DESIGN AND DEVELOPMENT OF ELECTRODE COATING FOR HARDFACING APPLICATION

A Thesis

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

MASTER OF ENGINEERING
IN
PRODUCTION & INDUSTRIAL

Submitted By:
KARANPREET SINGH
Roll No. 800982009

Under the Guidance

Mr. Kishore Khanna
Assistant Professor
Deptt. of Mechanical Engg.
Thapar University, Patiala

Mr. Yogesh Kumar Singla
Lecturer
Deptt. of Mechanical Engg.
Thapar University, Patiala

DEPARTMENT OF MECHANICAL ENGINEERING
THAPAR UNIVERSITY
PATIALA-147004, INDIA
July 2011

CERTIFICATE

This is to certify that the work done in this thesis report titled **"DESIGN AND DEVELOPMENT OF ELECTRODE COATING FOR HARDFACING APPLICATION"** submitted in partial fulfilment of requirement for the award of Master of Engineering degree in Production and Industrial Engineering in the Mechanical Department of Thapar University, Patiala is an authentic record of work carried out by me under the guidance of Mr.Kishore Khanna, Assistant Professor and Mr. Yogesh Kumar Singla, Lecturer, 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.

Karanpreet Singh

(Karanpreet Singh)

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

Mr. Kishore Khanna
Assistant Professor
Deptt. of Mechanical Engg.
Thapar University, Patiala

Mr. Yogesh Kumar Singla
Lecturer
Deptt. of Mechanical Engg.
Thapar University, Patiala

Countersigned by:

Dr. Ajay Batish
Professor & HOD
Deptt. of Mechanical Engg.
Thapar University, Patiala

Dr. S.K. Mohapatra
Dean,
Acadamic Affairs
Thapar University, Patiala

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 ***Mr. Kishore Khanna and Mr. Yogesh Kumar Singla*** *for his keen interest and valuable guidance, strong motivation and constant encouragement during the course of the work. I thank them 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 department ***Dr. Ajay Batish****, whose excellent leadership and administration made this research project very convenient in term of required stuff and nice working condition. I am extremely thankful to member of distinguished faculty.*

The non teaching staff ***Mr. Surender Singh, Mr. Rath, Mr. Surender Suri, Mr. Rajender, Mr. A. S. Cheema, Mr. Kuldeep, Mr. Purushotam, Mr. Narender, Mr.Sukhbir*** *deserve special thanks for their 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, and Patiala for their l support.*

Some friends were never too busy to give me a hand whenever they were needed. No words acknowledge the support I received from ***Ramandeep Singh Saini, Rajdeep Singh, Sorav Sharma, Lochan Sharma, Manjot Singh Cheema, Dhiman John*** *for their valorous help and co-operation. Last but not the least, I would like to thank my* ***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 endeavour.*

Karanpreet Singh

ABSTRACT

Hardfacing by welding is the most economic way to enhance the life of the components which are exposed to environment. The use of hardfacing is increasing rapidly because of the increasing costs of the components. From the literature survey, it has been found that, the experiments were performed to study the microstructure, hardness and wear behaviour of commonly available commercial hard facing alloys and their suitability for a specific application. Studies were also done to see the effect of certain additional elements on specific properties. Understanding the mechanism of wear resistance of these alloys can help customers to select an appropriate alloy for a specific application. Data created through this study will be of much use in selection of hard facing alloys. Six types of ferrochrome based hardfacing electrodes were selected to deposit layers, by the manual metal arc welding process on Low alloy steel plate. In this study, the wear responses, hardness and the microstructures were studied. Low alloy steel specimens of size 265x125x12mm were used for depositing the hardfacing layers. Further, for the various wear tests the cylindrical sample of 8mm diameter and 30mm length was made. Wear tests were carried out an a sliding wear testing machine. Microstructure characterization analysis were made using Scanning Electron Microscopy. The comparison in the wear response of hardfaced plate with the bare low alloy steel plate was also made in actual working conditions.

CONTENTS

LIST OF TABLE

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

1.1 WELDING

Welding is a process of permanent joining of two materials (usually metals) through localised coalescence resulting from a suitable combination of temperature, pressure and metallurgical conditions. Depending upon the combination of temperature and pressure from a high temperature with no pressure to a high pressure with low temperature, a wide range of welding processes has been developed.While there are many methods for joining metals, welding is one of the most convenient and rapid methods available. The term welding refers to the process of joining metals by heating them to their melting temperature and causing the molten metal to flow together. These range from simple steel brackets to nuclear reactors. Welding, like any skilled trade, is broad in scope and one cannot become a welder simply by reading a book. One need practice and experience as well as patience; however, much can be gained through study. For instance, by learning the correct method or procedure for accomplishing a job from a book, you may eliminate many mistakes that otherwise would occur through trial and error. Welding is not new. The earliest known form of welding, called forge welding, dates back to the year 2000 B.C. Forge welding is a primitive process of joining metals by heating and hammering until the metals are fused (mixed) together. Although forge welding still exists, it is mainly limited to the blacksmith trade. [1]

Fig. 1.1 Welding Process [1]

Welding is the joining of metals. What welding does is join metals or other materials at their molecular level with the technology we have at the moment. Welding technology is always changing, and with so many military forces relying on it to make their defense products, there are welding processes we are yet to hear about. What we know about modern welding is that there are four components to a weld. The four components are the metals themselves, a heat source, filler material, and some kind of shield from the air. The welding process works like this. The metal gets heated to its melting point, at the same time there is some sort of shielding from the air to protecting it, and then a filler metal is added to the area that needs to be joined ultimately producing a single piece of metal.[1]

1.1.1 Classification of Welding Processes

Various welding processes differ in the manner in which temperature and pressure are combined and achieved. The following are the classification of welding processes:

1. Gas Welding
❖ Oxyacetylene
❖ Oxy hydrogen
2. Arc Welding
❖ Carbon Arc
❖ Metal Arc
❖ Submerged Arc
❖ Inert-gas-Welding
❖ TIG and MIG
❖ Plasma Arc
❖ Electro-slag
3. Resistance Welding
❖ Spot
❖ Seam
❖ Projection
❖ Butt Welding
❖ Induction Welding
s4. Solid State Welding
❖ Friction Welding

❖ Ultrasonic Welding

❖ Explosive Welding

❖ Forge and Diffusion Welding

5. Thermo-chemical Welding

❖ Thermit Welding

❖ Atomic H_2 Welding

6. Radiant Energy Welding

❖ Electron Beam Welding

❖ Laser Beam Welding

In order to obtain coalescence between two metals there must be a combination of proximity and activity between the molecules of the pieces being joined, sufficient to cause the formation of common metallic crystals.

Proximity and activity can be increased by plastic deformation (solid-state-welding) or by melting the two surfaces so that fusion occurs (fusion welding). In solid-state-welding the surfaces to be joined are mechanically or chemically cleaned prior to welding while in fusion welding the contaminants are removed from the molten pool by the use of fluxes. In vacuum or in outer space the removal of contaminant layer is quite easy and welds are formed under light pressure.

1.1.2 Conditions for Obtaining Satisfactory Welds

The following are the conditions for satisfactory welds:

- Source of energy to create union by fusion or pressure
- Method for removing surface contaminants
- Method for protecting metal from atmospheric contamination
- Control of weld metallurgy[2]

1.2 HISTORY OF MANUAL METAL ARC WELDING

Shielded metal arc welding is one of the most versatile joining processes in industry and it is extensively used in the world over. Manual arc was first described by Davy in England in the year

1809, but the beginning of arc welding could become possible only with the improvements in electric dynamos or generators between 1877 and 1880. The joining of metals, using a carbon arc was suggested by Moissan (a Frenchman) in 1881, but it was only between 1885 and 1887 when, in Russia, Bernard’s and Olszewski got patented and used single carbon arc welding for joining metals. In 1889 Serener processed an idea, which aided later on to develop Twin Carbon arc welding.

In 1892, in Germany, N.G. Slavianoff proposed the use of bare wire metallic electrodes for joining metals. The arc being unshielded in this case, satisfactory welds could not be produced. In 1907, in Sweden, Oscar Kjellberg got a patent for covered electrodes. The coating which he employed contained only arc stabilizing materials, and thus a good welded joint was not obtained.

In 1912, in USA Strohmenger obtained another patent on covered electrodes and the first good welded joint was produced. Strohmenger used a coating of blue asbestos with sodium silicate as a binder. Since then a lot of changes and developments have occurred as regards the constituents of flux coating and core wire compositions. Covered electrodes were commercialized in the year 1929.

Arc and molten pool shielding, with an inert gas (CO_2) was ad vented by Alexander in USA in the year 1928 and the patent for TIG welding was received by Hobart and Devers in 1930 in USA. First gas tungsten arc spot welding torch based upon TIG welding was introduced around 1946. Metal Inert Gas (MIG) welding came out in 1948 as a result of further researches and developments carried out on Covered Electrode Metal Arc and Tungsten Inert Gas welding processes. The atomic hydrogen welding was developed on the basis of the research carried out by Langmuir (1921, USA) on the dissociation of diatomic molecule in electric arc. Stud welding was found by Martin in 1918 and was used in British (Royal). [1]

1.3 MANUAL METAL ARC WELDING

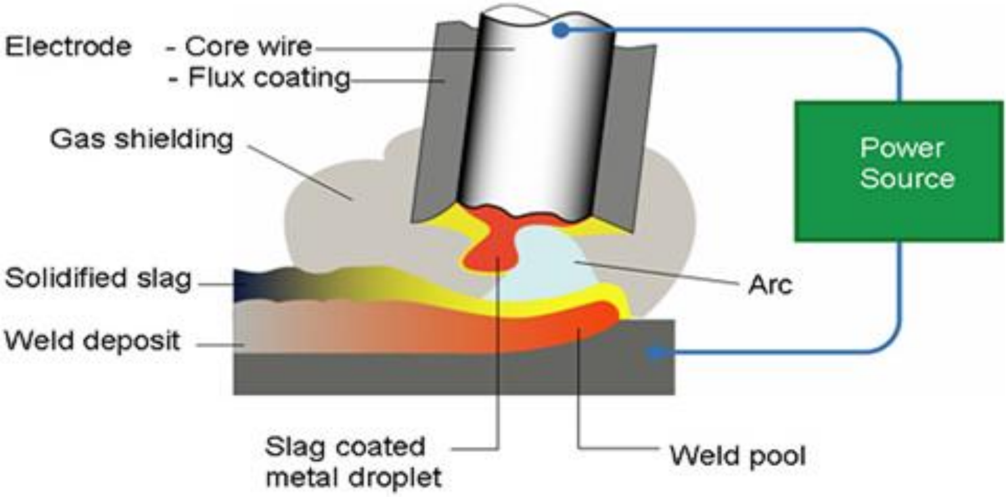


Fig. 1.2 Manual Metal Arc Welding Process [2]

In this process an arc is drawn between a coated consumable electrode and the work piece. The metallic core-wire is melted by the arc and is transferred to the weld pool as molten drops. The electrode coating also melts to form a gas shield around the arc and the weld pool as well as slag on the surface of the weld pool, thus protecting the cooling weld pool from the atmosphere. The slag must be removed after each layer. Manual Metal Arc welding is still a widely used hardfacing process. Due to the low cost of the equipment, the low operating costs of the process and the ease of transporting the equipment, this flexible process is ideally suited to repair work.

Shielded metal arc welding (SMAW), also known as manual metal arc (MMA) welding or informally as stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapours that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination. [1]

Because of the versatility of the process and the simplicity of its equipment and operation, shielded metal arc welding is one of the world's most popular welding processes. It dominates other welding processes in the maintenance and repair industry, and though flux-cored arc welding is growing in popularity, SMAW continues to be used extensively in the construction of steel structures and in industrial fabrication. The process is used primarily to weld iron and steels (including stainless steel) but aluminium, nickel and copper alloys can also be welded with this method.[1]

1.3.1 Variants of SMAW Process

The standard SMAW process is carried out with coated electrodes having diameter between 2.5 to 6.3 mm; using short to medium arc lengths. However, there are few variants of processes, typical ones of which included:

a. Touch electrode welding
b. Bunched electrode welding
c. Multi arc welding
d. Massive electrode welding

(a) Touch Electrode Welding

Touched electrode welding is comparatively a newer technique which helps in improving both the production rate and welding quality.

In touch electrode welding the arc is struck the usual way but as soon as a stable arc is established the electrode is pushed down towards the work piece so that the coating touches it. The electrode is then moved on the intended path while coating remains continuously in touch with the work piece. The electrode is tilled 10^0 to 15^0 from the vertical in the direction of welding.

The success of this welding is based on the fact that the rate of melting of the coating material is lower than that of core wire. This provides a barrel of coating around the arc and the material is transferred the protected passage. The arc length can be manipulated by the pressure exerted on the electrode. Touch electrode welding gives deeper penetration than achieved by the conventional method; this is due to concentration of heat within the small area bounded by the un burnt lip of coating. Touch welding is applicable to down hand single layer butt and fillet welds. This method can be used for multi-run welds but with reduced efficiency.[2]

(b) Bunched Electrode Welding

Welding with electrodes is employed to enhance the rate of metal deposition. Two to six electrodes may be bunched with fine wire at three or four places along their lengths and tack welded at the top be held in specially holders. Though the current is conducted through all the electrodes in the bunch but the arc is established between the work and the nearest electrode. The arc stays on that electrode till the arc length is too long to sustain itself and meanwhile another electrode has travelled much closer to the weld pool surface. The arc, therefore, jumps to the electrode with the least gap between it and the work, and the process is repeated. Thus, the arc jumps from one electrode to another at regular intervals. With bunching of two electrodes the production rate is increased by about 30% compared with normal SMAW technique using single electrode of the same size. This is because it is possible to carry heavier welding current without overheating the electrodes (due to cooling inverals) the time of electrode replacement is reduced and higher heat input efficiency can be achieved. Sometime it becomes very difficult to maintain the weld width by this method. Also, it requires bunching of electrodes and special electrodes holders to hold them.[2]

(c) Multiple-Arc Welding

In multiple-arc welding, use is made of twin electrodes which are insulated from each other. It is clamped in specially designed electrode holder which conducts current to each of the electrodes separately. The spacing ‘S’ between electrodes is 5 to 6 mm.

Two phases are connected to the electrodes and the third phase to the work. Three arcs are maintained at a time, two of which ‘b’ and ‘c’ are established between each electrodes and the work, while the third ‘a’ is established between the electrodes. As a result, the melting of electrodes and production rate are nearly doubled in comparison with a single phase arc welding. The heat of the arc is better utilised that leads to the energy consumption per kg of metal deposited as 2.75 Kwh instead 3.5 to 4 Kwh with single phase arc welding.

Three phase welding transformer is used to supply current for multiple-arc welding. The three phase primary winding is either star or delta connected (for 440 or 220 volts respectively). The secondary consists of two coils, each wound with bare copper strips on one of the core limbs. The open circuit secondary voltage is 68 volts.

Three phase welding transformers are usually designed for supplying a maximum current of 400A in manual SMAW. The advantages of multiple-arc welding includes increased production rate, lower power consumption , improved power factor, and balanced load on the supply lines.[2]

(d) Massive Electrode Welding

Another way to increase the production rates in welding is to use massive electrodes with diameter ranging between 8 to 19 mm and having a maximum length of about one metre. These electrodes are made especially for repairing castings and obviously need high welding currents. These electrodes are so large and heavy that it is not feasible to use them in normal manual fashion; instead they are clamped in manipulators to feed them into the work. [2]

1.4 SMAW OPERATION

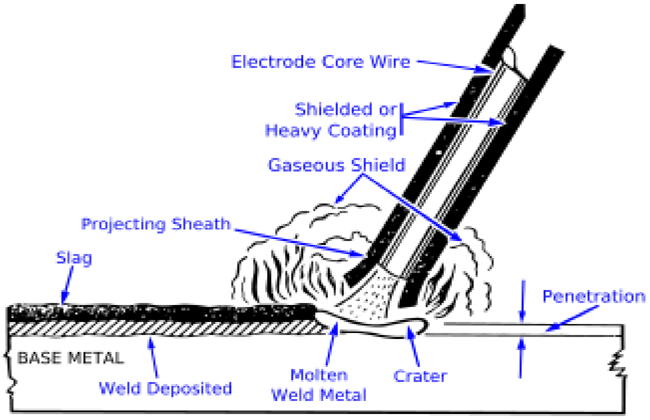


Fig. 1.3 SMAW Weld Area [1]

To strike the electric arc, the electrode is brought into contact with the work piece in a short sweeping motion and then pulled away slightly. This initiates the arc and thus the melting of the work piece and the consumable electrode, and causes droplets of the electrode to be passed from the electrode to the weld pool.

As the electrode melts, the flux covering disintegrates, giving off vapors that protect the weld area from oxygen and other atmospheric gases. In addition, the flux provides molten slag which covers the filler metal as it travels from the electrode to the weld pool. Once part of the weld pool, the slag floats to the surface and protects the weld from contamination as it solidifies.

Once hardened, it must be chipped away to reveal the finished weld. As welding progresses and the electrode melts, the welder must periodically stop welding to remove the remaining electrode stub and insert a new electrode into the electrode holder. This activity, combined with chipping away the slag, reduce the amount of time that the welder can spend laying the weld, makings SMAW one of the least efficient welding processes. In general, the operator factor, or the percentage of operator's time spent laying weld. The actual welding technique utilized depends on the electrode, the composition of the work piece, and the position of the joint being welded. The choice of electrode and welding position also determine the welding speed. Flat welds require the least operator skill, and can be done with electrodes that melt quickly but solidify slowly. This permits higher welding speeds. Sloped, vertical or upside-down welding requires more operator skill, and often necessitates the use of an electrode that solidifies quickly to prevent the molten metal from flowing out of the weld pool. However, this generally means that the electrode melts less quickly, thus increasing the time required to lay the weld. [1]

1.5 EQUIPMENTS

Shielded metal arc welding equipments typically consists of a constant current welding power supply and an electrode, with an electrode holder, a ground clamp, and welding cables (also known as welding leads) connecting the two.[1]

1.5.1 Power Supply

The power supply used in SMAW has constant current output, ensuring that the current (and thus the heat) remains relatively constant, even if the arc distance and voltage change. This is important because most applications of SMAW are manual, requiring that an operator hold the torch. Maintaining a suitably steady arc distance is difficult if a constant voltage power source is used instead, since it can cause dramatic heat variations and make welding more difficult. However, because the current is not maintained absolutely constant, skilled welders performing complicated welds can vary the arc length to cause minor fluctuations in the current. It preferred polarity of the SMAW system depends primarily upon the electrode being used and the desired properties of the weld. Direct current with a negatively charged electrode (DCEN) causes heat to build up on the electrode, increasing the electrode melting rate and decreasing the depth of the weld. Reversing the polarity so that the electrode is positively charged (DCEP) and the work piece is negatively charged increases the weld penetration. With alternating current the polarity changes at 100 times per second, creating an even heat distribution and provides a balance between electrode melting rate and penetration. Typically, the equipment used for SMAW consists of a step-down transformer and for direct current models a rectifier, which converts alternating current into direct current. Because the power normally supplied to the welding machine is high-voltage alternating current, the welding transformer is used to reduce the voltage and increase the current. [1]

Fig. 1.4 High Output Welding Power Supply for SMAW [1]

1.5.2 Electrode

Fig. 1.5 (a) Welding Electrodes[3]

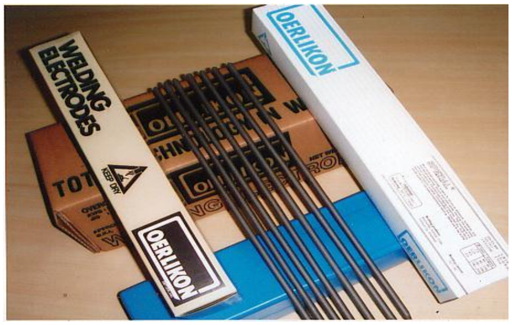


Fig. 1.5 (b) Welding Electrodes[3]

Electrodes produce the current needed for arc welding to take place. They are generally in the shape of long rods or stable wires, with a contact point at the tip of the rod that is used to channel a powerful electrical current into the metal. When the tip of the electrode nears the metal, the current jumps into the metal, creating the dazzling arc from which arc welding receives its name. This in turn creates the heat that melts the metal.

Different SMAW electrodes are made for different tasks and different currents, both AC and DC, and they can differ in strength and which kind of electrical arc they produce. All electrodes are made with special materials that help welders by clearing away contaminants, and creating a clean, efficient weld.

The choice of electrode for SMAW depends on a number of factors, including the weld material, welding position and the desired weld properties. The electrode is coated in a metal mixture called flux, which gives off gases as it decomposes to prevent weld contamination, introduces deoxidizers to purify the weld, causes weld-protecting slag to form, improves the arc stability, and provides alloying elements to improve the weld quality.

Electrodes containing calcium fluoride (CaF_2), sometimes known as basic or low-hydrogen electrodes, are hygroscopic and must be stored in dry conditions. They produce strong welds, but with a coarse and convex-shaped joint surface.

Electrodes made of cellulose, especially when combined with rutile, provide deep weld penetration, but because of their high moisture content, special procedures must be used to prevent excessive risk of cracking. Finally, iron powder is a common coating additive, as it improves the productivity of the electrode, sometimes as much as doubling the yield.

Electrodes are rated according to a system designed by the American Welding Society, using a letter, such E, followed by series of four or five numbers. Often, the diameter of the electrode is also expressed in inches before the identification, so the entire code looks like 1/16-inch E6010. This electrode has a diameter of 1/16th inch (the smallest electrodes are rated) and is used for arc welding (shown by the "E"). The number system shows what the tensile strength of the electrode is by the first two numbers, while the latter numbers show what type of coating the electrode has and what currents it can be used with. Sometimes other letters or numbers are added to show specific information. [3]

1.5.3 Process Variations

Though SMAW is almost exclusively a manual arc welding process, one notable process variation exists, known as gravity welding or gravity arc welding. It serves as an automated version of the traditional shielded metal arc welding process, employing an electrode holder attached to an inclined bar along the length of the weld. Once started, the process continues until the electrode is spent, allowing the operator to manage multiple gravity welding systems. The electrodes employed (often E6027 or E7024) are coated heavily in flux, and are typically 28 in (0.8 m) in length and about 0.25 in (6 mm) thick. As in manual SMAW, a constant current welding power supply is used, with either negative polarity direct current or alternating current. Due to a rise in the use of semiautomatic welding processes such as flux-cored arc welding, the popularity of gravity welding has fallen as its economic advantage over such methods is often minimal. Other SMAW-related methods that are even less frequently used include firecracker welding, an automatic method for making butt and fillet welds, and massive electrode welding, a process for welding large components or structures that can deposit up to 60 lb (27 kg) of weld metal per hour. [3]

1.6 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. 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 deoxidize the weld pool
- Provide deoxidants [3]

1.7 BASICITY INDEX

The flux is termed acidic or basic depending on the value of BI. 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. 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 BI as adopted by International Institute of Welding is given in terms of the weight percentage of various oxides and fluorides constitutes.

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

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

1. Fluxes having basicitys index less than 1 are incapable of controlling the sulphur content of the weld metal effectively. In short BI <1=Acidic.

2. 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.

3. 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.

4. 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 microstructure of weld metal suitably. In short BI>2.5=High Basic [3]

1.8 PLAIN CARBON STEEL

Carbon steel, also called plain-carbon steel,is steel where the main interstitial alloying constituent is carbon. The American Iron and Steel Institute(AISI) defines carbon steel as: "Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, niobium,molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent. The term "carbon steel" may also be used in reference to steel which isany other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent. [7]

1.8.1 Types of Plain Carbon Steels

Followings are some of the types of plain carbon steels:

(a) Mild and low carbon steel

Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29% carbon, therefore it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm^3 (0.284 lb/in^3 and the Young's modulus is 210,000 MPa (30,000,000 psi). [4]

(b) Higher carbon steels

Carbon steels which can successfully undergo heat-treatment have carbon content in the range of 0.30–1.70% by weight. Trace impurities of various other elements can have a significant effect on the quality of the resulting steel. Trace amounts of sulfur in particular make the steel red-short. Low alloy carbon steel, such as A36 grade, contains about 0.05% sulfur and melts around 1426–1538 °C (2599–2800 °F). Manganese is often added to improve the harden ability of low carbon steels. [4]

(c) Medium carbon steels

It contains approximately 0.25–0.30% carbon content. Balances ductility and strength and has good wear resistance; used for large parts, forging and automotive components. [4]

1.9 SLAG METAL REACTION

It is proposed that chemical interaction between the slag and the metal occurs in three zones are as follow:

(1) The zone of droplet reactions,

(2) The zone of dilution and weld pool reactions, and

(3) The zone of cooling and solidifying weld pool

1.9.1 Zone of Droplet Reactions

In this region, the droplet forms at the electrode tip and then travel through the arc column.

1.9.2 Zone of Dilution and Weld Pool Reactions

In this zone, the falling droplets become "diluted" with molten metal from the base plate. The high temperature and the large convective forces in this region lead to intimate mixing of the molten metal and result in vigorous chemical reactions at the slag-metal interface near the arc.

1.9.3 Zone of Cooling and Solidifying Weld Pool

In this region, the molten weld pool behind the electrode starts to cool and solidify as the electrode moves away from it. There is a small drop in the manganese content near the slag-metal interface in manual metal arc welds. They attributed this interfacial phenomenon to the increasing stability of oxides at lower temperature and the consequent shifting of the equation. [4]

1.10 ADVANTAGES OF SMAW WELDING

Following are some of the advantages of SMAW:

1. Flux Shielded Manual Metal Arc Welding is the simplest of all the arc welding processes.
2. The equipment can be portable and the cost is fairly low.
3. This process finds innumerable applications, because of the availability of a wide variety of electrodes.
4. A big range of metals and their alloys can be welded.
5. Welding can be carried out in any position with highest weld quality.
6. The process can be very well employed for hard facing and metal deposition to reclaim part .
7. SMAW welding is the simplest of all the arc welding processes.
8. Welding can be carried out in any position with highest weld quality.
9. The process can be very well employed for hard facing and metal deposition to reclaim parts or to develop other characteristics like wear resistance etc. [6]

1.11 DISADVANTAGES OF SMAW WELDING

Following are some of the disadvantages of SMAW:

1. Because of the limited length of each electrode and brittle flux coating on it mechanization is difficult.
2. In welding long joints (e.g., in pressure vessels), as one electrode finishes, the weld is to be progressed with the next electrode. Unless properly cared, a defect (like slag inclusion or insufficient penetration) may occur at the place where welding is restarted with the new electrode.
3. The process uses stick electrodes and thus it is slower as compared to MIG welding.
4. Because of flux coated electrodes, the chances of slag entrapment and other related defects are more as compared to MIG or TIG welding.
5. Because of fumes and particles pf slag, the arc and metal transfer is not very clear and thus welding control in this process is a bit difficult as compared to MIG welding. [5]

1.12 APPLCATIONS OF SMAW WELDING

The following are the applications of SMAW:

1. Maintenance and repair industries
2. Naval Industry
3. Pipelines
4. Offshore platforms
5. Construction of steel structures
6. Weld carbon steel, low and high alloy steel, stainless steels, cast iron, aluminum, nickel and cooper alloys. [5]

1.13 HARDFACING

Hard facing is the process of depositing, by one of various welding techniques, a layer or layers of metal of specific properties on certain areas of metal parts that are exposed to wear. By expanding this definition a little further, it can be seen that hardfacing has more to offer than most other wear prevention treatments:

1. It is performed by welding. Thus it is part of a well established practice with which people are familiar. There are very few new skills to be learned and in the vast majority of cases, existing equipment can be employed.
2. A layer or layers of metal can be deposited. This means that hardfacing provides protection in depth. It can be applied in a thickness required to give long lasting protection.
3. Metal of specific properties is deposited. There are a wide variety of deposit types available, each specifically designed to withstand certain forms of wear and service conditions.
4. Hardfacing is applied only to specific areas of metal parts that are exposed to wear. There is often no need to protect the entire surface of a component from wear. Hardfacing can be applied selectively and in different thicknesses to suit the exact requirements of a piece of equipment, thereby proving a most economical way of combating wear.
5. Hardfacing is a particular form of surfacing that excludes the application of materials primarily for corrosion prevention or resistance to high temperature scaling or the application of low hardness, friction over-lays to prevent galling - e.g. bronze surfacing. It also excludes the hardening of surfaces solely by heat treatments such as flame hardening, or Nitriding. [7]

1.14 WHY SHOULD HARDFACING BE CARRIED OUT

1. Hardfacing extends the life of worn components and equipment: Build-up or hard surfacing can extend the life of a component by as much as 250% compared to that of a new or non hardfaced component.
2. Hardfacing increases the operating efficiency of equipment by reducing downtime: Hardfaced components last longer, cause fewer shutdowns or stoppages and therefore increase the operating efficiency of the equipment.
3. Hardfacing reduces overall costs: The cost of a worn component is typically 50-75% of the cost of a new component.
4. Hardfaced parts can be manufactured from cheaper base metals: A part which is hard surfaced before use can often be manufactured from a cheaper base metal than one which is no designed to be hard surfaced before use. [7]

1.15 WELDING PROCESSES TO BE USED

The welding processes most commonly used now days for hardfacing are:

1. Manual Metal Arc Welding
2. Flux Cored Arc Welding
3. Submerged Arc Welding

Other processes such as oxy- acetylene welding and gas tungsten arc (GTA or TIG) welding are more often used for specialist hardfacing applications because of their low deposition rates. [7]

1.16 STEPS TO BE CONSIDERED FOR HARDFACING

Following steps are should be considered while doing hardfacing:

1. Identify the mode of wear
2. Identify the base material
3. Select the Product
4. Select the process
5. Select the thickness, diameter, and package

1.17 HARDFACING PROCESSES

The following are the processes used for hardfacing:

1. Manufacture and application of Supercuts Composite Rod wear and cutting grades.
2. Quick Tip application of tungsten carbide inserts.
3. Application of Flexi coy fused tungsten carbide nickel matrix.
4. Metal Spraying
5. MIG, TIG, MAG welding
6. Cylindrical Grinding up to 36" dia x 108" long. [7]

1.18 REASONS FOR HARDFACING

Companies use hard surfacing products to:

1. *Reduce costs* - Hard surfacing a worn metal part to like new condition is usually 25-75% of the cost of a replacement part.
2. *Prolong equipment life* - Surfacing extends life 30-300 times, depending upon application, as compared to that of a non surfaced part.
3. *Reduce downtime* - Because parts last longer, fewer shut downs are required to replace them.
4. *Reduce inventory of spare parts* - There is no need to keep numerous spare parts when worn parts can be rebuilt. [7]

1.19 HARDFACING WEAR FACTOR

The wearing of metal parts might be defined as a gradual decay or breakdown of the metal. When a part becomes so deformed that it cannot perform adequately, it must be replaced or rebuilt. While the end results of wear are similar, the causes of wear are different. It is essential to understand the wear factors involved before making a hard surfacing product selection. It would be easy to select a surfacing alloy if all metal components were subjected to only one type of wear. However, a metal part is usually worn by combinations of two or more types of wear. This makes an alloy selection considerably more complicated. A hard surfacing alloy should be chosen as a compromise between each wear factor. The initial focus should centre on the primary wear factor and then the secondary wear factor(s) should be examined. For example: upon examining a worn metal part, it is determined that the primary wear factor is abrasion and the secondary wear factor is light impact. The surfacing alloy chosen should have very good abrasion resistance but also have a fair amount of impact resistance. [7]

1.20 HARDFACING ELECTRODES

A medium heavy coated rutile type good running hard facing welding electrodes, deposit a tough air hardening type of weld metal of approximately 350 to 600 BHN hardness. The weld metal is machinable and recommended for application involving maximum hardness as required. Typical applications suitable for shear blades brake shoes, coupling, conveyor parts, roller tractor wheels, steel casting, shafts, and axles. [7]

Following are the some of the hardfacing electrodes with their desginations:

1. ROYAL – CI

A medium heavy coated rutile type hard facing electrodes It deposits a tough air hardening type of weld metal approximately 250 BHN hardness. The weld metal is machinable and recommended for hard surfacing on hard base material.

Application: Suitable for gears, shafts, axles, hammers, pinion teeth, pulleys, couplings, spindle. [7]

2. ROYAL - CII

A medium heavy coated rutile type good running hard facing electrode, deposit a tough air hardening type of weld metal of approximately 350 BUN hardness. The weld metal is machinable and recommended for application involving maximum hardness as required.

Application: Suitable for shears blades and croppers, bamboo chipper knives, coupling conveyer parts, roller, tractor wheels steel casting, shafts. [7]

3. ROYAL - C III

With a medium heavy coated rutile type electrode, in air hardening type of weld metal where approximately 600 Brinell hardness can be achieved. Weld is non machine able and finished by grinding. The electrode is recommended for hard facing applications on mild steel, carbon steels & low alloy steels where severe conditions of abrasion, friction, accompanied by moderate impact exist. Suitable for couplings, conveyor buckets, shears blades, steel castings, etc. **Application**: Mine rails & crane wheels, hot & cold punching dies, metal cutting & forming tools, crush hammers & caterpillars treads, drilling bits, crane wheels, conveyor buckets, oil expellers, shears & croppers.[7]

4. AFROX-300

Afrox 300 is a basic coated, AC/DC all-position electrode depositing a tough chromium alloy weld metal with a hardness of 250-300 HV (up to 30 HRc). The weld metal may be hardened to above 480 HV (48 HRc) by heating to 900°C and quenching in oil. The weld deposit is capable of withstanding moderate rolling loads, mild abrasion and frictional loading with good resistance to impact.

Application: Afrox 300 is suitable for rebuilding worn steel or low alloy machine parts, which require machining after welding. It can also be used as a buffer layer between base material and harder overlays. Typical components to be welded with this electrode include shafts, mine car wheels, track links, dragline chains, worn rail ends, tractor rails, drive sprockets, etc. Afrox 300 may be multi-layered. [7]

5. AFROX 452

It is a basic coated AC/DC all-position electrode depositing a weld containing chromium, nickel and molybdenum. The weld metal, which comprises metallic carbides in a martensitic matrix, has a hardness of 420-480 HV (43-48 HRC). The weld metal provides good resistance to abrasion and impact under rolling and to impact loads in wet and dry conditions.

Application: This versatile electrode is suitable for use in applications where frictional loads and metal-to-metal wear conditions occur. The weld metal is extremely resistant to breakout or spalling, which makes it eminently suitable to use on permanent way crossings, rail ends, excavator bucket lips, tractor drive sprockets and track links, crane drive wheels, etc. The deposit, which is machinable with carbide-tipped tools, is also suitable for useas a low cost buffer layer for the deposition of high alloy wear resistant deposits. [7]

1.21 APPLICATIONS OF HARDFACING

Following are the main applications of hardfacing:

1.21.1 Hardfacing of Strips and Disks for Coal and Cement Crushing

Generally such strips do consist of materials which are unweldable, having a high carbon-chromium- or nickel-content. Any how this is the second-largest application worldwide compared to casting materials, the achieved lifetime is twice or three times longer and the grinding result is much better for a long period of time. In the same way the disk (Fig. 1.7), on which the strip rolls, can thus be regenerated and the life time extended. [8]

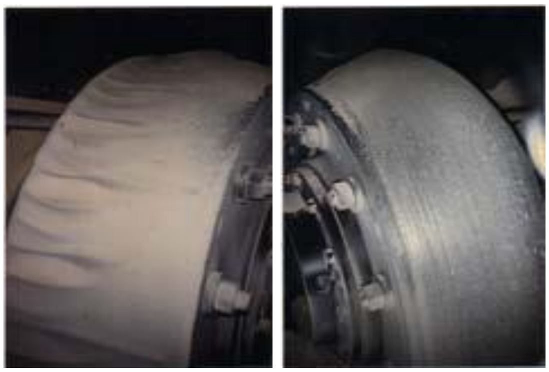


Fig. 1.6 Rollers [9]

Fig.1.7 Disks[9]

1.21.2 Sinter-Crushers Stars with Cobalt Base Alloys and Inserted Mixed Carbides

Sinter crushers are a considerable wear problem in each iron and steel work worldwide. Generally their lifetime in hardfaced condition is about 2-4 months. Actually tests are made, in order to find out if the use of tungsten-chromium carbides can increase lifetime significantly, which are promising. But with regard to bar frames (the counter-part) it already became obvious that with such materials a longer lifetime is not achieved, due to even higher temperatures. [8]

Fig. 1.8 Sinter Crusher Blades [8]

CHAPTER 2 LITERATURE REVIEW

M.F. Buchely *et al.* [2005][10] studied the comparison of the microstructure and abrasion resistance of hard facing alloys reinforced with primary chromium carbides, complex carbides or tungsten carbides. The hard facing alloys were deposited onto ASTM A36 carbon steel plates by a shielded metal arc welding (SMAW) method. Three different commercial hard facing electrodes were employed to investigate the effect of the microstructure. The abrasion tests were carried out in a dry sand–rubber wheel abrasion machine. The typical microstructure of the studied hard facing alloys having two layers, the first and second layers of Cr-rich deposits have a eutectic matrix with proeutectic M_7C_3-type chromium carbide. In the second layer, both the volume fraction and the mean size of chromium carbides are higher than in the first one. The microstructure of the W-rich deposit is composed by proeutectic MC-type carbides surrounded by the eutectic structure containing M_6C-type (fishbone-type) carbides and some marten site. The first layer of the complex carbides deposit is mainly eutectic with finely dispersed (Nb, Mo)-rich hard particles, while the second and third deposit layers have a similar microstructure which includes chromium-rich M_7C_3, Nb-rich MC, Mo-rich M_2C and W-rich WC carbides. After the investigation, it was concluded Three-layer complex carbide deposits showed the best abrasive wear resistance of all the tested hard facing alloys. Nevertheless, when only one layer was deposited the high dilution levels changed the microstructure and strongly reduced the wear resistance. W-rich hard facing alloys showed a very good abrasive wear resistance with only one layer, due to their unique combination of tough M_6C and hard, massive MC carbides in a eutectic matrix.M_7C_3 carbides played a crucial role in the abrasive wear resistance.

Yilmaz Bayhan [2005][11] presented the study of increasing the wear resistance by covering the chisel ploughshare produced from low-alloy steel with three different hard facing electrodes. In this investigation, the three different hard facing electrodes were used, which are designated EH-600, EH-350 and EH-14Mn, were used for hard facing. There are two reasons for these electrodes being chosen. The first is that they provide high resistance to wear and the second one is that they are relatively cheaper on the market..In the welding process, Shielded Metal-Arc Welding (SMAW) method was used. Base metal is carbon steel and filler metals are hard facing electrodes. The welding machine was using DC current with reversed polarity. A prototype abrasive wear tester has been built in four stages. The first is the soil bin, the second is the main shaft and the branches on the shaft and the extension legs that are connected to the branches, the third is the transmission power system and the last is the main framework of the roof. After the investigation, it was concluded that, EH-600 andEH-350 electrodes can be recommended for hard facing. The wear rate is related to both on hardness and chemical composition of the materials. Mainly, carbon and manganese proportions of the steels are effective on the wear rate EH-14Mn wasn't recommended because of higher composition of carbon and manganese Wear rate has decreased by increasing the Carbon (C) and the Manganese(Mn) proportion in the chemical composition of the share.

Amado Cruz Crespo *et al.* [2007][12] studied the operational behavior of experimental coated tubular electrodes for hardfacing, comparatively to a conventional commercial coated electrode. Bead-on-plate welds were carried out, covering a wide range of setting current. In this investigation the coated tubular electrodes having same basic coating and coating ratio but difference was in grain size of the Fe Cr Mn. Through processing of the instantaneous voltage and current signals, the metal transfer behavior of the electrodes was determined at each current. Fusion and deposition rates, and respective deposition efficiency, were measured by weighing electrode and test plates before and after welding. The geometric parameters were taken from cross sections from the weldments and the dilution was calculated. The outputs were analyzed under conditions of either the same current or the same bead volume. It was concluded that, from the operational point of view, the coated tubular electrodes present a favorable performance in comparison to the conventional coated electrode, making possible to reach lower dilutions yet keeping the same deposition rates.From the investigation, it was concluded that the manufacturing conception of electrodes for hardfacing by SMAW through use of tubular core presents differences in the operational behavior when compared to a similar commercial electrode made of solid core (same class and application).Current range for each electrode that gives to then better performance concerning operational stability, bead aspect and formation, deposition efficiency. For obtaining the same deposition rate, consequently producing beads similar dimensions for a given travel speed, it is necessary to use higher setting currents for then conventional solid rod electrode (higher welding energy therefore higher thermal tensions). In the case of the tubular electrodes, there are transitions current which once overcome increases remarkably the transfer frequency, with smaller droplets. This effect was not observed with the conventional electrode, at least upto the upper limit of the current range. In this case, as current was increased the droplets were larger, since the transfer frequency was the same.

Kemal Yildizli *et al.* [**2007**][13] studied the microstructure and erosive wear behavior of weld deposits of high manganese electrode. Low carbon steel plates were surfaced with single, double and triple pass bead on-plate welds using the shielded metal arc welding technique with a high manganese electrode. After the investigation, it was concluded that, three weld deposits layer are observed. The increase in the number of the deposit layers leads to variety and enrichment of chemical composition on the surface. C, Mn and Ni contents result in micro structural differences revealing in each occasion. The microstructure of the first layer is composed of martensite with retained austenite. The microstructure of the second layer consists of austenite and martensite in general is shown in Hard martenstic structure appears in the form of a precipitation island grown in the austenite matrix as dark spots. The microstructure of the third layer appears to be fully of austenite. As the contents of C, Mn and Ni are increased, the microstructure changes from martensite to austenite. From the results of erosive wear tests, it was concluded that, the wear resistance of austenitic manganese steels, showed a higher work-hardening capacity and a better wear resistance under low speed impact velocity. However, it was concluded that for erosive wear in the surface coating by arc welding using high manganese electrode.

V.E.Buchanan *et al*. [2007][14] presented the comparison of abrasive wear behavior of shielded metal arc welding (SMAW) hard faced Fe–Cr–C deposits used in the sugarcane industry which have been compared with experimental arc-sprayed Fe–Cr–B coating. The main aim was to identify an alternative process which is equally or better than SMAW and to improve the wear resistant under specific wear environment. In this investigation they were use grey cast iron disc for SMAW and 240-metallisation twin wire electric spraying system for electric arc spraying. The microstructure of SMAW deposits containing primary M_7C_3 carbide in eutectic matrix. The structure of arc-sprayed consists of lamellar splats and rich oxygen layers. The arc sprayed coating had higher porosity and low micro hardness as compare to SMAW coating. After the wear test, the result showed that sub surface zone of arc-sprayed coating that material removal occurred not only through plastic deformation and cutting but also by fracture as a result of separation of top layers (splats) from the surface. The primary M_7C_3 carbide is better able to resist abrasion and minimize the depth of subsurface deformation in matrix. It was also protect the matrix from widespread plastic deformation that would increase the wear.

Fernando Casanova *et al.* [2007][15] investigated the wear of sugar cane rolls. In this process, sugarcane fiber – commonly called bagasse is squeezed between grooved roll shells to extract sugar. This research was conducted to understand the wear process in roll shells made of steel. Wear tests were done with a prototype based on the ASTM-G65 standard machine. After the investigation; it was found that the wear is increased due to load. A potential effect of load on wear exists. Wear has an asymptotic behavior dependent on the silica content in the bagasse. The experimental data fit a model where wear tends to be constant when the silica content increases. In this research, it was discovered that the wear mechanism generated by the clean bagasse had basically to do with the detachment of previously deformed particles: the bagasse wears the steel surface when it detaches plastically deformed particles generated during the machining process or in the wear processes by ploughing, produced by the silica grains. Data showed that MEM was the basic cause of wear. The steel surfaces submitted to slight conditions of wear, like low load and/or low silica content, display a high decrease of roughness. The surfaces of steel worn under more severe conditions display greater roughness than those slightly worn, but all of them have less roughness than the surfaces in a machined state. This implies that in all conditions tested, the worn surfaces end up more polished than in their initial machined condition. The plastically deformed zone resulting from the wear process is smaller than that generated during the machining process. The wear process does not generate a very extensive, deformed layer.

Xinhong Wang *et al.* [2007][16] studied the microstructure and wear properties of the Fe–Ti–V–Mo–C hardfacing alloy In this investigation, different hardfacing layers were produced by shield manual arc welding (SMAW) process in which a bare electrode of H08Awas coated with fluxes, to which different measures of ferrotitanium (Fe–Ti), ferrovanadium (Fe–V), ferromolybdenum (Fe–Mo) and graphite had been added. The hardfacing was carried out on

AISI 1020 steel substrate by means of manual shielded metal arc welding (SMAW) under direct current with a reverse polarity. After welding, the small white carbides particles can be seen in the matrix. The particles are irregularly cuboidal form with a dispersed distribution in. It indicated that the hardfacing layer is composed of TiC, VC, Mo_2C, Fe_3C and Fe, which means that the TiC, VC andMo_2C carbides were, formed during SMAW procedure the matrix. In addition, there was no remaining graphite, Fe–Ti, Fe–V or Fe–Mo. After the investigation, it was concluded that TiC–VC–Mo_2C carbides particles were formed by metallurgical reaction during SMAW process. Carbides are uniformly dispersed in the matrix. The hardfacing layer produced by Fe–Ti–V–Mo–C hardfacing materials possess much higher wear resistance and a lower friction coefficient The microstructure, hardness and wear resistance of the hardfacing layer were affected obviously by the amount of Fe–Ti, Fe–V, Fe–Mo and graphite. The hardness and wear resistance of the hardfacing layer increases with increasing of Fe–Ti, Fe–V, Fe–Mo and graphite. While the amounts of graphite, Fe–Ti, Fe–V and Fe–Mo are controlled within a range of 8–10%, 12–15%, 10–12% and 2–4%, respectively, a higher hardness and wear resistance of the hardfacing layer can be obtained. It can be seen that graphite influences directly not only on the formation of carbides but also hardness, as well as its wear resistance. The hardness increases rapidly with graphite content increasing. Wear resistance of materials depends on their hardness, therefore, with increase of graphite in the coating of the electrode, the hardness of the hardfacing layers increases, so their wear volume loss decreases.

M. Kirchgabner *et al.* [2008][17] studied the behavior of iron-based hardfacing alloys under abrasion and impact. Iron-based hardfacing alloys are widely used to protect machinery equipment exposed either to pure abrasion or to a combination of abrasion and impact. The specific wear behavior of a welding alloy under these conditions depends on its chemical composition, the microstructure obtained after welding and finally the welding technology used to apply them respectively the parameter settings which strongly influence, for example, dilution with the base material or formation of metallurgical precipitated hard phases. Six different hardfacing alloys produced as flux cored wires on iron basis were selected and welded onto 1.0038 mild steel plates with a dimension of 195mm×125mm×6 mm. The interpass temperature was kept in a level of about 150–200 ^{0}C. After the investigation, it was concluded that though very important, hardness is only one factor to be evaluated when comparing the wear resistance of Fe-based hardfacing welding alloys. For pure abrasion either synthetic materials using tungsten carbides or complex alloys providing both hard phases, and a hard and tough nanostructure matrix at the same time are performing best and very similar. Under erosive wear or high impact loads, the tungsten carbide-containing hardfacing alloy underperforms significantly compared to this new complex type of Fe-based alloy. State of the art hypereutectic FeCrCNb alloys provide reasonably good behavior under all test conditions but never being the leading edge.

S. Selvi *et al.* [**2008**][18] investigated the hardfacing of valve seat ring is done by manual metal arc welding (MMAW) process by using three different electrodes E410,E430 and newly developed E430 in order to compare the performance of the weld overlays. In this investigation, they were analyzed the influence of C and Cr on wear resistance, hardness and effect of microstructure by conducting wear test, hardness survey and microstuructre was analyzed. The main aim of the hard facing chosen here as a method of repairing or improving or extending the service life of the valve seat ring economically is to provide excellent wear resistance, increasing hardness and better corrosion resistance.. It was found that carbon and chromium supports the improvement of wear resistance, hardness and refined, microstructure. It was also found that the wear rate increase with increase in sliding velocity and applied load. An increase in Cr, the hardness was increase due to formation of chromium carbide at the grain boundaries but PWHT drop the hardness.

Z. Horvata *et al.* [**2008**][19] presented the comparison of wear of regular mould board plough shares and two plough shares made of different basic materials, steel EN 10027 (HF-1) and EN $50Mn_7$ (HF-2), hardfaced by a combination of two welding processes, namely shielded metal arc welding(SMAW) and high-frequency induction welding (HFIW).The set of plough shares were regular commercial shares made of steel alloyed with1.16%Mn, 0.19% C, 0.3% Si, 0.014% P, 0.023% S, 0.23% Cu, 0.17% Cr, 0.08% Ni and 0.01% Mo. The other plough share sets were made in the workshop from material with the following components: the first set of hardfaced shares (HF-1) was made of steel EN 10027 (S 355 JO) alloyed with 1.32% Mn, 0.17% C,0.5% Si, 0.035% P, 0.03% S and 0.008% N, and the second set (HF-2) of steel EN 50Mn7 alloyed with 1.7%Mn, 0.49% C, 0.4% Si, 0.04% P, 0.04% S and 0.007% N. Then both ploughshare sets were hardfaced by a combination of two welding processes, namely SMAW and HFIW. SMAW is commonly used for hardfacing due to the low cost of electrodes and easy application [18]. HFIW equipment has a high degree of automation, but is rarely used because it's great initial investment. After the investigation, it was concluded that the dimension losses were significantly lower for both types of hardfaced plough shares compared to regular shares. The weight losses were also lower for both types of hardfaced plough shares compared to standard shares, but the differences were not significant. Lower fuel consumption and a higher rate of work in ploughing compared to regular shares were achieved with hardfaced plough shares. The production costs of hardfaced plough shares compared to regular shares were lower 3.0% and 11.1% for HF-1 and HF-2, respectively. According to the overall results, this combination of two welding processes can be recommended as efficient solution of plough share wear protection.

A.H. Jones *et al.* [**2009**]**[20]** presented the improvement of hard facing coatings for ground engaging applications by the addition of tungsten carbide. In this investigation wear resistance is measured using Sic and SiO_2 abrasives and rubber wheel tests using sand abrasives in both dry and wet conditions. A boron steel (C-0.3%, B-0.003%, Mn-1%, Si-0.3%, Cr-0.4 %,), the unmodified coating and a WC tile (6% Co binder) were also tested for comparison. The material is produced by water atomization. The powder also has a clay based suspension agent and a sodium borate flux added. Densification and microstructure development is achieved through sintering under nitrogen at 1000 ◦C on a belt furnace. The sintered microstructure of the unmodified coating have three phases can be distinguished by the elemental contrast; the matrix phase (bright) and two distinct blocky phases. The matrix was predominantly rich in Fe, Ni and Si and formed a phase based on the cubic Fe–Ni phase .The two blocky phases are based on Me_2B and Me_3C_7 where Me = Fe,Cr or Ni and the B and C can be partly substituted for each other in both cases, forming boro-carbide. A hard facing coating consisting of hard carbo-borides in a Fe–Ni–Si matrix has been modified by the use of WC andW_2C/WC powders. A hard facing alloy which can be applied to tools as slurry and then sintered was modified by the addition of hard powder materials has been modified using a range of WC additions. After the investigation, it was concluded that, using the same sintering conditions as for the unmodified coating the WC particles were well incorporated within the coating. A reaction between the WC and the coating had taken place which helps bind in the particles but which may form undesirable brittle phases which could be detrimental to the performance. Wear testing using Sic abrasive is not suitable for measuring the potential of these materials in terms of resistance to soil wear as it is too aggressive and only produces a three-body rolling wear mechanism here is a relationship between the wear performance, the abrasive size and the size of the WC addition. When a large abrasive is responsible for wear then the lowest wear rate is achieved using large WC particle additions. When a small abrasive responsible for wear then the lowest wear rate is achieved using small WC particle additions.

Mehmet Eroglu [**2009]**[21] investigated the effects of the boron content in the electrode shield on the microstructure and hardness In this investigation they used Ferro boron as the boron source in electrode shield. From the results, it was seen that different boron contents formed primary and eutectic Fe_2B, and consequently had an effect on the hardness of the coating. The effects of the boron content in the electrode shield on the microstructure and hardness, the microstructure was changed from hypoeutectic to a hypereutectic, one consisting of primary Fe_2B borides and small quantity of Fe_2 B martensite eutectic. The micro hardness of coating was increase with boron content. The hardness of coating developed is very high and use for hardfacing to improve the surface properties agricultural tools, components for mining industry etc.

M. Balakrishnan *et al.* [2010][22] presented the effect of buttering and hardfacing on ballistic performance of shielded metal arc welded armour steel joints. Quenched and tempered (Q & T) steel closely confirming to AISI 4340 is well known for its superior ballistic performance and hence used in the fabrication of armour vehicles. These steels are traditionally welded by austenitic stainless steel (ASS) fillers to prevent hydrogen induced cracking. This paper reports the influence of ASS buttering layer between armour plate (base metal) and weld metal/hardfaced metal. Welding of armour steel plates was carried out by shielded metal arc welding (SMAW) process using ASS and low hydrogen ferritic steel(LHF) electrodes. The ballistic test results were correlated with the interface microstructure, and hardness distribution across different weld combinations. In this investigation, double Vee joint configuration was prepared. SMAW process was selected because it is traditionally used in combat vehicle construction works. Two types of welding electrodes and one type of hardfacing electrodes were used. ASS electrode was selected because it avoids time delayed cracking tendency of Q & T steel weldments. A low hydrogen ferritic (LHF) electrode was selected for its cost effectiveness Microstructures reveal that there is a clear bonding between each layer and the buttering layer, and also no interfacial cracks in between layers or hardfacing. Similarly, there is no crack at the interface between the weld and base metal due to the presence of soft ASS buttering layer. The microstructure of base metal consists of acicular martensite structure with fine needles of lath martensite. The hardfaced region of capping weld was consisting the microstructure of homogeneous cast like structure. It is composed of hard phase precipitates (carbides) of hexagonal chromium carbides of different sizes on softer austenitic matrix. Large spine like carbides are clearly visible in the microstructure on both sides of the hardfaced layers on both (AHA and AHF) the joints. An attempt was made to improve the ballistic performance of armour steel welds by depositing an ASS buttering layer on the beveled base metal, above which a multilayered structure was fabricated and evaluated. Buttering layer supports for ballistic performance by the resultant microstructure and hardness distribution and keeps the weld layers intact successfully when the projectile is fired at interfaces and HAZ. At WCL, further investigation is required with different layer thickness and joint configuration; because the current study carries the hardfaced layer thickness of around 4 mm on both sides of the root in double V joint did not support the resistance against the projectile penetration.

Renzo Victoria Prado *et al.* [2010][23] studied the abrasive wear effect of sugarcane juice on sugarcane rolls. Corrosion seems to be an important factor affecting the wear of sugarcane rolls. In this investigation the evaluation of corrosive effect of sugarcane juice on carbon steel rolls. An effective way to reduce the corrosion effects on the wear of carbon steel rollers may be by depositing hard-facing materials over a stainless steel buffer. This buffer would cover the whole tooth and avoid its corrosion. In this investigation they were used machine which is composed of a steel ring (specimen), which rotates and slides against compressed bagasse. The ring is V-shaped, geometrically similar to the teeth of the sugarcane rolls. A screw drives the bagasse ahead compressing it against the ring, the specimen sliding against the bagasse. Tests were performed on specimens made of ASTM-A36 steel (low carbon steel). No important improvement was found in the performance of the roll welded with stainless steel. After the investigation, it was concluded that no improvement of the roll welded with a buffer of austenitic stainless steel was observed in the field test. Severe wear and detachment of the hard-facing deposits occurred. The corrosive effect of the sugarcane juice increased the wear of the specimens made of carbon steel, even when the test was done without MEM. Traces of corrosion were found on the carbon steel surface tested without silica grains. In the specimens tested with silica grains, the rubbing of the silica grains removed base material and corrosion products. Higher variability in the results for the welded specimens was found with respect to the machined specimens. This variability is mainly induced by the high roughness of the as-welded surfaces. To take into count the difference in specimen roughness, the quantity of bagasse and the reduction in the bagasse particle size must be used as indicators of the work done by the specimen. Silica grains produced similar wear mechanisms on both carbon steel and austenitic stainless steel deposited by welding.

R. Arabi Jeshvaghani *et al.* [2010][24] presented the effects of surface alloying on microstructure and wear behavior of ductile iron surface-modified with a nickel-based alloy using shielded metal arc welding. The base material for the deposition of the clad layers was pearlitic ductile iron. The dark and round shaped particles are graphite nodules embedded in a pearlitic– feritic matrix in the microstructure. The first phase was formed during cooling of nickel-based hardfacing alloy from the liquid state is the primary Ni-rich solid solution and the remaining liquid eventually solidifies by a eutectic reaction into an interdendritic mixture of Cr-rich carbides. After the investigation, it was concluded that surface alloying of ductile iron using manual shielded metal arc welding was carried out to achieve layers with increased hardness and better wear resistance. The microstructure of cladded layers mainly consists of α(Fe,Ni), (Fe, C) and small amounts of carbides such as Cr_7C_3, $Fe_7C_3$and Fe_3C.The interface between cladding and substrate had a complex structure comprising remelted regions, undisclosed graphite, martensite, fine pearlite, coarse pearlite and some ferrite. Microhardness of single pass coating was higher than that of double pass coating. The wear rate in cladded layers was lower than that in ductile iron. The weight loss was found to decrease with an increase in material hardness. In both cladded layers and in all sliding distance, a stable wear rate was achieved. The dominant wear mechanism was delimitation in the clad layers and substrate.

CHAPTER 3 PROBLEM FORMULATION

Hardfacing is a commonly employed method to improve surface properties of agricultural tools, components for mining operation, soil preparation equipments etc. An alloy is homogeneously deposited onto the surface of a soft material (usually low or medium carbon steels) by welding, for the purpose of increasing hardness and wear resistance without significant loss in ductility and toughness of the substrate. In industries the equipments, tools, worn parts are made up steels. The major problem is the wearing of tools used for ploughshare, rollers used in sugarcane industry, valve seat ring etc.

The problem associated is to study the wear behaviour of hard facing alloys formed by the addition of varying percentage constituents of fluxes by SMAW.

For the achievement of the above, an experiment set up was prepared to deposit the hard facing layers on base material. The aim of the experiment was to design and development of electrode coatings and to study the effect of variation of the percentage composition on wear rate and change in micro hardness values. For this purpose some hard facing alloys as fluxes (ferrochrome, ferromanganese, chromium etc) were used to achieve the above objective. The experiment was carried out by preparing the fluxes of different percentage compositions and deposits the layers of the prepared electrodes on low carbon steel plates. From welded plates specimens were made to carry out different tests viz. wear rate, micro hardness, impact toughness etc.

OBJECTIVE: 1.To study the effect of addition of flux constituents on microstructure and micro hardness of the weld deposit.

2. To improve the wear resistance of the weld deposit.

CHAPTER 4 EXPERIMENTATION

4.1 INTRODUCTION

During the course of this work, a series of experimental electrodes with different flux compositions was produced. The experimental electrodes were produced in small batches (100g each). Steps performed for in the experimental program are as follows:

(a) The first step was the manufacturing of flux, for this various compounds was used viz. ferrochrome, ferromanganese, chromium etc.

(b) The second step was the preparation of steel plate (low carbon steel) specimen, having dimension of 265x125x12mm. To carry out welding process V-groove was machined on these plates.

(c) The third steps was to deposits the layers of hardfacing electrodes in machined plates to make the specimens ready for testing are as follows:

- Wear Test
- Toughness Test
- Micro Hardness Test
- Microstructure Test
- Chemical Composition of Weld-Metal
- SEM(Scanning Electron Microscope

4.2 COATING INGREDIENTS USED

Followings are the common ingredients used for the preparation of hardacing electrodes:

- *Fluxing agents:* Silica, CaO_3
- *Slag formers*: Rutile, Alumina, Iron Oxide, Fluorspar
- *Arc stabilizers*: Potassium Silicate
- *Gas forming material*: Cellulose, Lime Stone
- *Slipping agents (for easy extrusion)*: Glycerine, Mica
- *Binding agent*: Sodium Silicate, Potassium Silicate

- *Deoxidizers and alloying elements*: Ferro-chrome, Chromium

(a) **(b)**

Fig. 4.1 (a & b) Major compounds used for coating.

The major compounds used for coatings in powder form for the manufacturing of hardfacing electrodes are shown in Fig.4.1 (a & b)

4.3 CHEMICAL COMPOSITION OF BASE METAL AND ELECTRODE

The composition of base metal and welding electrode was found by using spectrometer (AAS). The following Table 4.1 and 4.2 shows the chemical composition of base metal and electrode respectively.

Table 4.1: Chemical Composition of Base metal

C	Si	Mn	P	S	Cu	Nb	Cr
0.24	0.21	0.4	0.08	0.06	0.06	0.004	0.052

Table 4.2: Chemical Composition of Electrode

C	Si	Mn	P	Si	Cu	Cr
0.02	0.01	0.3	0.05	0.03	0.02	0.046

4.4 MATERIAL USED FOR WELDING

Low carbon steel plate of 265x125x12mm dimension was used for welding, low carbon steel was selected because it is most commonly used for making cutting tools, some parts of automobiles and applications in order to increase hardness and wear resistance.

4.5 PERCENTAGE VARIATION OF COMPOUNDS USED FOR COATING

The following Table 4.3 shows the various dry mix constituents used for coating of electrodes and the percentage variation of these constituents to prepare the flux of required Basicity index.

· BI= $CaF_2 + CaO + R_2O + 0.5(MnO+FeO)/SiO_2 + 0.5(Al_2O_3+TiO_2+ZrO_2)$

Table 4.3: Coating Composition (wt %)

Dry Mix Constituents Used for Coating	Percentage of Constituents					
	Flux 1	**Flux 2**	**Flux 3**	**Flux 4**	**Flux 5**	**Flux 6**
Ferro Chrome	5	7	9	11	13	15
Ferro Manganese	10	7	10	6	6	4
Cellulose	4	4	4	4	4	4
Quartz	8	8	8	8	8	4
China clay	13	10	6	5	5	4
TiO_2	15	22	24	27	20	20
High carbon	20	22	20	25	27	30
Calcite	13	6	2	8	5	2
Iron powder	9	6	6	6	4	4
Chromium powder	3.5	5	8.5	12.4	14.6	16.5
Basicity index	**1.32**	**1.21**	**1.62**	**1.73**	**1.82**	**1.92**

4.6 PREPARATION OF SMAW ELECTRODES

The materials (ferromanganese, ferrochrome, chromium etc. in the form of powder) used for making flux was first weighed and a required percentage of powders were mixed together to obtain a homogeneous dry flux mixture in dry mixture machine (Fig. 4.2) for approx. 10 minutes. A liquid silicate binder (jelly form) was added to the dry flux mixture in wet mixture machine (Fig. 4.3) followed by mixing for further 10 minutes. The binder consists of a complex mixture of different alkali silicates with a wide range of viscosities. After proper mixing of flux with binder in wet mixture machine, the wet mixture was extruded from the cylindrical tube of diameter 20 to 25 mm approx. to achieve the required diameter of electrode from extrusion machine (Fig. 4.4) (available at Golden Electrode, Samana) onto a mild steel core wire of 3.15mm diameter, because in extrusion machine only cylindrical rods were can be placed inside the extrusion machine. After extrusion electrode was kept at room temperature for about 10-20 minutes for baking purpose. Same type of core wire i.e. mild steel core wire was used for all the experiments. The electrodes made were first tested by taking trials so as to check the porosity, slag removal, spatter etc. After trials finally 6 types of flux coating composition were obtained by varying the ferrochrome from 5 to 15 wt% at the expense of ferromanganese, mica, high carbon, iron powder etc in take dry mix.

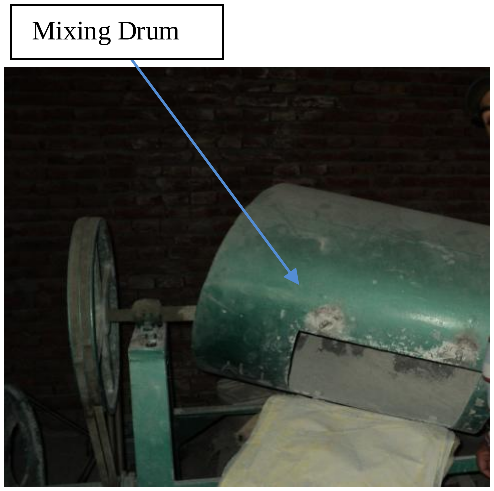


Fig. 4.2 Dry Mixture Machine

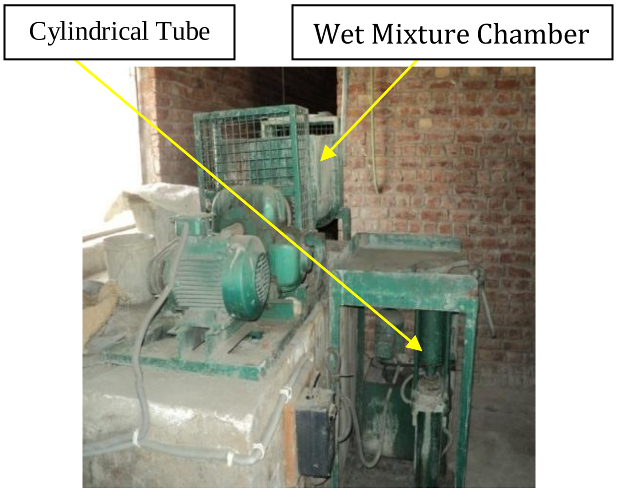


Fig. 4.3 Wet Mixture Machine

Fig. 4.4 Extrusion Machine

4.7 FIXED PAPRAMETERS

The following are the parameters that were kept constant throughout the experiment.

- **Total dimensions of specimen**: 265x125x12mm
- **Welding parameters:** Current (140 amp), Voltage (30 V), Welding speed (3.8 mm/s), Power supply (AC)

4.8 SPECIMEN PREPARATION

Low carbon steel plate was machined on shaper to make V groove of 60^0 angle and root face of depth 2mm was made as shown in (Fig. 4.5). The machined plates were then cleaned with acetone to remove impurities from the surface to make the specimens ready for welding (Fig. 4.6).

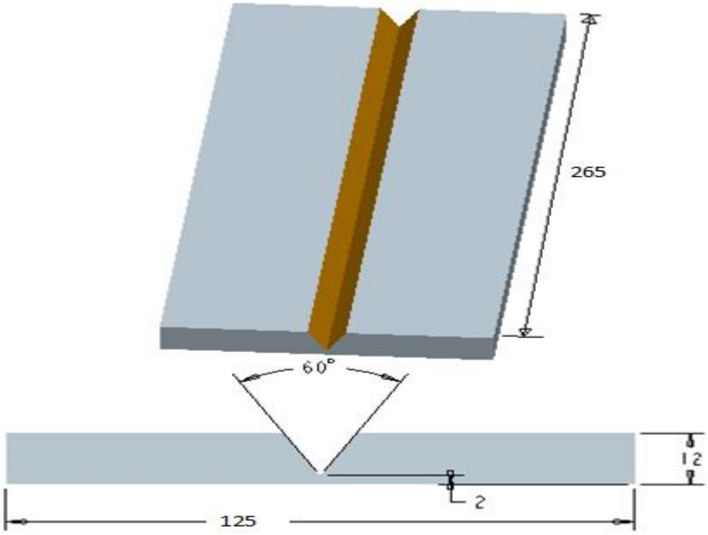


Fig. 4.5 Weld Groove Geometry (All dimensions in mm)

Fig. 4.6 Plates after Machining on Shaper

4.9 COMPLETE SET UP

The specimens were welded using SMAW machine as shown in Fig 4.7. The welding procedure, material and geometry of steel plate, fluxes used to make the weld beads have already been discussed earlier. Fig 4.8 shows the welding plate on which the hardfacing layers were deposit to carry out the different testing's discussed below:

Fig. 4.7 Complete Set Up of MMAW Machine

Fig. 4.8 Welded Plate

4.10 TESTING OF WELDED SPECIMENS

The followings are the tests performed on the welded specimens to achieve the objective:

4.10.1 Micro Hardness Testing

Microhardness measurement of specimen was done on the welding bead on microhardness machine. The hardness was taken on the welding bead as shown in the Fig. 4.9.load was kept constant for all specimens that is 300 gm. Before microhardness testing all specimens (Fig. 4.9) were polished on belt grinder.

Fig. 4.9 Specimens Used to Measure Microhardness

4.10.2 Chemical Composition

Weld metal chemical composition was obtained from weld bead using spectrometer (AAS-Atomic absorption spectrometer).

4.10.3 Microstructure

A microscope used for microstructure examination 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. Before microstructure examination the specimens were grinded on a disc which was attached to a belt grinder. Different grades of emery papers viz. 100, 220, 320, 400, 600, 800 and 1000 were used to polish the specimens. After polishing, etching of the specimens was done to make the samples ready for microstructure examination as shown in Fig. 4.10.

Fig. 4.10 Specimens Used for Microstructure Test

4.10.4 Impact Toughness Testing

The Impact toughness of a material can be determined with a Charpy or Izod test. The Charpy impact test, also known as a Charpy V- notch test, is a standardized high strain rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given a e test material’s toughness. According to ASTM A370, the standard specimen size for Charpy impact testing is 10×10×55mm as shown in Fig. 4.11 & 4.12.

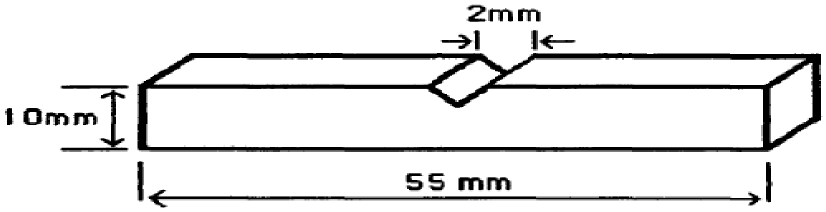


Fig. 4.11 Geometry of Impact Specimen

Fig. 4.12 Specimens Made for Impact Testing

4.10.5 Wear Test

Sliding wear tests were conducted on pin-on-disc wear testing apparatus (Fig.4.13) under constant applied load of 70kg at fixed interval time of 10 min against EN32 steel disc of 200 mm diameter. The pins were made from the welding plates. The pin specimens were 30 mm in length and 8 mm in diameter according to the machine standards. The surfaces of the pin specimens were rubbed against emery paper of 400 grades prior to test in order to ensure the contact of fresh and flat surface onto the steel disc. During sliding, the load was applied on the specimen through cantilever mechanism. The wear rate was calculated from the weight loss technique and expressed in terms of volume loss per unit time.

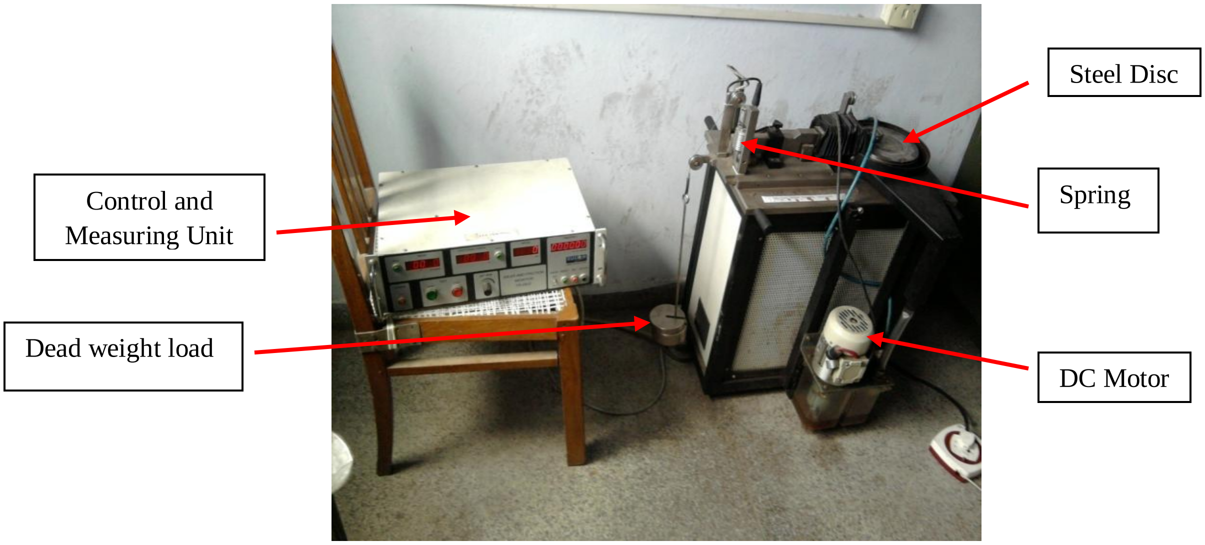


Fig. 4.13 Wear Testing Machine

Fig. 4.14 Pins Used for Wear Test

4.10.6 Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) is an important tool for microstructure analysis. The microstructural characteristic of the specimens correlate the effect of different processing condition with properties and behaviour of materials that involves their micro structural changes. The SEM provides information relating to topographical features, morphology, phase distribution, compositional differences, crystal orientation and presence of defects and their location.

5.1 MECHANICAL PROPERTIES

5.1.1 Charpy V Notch Impact Toughness Results

Results of impact tests carried out at room temperature for each specimen and average value for each coupon is shown in Table 5.1 & 5.2. For each specimen four readings were taken and the average value was calculated.

Table 5.1 Impact Toughness Result of Base Metal

Base metal readings	Average Value
85-60-75-100	80

Table 5.2 Charpy V Notch Impact Toughness Results (Joule)

Fluxes	Charpy V	Average Value for each specimen
Flux 1	47-58-66-59	52
Flux 2	71-73-68-80	78
Flux 3	78-90-95-105	95
Flux4	102-114-95-135	116
Flux 5	117-125-114-105	130
Flux 6	121-115-153-128	148

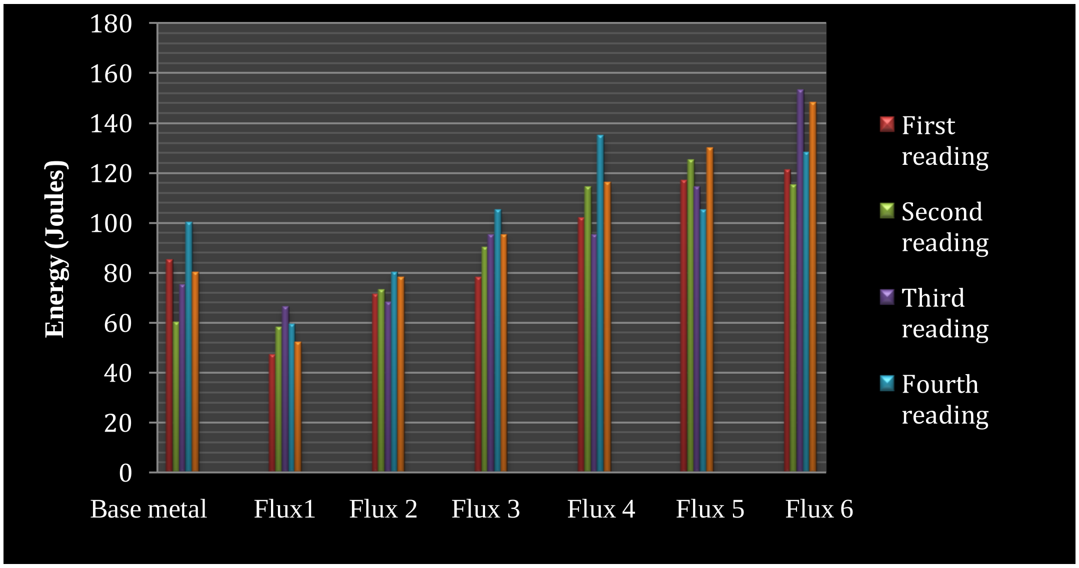


Fig. 5.1 Energy Vs Ferrochrome Variation Graph of Impact Toughness Results

Discussion of Impact Toughness

A uniform increase in Charpy impact toughness can be seen from Fig. 5.1 for flux 6. There are several parameters affecting impact toughness of welds viz. hardness level and microstructure. Toughness increases with increasing hardness because the ability of material for plastic deformation increases, and hence work off fracture increases.

5.1.2 Micro Hardness Measurements

Hardness is the ability of the metal to resist penetration, abrasion wear or the absorption energy under impact load. Hardness measurement provides the information about the metallurgical changes caused by welding. The hardness tests were carried out using Vickers micro hardness tester at 300 gm constant load for all the specimens in order to analyze the above mentioned properties of the welds. The results are shown in Table 5.3

Table 5.3 MicroHardness Test Results (MVH)

Sr. no.	Hardness value (VHN)
Base metal	222
Flux 1	283
Flux 2	290
Flux 3	400
Flux 4	441
Flux 5	480
Flux 6	500

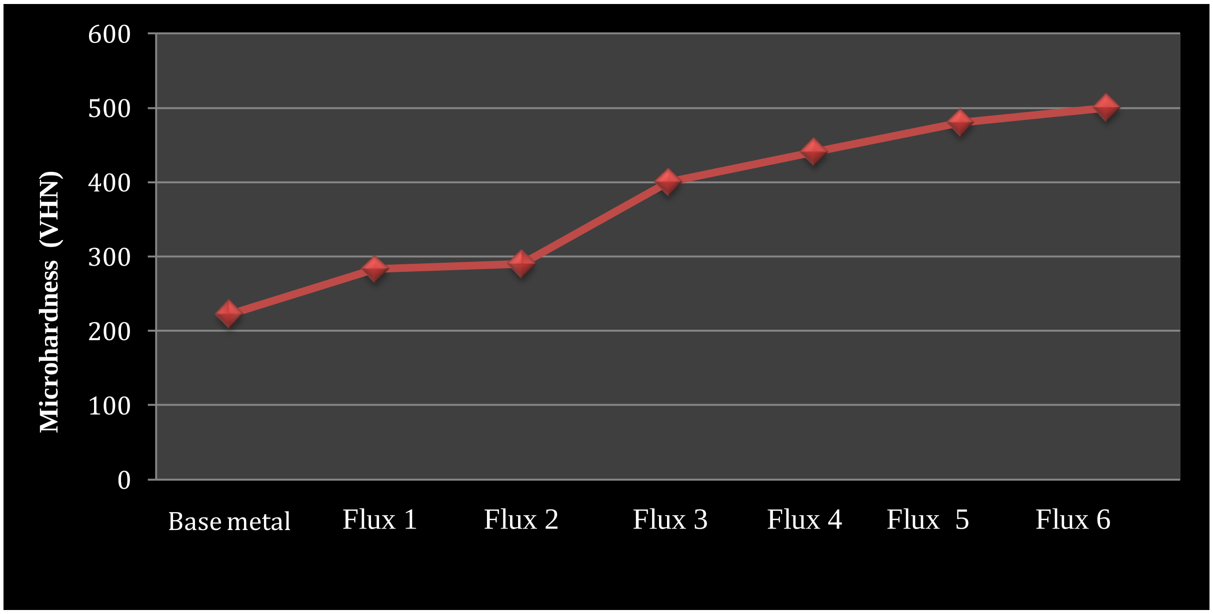


Fig. 5.2 Micro Hardness Vs Ferrochrome Composition (At welded region)

Discussion of MicroHardness

It is clear from Fig. 5.2 that microhardness values are increasing uniformly. It can be seen that the hardness level increases as percentage of ferrochrome (5% to 15%) increases. The maximum micro hardness on weld centre is observed for flux 6.

5.1.3 Wear Test Analysis

The organisation for Economic Cooperation and Development (OECD) defined wear as: “The progressive loss of substance from the operating surface of a body occurring as result of relative motion at the surface. Also it is damage to a surface as a result of relative motion with respect to another surface under load in dry conditions. The wear tests were conducted in normal atmospheric conditions. Before the wear test, all the specimens taken for analysis were cleaned with acetone and the weighed using a digital electronic balance with an accuracy of ±0.1 mg. Specimens were in the form of cylindrical pin of 8 mm dia and 30 mm length was used. The wear test was carried out at 800 rpm with an applied load of 70 kg for 5 to 35 minutes duration as shown in Table 5.4.During sliding, the load was applied on the specimen through cantilever mechanism and the specimens brought in intimate contact with the rotating disc at a track radius of 100 mm. After completion of wear test, the specimen was removed, cleaned by acetone and dried at room temperature, then weighed to measure the weight loss and expressed in terms of volume loss per unit sliding distance. Table 5.4 shows the experimental results of wear tests conducted on all the specimens.

Table 5.4 Data of Wear Loss of Welding Sample (pins)

Time period (sec)	Wear loss of B1 Base metal	Wear loss of S1	Wear loss of S2	Wear loss of S3	Wear loss of S4	Wear loss of S5	Wear loss of S6
300	0.14	0.035	0.032	0.030	0.028	0.023	0.020
600	0.13	0.034	0.032	0.030	0.028	0.023	0.020
900	0.13	0.034	0.031	0.029	0.027	0.022	0.019
1200	0.12	0.033	0.030	0.029	0.026	0.021	0.018
1500	0.12	0.032	0.030	0.028	0.025	0.021	0.018
1800	0.11	0.032	0.029	0.028	0.025	0.020	0.017
2100	0.11	0.032	0.029	0.27	0.024	0.019	0.017

B1 = Base Metal Pin
S1 = Welding Specimen Pin 1
S2 = Welding Specimen Pin 2

S3 = Welding Specimen Pin 3
S4 = Welding Specimen Pin 4
S5 = Welding Specimen Pin 5
S6 = Welding Specimen Pin 6

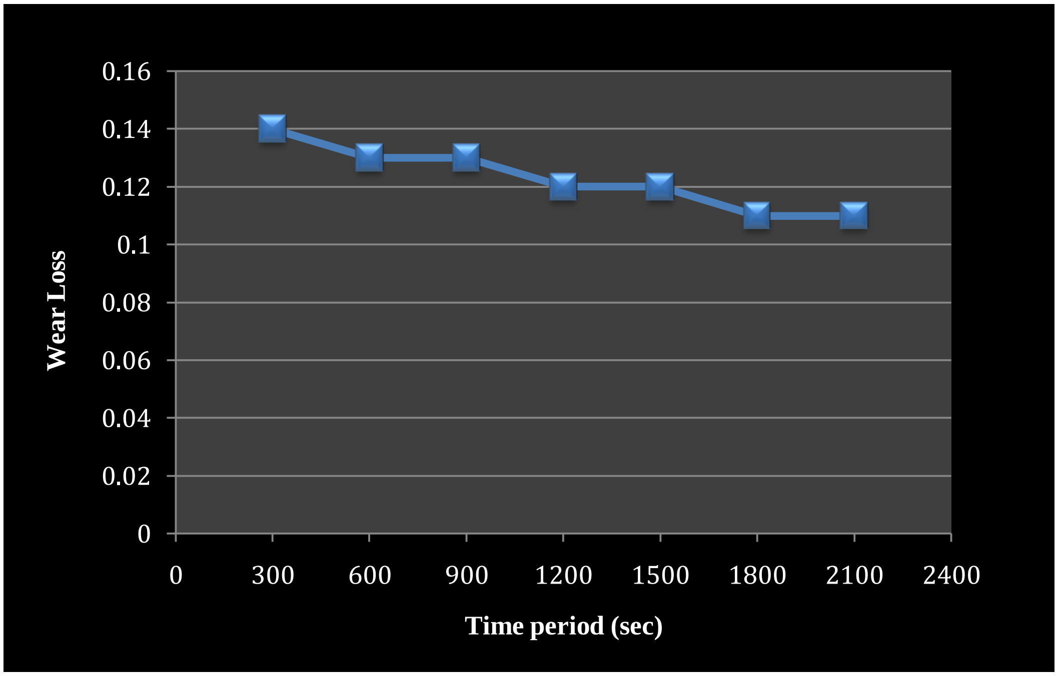


Fig. 5.3 (a) Wear Loss of Base Metal w.r.t Time Period

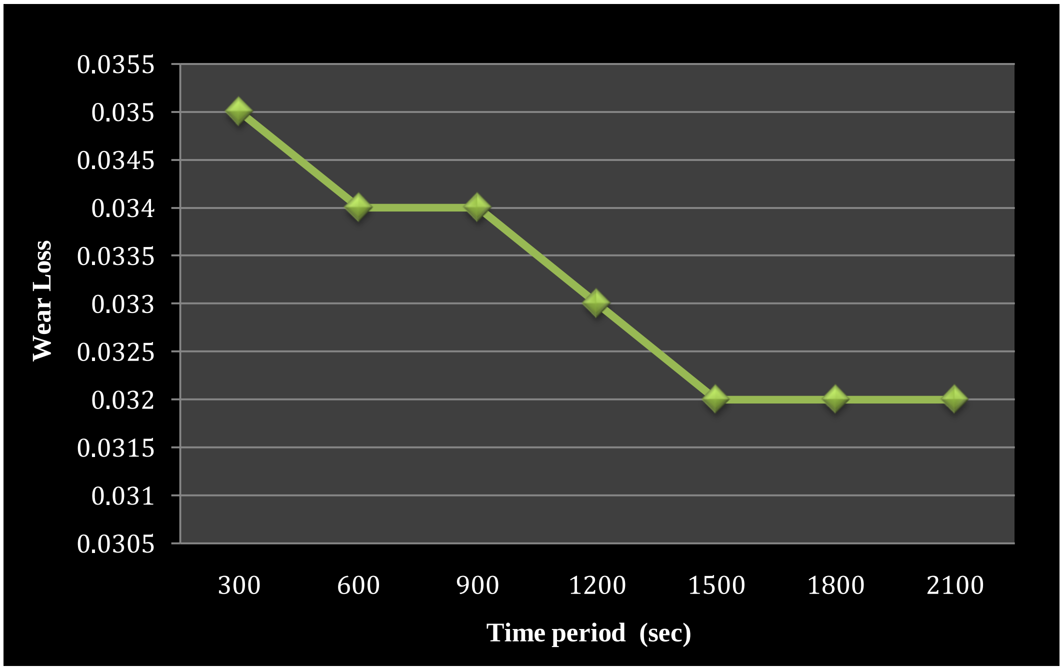


Fig. 5.3 (b) Wear Loss of Welding Pin (S1) w.r.t Time Period

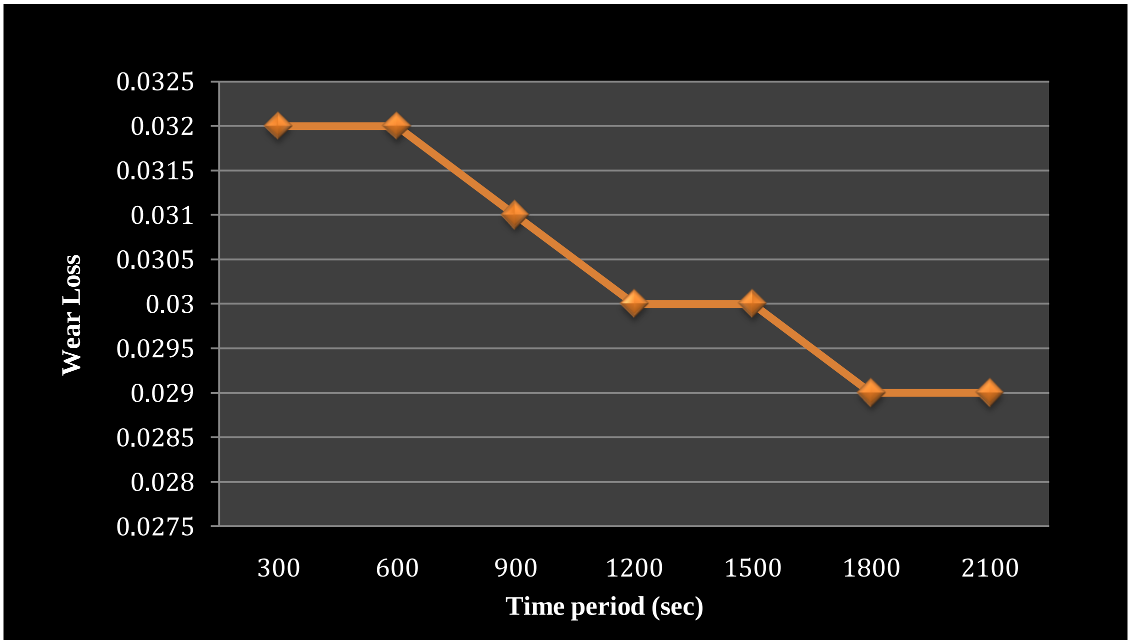


Fig. 5.3 (c) Wear Loss of Welding Pin (S2) w.r.t Time Period

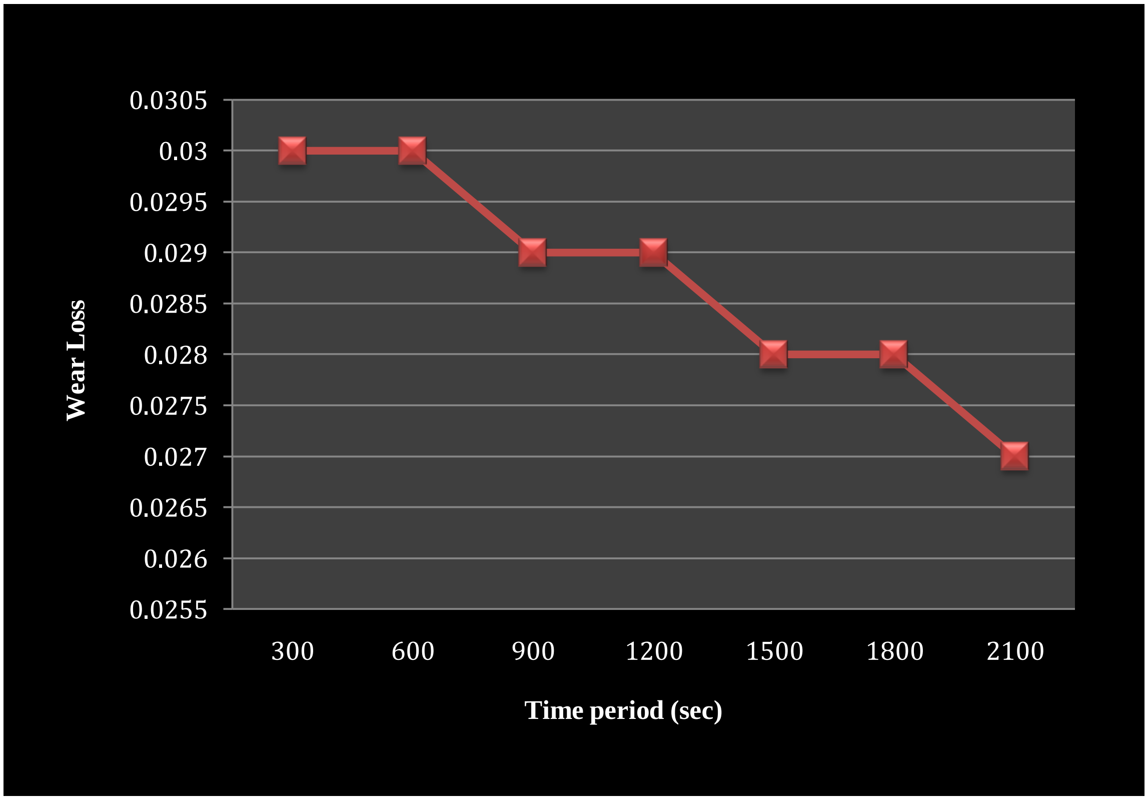


Fig. 5.3 (d) Wear Loss of Welding Pin (S3) w.r.t Time Period

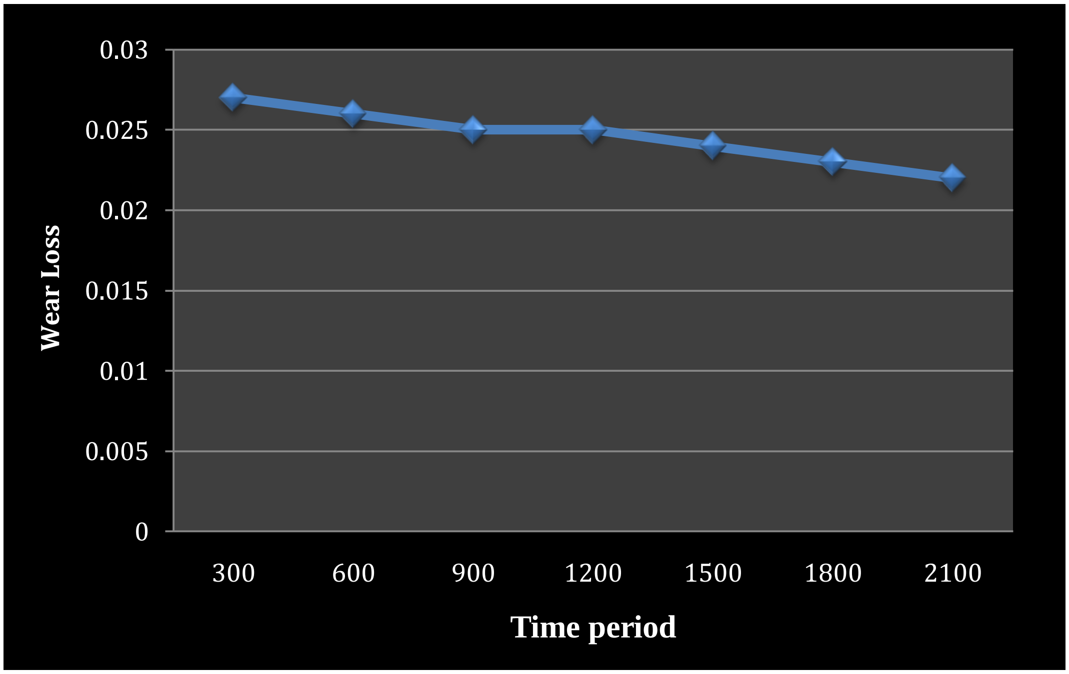


Fig. 5.3 (e) Wear Loss of Welding Pin (S4) w.r.t Time Period

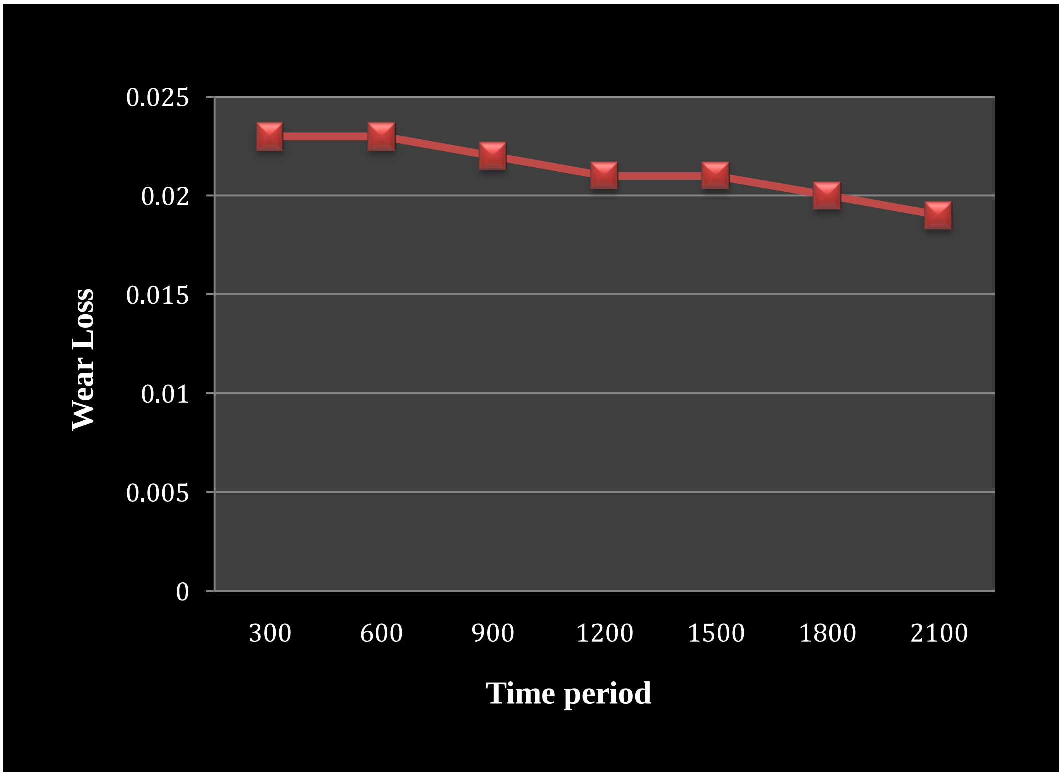


Fig. 5.3 (f) Wear Loss of Welding Pin (S5) w.r.t Time Period

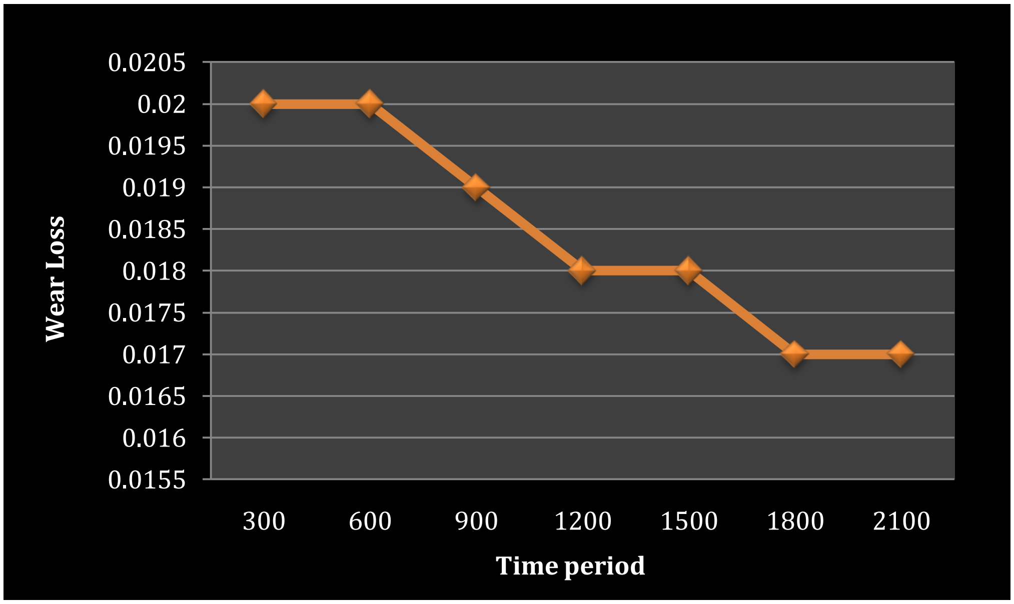


Fig. 5.3 (g) Wear Loss of Welding Pin (S6) w.r.t Time Period

Discussion of Wear Test

The graphs were plotted for percentage of wear loss with respect to time period. The result shows that (Fig. 5.3(a)) the wear loss for 300 sec time period is maximum and continuously goes on decreasing with increase in time as the percentage of Cr (3.5% to 16.5%). Wear loss has been decreased by addition of Cr (3.5%) as compared to base metal. After 1500 seconds the wear loss becomes constant (Fig. 5.3 (b)). All the specimens have nearly same trend (decreasing) of wear loss. From Fig. 5.3 (a-g), it can be seen that wear loss is continuously goes on decreasing with time and with increase of percentage of chromium. This all is because of Cr which is wear resistant substance.

5.1.4 Chemical Composition Results

The measured chemical composition of coatings is listed in Table 5.5 and 5.6. A steady increase in weld metal silicon concentration is observed. In other elements (carbon, manganese & chromium) there is sudden increase or decrease in a weld metal. It is due to sensitivity of these elements to oxidation and welding parameter that cannot be adjusted accurately in SMAW technique.

Table 5.5 Percentage Composition and Change in Percentage Composition

Flux	%age of Carbon in weld metal	%age of Carbon in electrode	%age change in Carbon	%age of Mn In weld metal	%age of Mn in electrode	%age change in Mn
Base metal	0.221	0.02	[(0.221-0.02)/0.02]*100=1005	0.490	0.3	[(0.490-0.3)/0.3]*100=63.3
Flux 1	0.145	0.02	[(0.145-0.02)/0.02]*100=625	1.180	0.3	[(1.180-0.3)/0.3]*100=293.3
Flux 2	0.180	0.02	[(0.180-0.02)/0.02]*100=800	1.140	0.3	[(1.140-0.3)/0.3]*100=280
Flux 3	0.345	0.02	[(0.156-0.02)/0.02]*100=1625	0.510	0.3	[(0.510-0.3)/0.3]*100=70
Flux 4	0.754	0.02	[(0.754-0.02)/0.02]*100=3670	1.35	0.3	[(1.35-0.3)/0.3]*100=350
Flux 5	0.198	0.02	[(0.198-0.02)/0.02]*100=890	0.481	0.3	[(0.481-0.3)/0.3]*100=60.33
Flux 6	0.321	0.02	[(0.321-0.02)/0.02]*100=1505	0.851	0.3	[(0.851-0.3)/0.3]*100=183.3

Table 5.6 Percentage of Composition and Percentage Change in Composition

Flux	%age of Silicon in weld metal	%age of Silicon in electrode	%age change in Silicon	%age of Chromium in weld metal	%age of Chromium in electrode	%age change in change in Chromium
Base metal	0.213	0.01	[(0.213-0.01)/0.01]*100=2030	0.08	0.05	[(0.08-0.05)/0.05]*100=60
Flux 1	0.379	0.01	[(0.379-0.01)/0.01]*100=3690	0.489	0.05	[(0.489-0.05)/0.05]*100=878
Flux 2	0.190	0.01	[(0.190-0.01)/0.01]*100=1800	0.467	0.05	[(0.467-0.05)/0.05]*100=834
Flux 3	0.397	0.01	[(0.397-0.01)/0.01]*100=3870	0.669	0.05	[(0.153-0.05)/0.05]*100=1238
Flux 4	0.153	0.01	[(0.153-0.01)/0.01]*100=1430	0.685	0.05	[(0.235-0.05)/0.05]*100=1270
Flux 5	0.450	0.01	[(0.450-0.01)/0.01]*100=4400	0.734	0.05	[(0.345-0.05)/0.05]*100=1368
Flux 6	0.321	0.01	[(0.321-0.01)/0.01]*100=3110	0.987	0.05	[(0.1.23-0.05)/0.05]*100=1874

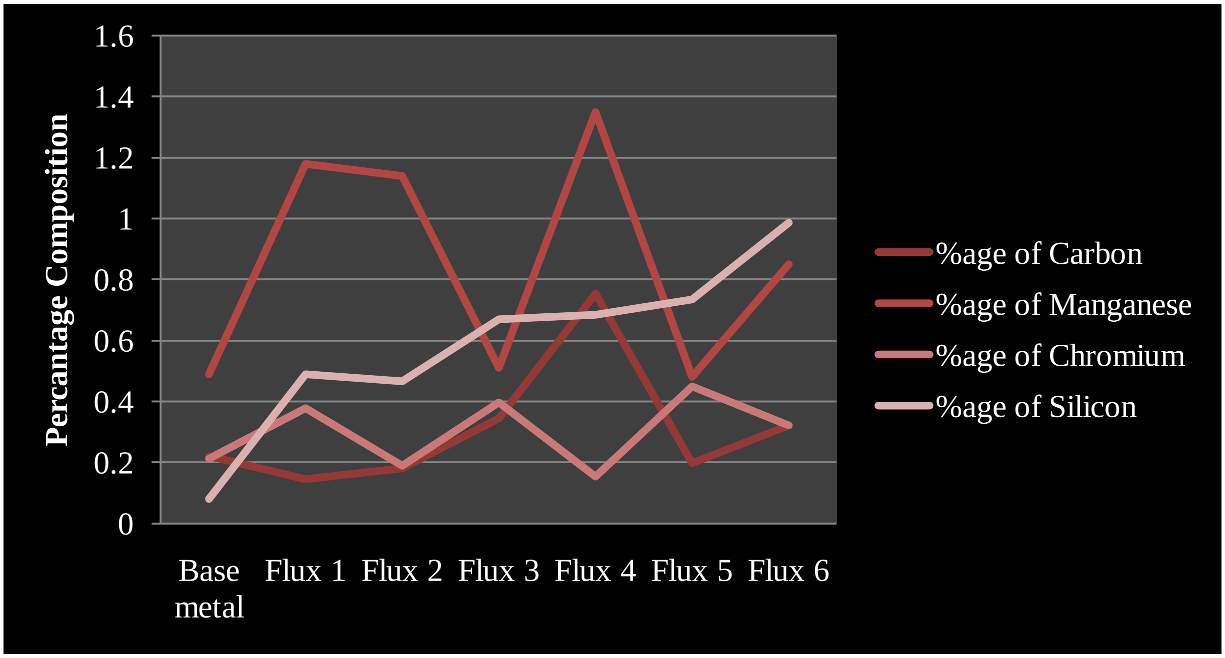


Fig. 5.4 (a) Percentage Composition of C, Mn, Cr, Si in Weld Metal s

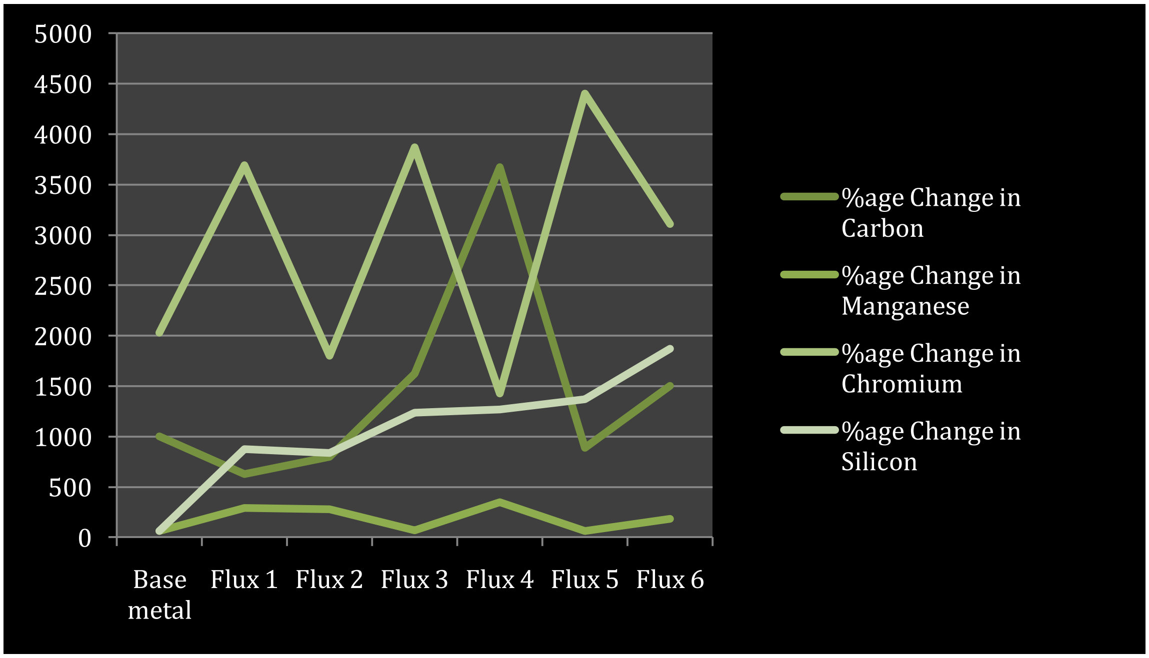


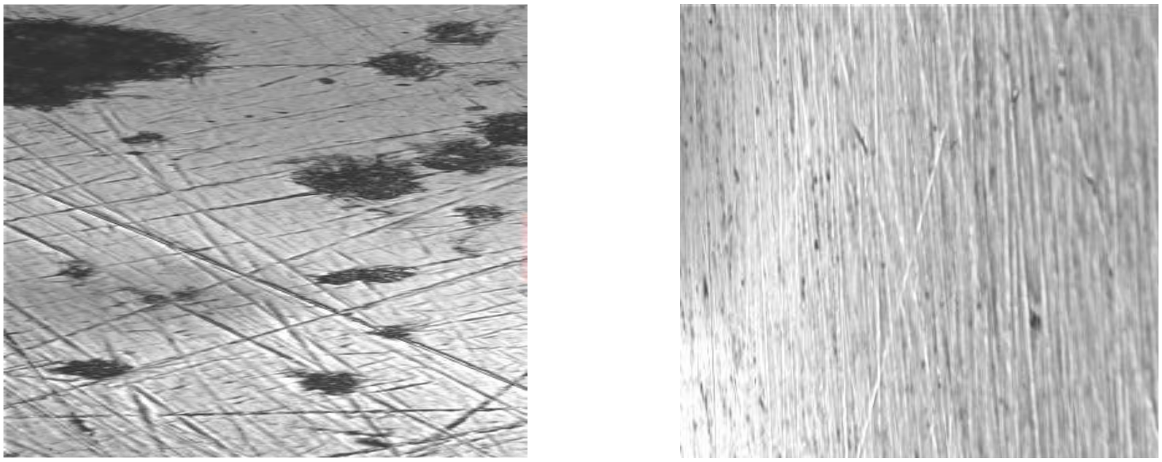
Fig. 5.4 (b) Percentage Change in Composition of C, Mn, Cr, Si in Weld Metal

Discussion of Chemical Composition

The graphs in Fig. 5.4 and Fig. 5.5 show element percentage composition and element percentage change for various compounds in welded region. It is observed that at the weld region there is sudden increase in various elemental compositions such as carbon, manganese, chromium and silicon. This increase was because of elemental diffusion from electrode towards the base metal.

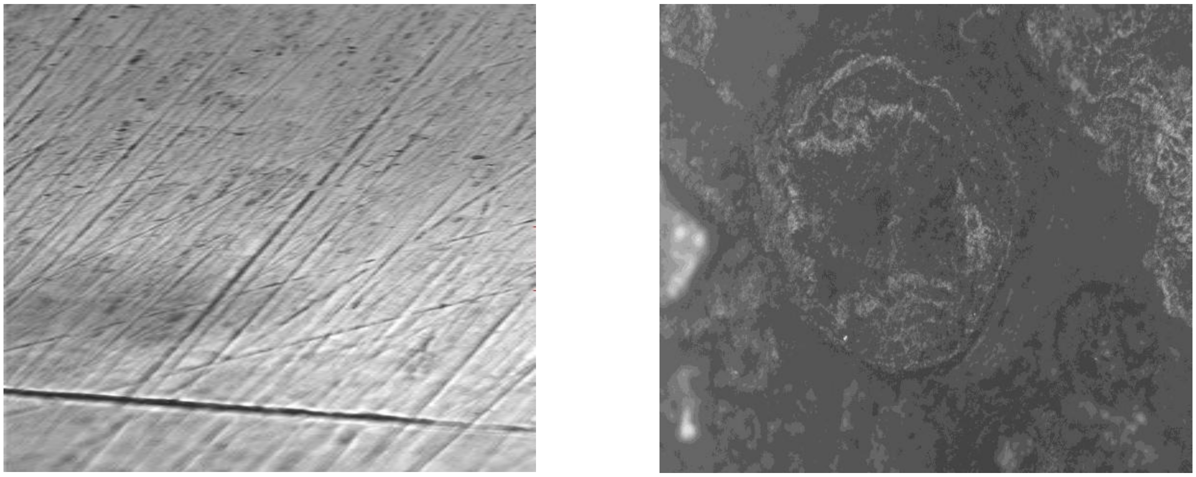
5.1.5 Microstructure Test of Specimens

The welded specimens were prepared metallographically by conventional grinding and polishing. The polished and etched surfaces were examined using an optical microscope and digital micrographs were taken as shown in Fig. 5.5(a) & Fig. 5.5 (b).



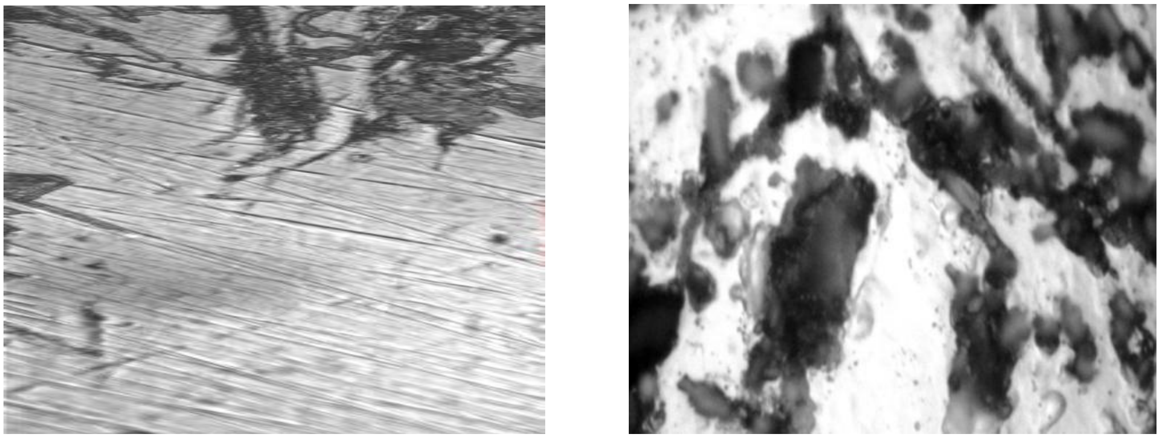
Weld Zone Base Metal

Fig. 5.5 (a) Microscopic Structure of Flux 1 at x 500 Magnifications



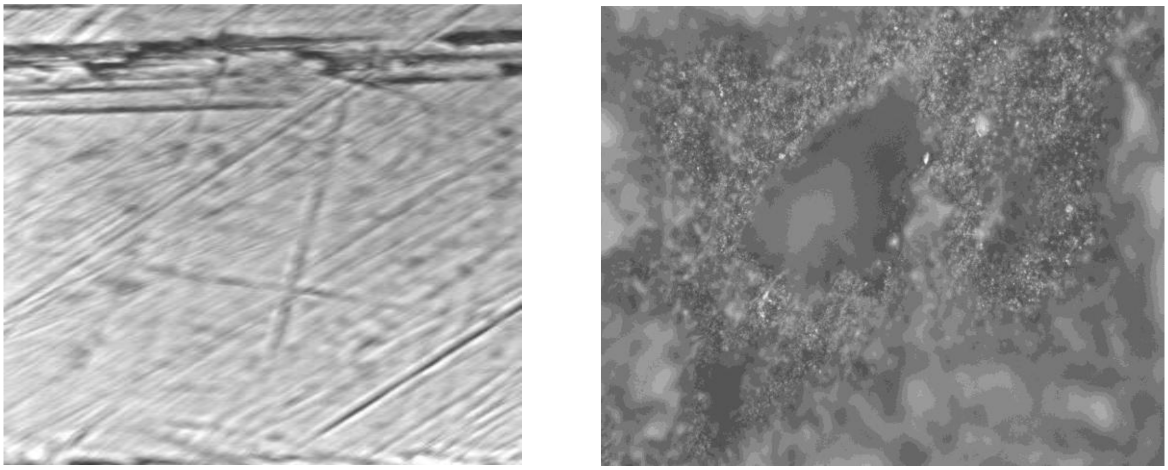
Weld Zone Base Metal

Fig. 5.5 (b) Microscopic Structure of Flux 2 at x 500 Magnifications



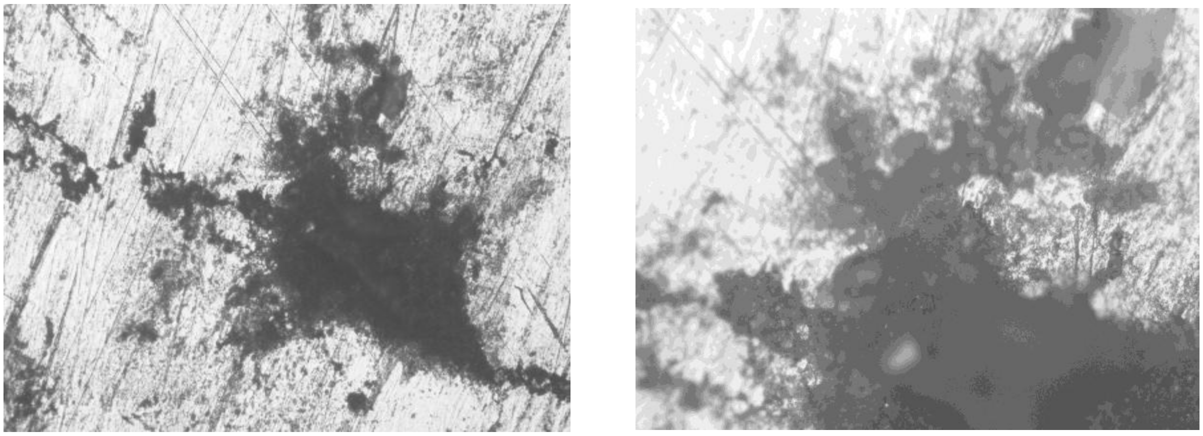
Weld Zone Base Metal

Fig. 5.5 (c) Microscopic Structure of Flux 3 at x 500 Magnifications



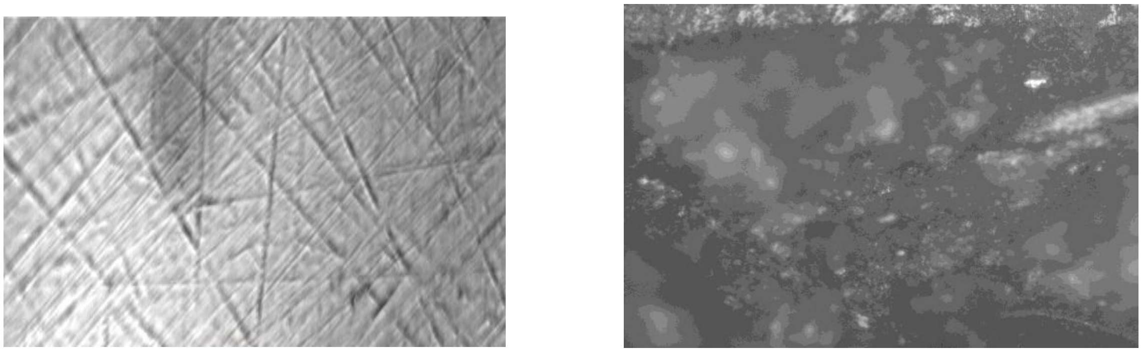
Weld Zone Base Metal

Fig. 5.5 (d) Microscopic Structure of Flux 4 at x500 Magnifications



Weld Zone Base Metal

Fig. 5.5 (e) Microscopic Structure of Flux 5 at x 500 Magnifications



Weld Zone

Base Metal

Fig. 5.5 (f) Microscopic Structure of Flux 6 at x 500 Magnifications

Discussion of Microstructure

The micrograph of the Fig.5.5 (a-f) reveals that there was presence of ferrite - pearlite microstructure. The density of flow lines that banding and morphology of ferrite and pearlite has been found to vary in specimens. The dark regions are the pearlite; it is made up from fine mixture of ferrite and iron carbide, which can be seen as a “wormy” texture. Dark region is not acicular. The light coloured region of the microstructure is the ferrite. The pearlite has a very fine structure, which makes the steel very hard. Unfortunately this also makes the steel quite brittle and much less ductile then mild steel. Some of the micrographs show ductility of the material. There was a deformation of the specimen and the grains in the microstructure fail by void formation as the metal flows around hard particles in the microstructure. This is also known as micro void coalescence. Voids as a dimple can be seen in under high magnification. This absorbs a lot of energy and toughness is high.

5.1.6 Scanning Electron Microscope

Followings are the results of SEM of different welded specimens by scanning it with a high-energy beam of electrons.

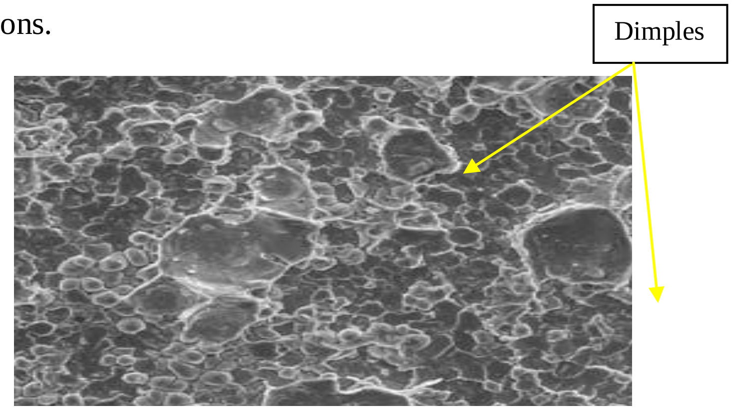
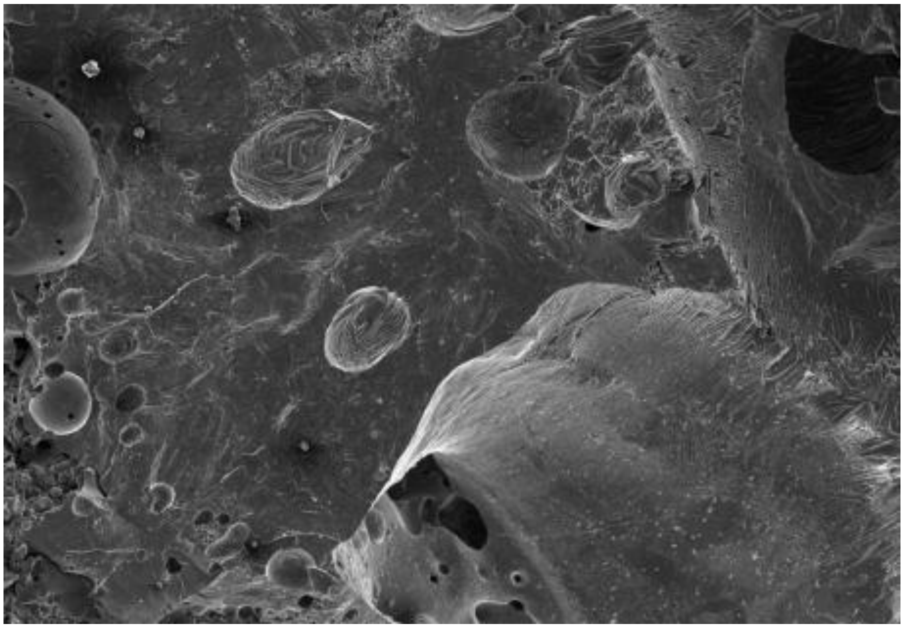
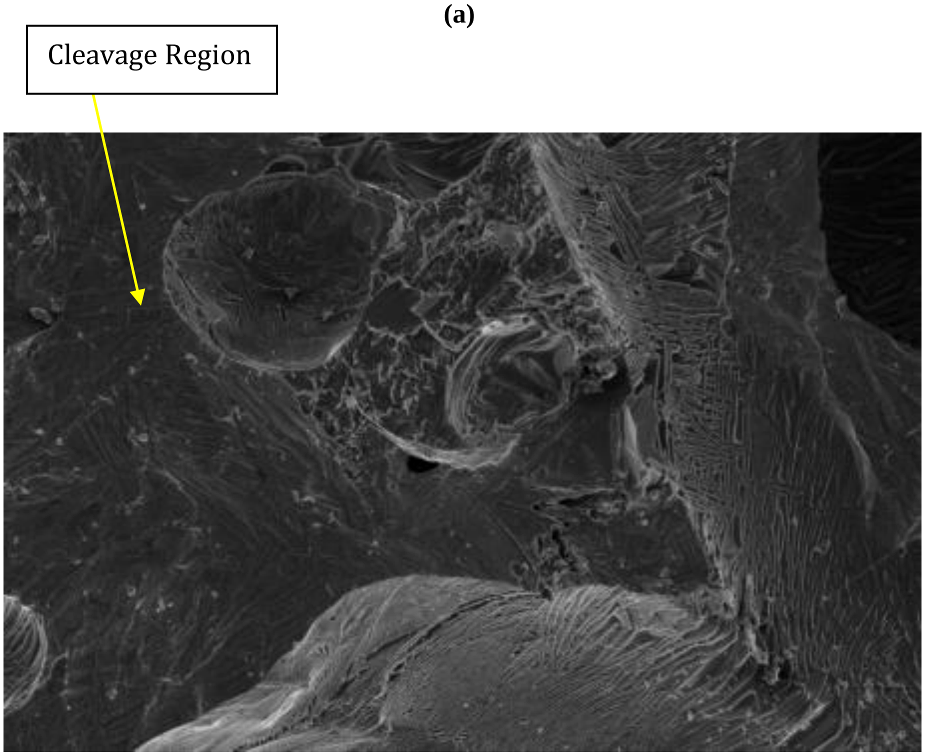


Fig. 5.6 SEM Measurement at x1000 Magnification for Base Metal Specimen on Fractured Surface

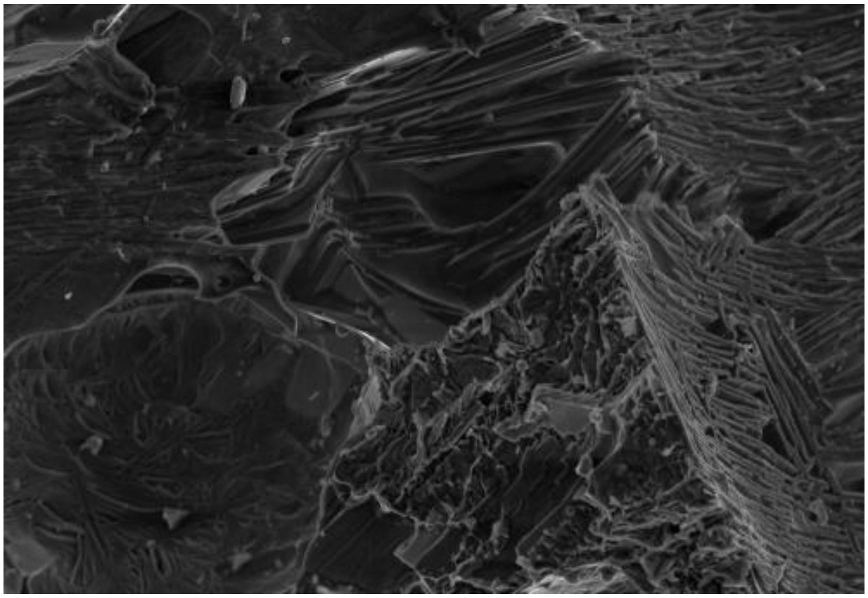


(a)



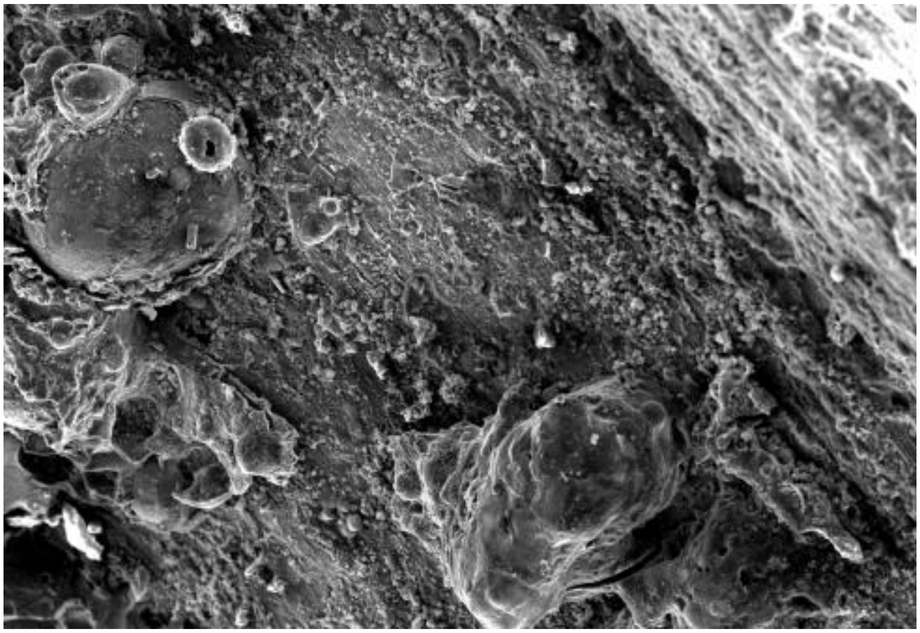
Cleavage Region

(b)

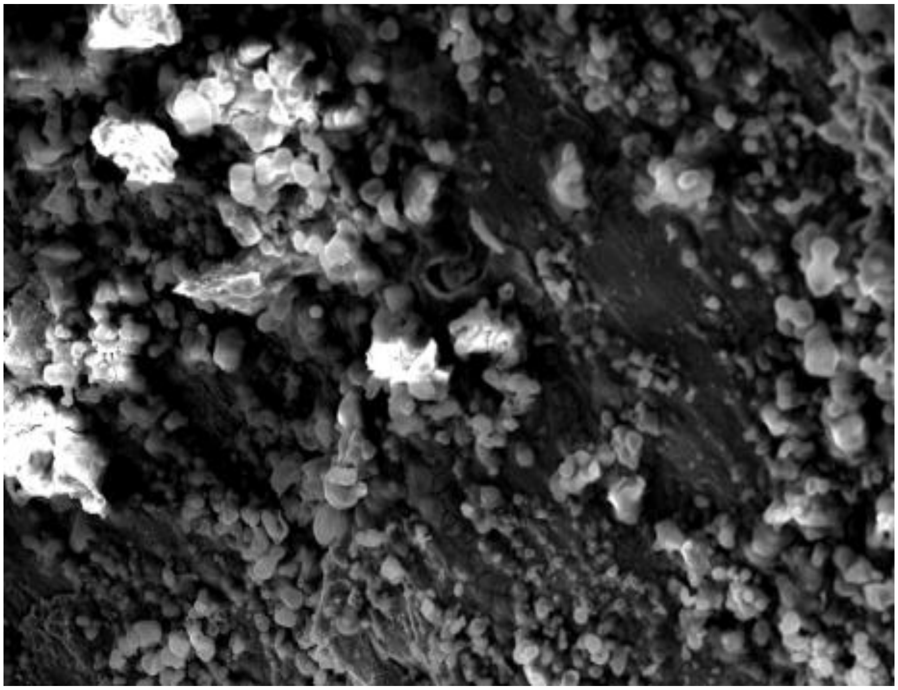


(c)

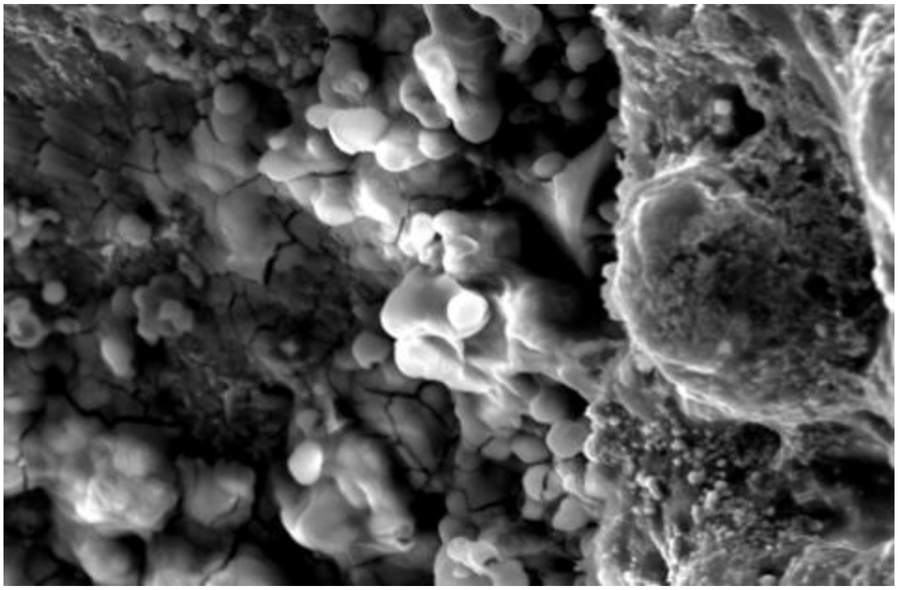
Fig. 5.7 (a, b, c) SEM Measurement at x50, 100, 1000 Magnification for Flux 1 on Fractured Surface



(a)

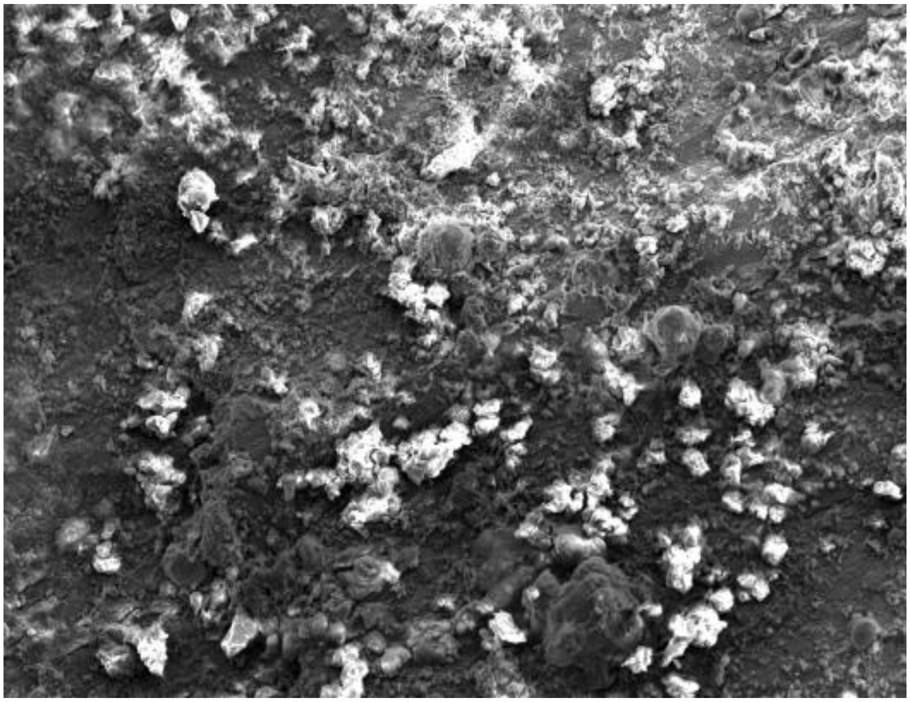


(b)

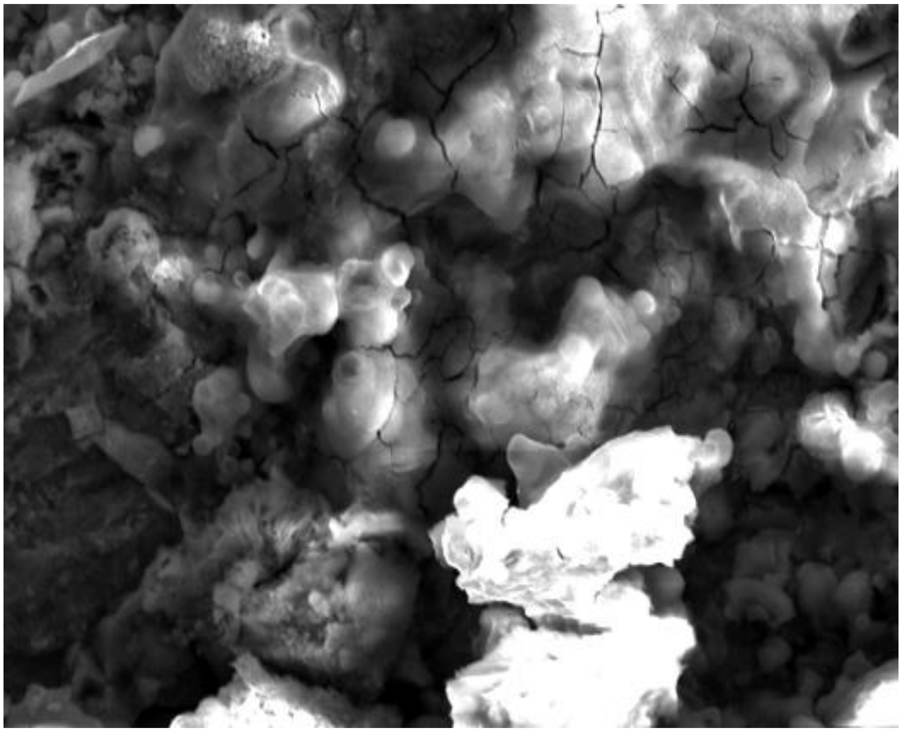


(c)

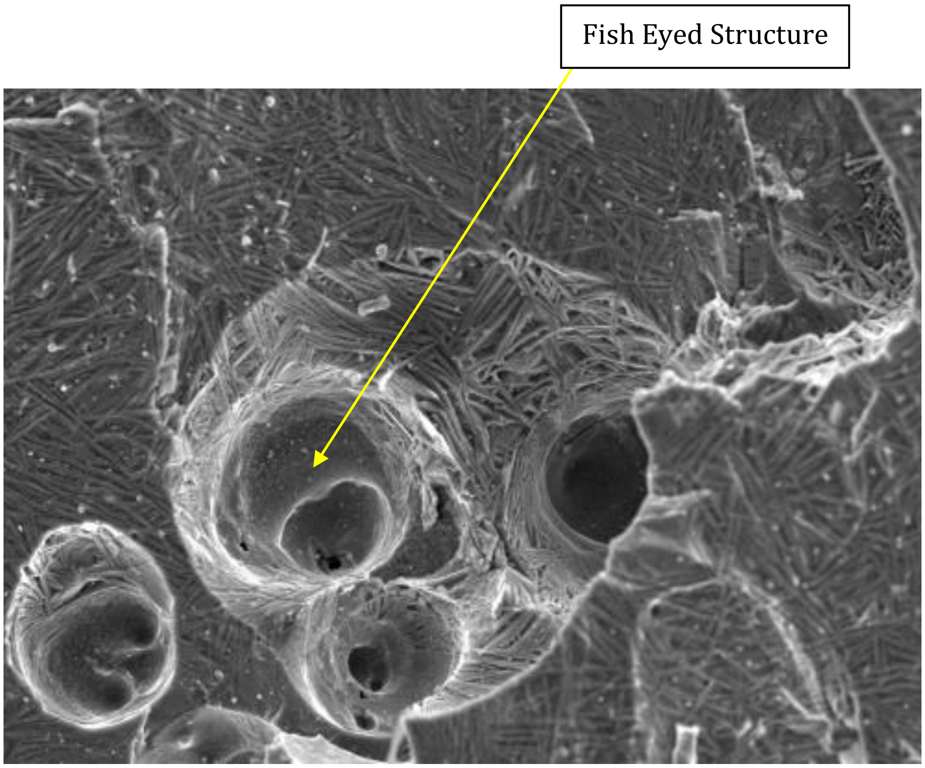
Fig. 5.8 (a, b, c) SEM Measurement at x100, 500, 1000 Magnification for Flux 2 on Fractured Surface



(a)



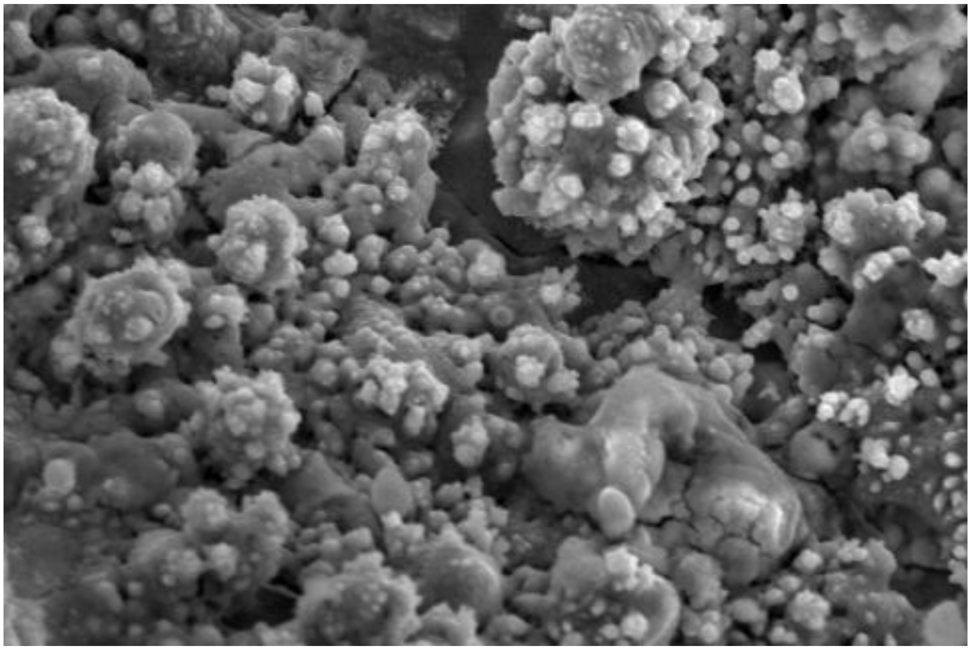
(b)



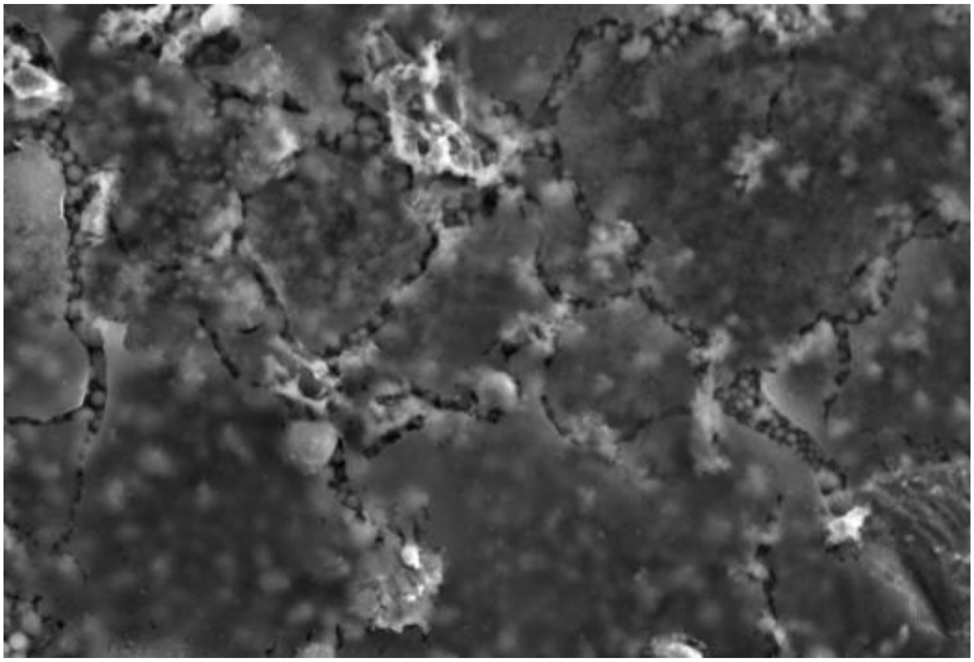
(c)

Fig. 5.9 (a, b, c) SEM Measurement at x100, 500, 1000, Magnification for Flux 3 on Fractured Surface

(a)

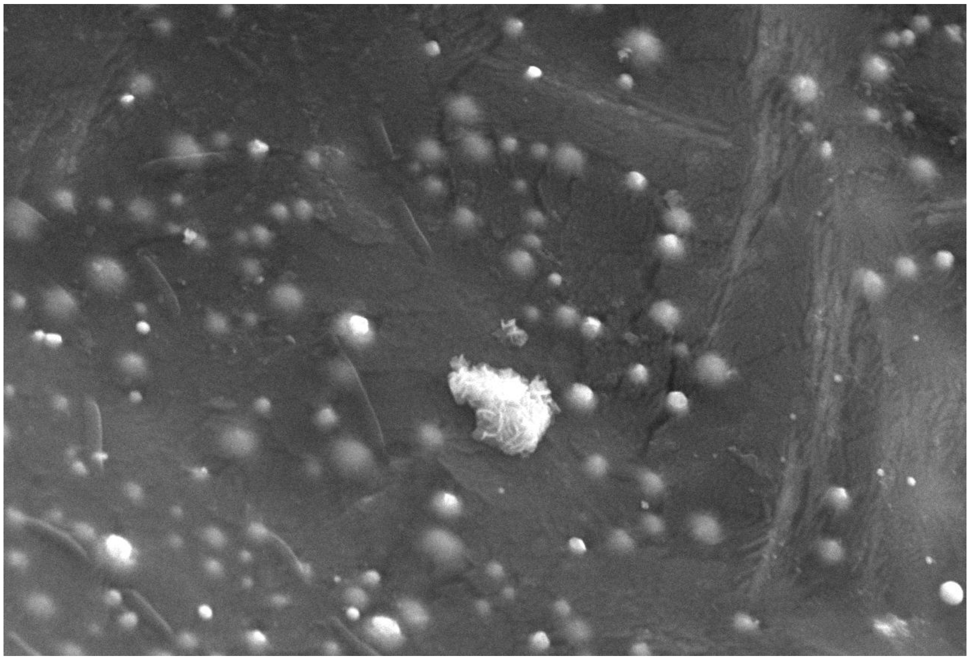


(b)

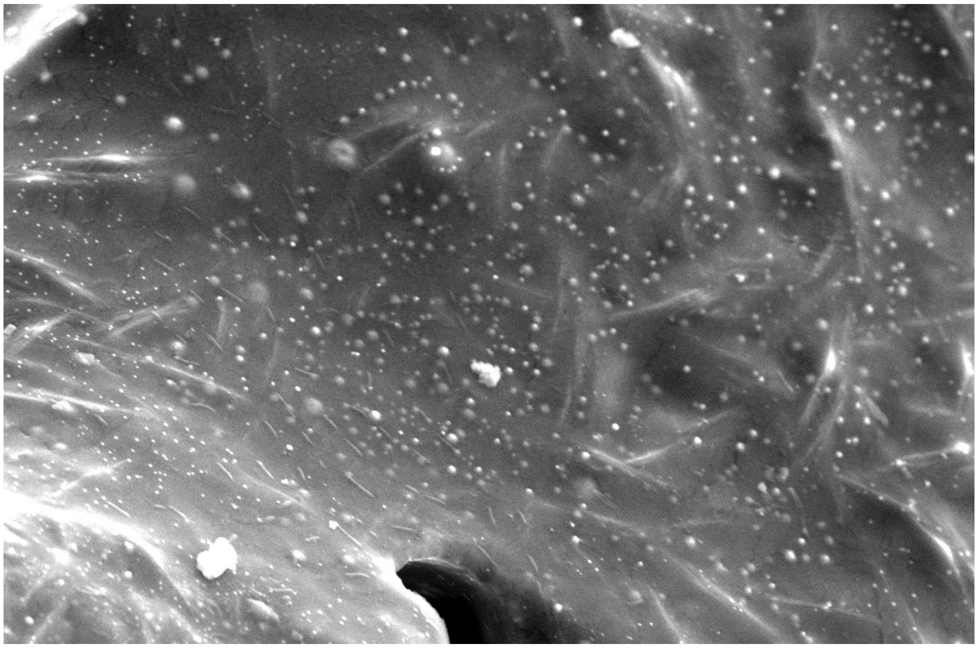


(c)

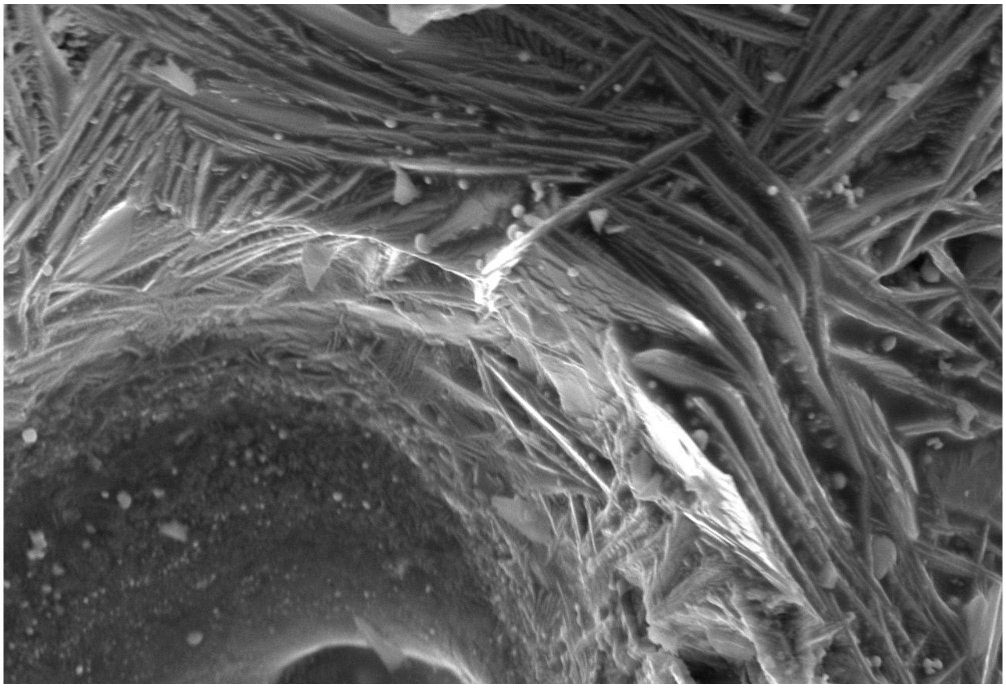
Fig. 5.10 (a, b, c) SEM Measurement at x100, 500, 1000 Magnification for Flux 4 on Fractured Surface



(a)

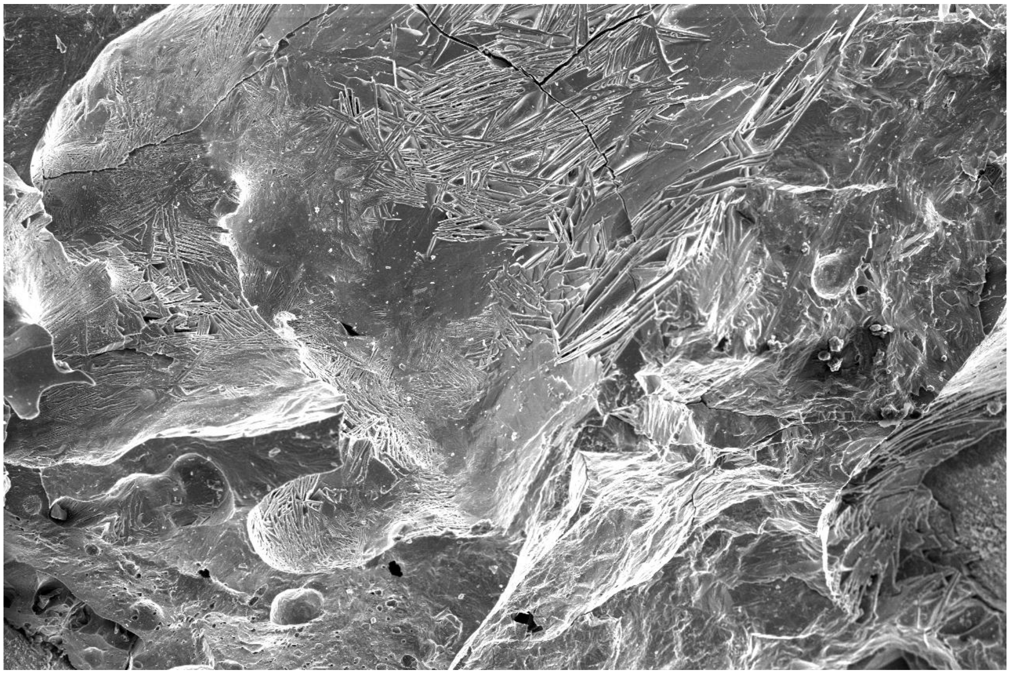


(b)

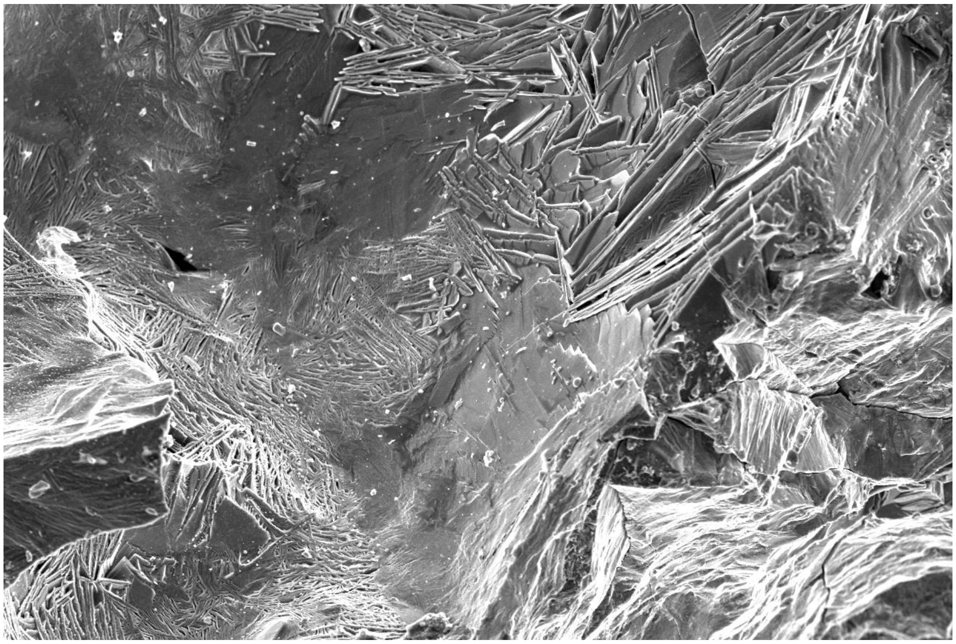


(c)

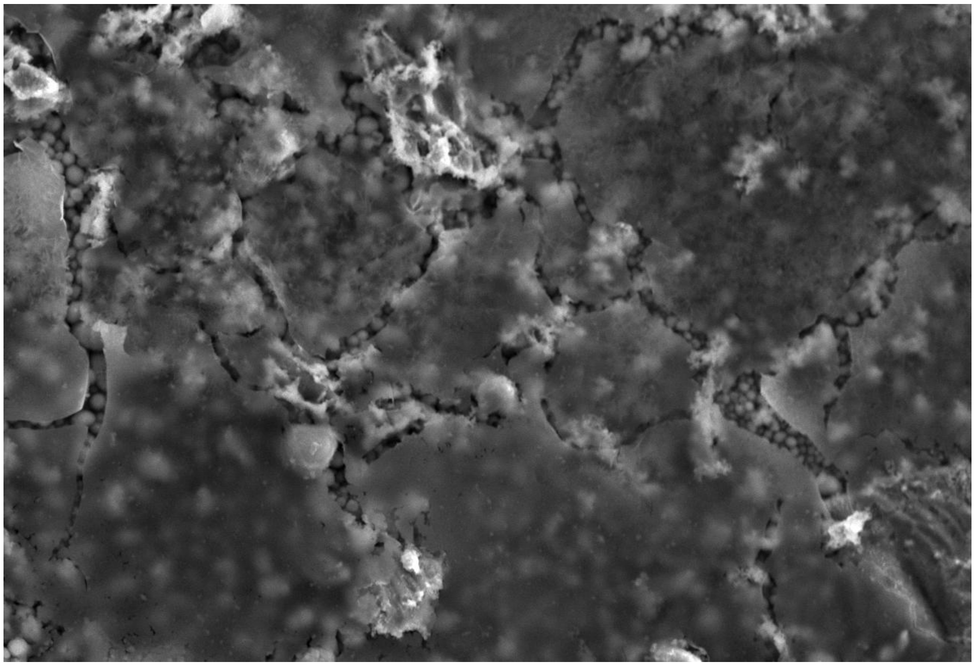
Fig. 5.11 (a, b, c) SEM Measurement at x100, 500, 1000 Magnification for Flux 5 on Fractured Surface



(a)



(b)



(c)

Fig. 5.12 (a, b, c) SEM Measurement at x100, 500, 1000 Magnification for Flux 6 on Fractured Surface

Discussion of SEM

SEM fractograph Fig. 5.7 shows the ductility of material. Dimples can be seen very clearly in the micrograph which makes the toughness high. In some fractographs cleavage can also be seen in which grains in the microstructure fail along certain crystal planes which makes the material brittle results in brittle fracture. Fig. 5.9 shows Fish Eyed Structure.

CHAPTER 6 CONCLUSION AND FUTURE WORK

- ✓ As Cr increased, the wear resistance in the weld has increased in specimen no. 3, which was hardfaced using modified electrode.
- ✓ As a result of increase in Cr from 3.5% to 8.5 %, and Ferrochrome 5% to 15% respectively, the hardness increases due to the formation of chromium carbide at the grain boundary.
- ✓ Due to increase in Cr value, there was also a progressive refinement in the grains of the welded layers, this has been observed from the microstructure photographs.
- ✓ Presence of cleavage can be seen in SEM micrographs which indicate brittle fracture. In some of micrographs dimples can be seen which results in ductile fracture.

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

- ✓ Compounds and their percentages can be varied to see the effect of variation on wear behaviour and hardness level.

- ✓ Chromium can be replaced by other hardfacing alloys Vanadium, Molybdenum, Boron, Titanium etc.
- ✓ High carbon or medium carbon steels can be used for welding.
- ✓ Post weld heat treatment can be done to improve grain refinement.

REFERENCES

1. www.wikipedia.com
2. www.Job Knowledge for welders2.com
3. www.google.com
4. U. Mitra and T.W. Eagar
5. www.ewf.com
6. www.welding-advisors.com
7. www.hardfacingweb.com
8. www.engineers.org

9. M.F. Buchely, J.C. Gutierrez, L.M. Leon, A. Toro, “The effect of microstructure on abrasive wear of hardfacing alloys”. *Wear,* 259, 52-61, 2005.

10. Yilmaz Bayhan, “Reduction of wear via hardfacing of chisel ploughshare”. *Tribology International*, 39, 570–574, 2005.

11. Amado Cruz Crespo, Americo Scotti, Manuel Rodriguez Perez,“Operational behaviorassessment of coated tubular electrodes for SMA hardfacing”. *Journal of Material Processing Technology*, 199, 265-273, 2007.

12. Kemal Yildizli , Mehmet Eroglu , M. Baki Karamis, “Microstructure and erosive wear behavior of weld deposits of high manganese electrode”.*Surface & Coatings Technology*, 201, 7166–7173, 2007
.

13. V.E. Buchanan b, D.G. McCartney a, P.H. Shipway, “A comparison of the abrasive wear behaviour of iron-chromium based hardfaced coatings deposited by SMAW and electric arc spraying”. *Wear*, 264,542–549, 2007.

14. Fernando Casanova, Yesid Aguilar, “A study on the wear of sugar cane rolls”. *Wear,* 265, 236–243, 2007.

15. Xinhong Wang , Fang Han , Xuemei Liu , Shiyao Qu , Zengda Zou,“Microstructure and wear properties of the Fe–Ti–V–Mo–C hardfacing alloy”. *Wear,* 265, 583–589, 2007.

16. S.Selvi, S.P.Sankaran, R.Srivatsavan, “Comparative study of hardfacing of valve seat ring using MMAW process”. *Journal of Materials Processing Technology* 2 0 7, 356–362, 2008.

17. M. Kirchgabner, E. Badisch , F. Franek, “Behaviour of iron-based hardfacing alloys under abrasion and impact”. *Wear,* 265, 772–779,2008.

18. Z. Horvat, D. Filipovic, S. Kosutic, R. Emertc, “Reduction of mouldboard plough share wear by a combination technique of hardfacing”. *Tribology International*, 41, 778–782, 2008.

19. A.H. Jones, P. Roffey, "The improvement of hard facing coatings for ground engaging applications by the addition of tungsten carbide". *Wear,* 267, 925– 933, 2009.

20. Mehmet Eroglu, "Boride coatings on steel using shielded metal arc welding electrode: Microstructure and hardness". *Surface & Coatings Technology*, 203, 2229-2235, 2009.

21. M. Balakrishnan V. Balasubramanian , G. Madhusuhan Reddy , K. Sivakumar, "Effect of buttering and hardfacing on ballistic performance of shielded metal arc welded armor steel joints". Materials *and Design* 32, 469– 479, 2009.

22. Renzo Victoria Prado, Beatriz Uquillas, Jose Y. Aguilar,Yesid Aguilar, Fernando Casanova, "Abrasive wear effect of sugarcane juice on sugarcane rolls". *Wear*, 270, 83–87, 2010.

23. R. Arabi Jeshvaghani , E. Harati , M. Shamanian, "Effects of surface alloying on microstructure and wear behavior of ductile iron surface-modified with a nickel-based alloy using shielded metal arc welding". *Materials and Design*, 2010.