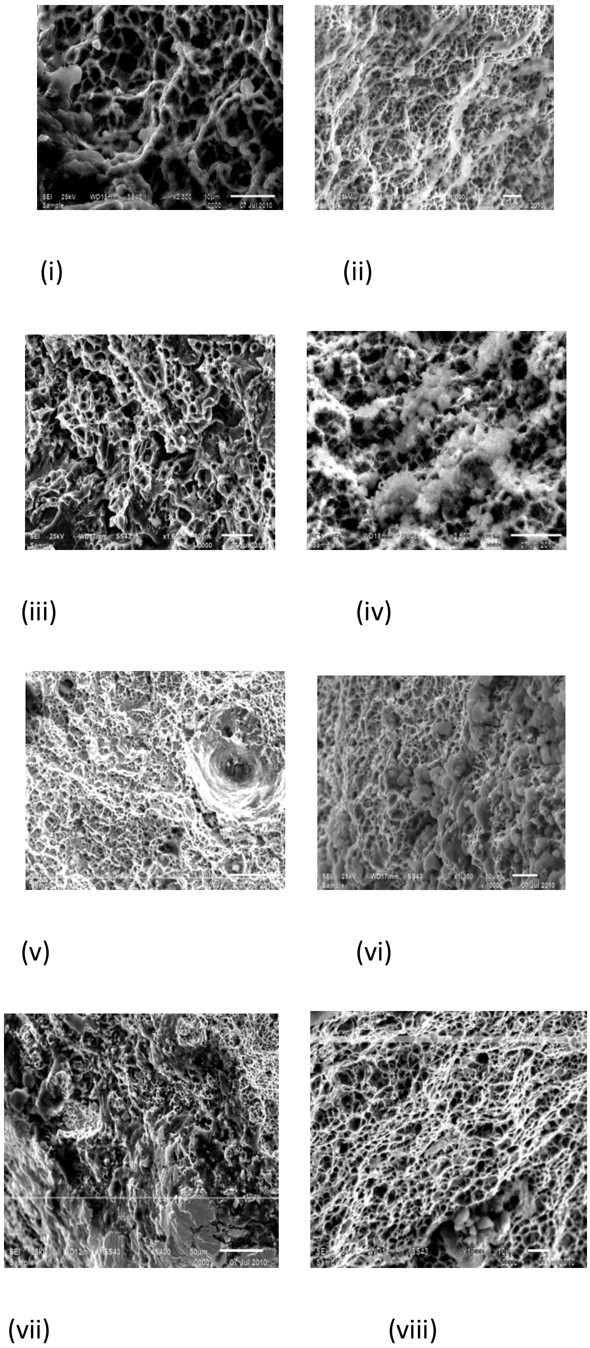
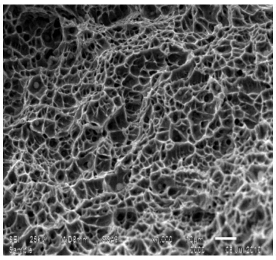
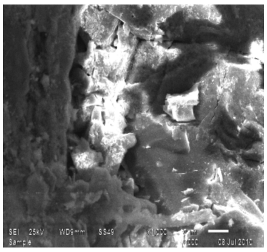
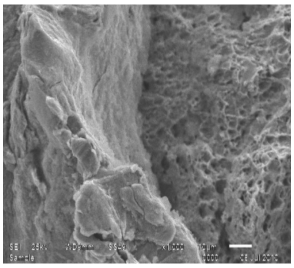


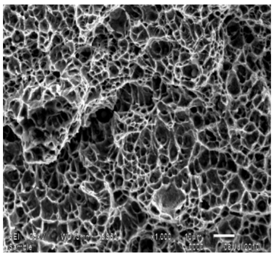
Fig 5.14: SEM measurement at x1000 magification for specimen after breakage of tensile test which weld from by using weling flux (i), (ii), (iii), (iv), (v), (vi), (vii), (viii)



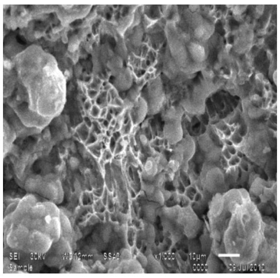


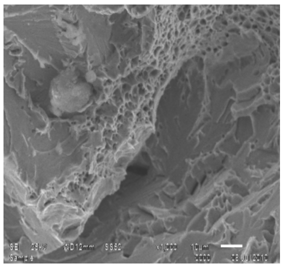
(i) (ii)



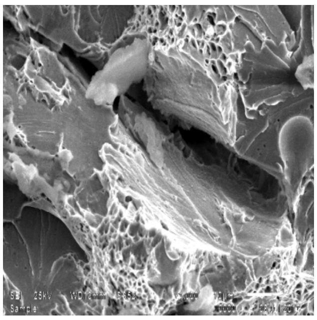


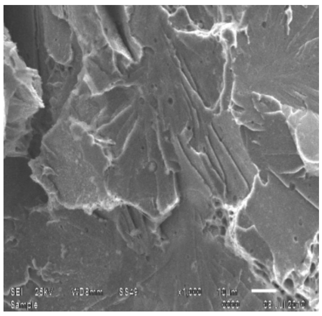
(iii) (iv)





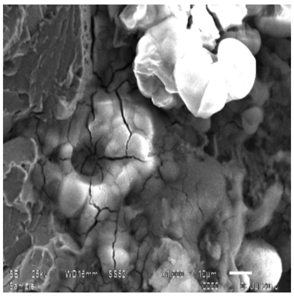
(v) (vi)

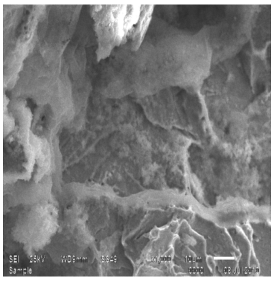




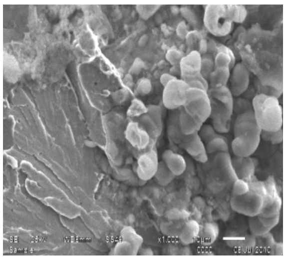
(vii) (viii)

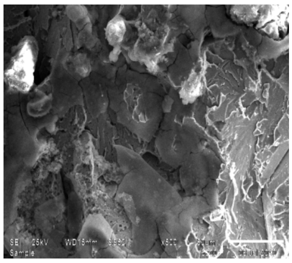
Fig 5.15: SEM measurement at x1000 magification for specimen after breakage of toughness at room temperature which weld from weling flux (i), (ii), (iii), (iv), (v), (vi), (vii), (viii)



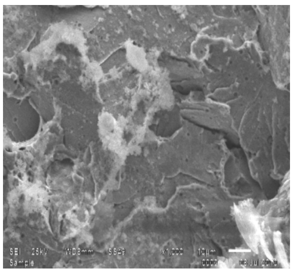


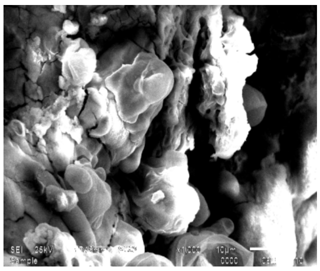
(i) (ii)



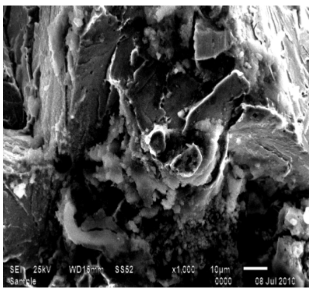


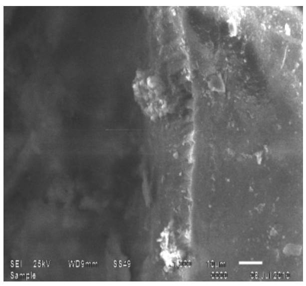
(iii) (iv)





(v) (vi)





(vii) (viii)

Fig 5.16: SEM measurement for specimen after breakage of toughness at -50 ^{0}C temperature which weld from weling flux (i), (ii), (iii), (iv), (v), (vi), (vii), (viii)

Discussion of Microstructure

As we can see from fig 5.14, 5.15 that at room temperature in tensile and Impact toughness specimen there are dimples present in the matrix in the SEM so, it is ductile fracture and toughness at -50^{0}C there is cleavage present in fig 5.16 which indicates brittle fracture.

5.6 X-Ray diffraction

X- ray diffraction patterns of slag shown in fig 5.17

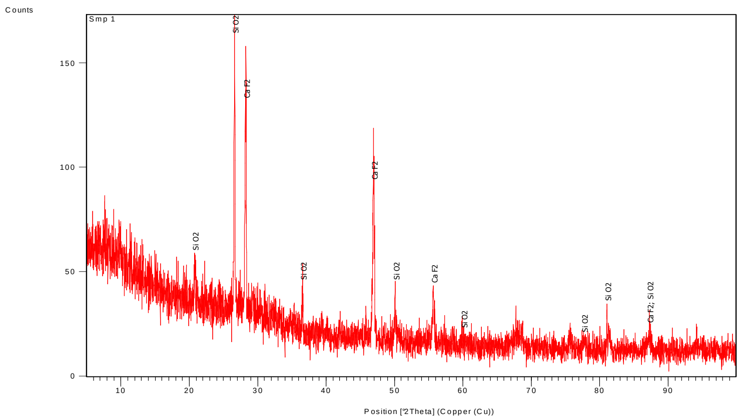


Fig 5.17 (a): X- ray diffraction patterns of slag 1

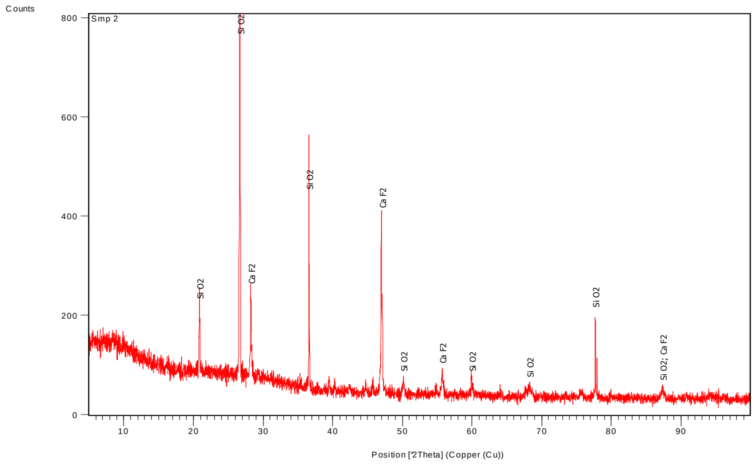


Fig 5.17 (b): X- ray diffraction patterns of slag 2

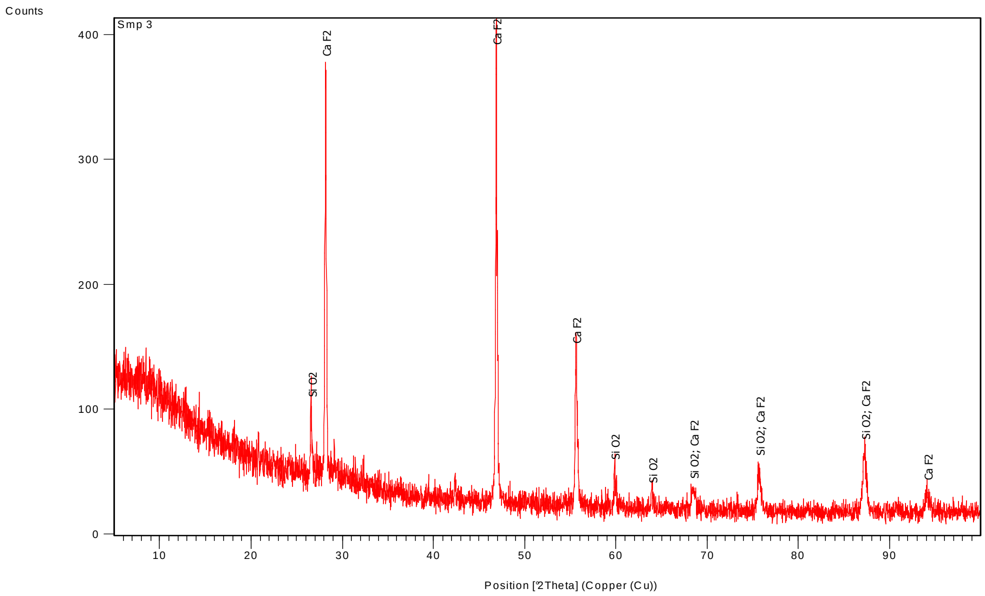


Fig 5.17 (c): X- ray diffraction patterns of slag 3

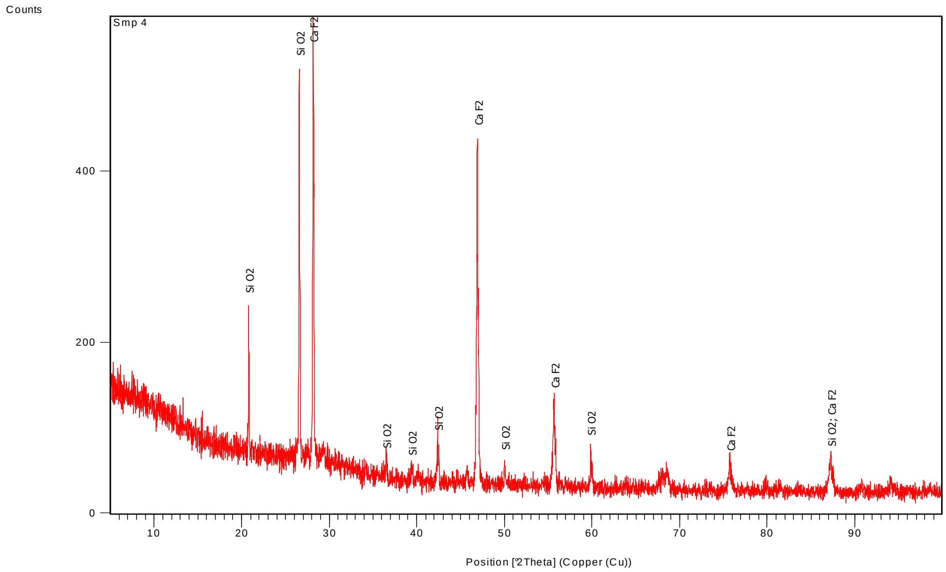


Fig 5.17 (d): X- ray diffraction patterns of slag 4

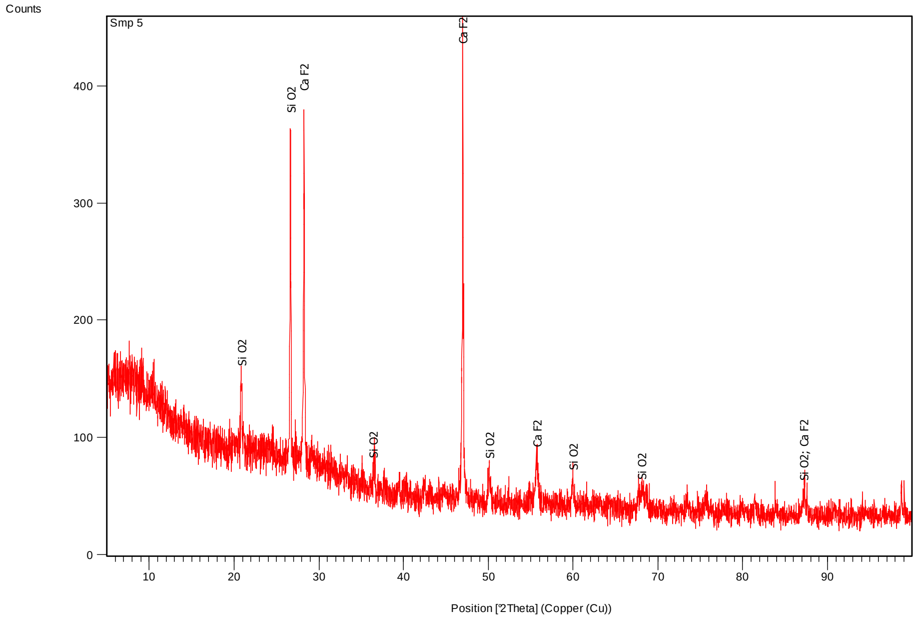


Fig 5.17 (e): X- ray diffraction patterns of slag 5

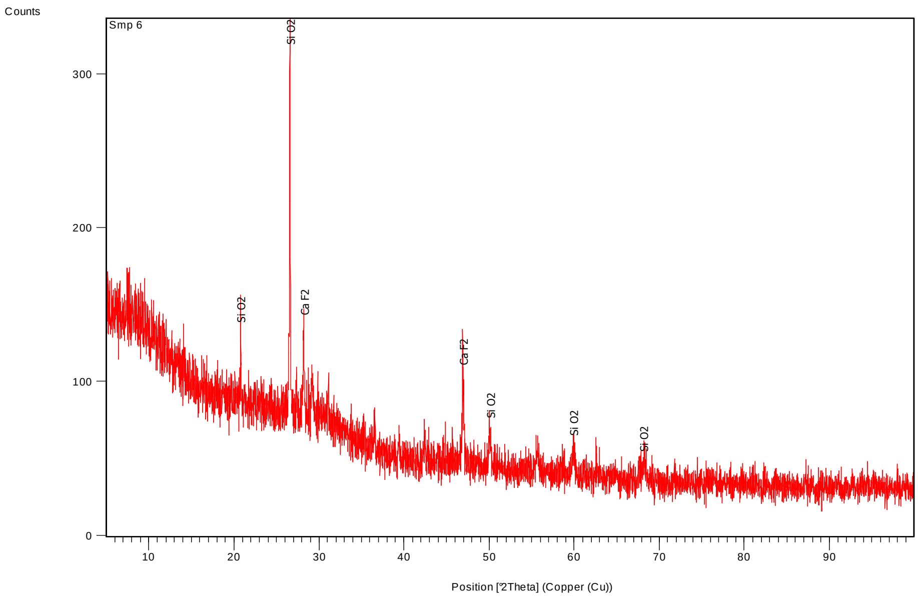


Fig 5.17 (f): X- ray diffraction patterns of slag 6

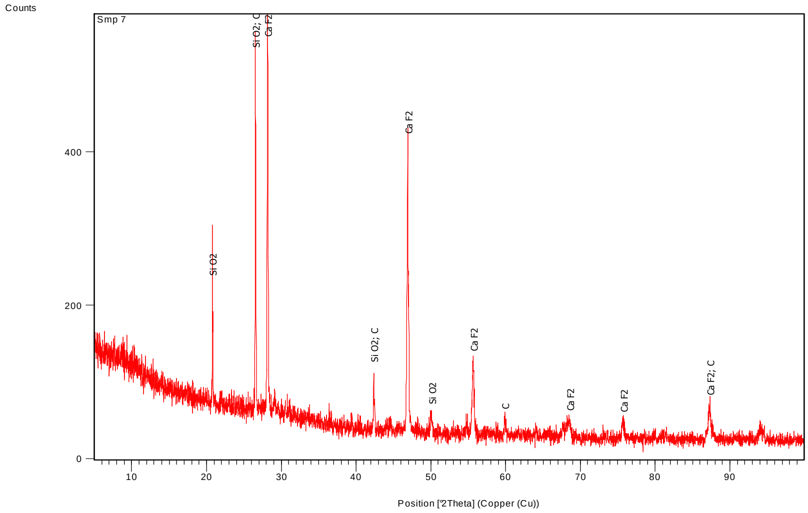


Fig 5.17 (g): X- ray diffraction patterns of slag 7

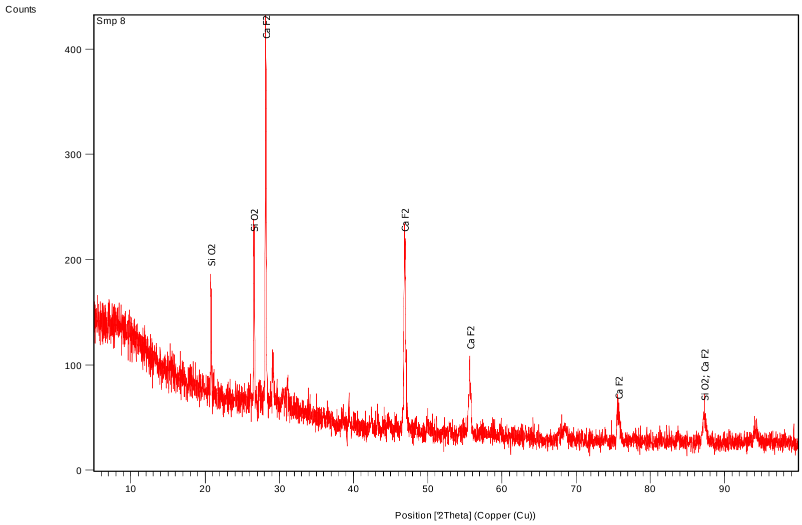


Fig 5.17 (h): X- ray diffraction patterns of slag 8

Discussion of XRD pattern of slag

It is clear from fig 5.17 that only two compound SiO_2 and CaF_2 remained in slag and all other compounds of flux burnt out during welding of HSLA steel. Only one peak of carbon present in slag 7.

5.7 Chemical composition of weld metal

The specimen after composition of weld shown in fig 5.18.

Fig 5.18: Specimen after checking composition

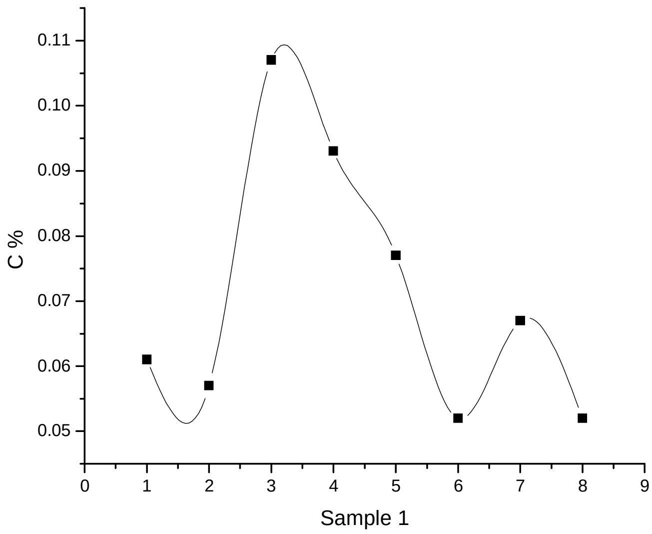


Fig 5.19 (a): %age composition of carbon in weld centre

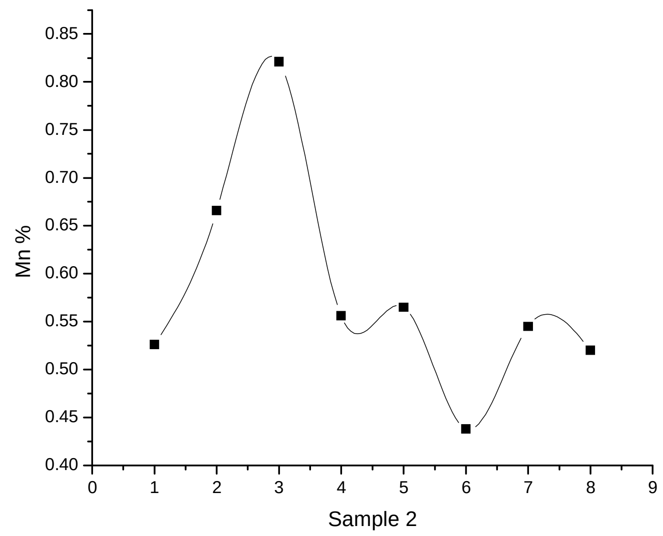


Fig 5.19 (b): %age composition of manganese in weld centre

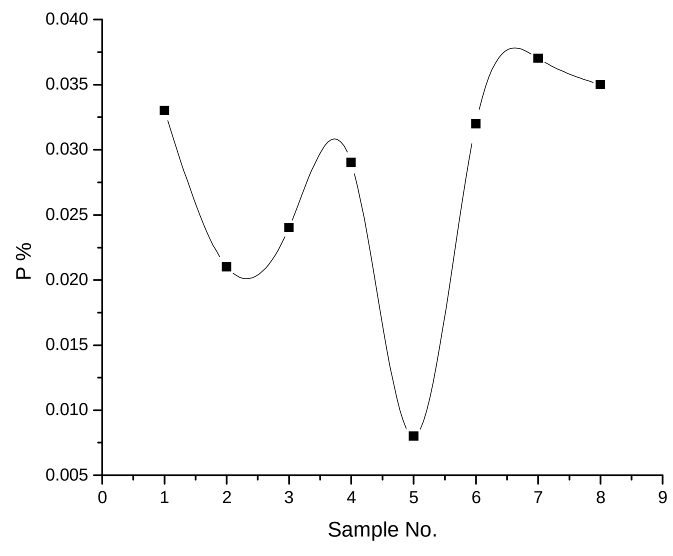


Fig 5.19 (c): %age composition of phosphorus in weld centre

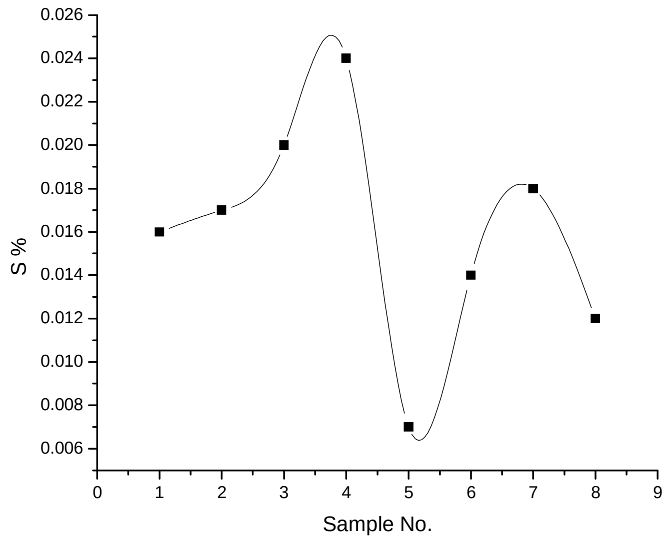


Fig 5.19 (d): %age composition of sulphur in weld centre

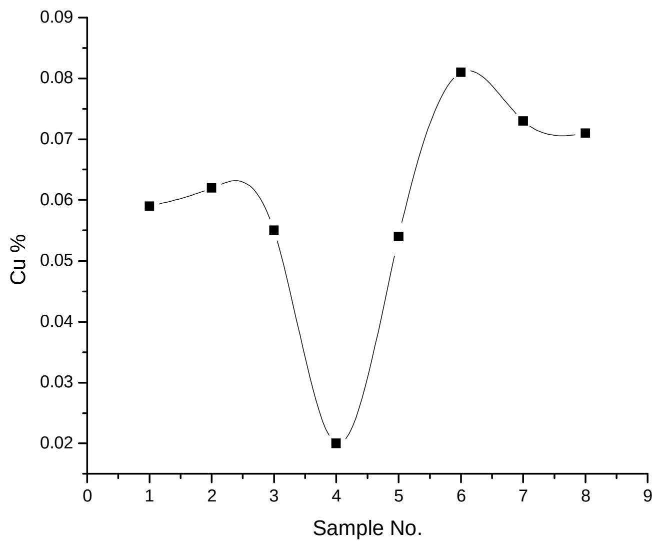


Fig 5.19 (e): %age composition of copper in weld centre

Table 5.4 Percentage change in chemical compostion

Flux	Carbon	Carbon in electrode	% change in Carbon	Manganese	Manganese in electrode	% change in Manganese
1	0.061	0.05	22	0.526	0.1	426
2	0.057	0.05	14	0.666	0.1	566
3	0.107	0.05	114	0.821	0.1	721
4	0.093	0.05	86	0.556	0.1	456
5	0.077	0.05	54	0.565	0.1	465
6	0.052	0.05	4	0.438	0.1	338
7	0.067	0.05	34	0.545	0.1	445
8	0.052	0.05	4	0.52	0.1	420

Flux	Phosphours	Phosphours in Electrode	% change in Phosphours	Sulphur	Sulphur in Electrode	% change in Sulphur
1	0.033	0.01	230	0.016	0.02	-20
2	0.021	0.01	110	0.017	0.02	-15
3	0.024	0.01	140	0.02	0.02	0
4	0.029	0.01	190	0.024	0.02	20
5	0.008	0.01	-20	0.007	0.02	-65
6	0.032	0.01	220	0.014	0.02	-30
7	0.037	0.01	270	0.018	0.02	-10
8	0.035	0.01	250	0.012	0.02	-40

Flux	Copper	Copper in electrode	% change in Copper
1	0.06	0.09	-34.44444444
2	0.06	0.09	-31.11111111
3	0.06	0.09	-38.88888889
4	0.02	0.09	-77.77777778
5	0.05	0.09	-40
6	0.08	0.09	-10
7	0.07	0.09	-18.88888889
8	0.07	0.09	-21.11111111

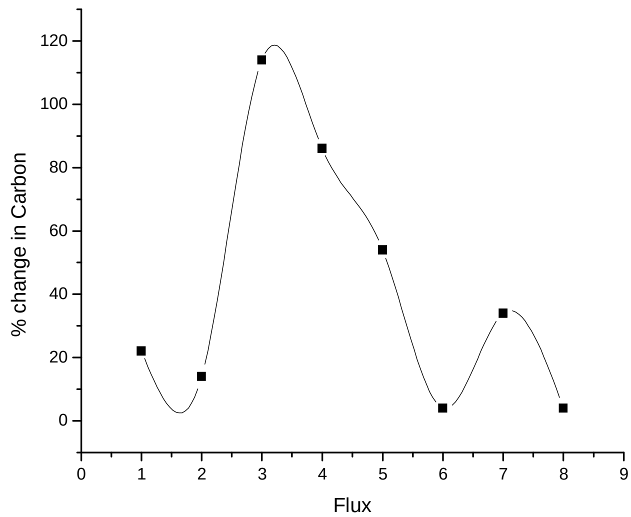


Fig 5.20 (a): Percentage change in composition of carbon in weld centre

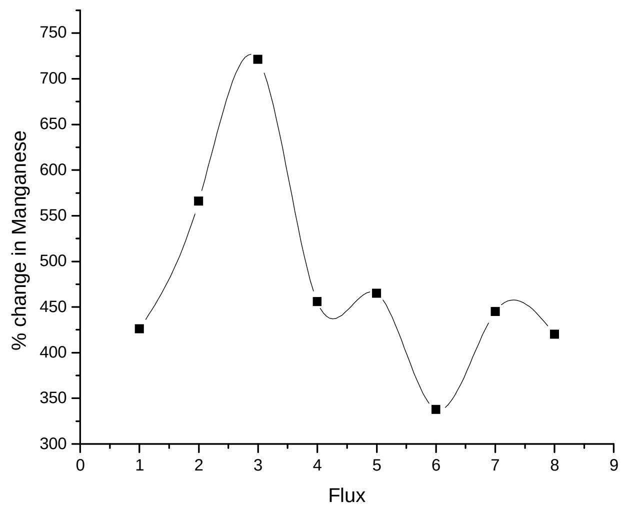


Fig 5.20 (b): Percentage change in composition of manganese in weld centre

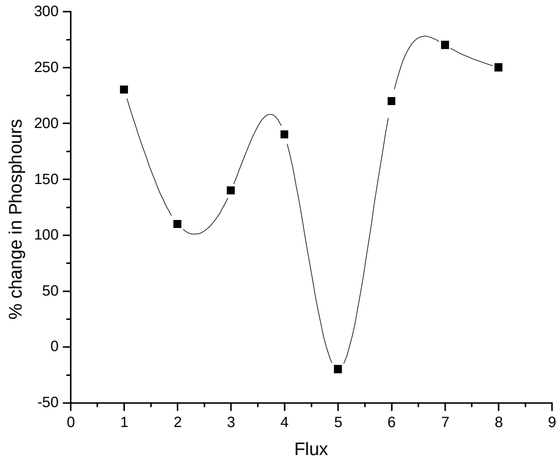


Fig 5.20 (c): Percentage change in composition of phosphours in weld centre

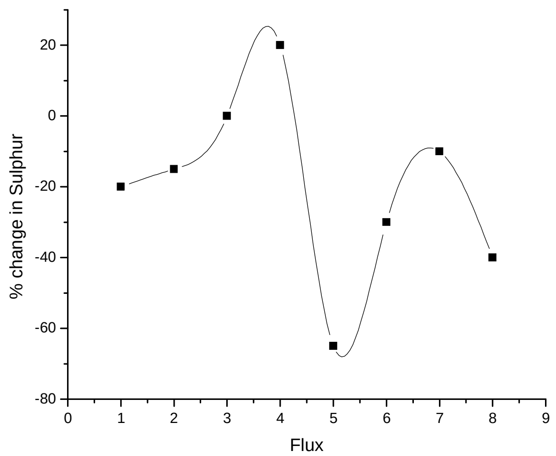


Fig 5.20 (d): Percentage change in composition of sulphur in weld centre

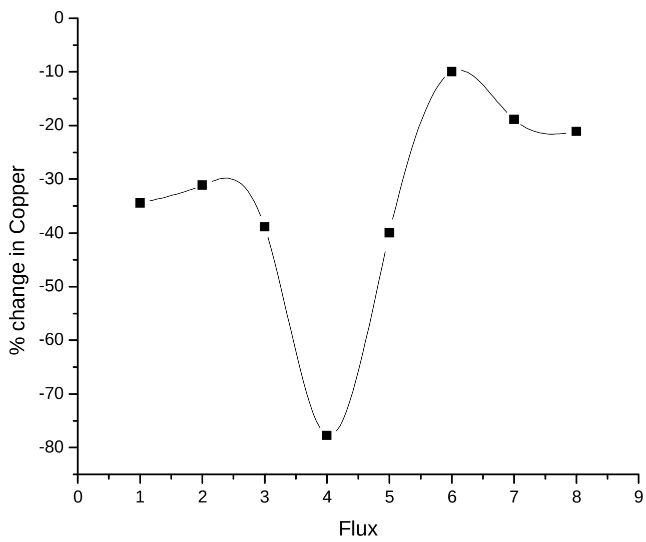


Fig 5.20 (e): Percentage change in composition of copper in weld centre

Discussion of Chemical compsition

It is clear from fig 5.20 that percentage change in carbon, manganese, sulphur contents are increasing in weld resion but the sulphur and copper contents are decreasing. So, it is conclude that some compounds of flux goes to the weld region.

Chapter 6 CONCLUSION & FUTURE SCOPE

The present study was carried out to study the effect of flux on the welding characterstics in the submerged arc welding by keeping all other variable keeping constant like current, voltage and welding speed.

1) Development of fluxes for submerged arc welding of high strength low alloy steel successively.
2) The Ultimate Tensile Strength values were also satisfactory for all the weld joints.
3) The Impact toughness value at room temperature increase with increase in basicity index of flux and at -50^0C the same pattern is followed.
4) Microstructure evaluation of the welded joints revealed different zones namely, Reheat refined coarse grain region of HAZ.
5) Highest micro hardness values are formed at the weld joint regions for welded specimens.
6) XRD pattern shows only two compound SiO_2 and CaF_2 remained in slag and all other compounds of flux burnt out during welding of HSLA steel.

In addition to the present work further work can be done in following directions:

1) Different fluxes can be made for different material.
2) CaF_2 can be replaced by NaF when manufacturing of flux.
3) Modeling of submerged arc welding process can be carried out using Finite Element packages.
4) Fatigue and corrosion properties can be measured and correlated with different submerged arc welding parameters.
5) 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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