DISSERTATION REPORT

ON

MICROSTRUCTURE & MECHANICAL PROPERTIES OF DUPLEX 2209 ON LOW CARBON STEEL SUBSTRATE USING ESSC PROCESS.

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

(Spl. in Manufacturing Technology)

To

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MAY, 2015

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CERTIFICATE

This is certify that the thesis report entitled "Microstructure & Mechanical properties of Duplex 2209 over Low carbon steel substrate using ESSC process". Being submitted by Mr. Harinder Singh Bedi to Lovely Professional university, Phagwara, Punjab, in partial fulfillment of the requirement for the award of the Degree of Master of Technology (Spl. in Manufacturing Technology) is a record of student's own work carried my supervision and guidance.

This thesis work is of desired standard and has not been submitted in any other University or Institution for the award of any other Degree.

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CANDIDATE'S DECLARATION

I, Harinder Singh Bedi , hereby certify that the work, which is being presented in the thesis, entitled **"Microstructure & Mechanical properties of Duplex 2209 over Low carbon steel substrate using ESSC process".** In partial fulfillment of requirement for the award of Degree of Master of Technology (Spl. in Manufacturing Technology) submitted in the Department of Mechanical Engineering at Lovely Professional University, Punjab, is an authentic record of my own work carried out during a period from August 2014 to May 2015 under the supervision of Mr. Hitesh Arora (Assistant Professor). The matter presented in this thesis has not been submitted to any other University/ Institute for the award of Master of Technology Degree.

Signature of the student

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Finally, I would like to take this opportunity to express my gratitude to my family members for their love, unfailing encouragement and support, specially my parents.

Date:

Place: LPU, PUNJAB. Harinder Singh Bedi

Abstract

In the modern world of industrialization the wear is eating metal assets worth millions of dollars per year. The wear is in the form of corrosion, erosion, abrasion etc. which occur in the process industries like oil & gas, refineries, cement plants, steel plants, shipping and offshore working structures. The equipments like pressure vessels, heat exchangers, hydro processing reactors which very often work at elevated temperatures face corrosion in the internal diameter.

The electro slag strip cladding technique is the modern technique in which a strip electrode is continuously fed into a shallow layer of electrically conductive flux. The heat required to melt the strip, the slag forming flux and the surface layer of the base metal is generated by resistance heating due to the welding current flowing through the molten conductive slag. The use of a conductive slag and resistance heating instead of an electric arc permits higher current densities to be used in ESSC without increasing penetration.

In the present work it includes cladding of high strength alloy Duplex 2209 used to develop overlay on SA 516 Grade 70 low carbon steel using S.S 309 as buffer layer and then top layer of duplex 2209. The developed deposits were characterized by Field emission Scanning Electron Microscope (FESEM), Energy Dispersive X-Ray Spectroscope, X-Ray Diffraction and measurement of Vickers hardness. To determine ferrite content in the clad deposits Fisher ferrite-scope MP30 is used. The result shows the black etching layer in substrate near fusion zone which resembles carbon depletion zone. The vermicular austenite forms in buffer layer where as in top layer chromium carbide also find along with ferrite-austenite phases.

Key Words: Electro lag strip cladding, Mechanical Properties, Microstructure, Micro hardness, Duplex 2209, Corrosion resistant alloys, FESEM, XRD, EDS

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Nomenclature and Abbreviations

SS	Stainless steels
DSS	Duplex Stainless Steel
ESSC	Electro Slag Strip Cladding
HAZ	Heat affected zone
FCAW	Flux cored Arc Welding
SASC	Submerged Arc Strip Cladding
CRA	Corrosion Resistant Alloy
fcc	Face centred cubic
bcc	Body centred cubic
IGC	Inter-granular corrosion
SCC	Stress corrosion cracking
IGSCC	Inter-granular stress corrosion cracking
U.T.S	Ultimate tensile strength
Y.S	Yield strength
MPa	Mega Pascal
DCEN	Direct current electrode negative
DCEP	Direct current electrode positive
AC	Alternating current
Q	Heat input
I	Welding current
S	Welding Speed

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Chapter 1
Introduction

1.1 Cladding

Cladding is a welding process in which a material with desired properties is deposited on the surface of a base material. The common C/Mn or low alloyed inexpensive base metal has mainly a load carrying function. The deposited sophisticated material imparts surface properties such as corrosion resistance; wear resistance, etc., to the substrate. To the manufacturer of pressure vessels, surfacing techniques are getting more and more important. Components reach sizes such that their fabrication calls upon the use of clad materials.

There are different processes to obtain a clad material:

- Clad plates produced by rolling which are mostly only available in standardized dimensions and grades
- Explosion clad plates
- Clad plates made by welding

Further Clad Plates made by welding can be done using various techniques:-

- Submerged arc welding (Wire electrode)
- Submerged arc welding (Twin Wire electrode)
- Submerged arc welding (Strip Electrode)
- Electro slag strip welding
- Shielded metal arc welding
- Flux cored arc welding

Among all the welding processes submerged arc and electro slag strip cladding offer maximum deposition rate, better bead characteristics and trouble free operation using unsophisticated welding equipment’s. Duplex stainless steel is a type of S.S which has some unique properties due to its microstructure. It contains ferrite (α) and austenite (γ) almost in same proportion due to which it exhibits unique mechanical and corrosion resistance properties [1-3]. Duplex stainless steel has higher toughness, strength, weldability and corrosion resistance as compared to other class of steels like austenitic and ferritic. High strength and corrosion resistance is imparted by ferrite phase whereas ductility and resistance to uniform corrosion is sustained by austenite. The problem with DSS arises when it is subjected to high temperature. It results in the imbalance of ferrite and austenite phase in DSS which is its basic strength. When heated up to 650-900°C precipitation of austenite (γ), sigma (б) and chi (א) phases takes place. Proper heat treatment helps us to retain the α/γ ratio. On annealing it reveals that the ferrite is higher in Heat affected zone (HAZ) while austenite is maximum at center zone of weld. Precipitation of sigma б phase chromium carbides at α/γ interface which are found to act as preferential nucleation sites for these precipitation phenomena [4]. The nucleation and growth of carbides results migration of б/γ interface boundary into ferrite phase with pattern of lamellar and larva, having cube-cube orientation relationship with the austenite [5].

DSS is widely used in industries like marine/offshore structures, dry-docks, pressure vessel manufacturing, food, chemical industry and pharmacy etc. Although DSS can be cladded by any fusion process like Shielded metal arc welding (SMAW), Gas Metal Arc welding (GMAW), Flux cored Arc welding (FCAW), Gas Tungsten Arc welding (GTAW), Sub-Merged Arc Welding (SAW), Sub-merged arc strip cladding (SASC) and ESSC (Electro slag strip cladding) but due to its unique properties of high deposition rates, lower dilution level and defect free welding SASC and ESSC are widely used for overlaying process [7,8]. But the influence of welding parameter on cladding definitely effect the performance of cladding in corrosion prone atmosphere like in hydrogen vessels etc[9-12]. Cladding of DSS is also possible by non fusion welding process of explosive welding but it is too costly as compared to other fusion welding processes. The electro-slag and explosively clad joints shows same mechanical and micro structural properties but shear strength and impact toughness is superior in explosively clad joints [13, 14]. To obtain desirable properties addition of metal powders like niobium etc is done. Powders are poured directly over the weld pool along with flux [15-17]. Among all welding processes ESSC is preferred for the current experimental work because there is no arc strike between the strip electrode and the base metal. The current passes through the electro conductive flux which contains Fluorides of calcium and sodium to increase its electrical conductivity. The higher amount of calcium fluoride promoted reduced dilution level and oxygen content which is one third as compared to SASC [9]. The only hindrance in performing ESSC is undercut defect which occur due to electromagnetic blow effect which tends the molten metal pool to coagulate toward centre from sides of molten pool. The defect occurs due to high current passing through the strip electrode. The overcome this problem an external magnetic field is applied in the opposite direction with the help of magnetic steering devices [18-20]

1.2 Material Used

SS 309 and Duplex 2209 is selected for present stainless study steel family therefore attempt is made to describe stainless steels; austenitic stainless steels 309 L and Duplex 2209 in this section of introduction.

1.2.1 Stainless Steel

A small amount of carbon alloyed with iron makes steel. Iron is allotropic in that it exists in at least two distinct crystalline forms, primarily dependent upon temperature. At high temperatures, the face centered cubic (fcc) crystal structure of iron is stable and the term used to describe this phase is austenite. At very high and low temperatures, the body cantered cubic (bcc) structure is the more stable face and is given the name of δ and α ferrite, re high solidification rates the form higher temperature the molten phase.

Stainless steels are classes usually contain from 12 to 27% Cr and 1 to 2% Mn by weight, with the addition of Ni in some grades. A small amount of carbon is also present, either deliberately added or as an unavoidable impurity. In general, they are alloyed with a number of other elements that make them resistant to a variety of different environments. These elements also modify the microstructure of alloy, which in turn has a distinct influence on their mechanical properties and weld ability. Cr provides the basic corrosion resistance to stainless steel. A thin layer of Cr-oxide from on the surface of metal when it is exposed to oxygen of the air. The film act as a barrier to further oxidation, rust and corrosion. Exposure to elevated temperature increases the thickness of the film and reduces the luster of the stainless steel. Stainless steels are extensively used in variety of applications where corrosion resistance is required in combination with good strength and toughness. Stainless steel can be classified into three major categories based on the structure: Ferritic, Martensitic and Austenitic.

1.2.2 Austenitic Stainless Steels 309L type

Among the various classes of stainless steels, the most widely used for welding dissimilar metals is S.S 309L. These steels contain typically 16-25% Cr, 7-20% Ni and less than 0.08% C. For improved corrosion resistance, 2-6% Mo, 0.1-0.2% N and niobium or titanium in the stabilized varieties are added. Austenitic stainless steels are usually the most corrosion resistant of all the stainless steels and generally have low yield strength and high ultimate tensile strength that is why are often very ductile and has excellent properties at cryogenics temperature.

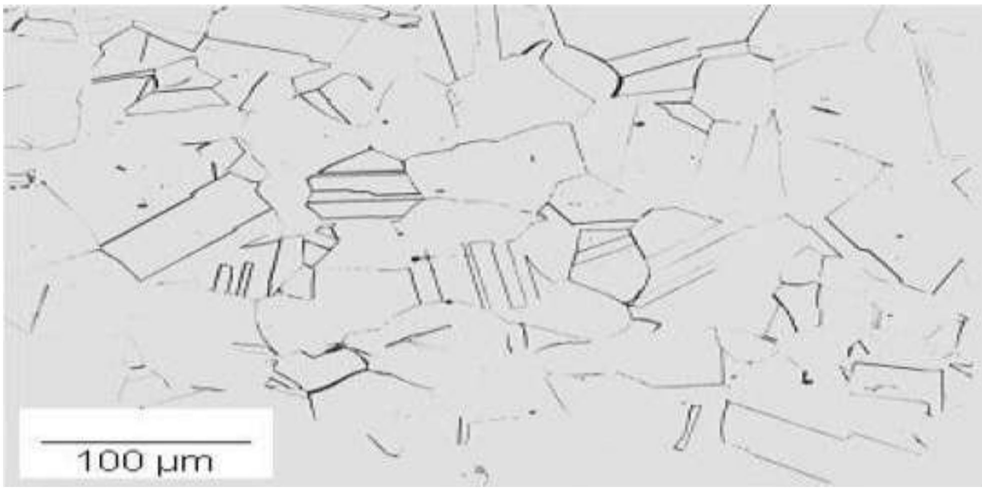


Figure 1.1 General microstructure of austenitic stainless steel. [21]

1.2.2.1 Chemical composition of Austenitic Stainless Steels 309L type

	C	Mn	Si	P	S	Cr	Mo	Ni
%age	0.009	1.68	0.13	0.015	0.001 5	20.34	2.84	13.45

Table 1.1 Composition ranges for 309 L grade of stainless steels.

1.2.3 Duplex 2209 Stainless steel

Duplex Stainless steels is the category of S.S which has been frequently in various applications due to its excellent property of corrosion resistance along with its mechanical properties.

The most important property of DSS is that it contains equal amount of ferrite and austenite phases. Duplex steels generally have good weld ability and can be welded using most of the welding methods used for austenitic stainless steel:

• Shielded metal arc welding (SMAW)

• Gas tungsten arc welding TIG (GTAW)

• Gas metal arc welding MIG (GMAW)

• Flux-cored arc welding (FCW)

• Plasma arc welding (PAW)

• Submerged arc welding (SAW)

Due to the balanced composition, the heat-affected zone obtains a sufficiently high content of austenite to maintain a good resistance to localized corrosion. The individual duplex steels have slightly different welding characteristics. The chemical composition as compared with other S.S grades is as follow

Table 1.2 chemical compositions of different S.S grades

Sr. No.	Types of steels	Cr %	Ni %	Mo %
1.	316 (Austenitic)	17	10	2
2.	430 (Ferretic)	16		
3.	2209 (Duplex)	22	5-9	3

1.2.3.1 Comparison of mechanical properties

Table 1.3 Mechanical Properties of different S.S grades

Sr. No.	TYPE OF STEEL	YEILD STRENGTH(KSI)	TENSILE STREGTH(KSI)	%AGE ELONGATION
1.	304 L	25	70	40
2.	316 L	25	70	40
3.	2205	65	95	25

1.3 Cladding Processes for Stainless Steels

The basic methods for cladding stainless steels are fusion welding. In fusion welding, heat is provided by an electric arc stuck between a carbon or metal electrode (connecting to one terminal of power supply) and the metal to be welded (which is connected to other terminal).

There are six basic principal processes for fusion welding stainless steels. They are:

1. Submerged arc welding (SAW)
2. Submerged arc welding (Tandem SAW)
3. Submerged arc strip cladding (SASC)
4. Electro slag strip welding(ESSC)
5. Shielded metal arc welding (SMAW)
6. Flux cored arc welding (FCAW)

Other fusion welding methods for cladding stainless steels include plasma arc, electron beam and laser. In all cases, the weld zone is protected from the atmosphere by gases, slag or vacuum, which is absolutely necessary to achieve and preserve optimum corrosion resistance and mechanical properties in the joint.

1.3.1 Welding Technique Used

ESSC is the process of choice for cladding SS 309L/Duplex 2209 because of following reasons.

- The fact that the flux is fed only on the front side of the strip - a visible weld pool at the rear side of the strip
- A radiation only in the visible and infrared spectrum, no ultraviolet radiations because of the absence of any arc
- An additional feature (magnetic control device) is used to optimize the weld bead profile
- The simplicity in use is very great, in principle it needs only the same type of equipment as the submerged arc strip cladding technique need.
- The electro-slag technique offers much higher deposition rates compared to the sub arc technique, at the same level of heat inputs and similar bead thickness
- The dilution with the base metal remains very low; typically dilution rates are between 7 and 10 %.
- The possibility of using fewer layers to obtain the required chemical analysis (e.g. low carbon stainless steel in a single layer).
- A very stable and regular welding process with a extremely low defects risk, such as slag inclusions, lack of penetration,
- A low flux consumption

1.3.2 Electro Slag Strip Cladding

The electro slag strip cladding technique is the modern technique in which a strip electrode is continuously fed into a shallow layer of electrically conductive flux. The heat required to melt the strip, the slag forming flux and the surface layer of the base metal is generated by resistance heating due to the welding current flowing through the molten conductive slag. In relation to the submerged arc strip cladding, the penetration and hence the dilution are reduced in electro slag strip cladding because the absence of arc, typical dilution levels lying between 10-15%. The use of a conductive slag and resistance heating instead of an electric arc permits higher current densities to be used in ESSC without increasing penetration. Thus deposition rates higher than that possible with SASC can be achieved in ESSC without increasing the degree of dilution.

The flux used in ESSC contains, in addition to oxides like Titanium oxide and iron oxide. A large quantity fluoride of Calcium and Sodium in order to achieve the required electrical conductivity. The high Calcium fluoride content in the flux has been shown to decrease dilution level and also reduce the oxygen content in the deposited cladding to a level which is just one third compared to submerged arc surfacing. Furthermore the solidification rate of the electroslag weld metal is lower, facilitating the escape of gases and the rise of slag particles to the surface. This reduces porosity and inclusion content.

1.3.2.1 The Process

Electroslag strip cladding is a more recent development of the strip surfacing technique. The principle of this process has been known for a number of years and publications concerning its fundamentals were first published in the early seventy's.

The principle of the Electroslag strip cladding process is shown in Figure and the bases is outlined as follows:

A strip electrode is continuously fed into a shallow layer of molten electro conductive slag. The heat which is needed to melt the strip, the slag-forming flux and the surface layer of the base metal is generated by the Joule effect as a result of the welding current flowing through the liquid electro conductive slag. The ELECTROSLAG strip process is started in the same way as a submerged arc cladding; the stabilization of the process into the electroslag mode is reached almost instantaneously.

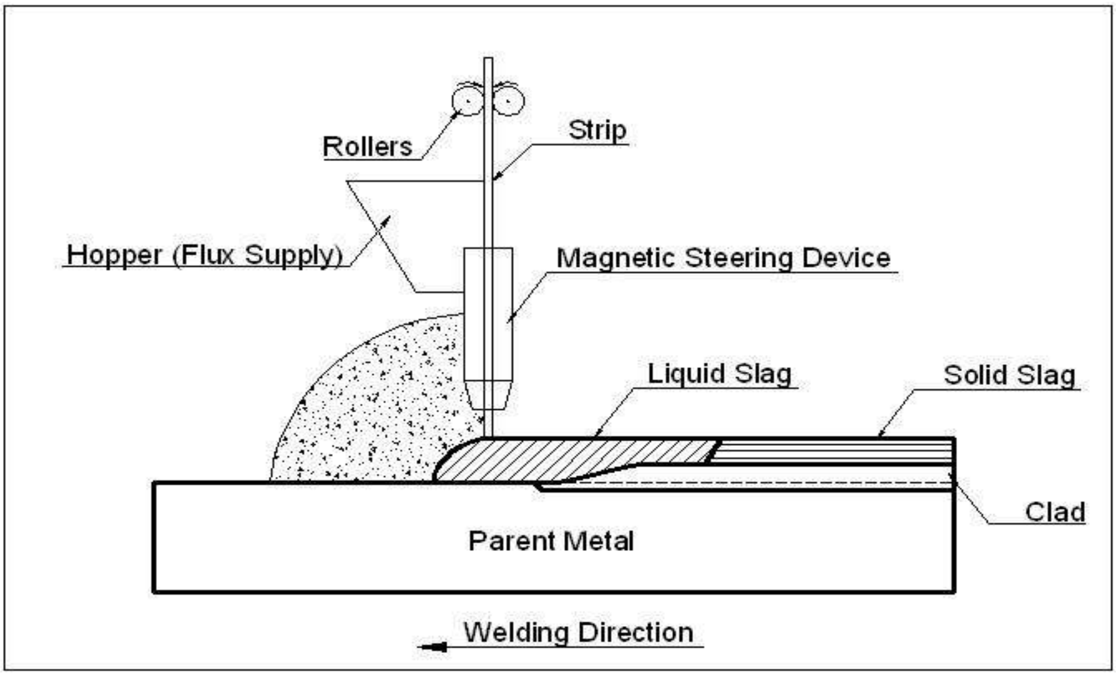


Figure 1.2 Schematic Diagram of electro slag strip Cladding [9]

1.3.2.2 Polarity

Direct current electrode positive (DCEP). This is also called the reverse polarity. The electrode is connected to the positive terminal of the power source. The electrode is strike once to start an arc between work pieces and strip to start the welding. Later the electric current flows through the electro conductive flux and the strip is continuously fed into the molten pool. There is no arc in this process hence any harmful radiation is emitted.

1.3.2.3 Electrodes

Electrodes are in the form of strips which are available in various sizes varying from 50mm to 150 mm width and 0.5 mm thickness. The electrodes are available in the form of rolls in different weight like 10 kg, 15 kg and 20 kg. For mass production there are strip rolls are available up to 50 kg also. Different widths of strips are used in order to achieve desired deposition rate and cover the large surface area**.**

1.3.2.4 Equipments

Following are the equipments used in ESSC

1. Power Source unit and cables.
2. Welding Heads
3. Strip feeding Nozzles
4. Magnetic Steering devices.

1.3.2.4.1 Power sources

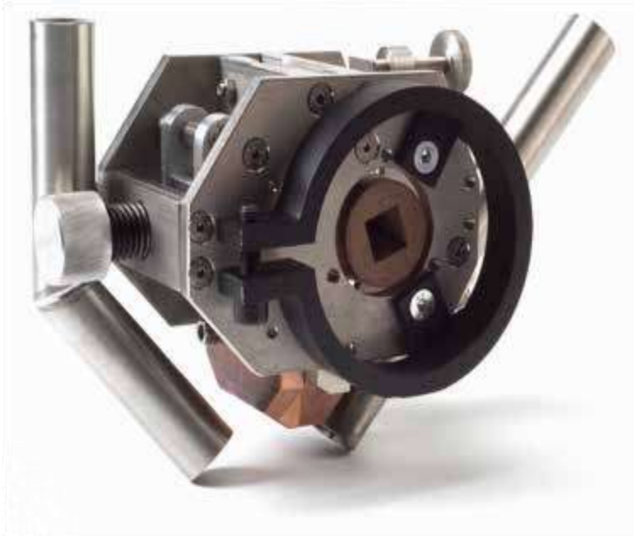
In view of keeping the strip feed rate and voltage variations within very narrow limits imposed with regard to the shallow depth of the slag pool, it is advised to use DCCP rectifiers. Since the electroslag process requires average optimized current densities of approx 40 A/mm2, the output of the power sources at a 100% duty cycle has to meet high amps such as 1250 A for a 60 mm strip (typical). In practice to obtain the required current intensity levels two power sources can be connected in parallel. It should be checked with the manufacturer whether given DCCP power sources can be connected in parallel without any additional precautions. To obtain optimum welding conditions and bead profile, it is necessary to use a power source which will give stable voltage outputs between 21 - 27 volts.

1.3.2.4.2 Welding Heads

The function of the welding head is to feed the strip at a constant speed which is related to the welding parameters. The strip feed rates for the electro-slag process range from 1 to 2, 5 m/min. In practice no special welding heads are required to carry out electro-slag strip cladding.

1.3.2.4.3 Strip feeding Nozzles

The main functions of the feeding nozzle are to guide the strip and to maintain it in the required position during the welding operation and to transfer the welding current from the power source to the strip by means of appropriate contact shoes. There is no fundamental difference in design between the sub arc and the electroslag feeding nozzle, however because of the high current densities involved, and due to the fact the rear side of the electro-slag is subject to the heat radiation from the slag pool, their construction is generally somewhat heavier. The electro-slag nozzle is also equipped with a water cooling possibility. FIG shows the most classic nozzle which can be used with strip widths from 30 mm up to 120 mm width.



(A) **(B)**

Figure 1.3 (A & B) Strip feeding nozzles [18]

1.3.2.4.4 Magnetic Steering Device

As mentioned previously, the slag pool is electro-conductive; therefore, the slag pool is subjected to electromagnetic forces which tend to make it flow from the sides towards the centre of the molten pool. This result in narrower beads, more unfavorable wetting angles resulting in a more difficult slag removal and increased risks from undercut. To compensate this phenomenon, magnetic steering devices are used. These magnetic field control systems works as following: an external magnetic field generating forces of the same nature is applied but in the opposing direction. The external magnetic field is created by means of two solenoids, a picture of an example of a magnetic steering device (CED 1) with the solenoids, the fittings to put the solenoids onto the cladding nozzle, the current cables and the steering control box. The location of the solenoids is very important. The tips should be placed beside the strip electrode at a distance of approx 15 mm from the strip edge and about 15 mm above the base material surface. The standard magnetic steering device is capable of putting five amps on each solenoid. For cases where the magnetic deflection from the work piece is intense solenoids with stronger magnetic fields have been used (CED M 1280).

(A) **(B)**

Figure1.4 (A & B) Magnetic steering device [18]

1.3.2.5 Advantages

- The fact that the flux is fed only on the front side of the strip - a visible weld pool at the rear side of the strip
- A radiation only in the visible and infrared spectrum, no ultraviolet radiations because of the absence of any arc
- An additional feature (magnetic control device) is used to optimize the weld bead profile
- The simplicity in use is very great, in principle it needs only the same type of equipment as the submerged arc strip cladding technique
- The electro-slag technique offers much higher deposition rates compared to the sub arc technique, at the same level of heat inputs and similar bead thickness

- The dilution with the base metal remains very low; typically dilution rates are between 7 and 10 %.
- The possibility of using fewer layers to obtain the required chemical analysis (e.g. low carbon stainless steel in a single layer).
- A very stable and regular welding process with a extremely low defects risk, such as slag inclusions, lack of penetration,
- A low flux consumption

1.3.2.6 Disadvantages

1. ESSC is very costly as the set up consist of big machinery set up and requires lot of expertise to operate.
2. Undercutting the commonly occurred defect in ESSC resulting from the electromagnetic pinch effect as the high welding current flows from the strip electrode. This is also called magnetic blow effect.

1.3.2.7 Applications

1. Overlaying CRA in pressure vessels industries.
2. Used to make protective layers in Dry-docks & shipyards.
3. Precision cladding in atomic energy, aircraft, chemical and instrument industries.

Chapter 2

Literature Review

2.1 Introduction

Literature survey is the important part of any project work. A large volume of literature is available in journals and books on this particular grade i.e. AISI 304 & Duplex Stainless steel explaining the different modes of welding. Following are some of the literature worth mentioning to get the direction of work and relevance to a large extent.

2.2 Literature Surveyed

Sunil D. Kahar *et al* [1] from metallurgical and material department of university of Baroda studied the corrosion behavior of electro slag strip clad overlay in different acid solutions. The 309 L and 309 LNb austenitic stainless steel strips were used to develop weld overlay on Cr-Mo steel by variation in welding speed. Amount of ferritic content has been evaluated by ferrite-scope, it reveals that there is decrease in ferrite content with the increase the welding speed from 160 to 200 mm/min for both weld overlay developed by 309L and 309Lnb.

P. Bala Srinivasan *et al,* [2] studied microstructure and corrosion behavior of shielded metal arc welded dissimilar joints comprising duplex stainless steel and low alloy steel. In chlorides environments, the LAS HAZ region has a marginally higher corrosion rate that its base material counterpart. General corrosion resistance of the weld metal produced with the E309 electrode is better than that produced with E 2209 electrode. Both weld metal produced with E 2209 and E309, have inferior pitting resistance when compared with the DSS base material , amd the pitting resistance ranking is DSS base material >> Weld metal A>> Weld metal B

El- Sayed M. Sherif [3] from centre of Excellence for research in engineering (CEREM), college of engineering, King Saud University, Saudi Arabia studied corrosion of duplex stainless steel alloy 2209 in acidic and neutral chloride solution and its passivation by ruthenium as an alloying element. It was found that the corrosion rate of DSS in Hcl solution is higher than obtained in NaCl. The cathodic reaction for DSS in Hcl solution was hydrogen evolution but in NaCl was oxygen reduction.

Riad Badji et *al*, [4] from University of paris , France has done TIG welding of 2205 duplex stainless steel using ER2209 and found significant variation in ferrite – austenite balance in HAZ and fusion zone as compared to base metal. Complex phase transformation takes place during annealing treatment. Brittle sigma phase and chromium carbides were formed through eutectoidal decomposition and sigma ferrite. Quantitative metallography showed that the amount of sigma phase decrease with increased annealing temperature.

Joanna Michalska et *al*, [5] from Department of Material science , Selesian University of Technology , Poland studied that the ferritic matrix in duplex stainless steel undergoes a variety of decomposition process when aged in the temperature range 650-900° C. The process involves precipitation of austenite, Sigma and Chi phases. The inter-metallic sigma and chi phases are found both at the grain boundaries and inside the ferrite grains.

Kwang Min Lee et *al*, [6] from department of Metallurgical engineering , Chonnam national university , South Korea studied about the relation between migration of α/γ relation between interface boundary and the growth of austenite as a function of aging treatment in SAF 2205 duplex stainless steel. The migration of the interface boundary into the ferrite phase region resulted from the nucleation and growth of chromium carbide with the pattern of "Lamellar" and " Larva " having a cube-cube orientation relationship with the austenite.

D.W Yu et *al*, [7] from Oregon Graduate Centre, Seawton, CR studied Electro-slag Surfacing: A potential Process for a rebuilding and restoration of Ship components. They concluded that the electro-slag strip cladding is the most economical and productive method to overlay a wide variety of corrosion and/or wear resistant deposits on structural ships components, such as propeller shafts. The highest deposition rates with lower dilution level are characteristics of ESSC as compared to conventional surfacing methods like SASC, SAW, FCAW, GMAW and SMAW.

J H Devletian ***et al*****, [8**] from Oregon Institute of science and technology make a comprehensive comparison between ESSC and SAW cladding using Ni alloy 625, Ni alloy 625 with low Fe content and Ni alloy 59. These three different types of material strips are used to repair a main propeller shaft of 25 inches diameter. The result shows that the Electro slag strip cladding provide less dilution and more uniform penetration , and higher deposition rate than does SAW under similar cladding condition**..**

Mitul patel ***et al*** [9] from Larsen and Toubro Ltd. HED ranoli works with Astt. Professor B.S chauhan and S.Sudaresan studied the application of ESSC for reactor in hydrogen based refinery service. Their work involve deposition austenitic Stainless steel weld overlays (309L347) on a 1.25 Cr-0.5 Mo low alloy steel and conduct the test like NDE , bend testing and IGC testing. During cladding and during Post weld heat treatment , structural changes occur especially in the weld interface region , which result in a carbon – depleted zone in the base metal and a carbon-enriched (alloy carbide) layer in the weld metal next to the interface.

Susan Pak ***et al*** [10] from ESAB welding Gotenborg Sweden studied Electro-slag and Submerged arc Stainless steel strip cladding. Submerged arc and electro-slag strip cladding. Understanding cladding and parent material/cladding interface region microstructures is illustrated in the present paper by the results of studies of:

The influence of welding procedures on the chemical composition of cladding and the ferrite content of SAW strip cladding. It is shown that several factors have to be considered when choosing process and welding parameters, since deposition rate, bead geometry, penetration depth, dilution level, travel speed and cooling rate all interact. For example, minimum dilution is achieved with a low travel speed, whereas higher deposition rates are achieved with a higher travel speed.

T. Kannan ***et al,*** [11] from department of mechanical engineering, kumara Guru College of technology, Coimbatore, Tamil Nadu studied effect of flux cored arc welding process parameters on duplex stainless steel clad quality. They concluded that dilution increase with the rise in welding current and nozzle to plate distance and decrease with rise in welding speed and welding torch angle. Reinforcement increases with the rise in welding current and nozzle to plate distance and decrease with the rise in welding speed and welding torch angle. Welding bead width and penetration with rise in welding current. Increase in welding torch angle decreases penetration when welding speed is high.

N. Murugan ***et al,*** [12] studied the effect of welding condition on the microstructure and properties of 316 L stainless steel submerged arc cladding. He conclude that either high voltage and high welding speed or low voltage and low welding speed produce low dilution. Ferrite content in multilayer cladding is more than in a single layer cladding. Optical metallography revealed that in as welded condition the micro-structural constituent of HAZ, fusion boundary and cladding surface at a low dilution condition were bainite and ferrite, martensite and austenite plus ferrite respectively.

I.G Rodionova et ***al,*** [13] published in chemical and petroleum engineering published the joining of bimetallic plates by means of four process named packet rolling, casting, explosive welding and electro slag hard facing. The cohesive strength is checked among all joints which reveals elctro-slag hard facing have highest whereas packet rolling have least cohesive strength.

V.V satya parsad ***et al*** [14] studied microstructure and mechanical properties of test piece made by ESSC and explosive cladding between low alloy and stainless steel. They conclude that the bond interface was wavy in Explosive clad joint and straight in Electro slag strip cladding joint. Diffusion width of element across the interface is more in strip cladding as compared to explosive cladding. The micro hardness of the region adjacent to explosive clad interface shows maxima while there existed a softened region adjacent to strip clad joint interface.

Ikuhisa Hamada ***et al*** [15] studied Inter-granular stress corrosion cracking behavior of niobium added type 308 stainless steel weld overlay metal in a simulated BWR environment. The niobium added type 308 weld overlay metal specified as type 308 NbL whose chemical composition and ferrite content were controlled were tested and SSRT and U-bend test with and without crevice in oxygenated high temperature pure water.

J. Tusek *et al,* [16] from faculty of mechanical engineering, university of Ljubljana studied High productivity multi wire submerged arc welding and cladding with metal powder addition. They use three different ways of supplying the metal powder to the welding area to the welding area. Their investigation shows that it is possible to submerged arc weld and clad with a multiple wire electrode and metal powder addition. In this way the deposition rate and the productivity are increased, the consumption of shielding flux is reduced, and the arc efficiency is improved. For industrial application of the process, it will be necessary to design a suitable welding head and to study the most suitable parameter.

S. Liu *et al,* [17] studied grain refinement in electro slag weldments by metal powder addition. The electro-slag process when operated with a modified strip electrode shows promise of becoming a viable alternative to high speed welding. They concluded that electro-slag welding with the metal powder cored strip electrode and consumable guide plate's demonstrated stable operation with increased travel speed and decreased specific heat input, indicating the strong potential of the process to become an alternative for the high speed welding.

2.3 Research Gap

No. of researchers had done a lot of work on SS 304, 309L & Duplex stainless steel using different welding processes like shielded metal arc welding, gas metal arc welding, flux cored arc welding and electro slag strip cladding but it is observed that there is no systematic work done on the cladding of Duplex stain steel using electro slag strip cladding. Literature survey also reveals that there is a scope of working in this direction because of the critical applications (like in pressure vessel industry, nuclear industry, chemical industry etc.) of this material and to make it safer for further use.

2.4 Objectives

Following objectives has been derived from the literature survey.

1. To study the mechanical properties of duplex stainless steel 2209 on low carbon steel like Micro-hardness.
2. To study microstructure under optical microscope with max 400 magnification and Scanning electron microscope (SEM)
3. To study material composition at various cross sections using Energy dispersive spectroscopy (EDS)
4. To check different phases formed in material after welding using X-ray Diffraction (XRD)
5. To find the ferrite content on the clad region.

Chapter 3

Experimentation and Testing

This chapter discusses the detail about the experimental data, base metal, filler metal, and welding procedure, welding parameters of welded specimen and testing.

3.1 Plan of Experimentation

Experimentation was conducted as per following flow chart

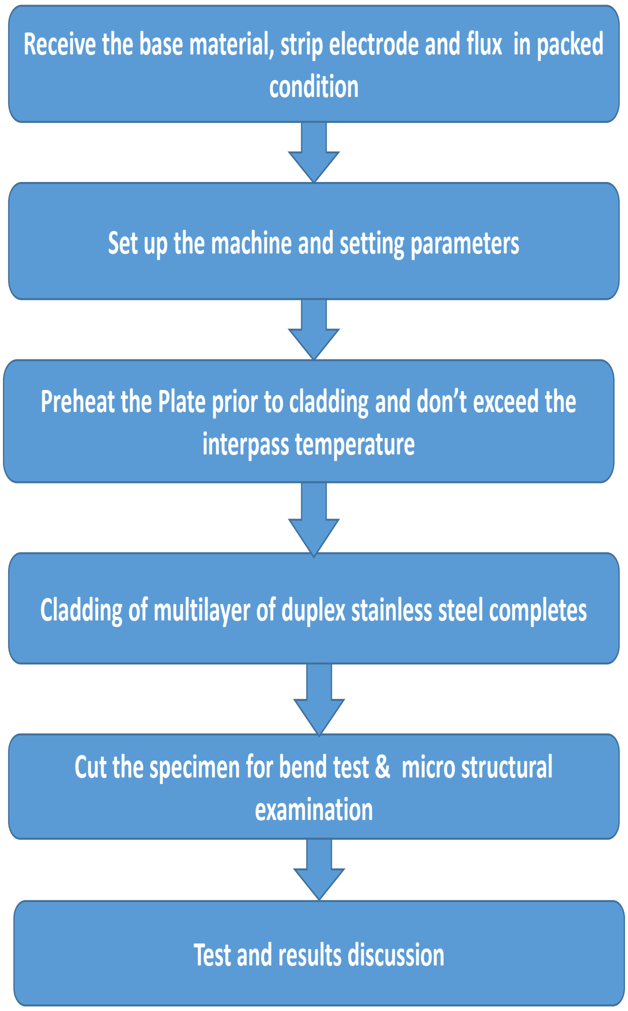


Figure 3.1 Flow chart shows how experimentation was conducted.

3.2 Base Metal and Strip Metal

The base plate of SA 516 Grade 70 low carbon steel of 50 mm received in normalized, accelerated cooled and tempered condition. The strips used were of S.S 309L and Duplex 2209 in 60 mm width and 0.5 mm thickness .Table 3.1 shows the chemical composition of base metal & strips used.

Table 3.1 Chemical composition (wt. %) of base metal, SS309 L and Duplex 2209

Elements	Base Metal	S.S 309 L	Duplex 2209
Carbon, C	0.27 under ½”, 0.28 between ½” to 2”	0.009	0.008
Silicon, Si	0.15 - 0.40	0.13	0.43
Sulfur, S	0.035	0.0015	<0.0005
Phosphorous, P	0.035	0.015	0.018
Manganese	0.85 - 1.20	1.68	1.51
Chromium	-	20.34	22.95
Nickel	-	13.45	8.59
Molybdenum	-	2.84	3.02

3.3 Welding Equipment

Welding machine used is shown in fig. 3.2, having following specifications.

- Manufacturer : Lincoln
- Supply voltage : upto 35 V
- Welding current range : upto 2500A (DC)
- Open circuit voltage : 100 V
- Weight : 530 kg

Figure 3.2 Welding machine used. [18]

3.4 Welding Parameters

- Material thickness : 50 mm
- Joint design : No joint only base plate

Figure 3.3 Cladding in Process on Low Carbon steel plate.[18]

Table 3.2 welding parameters used during cladding.

Parameters	Range
Welding current (I)	1200-1400 A
Voltage (V)	22-26V
Travel Speed	170 mm/min
Pre heat	130 degree Celsius
Interpass	Max 200
Electrode extension (Stick Out)	12-15 mm
Height of Flux	15mm
Polarity	DCEP

3.5 Flux Analysis

The flux used in the process is also supplied from the same manufacturer and received in 25kgs packing. Chemical composition of flux is in Table 3.3.

Table 3.3 shows the chemical composition of flux used by wt%

Silicon Oxide	Alumina	CaO+ MgO	Potassium oxide+ Sodium Oxide	Flourine
6	24	48	2	32

- Basicity Index 3.8
- Potential water 0.01%
- Apparent Density 1.1 Kg/dm^3
- Grain Size 0.2-1.2 mesh ASTM

3.6 Working Procedure

The base plate of SA 516 Grade 70 low carbon steel of 50 mm received in normalized, accelerated cooled and tempered condition. The size of plate as received is 12M X 3M from which a test specimen for cladding is cut of size 200 mm x 300mm. The test plate is placed on the flat surface to avoid any unevenness in the cladding bead. The plate is cleaned with the help of wire brush or buffing wheel mounted on the small grinding machine to remove the dust and greasy particles.

The plate is heated up to 150° C to remove the moisture content from the plate to avoid any porosity defect in the cladding. Flux is also preheated up to 100° C to remove moisture content from the flux. The buffer layer is overlaid with SS 309 L and the second layer is performed using Duplex 2209.

The picture shows the as cladded test piece of 200X 300 mm 50 thick plate

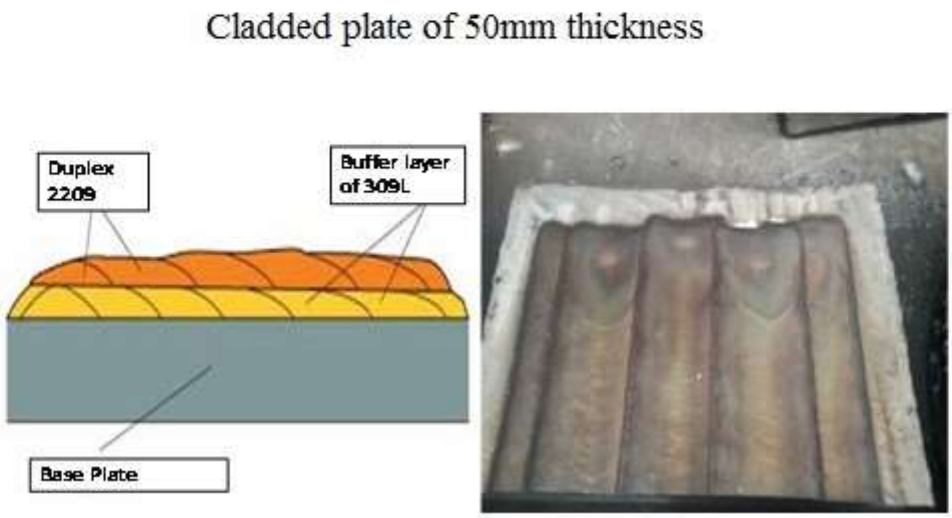


Figure 3.4 As deposited cladding of 2209 DSS.

3.7 Testing & Results Analysis

Micro structural studies and micro hardness were performed on as cladded specimens. The following tests has to be conducted

- Microstructure: - Test to be done on optical microscope under 100-400 X magnification. Microstructure will also be studied under SEM.
- Electron dispersive Spectroscopy (EDS)
- Different phases will be examined by XRD.
- Micro- Hardness Tests: - Test to be carried out as per ASTM E18.
- Ferrite No. Prediction.

3.7.1 Specimen Sampling

In order to evaluate the mechanical and micro structural properties of the Duplex 2209 weld overlays, the specimens for micro hardness testing and micro structural studies were machined out from welded pads.

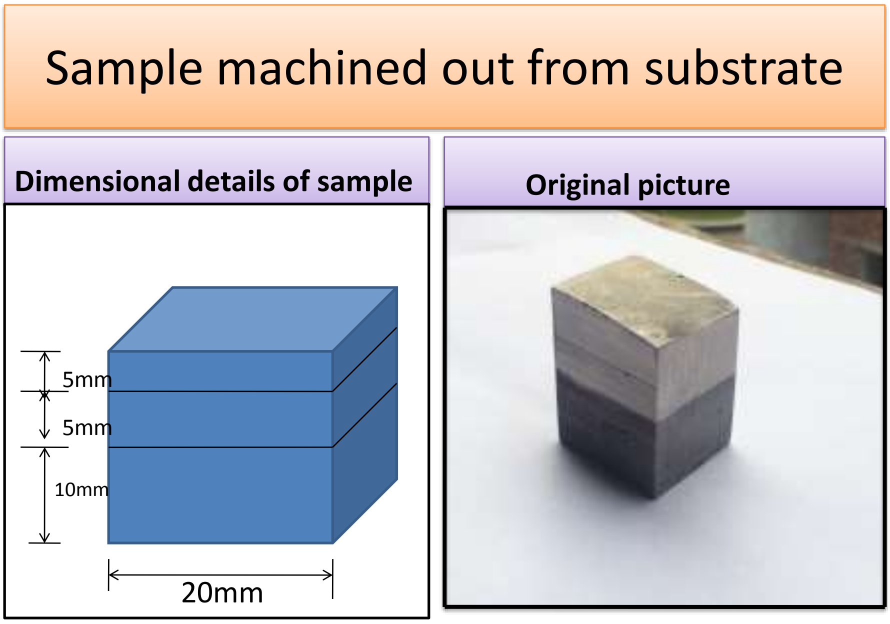


Figure 3.5 Test Specimen

The test specimen of 20 X 20 mm is cut from the main plate. In this specimen 10 mm thickness is of base plate over which buffer layer of 5 mm using S.S309L is done and rest 5 mm is top layer of duplex 2209.Further the test specimen is cut from the master specimen for SEM testing with the help of wire EDM process to avoid any heat input in the metal which can lead to phase transformation.

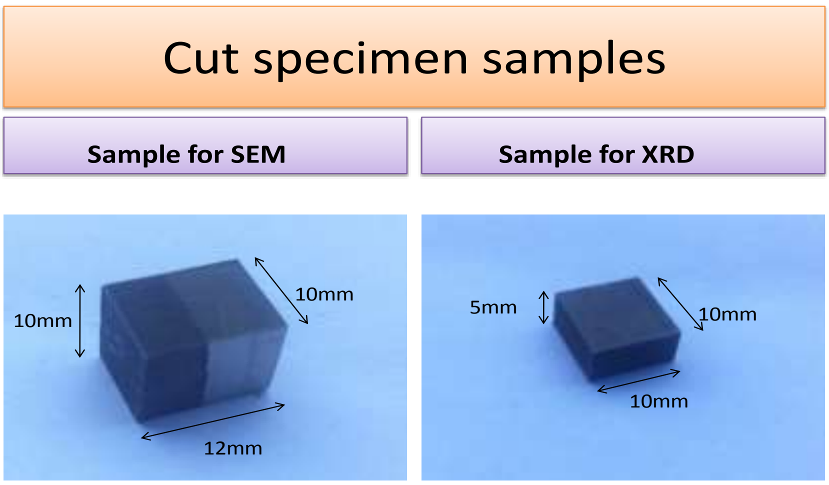


Figure 3.6 Specimen cut for SEM and XRD.

3.7.2 Micro hardness Measurements

The term micro hardness tests usually refer to static indentation made with loads not exceeding 1 kgf. The surface being tested generally requires a metallographic finish; the smaller the load, the higher the surface finish is required. The procedure for micro hardness testing is very similar to that of the standard Vickers hardness, except that it is done on a microscopic scale with higher precision instruments. Micro hardness measurements were carried out across the HAZ using Vickers hardness testing machine shown in fig. in accordance with IS 1501:2002 (Method for Vickers hardness test for metallic materials) at ISGEC Yamunanagar.

Figure. 3.7 Vickers hardness testing machine.

The micro hardness of the clad specimen across the entire cross section is evaluated. The intermediate distance between two indentations is kept 100 µm starting from the top of clad surface to the covering interface region and ending up to substrate. Load taken is 50g and dwell time is 10s. The micro hardness of clad region shows non uniform readings at different cross sections as shown in Fig 3.7(a)

Total of 14 readings were taken in clad region and the average of 528 Hv. This behavior of clad region is due to the presence of some hard phases like chromium carbide. But chromium carbide is present in non-uniform manner that’s why the hardness varies from place to place.

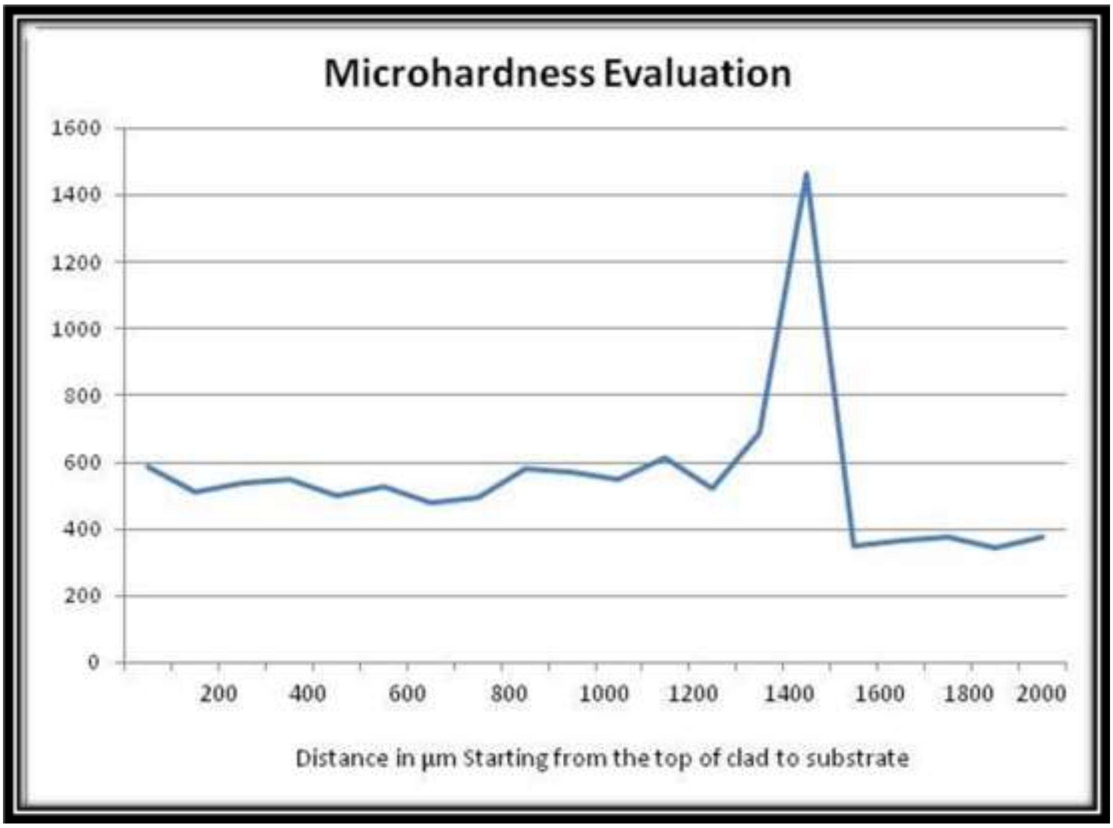


Figure 3.7 (a) Vickers's Micro-hardness graph across cross section of clad and substrate region

The hardness recorded at the clad interface is extremely high as compared to clad or substrate region. The micro-hardness recorded at the interface is 1464 Hv which is far more than other region shown in fig 3.7(b). This abnormal behavior is due the coarse grains formation in the heat affected zone. There is a gradual decrease in the hardness is recorded on the substrate region near the fusion boundary which is due to depletion of carbon in this region. The increase in hardness in the substrate near the fusion zone is due to the formation of martensitic and micro structural features are shown in fig 3.8(a)

However the micro-hardness of the substrate shows uniform hardness throughout. The total of five readings was taken which are 349,366,373,343 and 373 Hv respectively which indicate that substrate is soft.

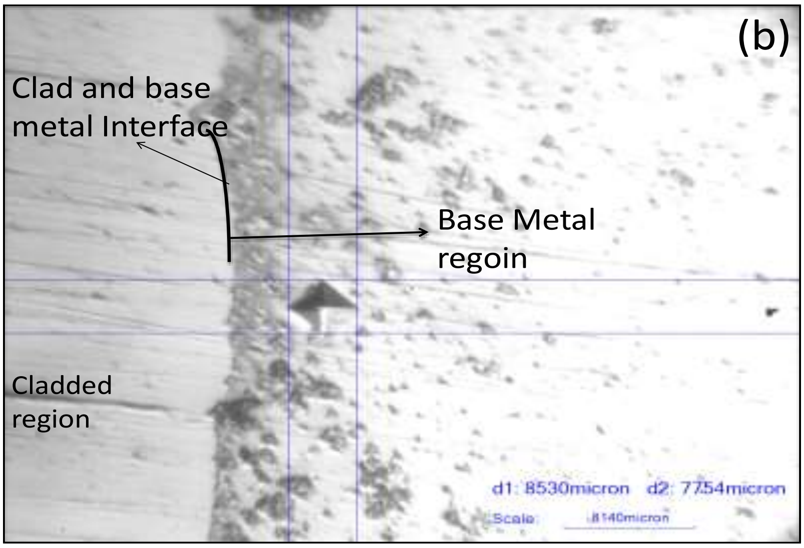


Figure 3.7 (b) **I**ndentation image of interface region with 1464 Hv

The hardness varies in all regions like clad, substrate and interface due to which the indentation size also varies in all interface regions respectively as shown in fig 3.7(c). The optical microscope image at 500X magnification shows that the size of indentation at the interface is smallest among all due to the presence to hard martensite phase which don't allow the indent to penetrate in the material. Whereas the clad region having big indentation size shows that the material is soft as compared to the heat affected zone.

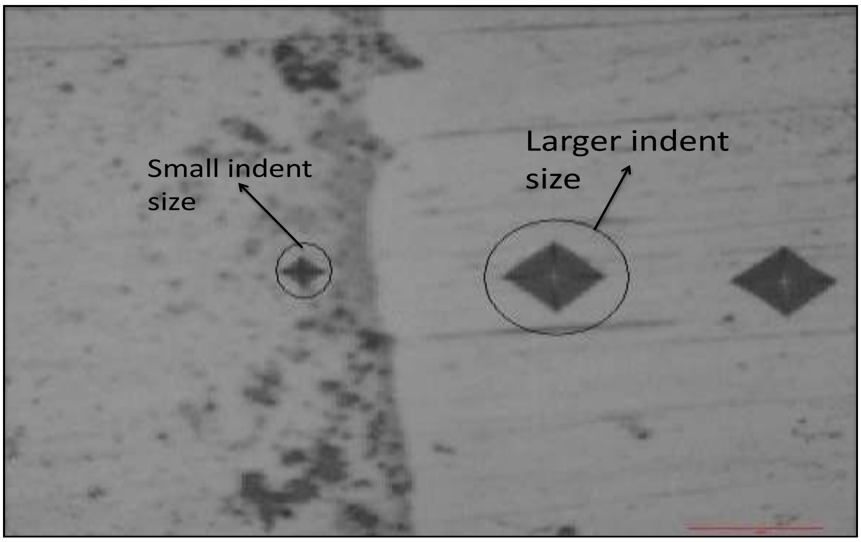


Figure 3.7 (c) Difference in size of indentation image of interface region

3.7.3 Micro structural Examination by SEM & Optical Microscope

Scanning electronic microscope shown in Fig.3.8 was used to test cladded specimen microstructure. The dimensioning of specimen was done according to block size of machine. The polishing of specimen was done prior to be tested. The polished specimen was used to observe the microstructure of specimen at different magnification.

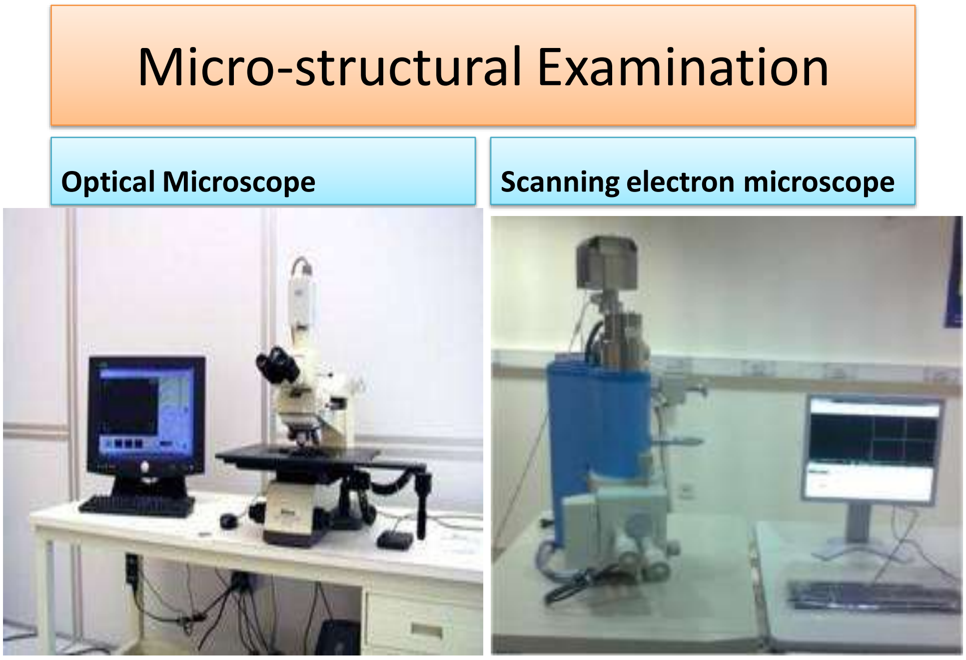


Figure 3.8 Scanning Electron Microscope & Optical Microscope

. The specimen are duly polished using different grades of emery papers. Final polishing is done on rotating polishing machine with mounted cloth using diamond spray and paste. The specimen is then etched with Villella's Reagent.

Table 3.4 Typical composition of Villella's reagent

Constituents	Quantity
Picric acid	1 gram
Hydrochloric acid	5 ml
Ethanol	100ml

The optical microscope is used to examine the micro structural changes occurred in the clad and substrate region as shown in fig 3.8(a). The micrograph shows a dark etching layer highlighting the transition zone between clad metal on right side and the base metal on the left side. On the base metal side the dark region resembles the decarburized zone having martensitic structure which is very hard. In micro hardness study it reveals that this region has highest micro hardness among all zones

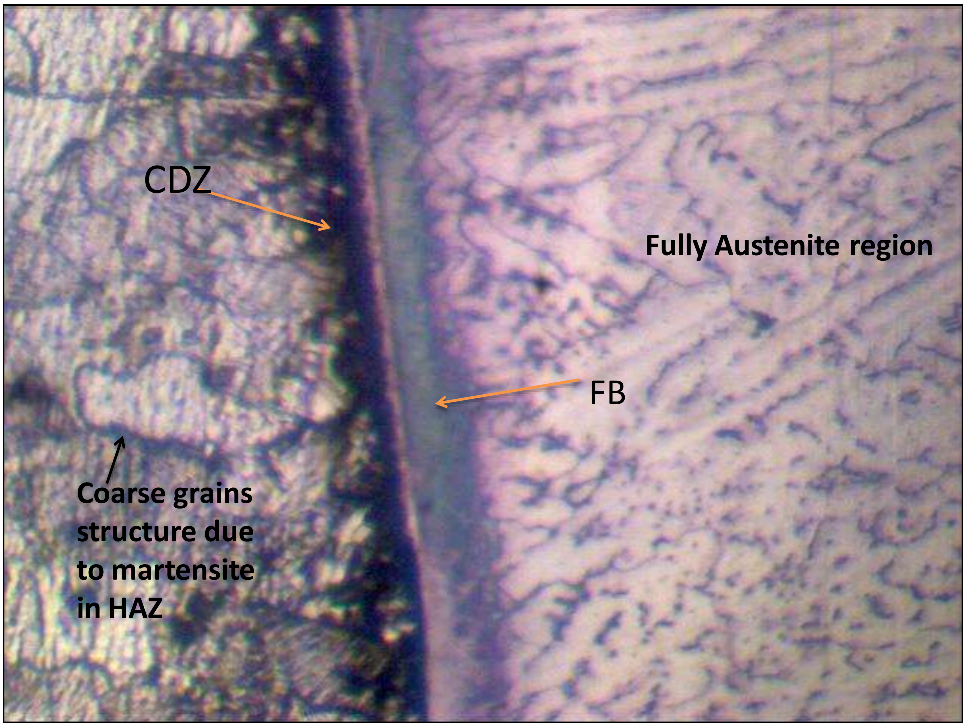


Figure 3.8 (a) Interface of buffer layer with substrate showing fusion boundary (FB) and Carbon Depletion zone (CBZ)

The basic reason of depletion of carbon the region adjacent to the fusion boundary is that the carbon has greater affinity towards chromium to form chromium carbide in the clad region because of chromium content in the austenitic stainless grade steel. Hence the carbon moves in the clad region near the fusion boundary and forms carbides. The typical elemental graphs obtained by EDS shows the percentage of different elements like iron, chromium, nickel etc in this region which shows that chromium joins carbon and form chromium carbide as shown in fig 3.9(b)

On moving from fusion boundary towards the base material the hard martensite forms due to excess heat in the heat affected zone. The coarsening of grain boundaries takes place in this region. The big size of the grains is shown in fig 3.8(b).The size of grains is big due to the absence of carbide phase. As we moves more towards the base metal the heat affected zone diminishes and the region of fine grains starts. The grain goes finer as we moves toward the unaffected area of the base metal. Toward extreme left the total ferritic structure is obtained. The typical elemental case study of this section is done in EDS as shown in fig 3.9(a) which reveals that there is 95 % of iron is present in the base metal.

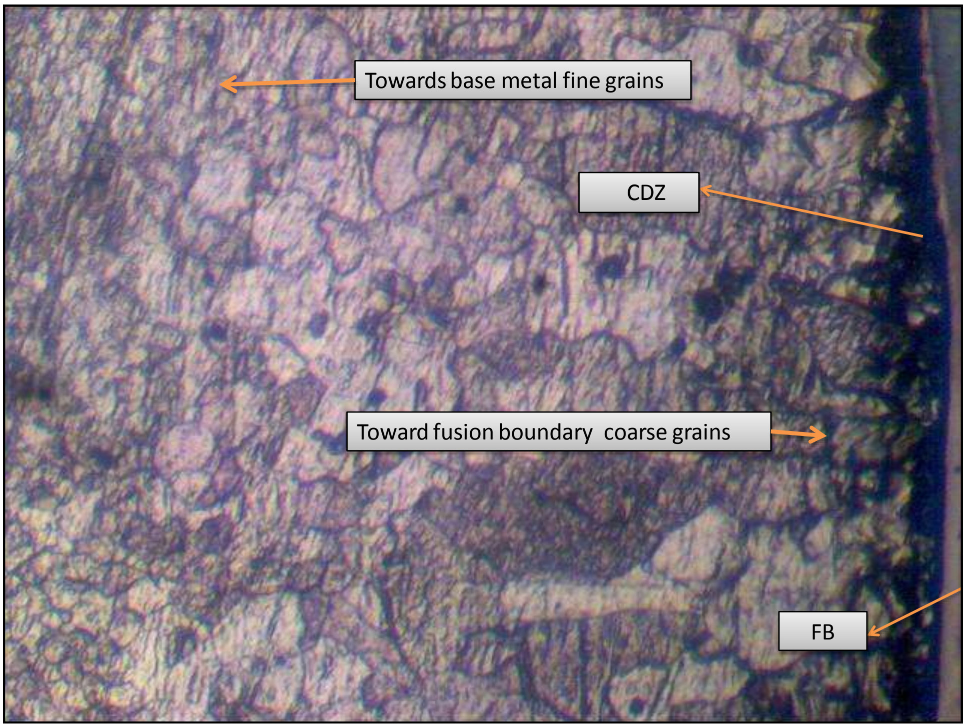


Figure 3.8 (b) Coarse and fine grain structure in Base metal

The interface of buffer layer and top layer is examined under optical microscope at 100 X magnification. Buffer layer is overlaid using 309L austenitic stainless steel and top layer is of duplex 2209. It may be noted that in fig 3.8(a) the weld metal immediately adjoining the transition zone contains virtually no ferrite and solidification has occurred fully as austenite. As we moves away from transition zone toward clad metal the solidification is still austenitic, but the remaining liquid between the dendrites solidifies as ferrite. As we move more toward buffer layer side the solidification mode changes from primary austenite to primary ferrite. Finally it becomes skeletal or vermicular ferrite, the ferrite being the primary phase forming at the core of the dendrites. Moving towards the interface of the buffer layer and top layer it is observed that the ferrite content of the buffer layer increased when moving toward the interface of buffer layer and top layer. This happened because of the reheating and partial re-melting of the buffer layer during cladding of top layer which cause ferretization during heating. The faster cooling slower down the ferrite to austenite formation and hence total amount of ferrite increased in this region. The ferrite morphology also disturbed from its vermicular shape to continuous vermicular shape close to the buffer/top clad interface as shown in fig 3.8(c).

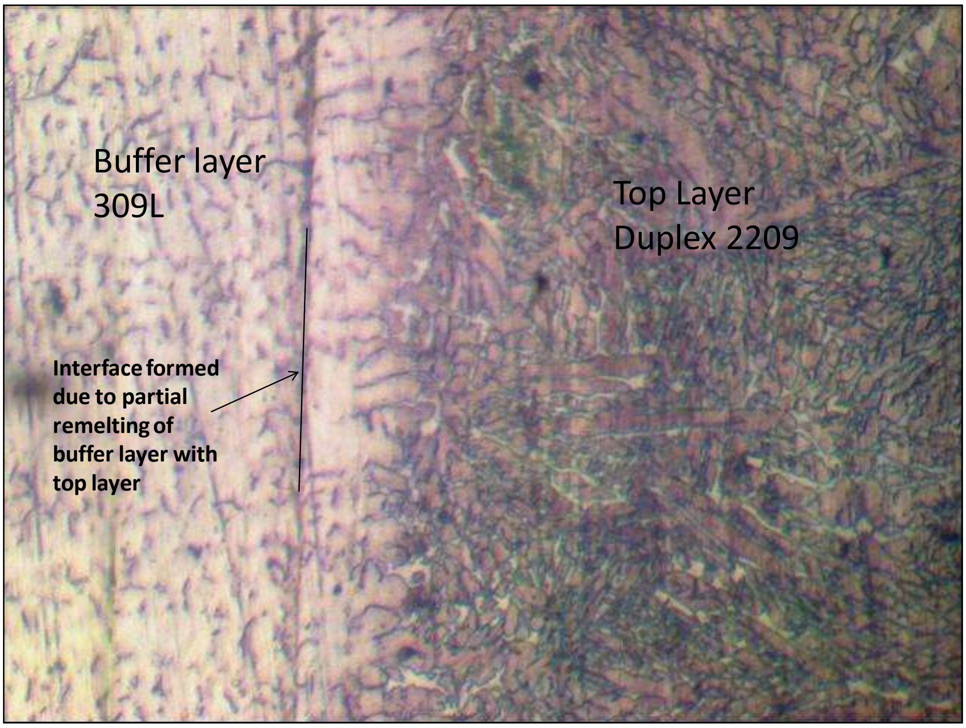


Figure 3.8 (c) Clad interface of buffer layer with Duplex 2209

On moving into the top layer of cladding there is not much difference in the elements of the buffer and top layer due to almost same chemical composition. On deeply studying the microstructure of top layer it is found that that the grains of austenite precipitated in the solid state by nucleation and growth. During the transformation process, the austenite and ferrite promoting elements were decided between austenite and ferrite grains. Solidification of top coating proceeded by arranging the atoms in the liquid phase on the existing ferritic – austenitic crystalline orientation. As a result formed continuous solidified grains of austenite in ferrite matrix. The prediction of phases in the top clad layer is determined by the X-ray Diffraction which clearly shows the austenite, ferrite and chromium carbide phase in top layer deposits. The graphical representation of phases is as shown in figure 3.10. The microstructure of duplex stainless steel at 100X magnification is as shown in figure 3.8(d). On viewing the same picture in figure 3.8(e). at 400 magnifications the phases can be differentiated easily. The austenite can be seen in white color embedded in brown ferrite matrix. Whereas chromium carbide precipitates can be spotted as black in the microstructure.

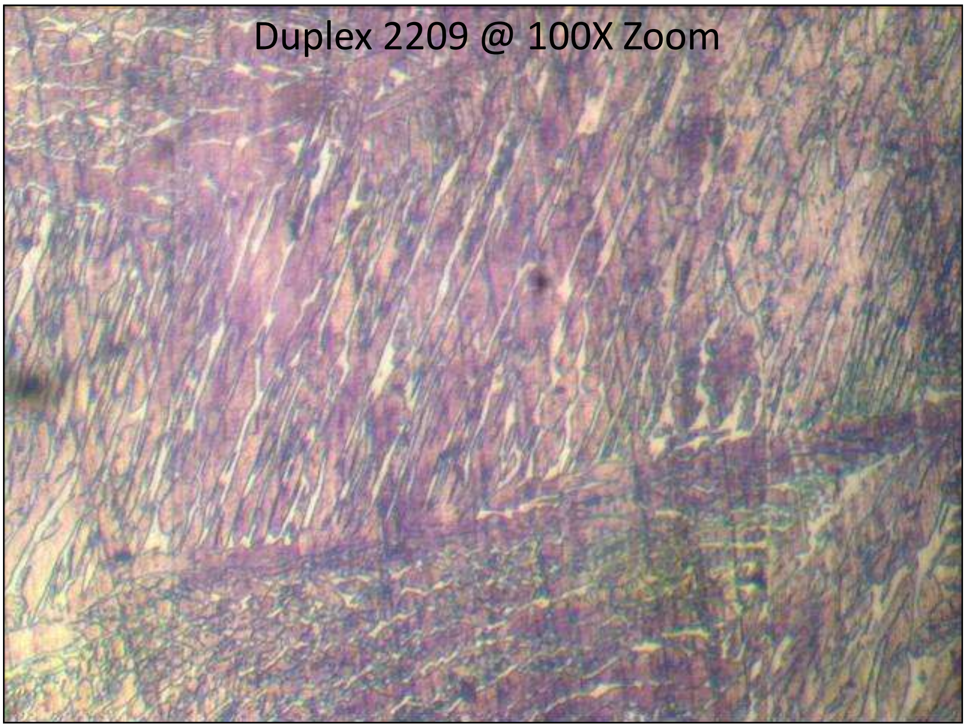


Figure 3.8 (d) Duplex 2209 picture top layer deposit at 100 X magnification

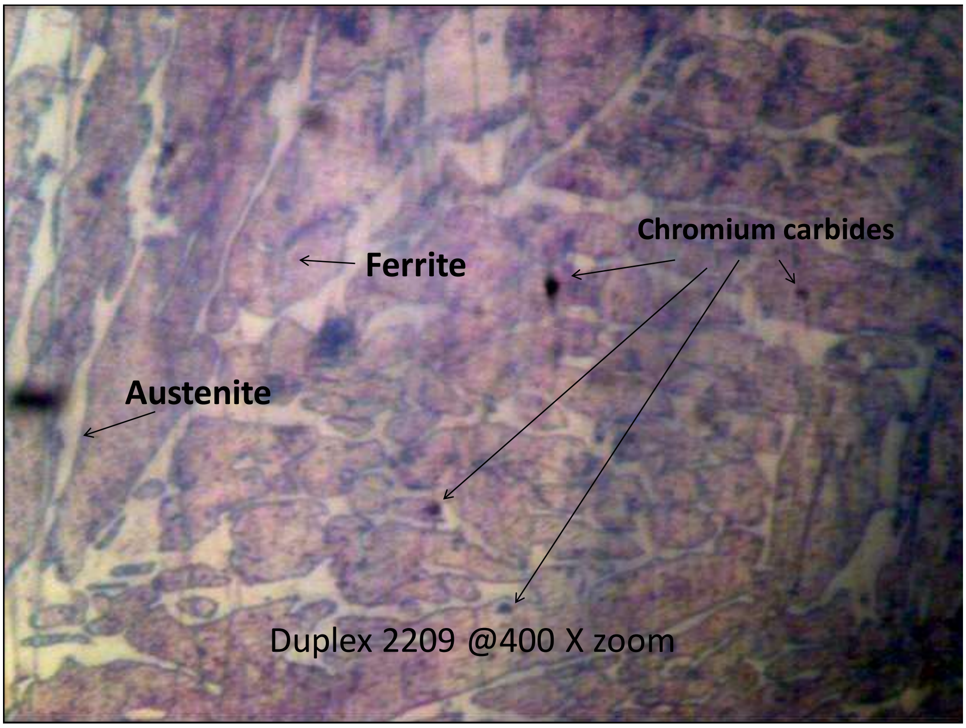


Figure 3.8 (e) Duplex 2209 picture taken at 400 X magnification

The typical scanning electron microscopy image is as shown in fig 3.8 (f). The figure can be interrelated with the optical image of the identical region shown in fig 3.8 (a). The interface boundary can be seen very clearly parting substrate region with clad region. The white area is identified as clad region where as the area on the left side is base metal. The heat affected zone can also be differentiated with unaffected zone very easily.

The heat affected zone has coarse grain structure which shows martenistic phase. This is due to fast cooling of the base metal. The base metal is low carbon steel hence its comprises of mainly iron and carbon. The unaffected region in the base metal shows ferritic phase which consist of mainly iron as we find out in EDS of base metal.

The carbon from base metal migrates toward the clad region to form chromium carbides. This is due to the affinity of carbon towards chromium to form carbides. The SEM image of the interface between substrate and buffer layer is as shown in fir 3.8(f) on next page.

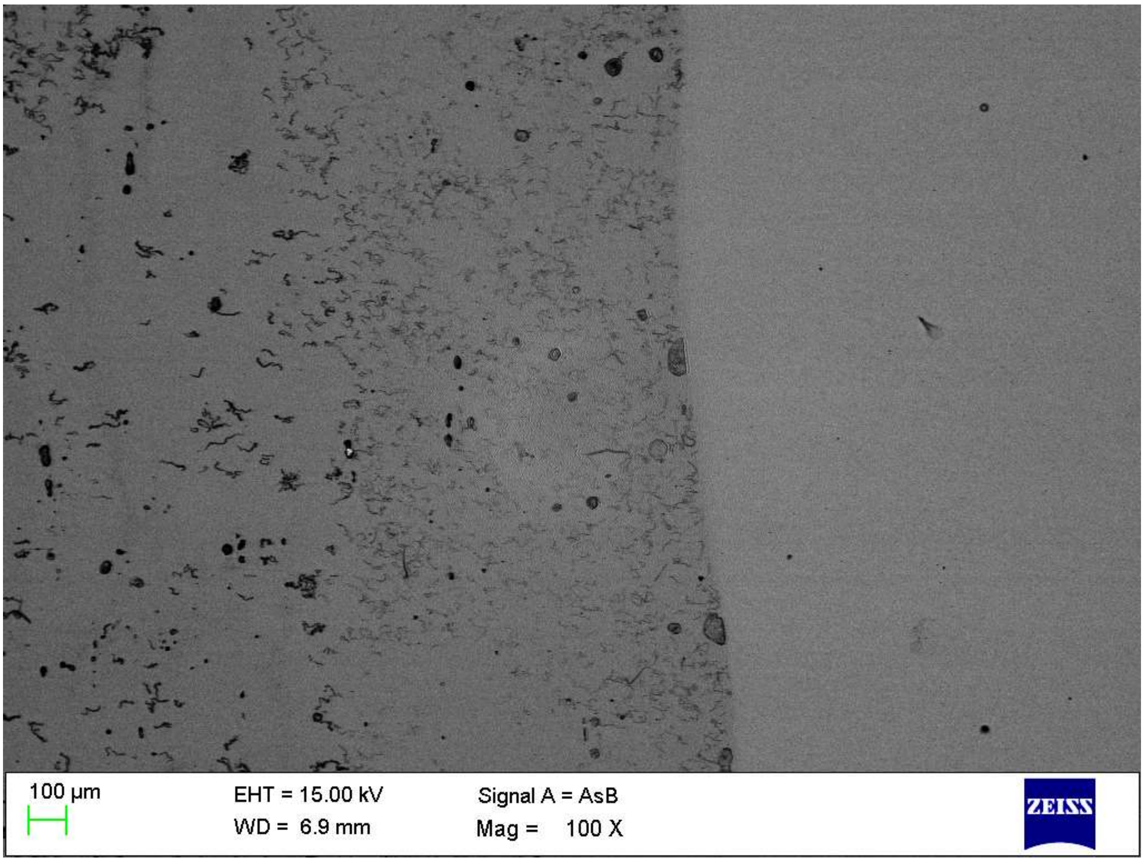


Figure 3.8 (e) SEM image of Interface between base metal and buffer layer.

3.7.4 Electron Dispersive Spectroscopy (EDS)

Electron dispersive spectroscopy is performed on the cladded specimen. The substrate is low carbon steel named SA 516 grade 70 which is used in pressure vessel manufacturing also known as boiler grade steel which mainly consist of iron and carbon. The typical section of base metal selected for EDS is as shown in fig 3.9(a) The percentage variation of iron and carbon is base metal is as follows

ELEMENT	WEIGHT %	ATOMIC %
C	4.96	19.52
Fe	95.04	80.48

Table 3.5 Weight and atomic % age of elements in base metal

The percentage of iron is 95 and remaining is carbon and other small alloying elements. The 1mm area is taken under consideration near the fusion line as shown by the scale marked on the picture. The yellow peaks show the presence of iron in the

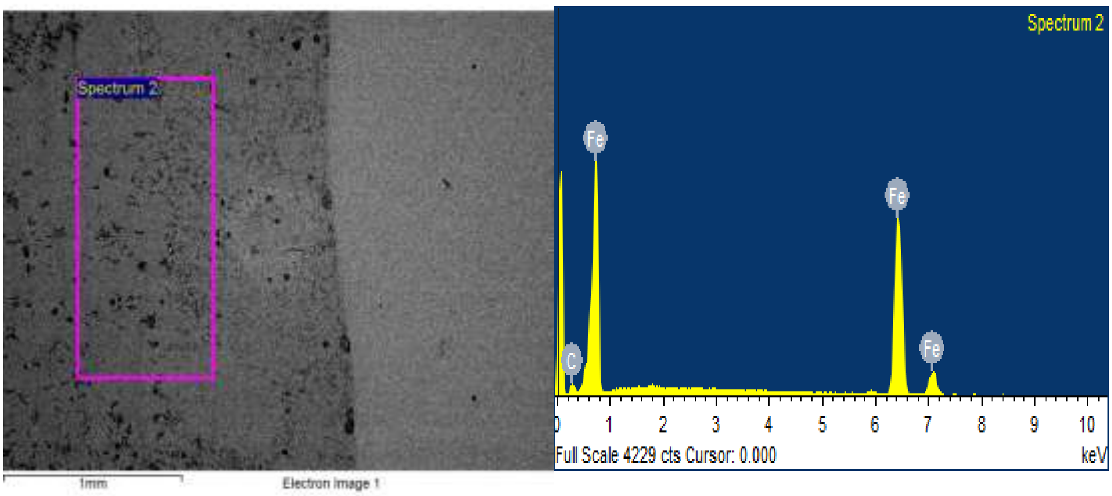


Figure 3.9 (a) EDS of base metal of low carbon steel

The second section selected is in the clad region. The buffer layer of 309L is taken into consideration. The 309L grade steel is austenitic type steel and consist of chromium and nickel as their main constituents. The percentage of various alloying elements in 309L is as follows.

Elements	Weight %	Atomic %
C	4.63	18.39
N	0.25	0.85
Cr	18.03	16.53
Fe	61.84	52.79
Ni	12.25	9.95
Mo	3.0	1.49

Table 3.6 Weight and atomic % age of elements in clad region

The percentage of chromium found is 18 % whereas nickel is 12.25% small amount of molybdenum and nitrogen is also recorded in the clad metal and rest is iron.

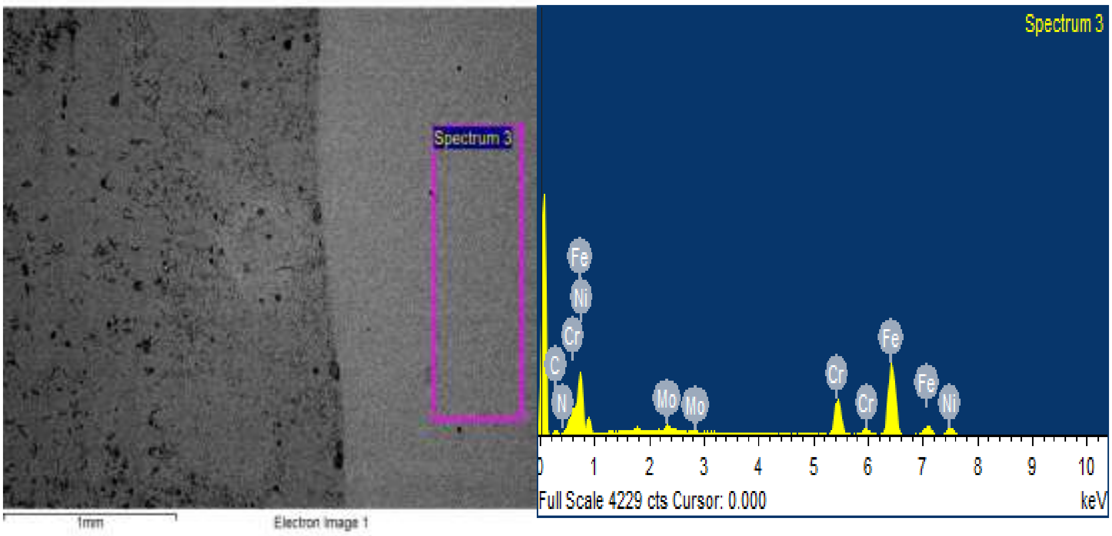


Figure 3.9 (b) EDS of buffer layer regions

The third section taken for EDS is clad and substrate interface is taken which clearly shows that the carbon in the base metal is extremely high due to which is shows completely ferritic phase in the base metal. As we moves toward the interface the carbon start decreasing and moves in the clad region due to its affinity towards chromium. The carbon depleted zone formed near the interface show gradual fall of iron here.

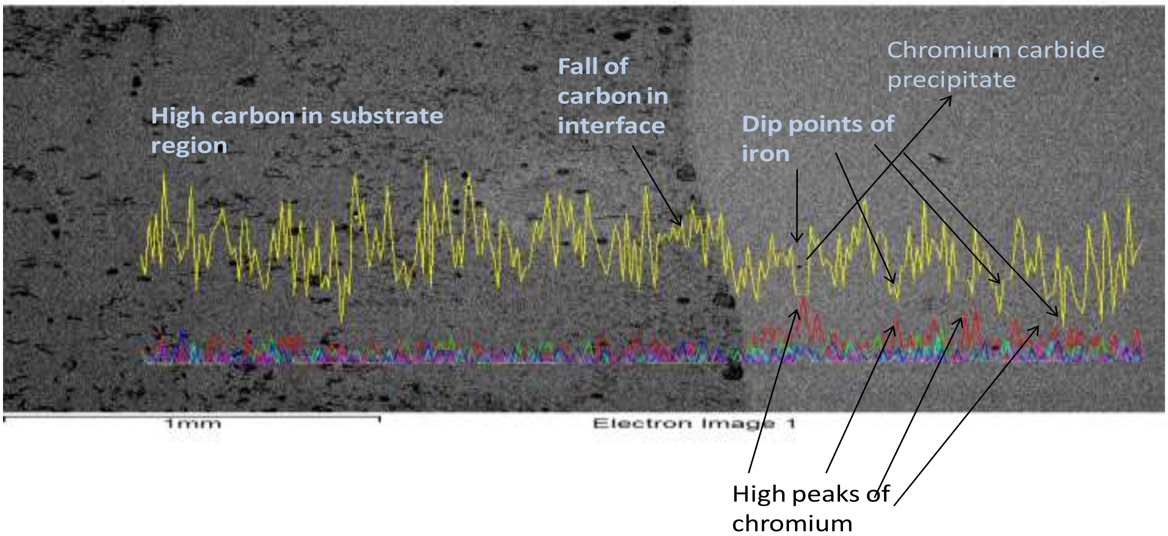


Figure 3.9 (c) EDS of substrate and buffer layer interface

As we moves toward the clad region beyond the transition zone the chromium content in red shown high peaks. It is noticeable that where there is a peak of chromium there is a dip recorded in iron content.

This behavior of carbon is due to its affinity towards chromium to form chromium carbide in the clad metal. The reason behind formation of chromium carbide in stainless steel is due to this phenomenon which is illustrated by this elemental graph mapping. The precipitates of chromium carbide are present as small black spots in fir 3.9 (c). Clearer picture of chromium carbide can be illustrated from fig 3.8(e) which is taken at 400 X magnification in optical microscope.

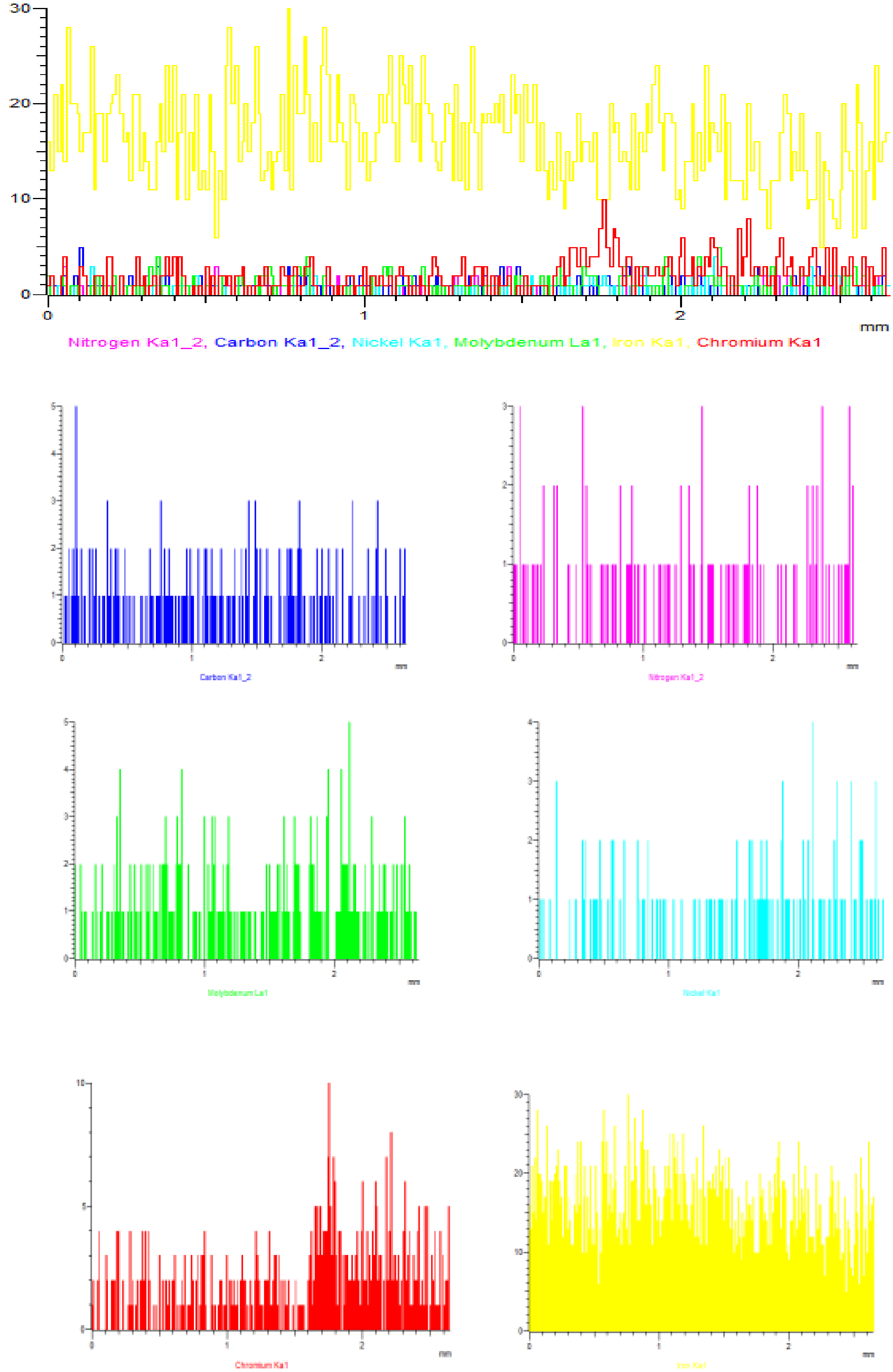


Figure 3.9 (d) Elemental graphs of individual constituent

3.7.5 X-Ray diffraction

The X-ray diffraction carried out to find out different phases formed in the clad region using Bruker 2 D system with Cu K α radiation (λ= 1.54056 A°) over an area of approximately 10x10 mm specimen as shown in figure 3.6.

The graph formed is as shown in the figure 3.10.

The phases formed in clad region are austenite and ferrite. This is because the clad metal is basically duplex stainless steel which contains ferrite and austenite in equal proportion. In addition to the above said phases one more phase is formed in clad that is chromium carbide. The chromium carbide is formed by reaction of chromium (major constituents of duplex stainless steel) with carbon which migrates from base metal toward clad region due to its affinity toward chromium.

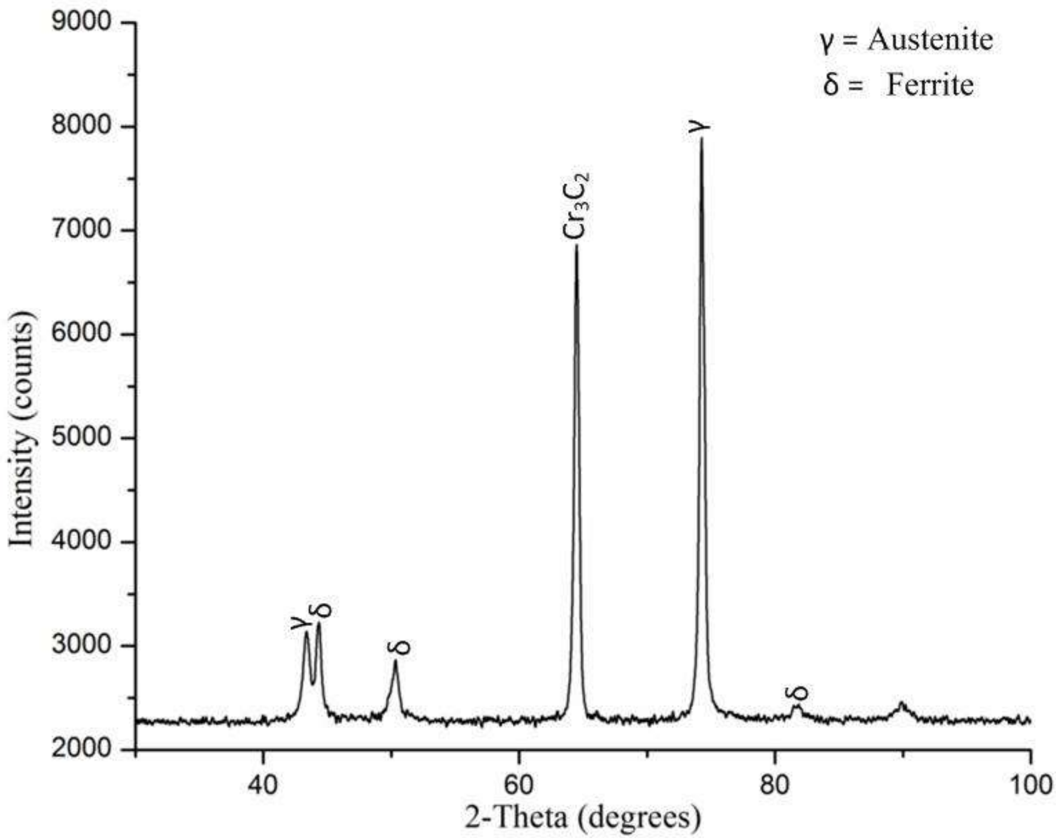


Figure 3.10 X-Ray Diffraction for different phases in clad

3.7.6 Ferrite No. Prediction

The Ferrite content was measured with the help of Fischer Ferrite –scope MP 30 for the cladded specimen. The no of reading taken is ten around the full cross section of the clad region.

The ferrite no is predicted as per ASTM E 1245/2008. The average of ferrite no found in the clad region is 36.729, which show satisfactory results as required ferrite no is between 30-55% as per code.

Ferrite no. Prediction

SID:BA-30059	Frame Area(mm²)	FERRITE(%)
Frame - 1	0.8595	39.538
Frame - 2	0.8595	37.228
Frame - 3	0.8595	36.595
Frame - 4	0.8595	34.166
Frame - 5	0.8595	33.850
Frame - 6	0.8595	33.792
Frame - 7	0.8595	36.415
Frame - 8	0.8595	40.095
Frame - 9	0.8595	38.626
Frame - 10	0.8595	36.987
Average	0.8595	36.729

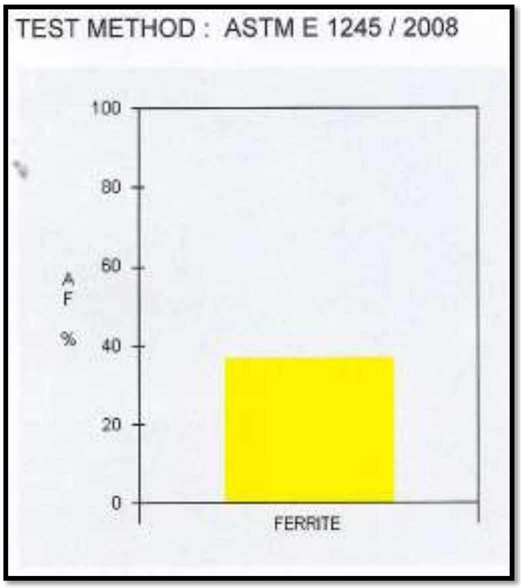


Figure 4. Ferrite no. evaluations.

4. Conclusions

This thesis is microstructure & mechanical properties study of duplex 2209 over low carbon steel substrate. The main results obtained and analyzed as follows:

- The Electro-slag strip cladding is economical, defect free and highly producible process for overlaying duplex stainless steel.
- Due to uncontrolled cooling the dark etching layer formed in interface on substrate side which resembles the carbon depletion region of base metal.
- The hard martensite phase formed at interface due to sudden cooling while rest of substrate exhibit ferrtic structure.
- The buffer layer shows austenitic structure with vermicular ferrite.
- The interface of buffer layer and top layer of deposit show small increase in ferrite due to re-melting of 309L layer.
- The top layer consists of austenite in ferrite matrix with formation of chromium carbide precipitates.
- Ferrite content prediction show that it is under acceptable range.

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6. Publication

The present thesis work is submitted to “International Journal of Engineering and research Applications “prior to any results and conclusions. The basic ideology, concept and methodology had been reviewed in advance to complete this work. So a “Review Paper “is published by the “IJERA” on my thesis topic name

“**Microstructure & mechanical Behavior of duplex 2209 on low carbon steel substrate using ESSC process**”

The copy of the publication is as attached under

RESEARCH ARTICLE OPEN ACCESS

Microstructure, Mechanical Properties & Corrosion Behavior of Duplex 2209 in Electro-Slag Strip Cladding over low carbon steel substrate: a Review Paper

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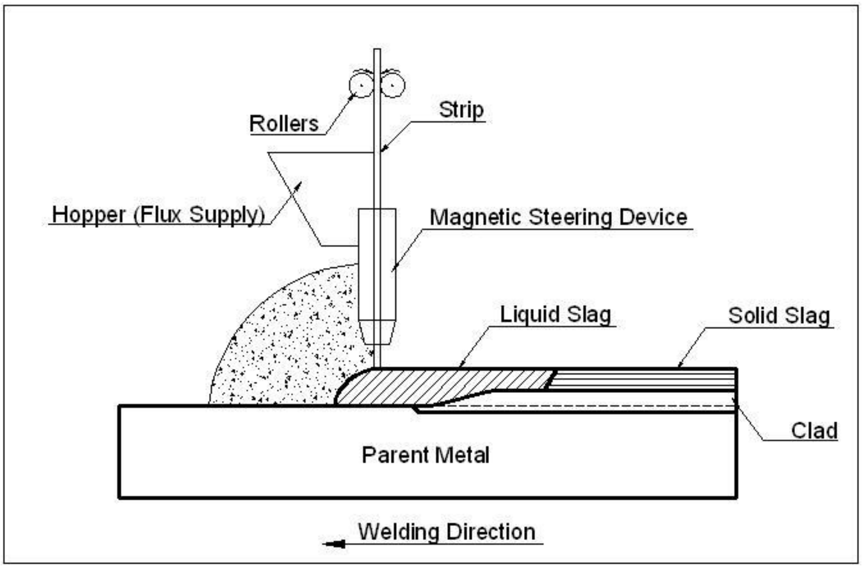
ABSTRACT
The purpose of this research work is todetermine the microstructure and mechanical properties of Stainless steel (Duplex 2209 and S.S 309) weld overlay on Low carbon steel plate (SA 516 Grade 70) developing multilayers. The buffer layer is done by using S.S 309 L strip electrode of 60mm width following by top layers of Duplex 2209.The Process used is Electro Slag Strip Cladding due to its unique properties like high deposition rate and low dilution level.The Microstructure characterization will be examinedby the use of SEM/EDS. In mechanical properties Micro hardnesswill be examined. Residual stress analysis will be done by XRD. The intergranular stress corrosion study will also be carried out as per ASTM G-5 standards.
Keywords–Electro-Slag Strip Cladding, Scanning Electrode Microscope,Duplex steel.

I. INTRODUCTION

In the Modern world of industrialization the wear is eating the assets worth millions of dollars per year. The wear is in the form of corrosion, erosion, Abrasionetc. which occur in the process industries like oil & gas, refineries, Cement plants, steel plants and dockyards. The pressure vessels or reactors which often work at elevated temperatures face corrosion in their internal diameter.



From last many decades CRA (Corrosion resistant alloys) are being used for overlaying a protective layer over base metal by various techniques like explosion welding, SAW, Submerged arc Strip Cladding (SASC) and Electro-Slag Strip Cladding.The most efficient and widely used technique these days is Electro-Slag Strip cladding due to its unique properties like high deposition rate, Low dilution and high quality defect free weld.

Electro-Slag Strip Cladding Process–

In ESSC the strip electrode is continuously fed into molten pool of electrically conductive flux. The principle is based on resistance heating by which the electric current flows through flux and melt it. The flux contains fluorides like CaF_2 and NaF which increase electrical conductivity. Electro-Slag Strip Cladding process is identical to SASC. The basic difference is that in ESSC there is no arc while welding. The arc is strike just to start the weld. Due to unavailability of arc there is no ultraviolet radiation but only infra-red rays.The basic problem in this process is undercut. The problem arise due to electromagnetic pinch effect. The electromagnetic forces due to high current passing through the metal strip tends the flow of molten metal from sides to the center of the weld bead. To overcome this problem we apply an external magnetic field by using magnetic steering device in the opposite direction. The metal deposition rate is up to 52kg/hour which is highest among other processes. The dilution level is recorded as low as 10-15% among all processes. A straight polarity is used in ESSC. Arc voltage is kept low at 24-26V and current is high 400-2400 A depending on strip size

Chemical Composition of Base Material and Strip electrode –

This grade of steel is as per the standard specification of Pressure vessel plate, carbon steel for moderate and low temperature service. Its composition is as follows

Elements	Base Metal	S.S 309 L	Duplex 2209
Carbon, C	0.27 under ½", 0.28 between ½" to 2"	0.009	0.008
Silicon, Si	0.15 - 0.40	0.13	0.43
Sulfur, S	0.035	0.0015	<0.0005
Phosphorous, P	0.035	0.015	0.018
Manganese	0.85 - 1.20	1.68	1.51
Chromium	-	20.34	22.95
Nickel	-	13.45	8.59
Molybdenum	-	2.84	3.02
Cobalt		0.023	0.11
Copper		0.078	0.12
Nitrogen		0.031	0.15

The strip electrode will be 60 mm X 0.5 mm dimension.

The flux used consist of following by %

SiO2	6
Al2O3	24
CaO + MgO	48
K2O + Na2O	2
F	32

II. Experimental Procedure -

The base plate of SA 516 Grade 70 low carbon steel of 50 mm received in normalized, accelerated cooled and tempered condition. In first case the buffer layer with SS 309 L will be performed followed by second and third layer of Duplex 2209.The overlays then will be tested under SEM/EDX. Micro hardness will also be tested along with residual stress analysis by XRD. Welding parameters used in performing ESSC

Parameters	Range
Welding current (I)	1200-1400 A
Voltage (V)	22-26V
Travel Speed	170 mm/min
Pre heat	130 degree Celsius
Interpass	Max 200
Electrode extension (Stick Out)	12-15 mm
Height of Flux	15mm
Polarity	DCEP

III. CONCLUSION

The analysis in this area over past few decades reveals that in ESSC generally Austenitic grades of Stainless Steel is used like 304, 309, 316 L etc. The review paper evaluates the new grade of Stainless steel i.e. Duplex 2209 which exhibits different mechanical and chemical properties as compared to conventional Austenitic Stainless steel. The mechanical properties along with corrosion behavior of the clad overlay will be evaluated.

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