SOME INVESTIGATIONS ON THE MECHANICAL CHARACTERISATION OF BIMETALLIC WELDS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

MECHANICAL ENGINEERING

(With Specialization in Welding Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this report entitled "**SOME INVESTIGATIONS ON THE MECHANICAL CHARACTERISATION OF BIMETALLIC WELDS**" is presented on behalf of partial fulfillment of the requirement for the award of the degree of **Master of Technology** with specialization in **Welding Engineering**, submitted to the Department of **Mechanical & Industrial Engineering,** Of **Indian Institute of Technology Roorkee, India**, under the supervision of Dr. Navneet Arora, Associate Professor and Shri Ajai Agarwal, Asst. Professor, Department of Mechanical & Industrial Engineering, Indian Institute of Technology Roorkee, India.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date: 30-06-2011

Place: **Roorkee**

(Bijendra Kumar)

CERTIFICATION

This is to certify that the above statement made by the candidate is correct to the best of our knowledge and belief.

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ABSTRACT

Dissimilar metallic welds between carbon steels and austenitic stainless steel are widely used in steam generator of nuclear power plants and is of great area of interest amongst the researchers. Stainless steel tubes are used in high temperature sections in combination with pressure and corrosive environment. In the lower temperature region of the plant, less expensive carbon steels with better creep resistance are used. For the safer operation of the plant we must ensure about the safety aspects of the bimetallic weld joint between the carbon steel and austenitic stainless steel. In this study German steel grade 20MnMoNi55 and AISI 304 austenitic stainless steel were joined by submerged arc welding (SAW) process using a stainless steel (ER316L) filler wire. The welding was performed with different flux combinations to study the influence of flux Basicity. After welding, ultrasonic non-destructive testing was carried out on welded plates to ensure the defect free weld joint. Tensile and Charpy tests were conducted using UTM and Impact testing machine to estimate the tensile and impact property of the as-welded samples. To study the effect of heat treatment on mechanical properties, heat treatment of as-welded samples was done.

SEM analysis of tensile test fractured samples was performed to study the failure mechanisms and is discussed in details.

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NOMENCLATURE

Symbols		Stands for
A	:	Ampere
Al	:	Aluminium
AC	:	Alternating Current
ASTM	:	American Society for Testing Materials
ASME	:	American Society of Mechanical Engineers
BI	:	Basicity Index
BM	:	Base Metal
BMWs	:	Bimetallic Welds
C	:	Carbon
Cr	:	Chromium
DMWs	:	Dissimilar Metal Welds
DC	:	Direct Current
E	:	Modulus of Elasticity
EBW	:	Electron Beam Welding
%El	:	% Elongation
Fe	:	Iron
Flux 1	:	Flux BB202
Flux 2	:	Flux Supershield SS
GS	:	German Steel

GL	:	Gauge Length
GTAW	:	Gas Tungsten Arc Welding
HAZ	:	Heat Affected Zone
HV	:	Vickers Hardness
kN	:	Kilo Newton
Mn	:	Manganese
Mo	:	Molybdenum
MPa	:	Mega Pascal
Ni	:	Nickel
NDT	:	Non-Destructive Testing
P	:	Phosphorus
%ROA	:	% Reduction of Area
S	:	Sulphor
SAW	:	Submerged Arc Welding Process
SS	:	Stainless Steel
Si	:	Silicon
USW	:	Ultrasonic Welding
UTS	:	Ultimate Tensile Strength
UTM	:	Universal Testing Machine
V	:	Voltage
WM	:	Weld Metal

YS	:	Yield Strength

Chapter 1

INTRODUCTION

Since ancient time people had joined dissimilar metals. Ornaments and trinkets were made with metals of differing colors and workability, even though the joining methods used in ancient times were very different from those in present.

Now-a-days, joining of dissimilar metal is required in manufacturing and construction industries with advance equipment and machinery. Different kind of metals has different chemical, physical, and metallurgical properties, some are more resistible to corrosion, some are lighter, and some are stronger. Therefore joining dissimilar metals is required to compose different properties of metals in order to minimize material cost and maximize the performance of the equipment and machinery. Presently, the methods of joining dissimilar metals include fusion welding, pressure welding, explosion welding, friction welding and diffusion welding, brazing, and soldering.

Pressure vessel steel (20MnMoNi55) of current interest has the application in nuclear power plants for the production of nuclear reactor pressure vessel. Today most of the electrical energy is generated using nuclear reactors. The reactor pressure vessel and heat transportation piping system of nuclear power plant are designed to withstand the large amount of pressure and temperature. Pressure vessels are designed to operate safely at a specific pressure and temperature. To implement the safe design of reactor pressure vessel it is important to understand the mechanical behavior of its material **[7]**.

1.1 Bimetallic weld:

When two different metals/alloys are joined together, it is termed as dissimilar metal/ bimetallic welding. A bimetallic weldment contains a weld deposit with a chemical composition that differs by several percent from the composition of either of two different metals that has been welded together. Metals dissimilar in the nature of their major constituents and metals dissimilar in the nature of their alloying elements are the two types of dissimilar metal welds **[30]**.

1.2 Need of Bimetallic weld:

Stringent material requirement of various components, which generally demands different metal component, necessitates the need of bimetallic welds. The Nuclear reactor, Pressurized water reactor and boiling water design where heavy sections low alloy Steel/ plain carbon steel component are usually connected to stainless steel (SS) primary piping systems. For pressurized water reactor, the bimetallic welds are of particular interest, which are used to connect the piping systems **[10]**.

Dissimilar metal welds (DMWs) between carbon steel and austenitic stainless steel are commonly found in fossil fired power plants. In fossil fired power plants the temperature and pressure of the steam that is produced control the efficiency of the plant. Therefore, the highest possible operating temperatures are desired to improve efficiency. The high temperatures, in combination with the steam pressures and corrosive environment, limit the materials that can be used for tubing. In the lower temperature regions of the plant, less expensive low alloy steels are used. However, in the superheated and reheated sections of the plant, the higher temperatures require the superior corrosion resistance and greater creep strength of more expensive austenitic stainless steels. These two different steels must be joined using a welding process **[8]**.

1.3 Nuclear Reactor:

Most nuclear electricity is generated using reactors which were developed in the 1950s and improved since. New designs are coming forward and some are in operation as the first generation reactors come to the end their operating lives. Over 16% of the world's electricity is produced from nuclear energy.

A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In a nuclear power reactor, the energy released is used to make steam to generate electricity. In most of the reactors, steam drives a turbine directly for propulsion. The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity.

1.4 Reactor Pressure Vessel:

The RPV is cylindrical with a hemispherical bottom head and a flanged with Gasket on upper head. The bottom head is welded to the cylindrical shell while the top head is bolted to the cylindrical shell via the flanges. The body of the vessel is of low-alloy carbon steel. To minimize corrosion, the inside surfaces in contact with the coolant are clad with a minimum of some 3 to 10 mm of austenitic stainless steel. Numerous inlet and outlet nozzles, as well as control rod drive tubes and instrumentation and safety injection nozzles penetrate the cylindrical shell. The number of inlet and outlet nozzles is a function of the number of loops or steam generators **[31]**.

1.5 Reactor Pressure Vessel material:

For manufacturing the reactor pressure vessel different materials are used for the different components. For example, the Westinghouse designer specifies American Society for Testing and Materials (ASTM) SA 302 Grade for shell plates of earlier vessels and ASTM SA 53 Grade B Class 1 for later vessels. Other vessel materials in common use include American Society of Mechanical Engineers (ASME) SA 508 Class 2 plate in the USA, 16MnD5 in France. SA-302, Grade B is a manganese-molybdenum plate steel used for a number of vessels made through the mid-1960s. German designation 20MnMoNi55 is used in Germany. As commercial use of nuclear power increases, the sizes of the vessels increased. For the greater wall thicknesses required, a material with greater hardening properties was necessary.

In mid of 1950s the forging steels have also been evolved. The SA-182 F1 Modified material is a Mn-Mo-Ni steel used mostly for flanges and nozzles in the 1950s and 1960s. Large forgings of these materials had to undergo a cumbersome, expensive heat treatment to reduce hydrogen blistering. Eventually these steels were replaced with steel known as SA-508 Class 2 that did not require this heat treatment. This steel has been widely used in ring forgings, flanges and nozzles. It was introduced into Germany with the designation 22NiMoCr36 or 22NiMoCr37. With slight modifications, this steel became the most important material for German reactors for a long time. In addition, SA-508 Class 3 (20MnMoNi55 in Germany and 16 MnD5 and 18MnD5 in France) is used in the fabrication of RPVs.

Chapter 2

LITERATURE REVIEW

Bi-metallic joints are generally used to connect ferritic pressure vessel nozzles or ferritic piping with austenitic piping. Recent international surveys of such welded joints have shown that there are several cracking problems, due to fabrication induced defects, ageing, corrosion or thermal fatigue caused by temperature changes during service life of plant. Defects in structural components often occur within or near welds across which tensile properties may vary significantly. This mismatch in tensile properties can affect the plastic deformation pattern of the defective component as suggested by **(I. A. Khan et al.)[9]**.

Dissimilar welds impose a challenge to the engineers concerned with the structural integrity assessment of these joints. This is because of the highly inhomogeneous nature of these joints in terms of their microstructure, mechanical, thermal, and fracture properties. Fracture mechanics-based concepts cannot be directly used because of the problems associated with the definition of a suitable crack-tip loading. Again, depending upon the location of initial crack (i.e. base, weld, buttering, different interfaces, etc.), further crack propagation can occur in any material.

The Author used micro-mechanical models of ductile fracture for initiation and propagation of cracks in the bimetallic welds. The author has developed a finite element formulation that incorporates the porous plasticity yield. The effectiveness of the damage model for predicting the crack growth in the actual bimetallic-welded specimen was suggested by **(M. K. Samal et al.) [1]**.

The fabrication of bimetallic aluminium sheathed/copper axis symmetric rods by explosive cladding and subsequent warm extrusion is reported. The effect of the cladding and the extrusion parameters on the macro and the microscopic features and the soundness of the product at the various stages of the fabrication are indicated using micro hardness testing and optical microscopy.

By employing warm extrusion as a post-welding forming technique, instead of the cold extrusion, the soundness of the components was improved due to advantageous plastic flow of the extruded composite rod at elevated temperatures and the minimization of the characteristic extrusion defects. A theoretical analysis pertaining to the extrusion of axis-symmetric bimetallic rods was proposed. By combining explosive cladding and multiple-pass warm extrusion, with the proper selection of the relevant operational/geometrical variables, sound bimetallic rods with sufficient strength and bonding integrity was fabricated by **(A. G. Mamalis et al.)[2]**.

Defects encountered in the rolling of bimetallic, such as curving could be minimized by selecting appropriate operational parameters, i.e. by avoiding both very small and relatively high reductions, for the materials and the processing conditions examined. Report on the fabrication of bimetallic components consisting of aluminium and copper plates by explosive cladding and subsequent rolling. Such components are used extensively in the electrical and ship-building industries as well as in vessel design, replacing components made from solid materials. The effect of the cladding and the rolling parameters on the sound fabrication and the micro-structural properties of the resulting bimetallic were evaluated by **(A. G. Mamalis et al.)[3]**.

Problems encountered in bimetallic welds and possible solutions were discussed by **(Z. Sun et al.)[4]**. the paper recalls the state-of-the-art EBW of dissimilar metals, with special emphasis on showing the potential of the process for achieving high-quality dissimilar-metal joints. Since EBW is a fusion-welding process, metallurgical phenomena associated with fusion still exist and cause difficulties. However, these were often minor as compared to those in conventional arc welding.

Electron beam welding (EBW) had been developed for many years. Joining dissimilar metals using EBW was also a subject of interest in recent years. Due to special features of EBW, e.g., high energy density and accurately controllable beam size and location, in many cases it has proven to be an efficient way of joining dissimilar metals.

Dissimilar metal joints are used widely in various industrial applications due to both technical and economic reasons. The adoption of dissimilar-metal combinations provides possibilities for the flexible design of the product by using each material efficiently i.e. to get benefit from the specific properties of each material in a functional way. Fusion welding is one of the most widely used methods for the joining of metals. Therefore, continuous efforts were made to apply those methods to the joining of dissimilar metal combinations to make a defect free weld.

These difficulties include problems associated with metallurgical incompatibility, e.g. the formation of brittle phases, the segregation of high and low melting phases due to chemical mismatch, and possibly large residual stresses from the physical mismatch.

It had been known that the difficulty of dissimilar metals joining between steel and aluminum alloy was caused by the formation of brittle intermetallic reaction phase. In order to suppress the formation of intermetallic reaction phase, self-brazing technique, which the molten zone of steel was controlled to be a partial penetration during lap-joint welding between steel/aluminum alloys. In order to suppress intermetallic reaction layer formation during dissimilar metals welding between steel/aluminum alloys, only laser beam welding as self brazing technique was applied. However, TIG welding process might be one of welding process candidate for joining dissimilar metals welding between steel/aluminum alloys due to its capability in joining thin section. **(Rattana Borrisutthekul et al.) [5].**

The French field experience in stainless steel bi-metallic welds (BMW) has shown different degradations like external surface corrosion cracks close to the low alloy steel / stainless steel interface or fabrication defects in different other locations. In many countries, some degradation has been encountered in different type of bi-metallic welds: stainless steel BMW or Ni based alloy BMW through different degradation mechanisms (corrosions). The critical crack size in different location of a BMW was a key safety issue. The worst crack location was close to the fusion line, the crack located in the austenitic steel tended to reach the low alloy steel interface, but never cross it and continue to grow by stable ductile tearing. **(Claude Faidy et al.)[6].**

Bimetallic welds (BMWs) play a critical role in the primary heat transport piping system of nuclear reactors. The primary heat transport system itself is the critical part of a nuclear reactor. Any failure of this system can lead to very grave consequences, not only speaking of huge monetary losses resulting from non-utilization of the reactor setup, but also immensely valuable and irreparable loss of human life.

Experimental efforts was made towards estimation of Gurson material parameters of base metal and weld metal regions of a BMW so as to use the micromechanical modeling approach for addressing the structural integrity issues in BMWs by **(R. Chhibber et al.)**[7].

Non destructive testing of bimetallic weld joints, made of Stainless steels cladding on low alloy steel base metal was investigated. Stringent material requirement of various components, which generally demands different component materials, necessitates need of bimetallic joints in nuclear equipment manufacturing. Development of bimetallic weld joints and its quality assurance procedure was carried out. Feasibility of different NDE methods for examining different weld configuration (like butt weld, T weld, corner welds with constrains) was evaluated. Ultrasonic scanning was not being feasible in case of bimetallic welds containing titanium or nickel alloys as cladding and steel as base metal. Non destructive examination of these bimetallic welds needs to be careful. Examination of acoustic properties to see their effect on feasibility of ultrasonic was performed by **(Vinod Kumar et al.)[10].**

The complex conditions and properties of the weldment, limits the ability of currently existing methods to construct the weldment, on the basis of actual failure mechanisms of bimetallic welds. The assessment was procedure by combining experimental and numerical fracture. The studied dissimilar ferrite (SA508) austenite (AISI 304) circumferential weld was one with a Ni-enriched buttering layer work comprises tensile and fracture mechanical characterization of the different microstructure zones of the bimetallic weld.

Bimetallic welds impose a challenge to fracture mechanics. Welds can be made using several metallurgical design concepts and the quantitative fracture mechanical properties. The decreased fracture resistance of fusion boundary regions was tends to low toughness ductile rupture mechanism. Constraint analysis was made on failure tendencies and specimen behavior by **(A. Laukkanen et al.) [11].**

Dissimilar metal weld failures were investigated. Each failure was different due to multiple simultaneous metallurgical and mechanical factors. However, DMW failures have many similarities. During fusion welding, the combination of the high alloy content of the austenitic filler metals and fast cooling rate produce a hard martensite band along the fusion line.

High temperatures encountered during either post-weld heat treatment (PWHT) or service, provide the activation energy for carbon migration from the ferritic base metal to the austenitic filler metal due to chemical potential gradient between the two steel. The carbon migration leads to carbon-enriched and carbon-depleted regions in the austenitic and ferritic steels, respectively, and the dissolution of carbides on the ferritic side and precipitation of chromium carbides on the austenitic side in the fusion zone.

A hardness gradient forms over a very short distance between the hard martensite and chromium carbides in the fusion zone and the softened carbon-depleted zone in the ferritic base metal. At the same time, stresses develop in the DMW from the differences in creep strength and thermal expansion coefficients of the steels. As a consequence of the hardness and strength gradients, these stresses were concentrated in the weak carbon-depleted zone, generating creep voids. Repeated thermal cycling at elevated temperatures causes the growth and eventual link-up of the creep voids, results in a final failure from micro-cracking along the fusion line in the ferritic steel as investigated by **(G. Brentrup et al.)[12]**.

The development and verification of analysis methods to describe the behavior of an external circumferential defect was done. The complexity of the problem results from the prevailing mixed mode loading conditions, variation in material constitutive equations across the weld zone and the presence of large residual stress field. Due to the complexity of the BMW for fabrication, inspection and analysis, specific programs as BIMET, was developed to confirm the quality of the present BMW design rules. BIMET program was important step considering tests and analysis of small diameter BMW at room temperature and can support the validation of different engineering methods by **(C. Faidy et al.)[13]**.

Serious concerns have been raised in recent years in the Oil & Gas Industry about the reliability of Dissimilar Metal Welds (DMWs) in sour service. The primary reason for these concerns is because DMW joints exhibit small-localized hard zones that were susceptible to Sulfide Stress Cracking (SSC). Preheating was suggested by the author to overcome the problem of hard zone formation. The problems are inherent with dissimilar metal weld joints. Sulfide stress cracking of bimetallic welds was investigated by **(Gasem M. Fallatah et al.)[14]**.

The influence of welding process, consumable type and post weld heat treatment (PWHT) on the phenomenon of disbonding was investigated. Small weld clad test blocks were thermally charged with hydrogen in an autoclave. A range of austenitic stainless steel consumables and a Ni-Cr alloy were used to make the claddings on 2.25Cr-1 Mo parent metal by submerged arc strip and wire, Electro-slag, plasma hot wire, and manual metal arc processes. The effects of simple and multiple post weld heat treatments at 565-690°C were determined and local hydrogen contents in clad materials were determined.

Some disbonding sensitivity was found with all consumable types, but the stainless steel overlays showed appreciably higher susceptibility than the Ni-Cr cladding. Disbonding resistance was higher with manual metal arc (MMA) welding than with the various high deposition rate methods. Disbonding is due to hydrogen embrittlement and is associated with the presence of martensite in the interface region, the martensite forming both during welding and following post weld heat treatment.

Cracking occurs almost exclusively on the cladding side of the interface with only a few isolated excursions into the parent metal. For submerged arc strip welding with 309L consumables, high current, high travel speed conditions produced claddings with improved resistance to disbonding compared to the slower, lower current welding conditions was investigated by **(M. F. Gittos et al.)[15]**.

The study of fundamental arc welding process characteristics is important for controlling both the formation of and the mechanical properties in weld metals. Automated and semi-automated welding procedures require accurate knowledge of the effects on weld-bead dimensions of changes in process variables, in order to fill joints rapidly without defects. In the SAW process, one such variable is the type of flux used.

Fluxes used in submerged arc welding, plays an important role in deciding the weld metal quality. Fluxes may cost up to half of the total welding consumable cost. A significant percentage of the flux gets converted into very fine particles, termed as flux dust, due to transportation and handling. Welding defects like porosity occur if welding was performed without removing these very fine particles from the flux, and if these fine particles were removed, the cost of welding will be increased significantly. Also if this flux dust is dumped, it creates pollution.

The development of an acidic agglomerated flux by utilizing wasted flux dust of the parent commercial acidic flux was done. The chemical composition and mechanical properties of the all-weld metal, prepared by using the developed acidic flux, were found to be in the same range as that of the weld metal, prepared from parent commercial acidic flux. Therefore the welding cost and pollution can be reduced, without any compromise in weld quality, by utilizing the developed flux, prepared from waste flux dust of the parent flux. Thus the work follows the concept of "waste to wealth" **(Vinod Kumar et. al.)[16].**

The influence of submerged arc flux composition on the inclusion morphology and weld metal microstructures of low carbon steels was investigated. Systematic weld oxygen variations and changes in inclusion shape and size were obtained by changing the welding flux composition. 'The influence of inclusion content, morphology, and distribution on achieving specific types of weld metal ferrite was described. The nucleation of weld metal ferrite was directly related to the oxide inclusions, and indirectly to weld metal oxygen content. Flux composition affects the morphology and size of the inclusions. Inclusion size seems to influence the weld metal microstructure. Inclusions 0.6 μm and smaller were located within the acicular ferrite, inclusions 1 μm and greater were found in the pro eutectoid grain boundary and polygonal ferrites. Small inclusions also pin the austenite grain boundaries when failed to be activated, thereby increasing the grain boundary interface available for nucleation of high temperature ferrites was investigated by **(J. W. Jang et al.)[17].**

Fluxes consisting of a system of oxides with high contents of silica and manganese are among those most widely used in welding carbon steels, because they possess good technological properties. Fluxes of this type have mainly been used in the metal mechanical and agricultural sectors.

The main field of application of fluxes has been related to the fabrication of steam boiler domes, a product that still requires an appreciable volume of flux, it has also been introduced in the production and repair of gas storage containers, and there are possibilities for growth in these field deposits of manganese ores. Manganese ores was used in the development of fluxes, and there were also ores, with appreciable quantities of silica, calcium magnesium and aluminium, which were all suitable for use as raw materials in flux production The results of the chemical composition of the flux Basicity, relative chemical activity and activities of the oxides MnO and SiO_2, and its technological behavior, allow its use in shallow submerged arc welding as investigated by **(A. Cruz et al.)[18].**

The effect of submerged arc welding parameters on grain development and weld metals chemistry (oxygen and nitrogen) on SA516 and A709 steel weld metals was done. The influence of oxygen and nitrogen concentration introduced into the weld metal during welding on grain development and nucleation of acicular ferrite was evaluated. The weld parameters affect the weld oxygen content. Indirect correlation exists between the weld oxygen content and acicular content. The prior austenite grain size was affected by the weld metal oxygen content. Significant variations in weld bead morphology occurred under identical heat input with different welding current and speed combinations. Within the range of welding current from 700 to 850 A, harden-ability elements of carbon and manganese do not vary with change in current and speed. Nitrogen was equally not affected by the parameter variations as investigated by **(James Amanie et al.)[19].**

The effect of TiO_2 additions in fluxes on the mechanical properties and micro structure of the weld metal formed during Submerged-Arc Welding (SAW) of ASTM A36 steel plates was investigated. The increase in the percentage of acicular ferrite and a decrease in its length were observed with an increase in titanium content. The increase in titanium content in fluxes also improved the toughness and ductility of the welds. The formation of Ti containing white inclusions in the sub-arc weld metals played a very important role for the heterogeneous nucleation of acicular ferrite. The increase in density of the white inclusions causes an increase in the percentage of acicular ferrite, as well as a decrease in its length. The increase in titanium content in fluxes improved the toughness and ductility of the welds, with a slight loss of tensile strength as suggested by **(Ana Ma. et al.)[20].**

To obtain metal coatings with complex chemical compositions and phases, as well as differing mechanical properties, the Submerged Arc Welding (SAW) process is often used, employing a great variety of types of agglomerate fluxes. The two constituents of the flux aggregate, by various processes, with the help of agglomerating agents. Agglomeration by granulation using liquid sodium and/or potassium glass was the most common and widely used for these types of fluxes.

The chemical activity and structural characteristics of the matrix of the agglomerate flux influence the efficiency of the transfer of the chemical elements alloyed to the metal deposited during SAW process was investigated by **(R Quintana et al.)[21].**

Problem Formulation

The conclusion from the literature survey is that bimetallic welds between dissimilar metal like steel i.e. Carbon steel and austenitic stainless have been made so far with TIG process, EBW process, SAW process etc. Some researcher's worked on dissimilar metals welding on SAW process. But the effort was not made towards welding of German steel by SAW process. German steel is of great interest for research work in recent years. The German steel is used in nuclear power plant due to its better creep resistant properties.

So we decided to check the feasibility of welding German steel with SAW process. Different types of fluxes will be used for SAW process to find the effect of parameters (fluxes) on mechanical properties of weld between German steel and stainless steel. As on date no standard paper exist to show the effect of welding parameter (Fluxes) on the mechanical properties of a bimetallic welding of german steel and stainless steel by submerged arc welding process. Thus effects of parameters on Mechanical properties of weld between 20MnMoNi55 and SS 304 has been studied by welding using submerged arc welding process, which is known to clean surface weld with high deposition rate which is useful for welding of thick plates.

Chapter 3

WELDING PROCESS

3.1 Processes for Dissimilar Metal Welding:

- Fusion Welding processes (GTAW, Resistance welding, and EBW etc.)
- Solid state welding processes (USW and friction welding.)
- Brazing.

3.1.1 Fusion Welding Processes:
Fusion welding is a process that uses fusion of the base metal to make the weld.

- **Dissimilar metals without filler material:** The two dissimilar base metal having proper edge preparations are put together to be weld. No filler material is used in this technique.
- **Dissimilar metals with filler material:** It is assumed that metal X may be joined to Y by brazing, but that Y metal is a heat treated alloy which cannot be reheated after assembly. It is also important that complete softening should not occur. Under such condition a piece of metal Z in used as filler material, which is brazed to X. The final joint Z to Y can be made by a rapid arc welding process with the minimum effect on the properties of metal Y. the technique known as Buttering.
- **Resistance Welding:** It is often easier to make satisfactory weld between dissimilar metals by resistance welding than by arc welding, since the problem of fluxing or provision of an inert atmosphere does not arise and the techniques available often minimize the danger of the formation of brittle intermetallic compounds within the joint.

3.1.2 Solid State Welding:
Solid state welding processes are characterized by the absence of melting. It is necessary that the surfaces should be clean and be in intimate contact. The processes are as below:

- Pressure welding.
- Ultrasonic welding.
- Friction welding.
- Diffusion bonding.

3.1.3 Brazing:

Brazing is a process of joining metals without melting the parent material. The filler material used is required to wet the faying surfaces and be drawn to fill the space between them by capillary action. Filler material for brazing should have a liquidus temperature above 450°C and below the solidus of the material being joined.

Brazing is of much importance in joining dissimilar metals because of good practice. Alloying between the dissimilar metals cannot occur, and no unsuitable phases can be formed. Materials susceptible to inter-granular penetration should normally be annealed before brazing. The zinc bearing silver solders and copper zinc alloys may be used for joining copper, copper alloys, steels of all types, heat resisting alloys and nickel alloys [30].

3.2 Submerged Arc Welding Process

Submerged arc welding is a process where coalescence of metal is produced by heating them with an arc maintained between a bare metal electrode and work piece. The arc is shielded by a blanket of granular fusible material (flux) placed over the welding area. Filler metal is obtained from the electrode and sometimes from a supplementary welding rod or other metallic addition.

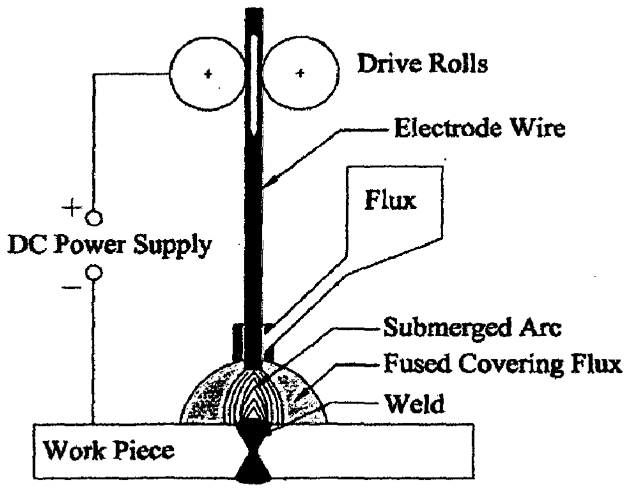

Fig. 3.1 Schematic diagram for submerged arc welding Process [32]

Basically, submerged arc welding (SAW) is an arc welding process that fuses together the parts to be welded by heating them with one or more electric arcs between one or more bare electrodes and the work piece. The submerged arc welding process utilizes the heat of an arc between a continuously fed electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode. Shielding is obtained from a blanket of granular flux. The flux close to the arc melts and intermixes with the molten weld metal and helps purify it. The flux forms a slag that is lighter in weight than the deposited weld metal and floats on the surface as a protective cover. The weld is submerged under this layer of flux and slag. Hence the name submerged arc welding. Fig. 3.1 shows the application of the SAW process [32].

3.3 Effect of Process Variable on Weldment

3.3.1 Effect of Welding Current

Welding current determines the rate at which the electrode is melted, the depth of penetration of the weld pool into the base metal and the amount of base metal fused. With increase in current at a given arc voltage and welding speed, the bead width, bead height, and penetration have been found to increase steadily. The steady increase in bead width and bead height with the increase in welding current may be caused by the higher amount of metal deposition due to high heat input. Increase heat input generally result in a larger weld pool size and fused area. Some application rule to remember regarding the welding current are **[32]**:

- Increase in amperage cause increase in penetration.
- Excessively high amperage results in a digging arc, an under cut, or a high narrow bead.
- Very low amperage results an unstable arc.

3.3.2 Effect of Welding Voltage

Welding voltage influences the shape of the weld cross section and the external appearance of the weld. Arc voltage adjustment varies the arc length between the electrode and molten weld metal. The change in arc voltage not only affects the outer dimensions of the bead but also influences the microstructure and even success and failure of the operation by affecting the mode of metal transfer. The arc voltage has less effect on the electrode deposition then that observed in the case of variation in welding current. The arc voltage mainly determines the shape of the weld cross section and its external appearance **[32]**.

3.3.3 Effect of Travel Speed

Travel speed is the linear rate at which the arc is moved along the welded joints. Travel speed is used primarily to control bead size and penetration. After the current, welding speed is the main factor controlling heat input and the dimensions of the HAZ. When travel speed is decreased the filler metal deposition per unit length increase and large weld pool is produced.

As the travel speed is increased, the thermal energy transmitted to base metal is slowed down and occurs nearer to surface of base metal. When current and voltage are kept constant it has been confirmed that electrode melting rates are unaffected with varying travel speed **[32]**.

3.2.4 Type of Flux

Submerged Arc Welding (SAW) is a very versatile process that can be used across range of materials and plate thicknesses for fabrication of water and petrochemical pipelines, gas cylinders, ship building and repair, and resurfacing (hard facing) applications in the mining, mineral processing and power industries.

Fluxes used in SAW are granular fusible minerals containing oxides of manganese, silicon, titanium, aluminium, calcium, zirconium, magnesium and other compounds such as calcium fluoride.

The flux is specially formulated to be compatible with a given electrode wire type so that the combination of flux and wire yields desired mechanical properties. All fluxes react with the weld pool to produce the weld metal chemical composition and mechanical properties. It is common practice to refer to fluxes as 'active' if they add manganese and silicon to the weld, the amount of manganese and silicon added is influenced by the arc voltage and the welding current level. The Silicon Oxide content imparts viscosity and density of the slag, which influence the speed of separation of slag particles from the solidifying weld metal. The addition of TiO_2 helps both ionization and stabilization to increase. The atmospheric oxides like Al_2O_3 produce a similar effect like SiO_2, CaO, also improve the arc stability. MnO helps high welding speed and deeper penetration and increases sensitivity to rust and porosity on the other hand it decrease current carrying capacity. CaF_2 increase the fluidity and it may lead to spray transfer **[32]**.

The Basicity index (B.I) of flux play an important role that governs composition of the weld metal and hence the weld joint. The concept of the Basicity index (BI) was adopted in steel making to explain the ability of the slag to remove sulfur from the molten steel. It was later broadened to indicate the flux oxidation capability. The BI of a flux (especially an oxide-type one) can be defined in the following general form **[19]**:

$$\text{Basicity Index (B.I)} = \frac{\sum \text{(Basic Oxide)}}{\sum \text{(Acidic Oxide)}}$$

The concept of the BI was applied to welding. The following well-known formula for the fluxes in SAW:

$$\text{B.I.} = \frac{CaO + CaF2 + MgO + SiO2 + Na2O + K2O + 0.5(MnO + FeO)}{SiO2 + 0.5(A2lO3 + TiO2 + ZrO2)}$$

Where components are in weight fraction, Using the above expression, the flux is regarded as acidic when $BI < 1$, as neutral when $1.0 < BI < 1.2$, and as basic when $BI > 1.2$. The formula correlates well with the oxygen content in submerged arc welds. The main types of flux for SAW are:

- **Bonded flux** - produced by drying the ingredients, then bonding them with a low melting point compound such as a sodium silicate. Most bonded fluxes contain metallic deoxidizers which help to prevent weld porosity. These fluxes are effective over rust and mill scale.
- **Fused flux** - produced by mixing the ingredients, then melting them in an electric furnace to form a chemically homogeneous product, cooled and ground to the required particle size. Smooth stable arcs, with welding currents up to 2000A and consistent weld metal properties, are the main attraction of these fluxes.

Chapter 4

EXPERIMENTAL WORK

The purpose of this work is to find out the mechanical properties of the bimetallic weld between German steel and SS304.

4.1 Chemical Composition:

The chemical composition of the base metals, filler wire and fluxes are shown in table given below.

Table 4.1

Chemical composition of base metal German steel (20MnMoNi55)

Elements	C	Mn	Si	Cr	Ni	Mo	S	P
% Wt.	0.2	1.25	0.24	0.2	0.6	0.5	0.005	0.008

Table 4.2

Chemical composition of base metal SS 304 [26]

Elements	C	Mn	Si	Cr	Ni	S	P
% Wt.	0.08	2.0	1.0	18 – 20	8 – 12	0.025	0.045

4.2 Welding Process:

Submerge Arc Welding (SAW) process with different fluxes was used for producing weld joint as shown in **Fig.4.1.**

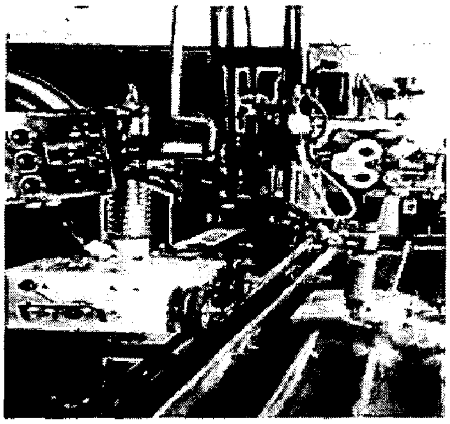

Fig. 4.1 Submerged Arc Welding (SAW) Process

4.3 Filler Wire:

Filler wire ER-316L was used for producing joint confirms AWS 5.9 Class ER316L. The diameter of filler wire used is 4.0 mm. The chemical composition of filler wire has been shown in **Table 4.3**

Table 4.3

Chemical composition of SS 316L filler wire used for SAW process [26]

Elements	C	Mn	Si	Cr	Ni	Mo	S	P
% Wt.	0.03	2.0	1.0	16 – 18	10 – 14	2 – 3	0.03	0.045

4.4 Welding Parameters:

The welding parameters for the double V groove joint was adopted as per the welding filler wire ER - 316L, the parameters are given below:

Voltage	:	32 V
Current	:	400 A
Welding Speed	:	25 m/hr
Wire feed rate	:	2.5 mm/sec.
Nozzle to plate distance	:	30 mm

4.5 Welding Flux Used:

Fluxes BB202 (Flux 1) and Supershield SS (Flux 2) were used with the filler wire SS316L. The chemical composition and Basicity of the fluxes are given in table below:

Table 4.4

Chemical composition of SAW flux (Flux 1) BB202 [27]

Elements	$SiO_2 + TiO_2$	Al_2O_3	CaF_2	$CaO + MgO$	B.I.
% Wt.	10	38	50	2	2.3

Table 4.5

Chemical composition of SAW flux (Flux 2) Supershield SS [28]

Elements	$SiO_2 + TiO_2$	Al_2O_3	CaF_2	$CaO + MgO$	B.I.
% Wt.	15	21	26	35	3.1

4.6 Welding Procedure:

Steps for welding of German steel and SS304 by SAW process

- Edge preparation for both the base metals German steel and SS304 steel plates.
- Positioning the plates for welding.
- Depositions of SS316L weld metal with SAW process.

Fig. 4.2 shows the steps involved during welding of German steel and SS304 by SAW process.

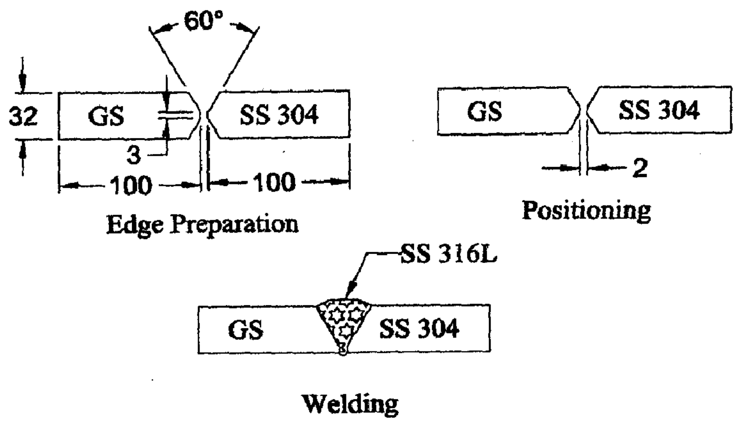

Fig. 4.2 Welding Steps for SAW process of SS304 and German steel

Before welding, the groove region of the weld was thoroughly cleaned with the help of wire brush, to remove any unwanted contamination on the surface. The welding was done keeping the current constant of 400A and electrode extension of 30 mm on the plates. Welding interval was maintained such that inter pass heat input is same. During the whole welding of single piece all welding parameters remain constant. Flux 1 was baked before use at 300^0 C for two hours and flux 2 was baked at 200^0 C for one hour in furnace as recommended by the manufacturer. The submerged arc welding was carried out at different fluxes. The multi- pass welding was carried out by keeping welding parameters constant. Prior to start next welding pass slag was perfectly removed by chipping hammer and wire brushing to avoid inclusion entrapment. **Fig. 4.3** shows welded plates with flux 1 and flux 2.

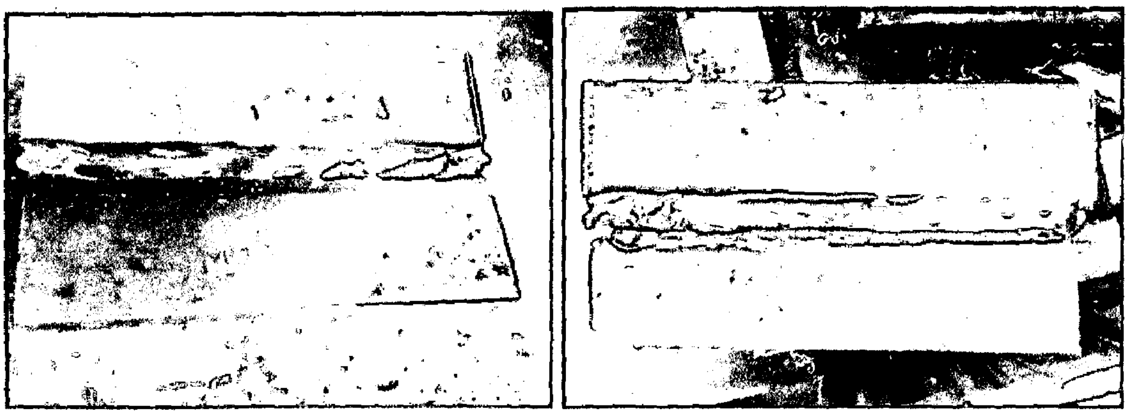

Fig. 4.3 Welded plates with flux 1 and flux 2.

4.7 Non-destructive Testing

Ultrasonic Non-destructive testing was performed on welded plates to evaluate the soundness of the welded joint with ultrasonic non-destructive testing machine with specification

- TR Probe (Transmit Receive Transducers)
- 10 mm diameter
- 4 MHz frequency

1. Straight beam pulse echo system.
2. Couplant to transfer the ultrasonic wave into the alternating voltage.

4.8 Micro-hardness Testing

Weld specimen were prepared for the micro-hardness containing all the zones i.e. base metal, HAZ and weld metal. Hardness was measured across the weld joint on a line. Each point is taken at 1 mm distance on both side of the weld center. A constant load of 100gm is applied during testing for 10s. Micro-hardness is taken in Vickers hardness as shown in **Table 5.9 to 5.12.**

4.9 Tensile Testing

The tensile test specimens were prepared from the welded plates as per the ASTM E 8 standard after and before heat treatment. Due to restriction of machine load capacity some non standard specimens were also prepared. Tensile test data will be shown in **Table 5.1 to 5.6.** A typical round test specimen was prepared as shown in **Fig. 4.4.** (All dimensions are in mm). The tensile testing was carried out on a servo hydraulic Universal Testing Machine (UTM) having a maximum load capacity 60 KN under static load condition at room temperature. The load was applied axially on the specimen at a speed of 1.0 mm/min and stress v/s % strain curve was plotted. The ultimate tensile strength was determined from the ratio of the maximum load divided the original cross-section area of specimen. Elongation of the specimen at fracture was measured under the static tensile loading at gauge length of 50 mm.

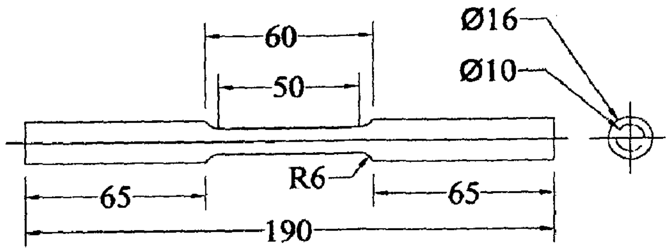

Fig. 4.4 Schematic diagram of typical tensile test specimen

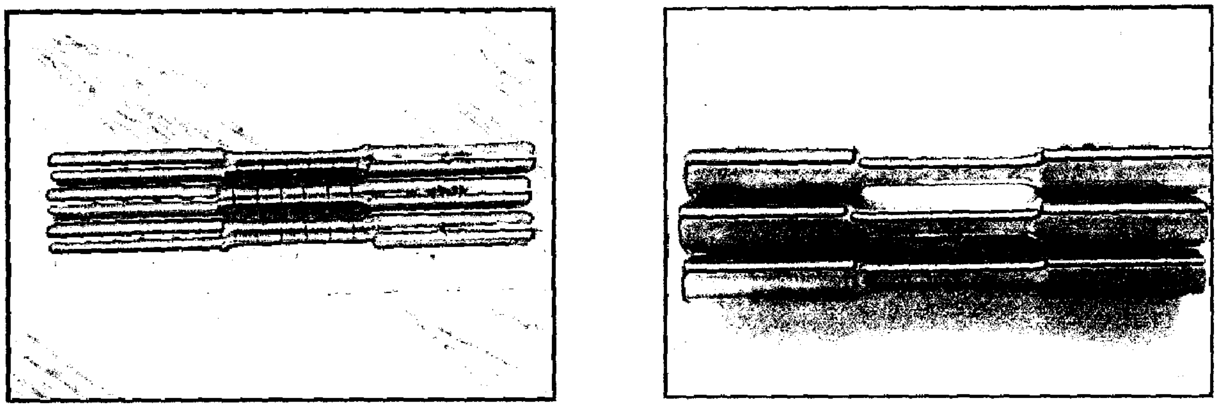

Fig. 4.5 Tensile test specimen before fracture.

4.10 Impact Testing

The Impact test specimens were prepared from the welded plates as per the ASTM E 23 standard. Impact test data will be shown in **Table 5.7 to 5.8.** A standard Charpy V-notch impact test specimen was prepared as shown in **Fig. 4.6.** (All dimensions are in mm). The test was conducted at room temperature. The notch was machined at the centre of transverse section of the weld and along the direction of welding as shown in **Fig. 4.7.** Before machining of notch, the weld centre was identified by etching the specimen in etchant. The tests were performed on a pendulum impact tester, having a scale of maximum range of 300 Joule at room temperature to estimate the impact toughness.

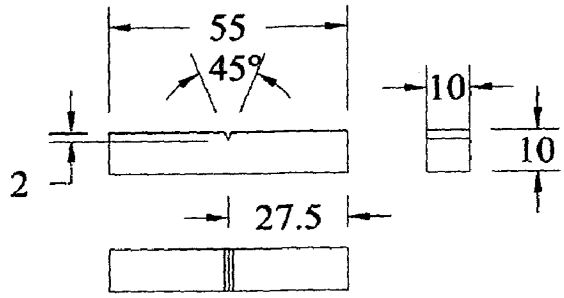

Fig. 4.6 Schematic diagram of typical V-Notch charpy test specimen

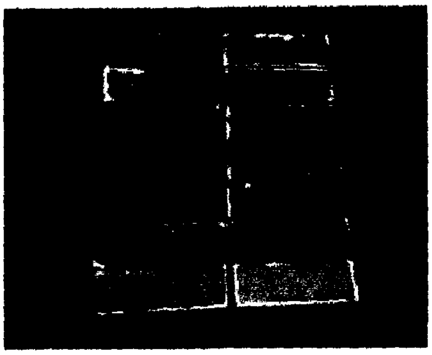

Fig. 4.7 V-Notch Charpy test specimen before fracture.

4.11 Heat Treatment

To study the effect of heat treatment on the mechanical properties of the as-welded samples, the samples were heated in the furnace at 1050 °C for 1 hour and subsequently quenched in the water.

4.12 Metallographic Testing

Samples were prepared from the welded plates for metallographic examination before and after heat treatment process. First of all emery paper polishing was performed with 220 to 1200 grade emery paper. After that cloth polishing was done with Al_2O_3 and water paste. Etching was done after cloth polishing with etchant (5 ml Glycerin + 10 ml Acetic acid +10 ml Nitric acid +15 ml Hydrochloric acid). This had revealed the grain boundaries and then the sample was analyzed under the optical microscope.

Chapter 5

RESULTS AND DISCUSSION

5.1 Tensile Testing

The data generated in various experiments conducted during the project work was analyzed in this chapter, calculation were performed subsequently according to the standard formulas to convert the data into useful results. The results thus obtained were analyzed and discussed in support of their various affecting parameters. **Table 5.1** represents the summary of results obtains with the tensile testing of typical calculations were made as per the formula given below:

YS = (Yield point load /initial area) MPa.

UTS = (Maximum load/initial area) MPa.

%Elongation = [(final length – gauge length)/gauge length]*100.

%ROA = [(initial area – final area)/initial area]*100.

Table 5.1 Summary of tensile test properties

Materials	YS MPa	UTS MPa	% EL	% ROA
Base metal 20MnMoNi55	504.6	648.9	22.3	34.2
Base metal SS 304 [29]	205	515	40	50
Weldment with flux 1, As-welded	531.8	632.4	14.7	28.4
Weldment with flux 2, As-welded	555.1	643.0	26.0	26.7
Weldment with flux 1, after Heat Treatment	413.5	575.6	15.7	24.4
Weldment with flux 2, after Heat Treatment	428.9	589.7	29.4	41.6

The table is summarized on the basis of calculation of observed data during experiments, which is given in **Tables from 5.2 to 5.6;** graphs will be shown in **Fig. from 5.1 to 5.9**.

Table 5.2 Tensile strength of base metal German steel

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	10	50	78.54	39.7	51.2	61.24	8.12	51.78	505.5	651.9	22.48	34.07
2	10	50	78.54	39.2	50.0	60.82	8.20	52.80	499.1	636.6	21.64	32.76
3	10	50	78.54	40.0	51.7	61.36	8.02	50.52	509.3	658.3	22.72	35.68

Table 5.3 Tensile strength of weldment with flux 1 as welded

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	10.0	50	78.54	42.8	50.8	58.26	7.52	44.41	545.0	646.8	16.52	43.44
2	10.0	50	78.54	41.6	48.7	56.54	8.96	63.05	529.7	620.0	13.08	19.71
3	10.0	50	78.54	40.9	49.5	57.28	8.82	61.10	520.8	630.3	14.56	22.20

Table 5.4 Tensile strength of weldment with flux 2 as welded

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	10.0	50	78.54	43.0	49.0	62.94	8.44	55.94	547.5	623.9	25.88	28.76
2	10.0	50	78.54	43.8	51.5	63.52	8.72	59.72	557.7	655.7	27.04	23.96
3	10.0	50	78.54	44.0	51.0	62.54	8.52	57.01	560.2	649.4	25.08	27.41

Table 5.5 Tensile strength of weldment with flux 1 after Heat Treatment

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	9.8	50	75.46	30.6	42.8	57.12	8.32	54.37	405.5	567.2	14.24	27.94
2	9.8	50	75.46	31.0	43.5	58.54	8.64	58.63	410.8	576.5	17.08	22.30
3	9.8	50	75.46	32.0	44.0	57.94	8.60	58.08	424.1	583.1	15.88	23.02

Table 5.6 Tensile strength of weldment with flux 2 after Heat Treatment

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	9.8	50	75.46	32.5	44.9	65.16	7.24	41.17	430.7	595.0	30.32	45.44
2	9.8	50	75.46	33.2	45.4	64.84	7.68	46.33	440.0	601.6	29.68	38.61
3	9.8	50	75.46	31.4	43.2	64.12	7.54	44.65	416.1	572.5	28.24	40.82

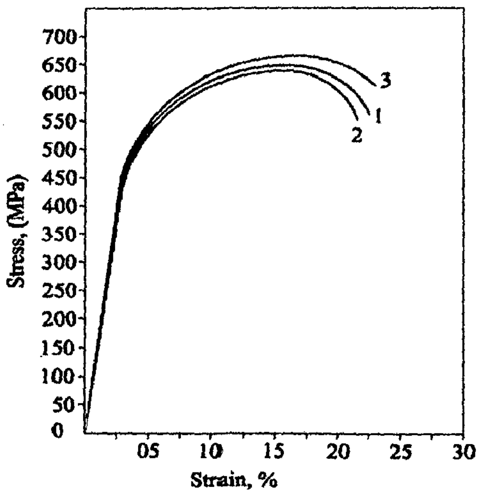

Fig. 5.1 Base Metal German Steel

Table 5.5 Tensile strength of weldment with flux 1 after Heat Treatment

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	9.8	50	75.46	30.6	42.8	57.12	8.32	54.37	405.5	567.2	14.24	27.94
2	9.8	50	75.46	31.0	43.5	58.54	8.64	58.63	410.8	576.5	17.08	22.30
3	9.8	50	75.46	32.0	44.0	57.94	8.60	58.08	424.1	583.1	15.88	23.02

Table 5.6 Tensile strength of weldment with flux 2 after Heat Treatment

S. No.	Dia. (mm)	G.L. (mm)	Initial Area (mm^2)	Yield Point Load kN	Max. Load kN	Final Length (mm)	Final Dia. (mm)	Final area (mm^2)	YS (MPa)	UTS (MPa)	% EL	% ROA
1	9.8	50	75.46	32.5	44.9	65.16	7.24	41.17	430.7	595.0	30.32	45.44
2	9.8	50	75.46	33.2	45.4	64.84	7.68	46.33	440.0	601.6	29.68	38.61
3	9.8	50	75.46	31.4	43.2	64.12	7.54	44.65	416.1	572.5	28.24	40.82

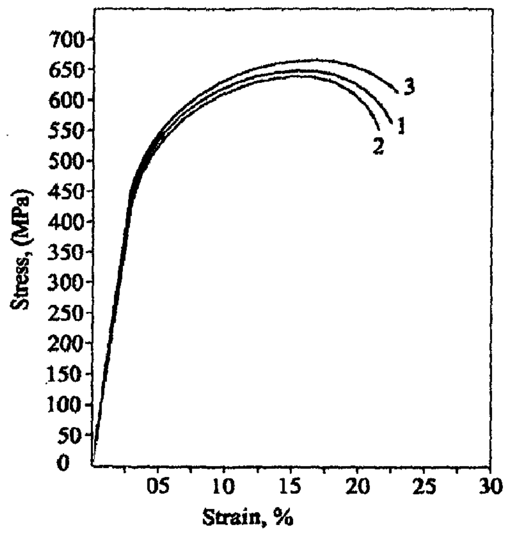

Fig. 5.1 Base Metal German Steel

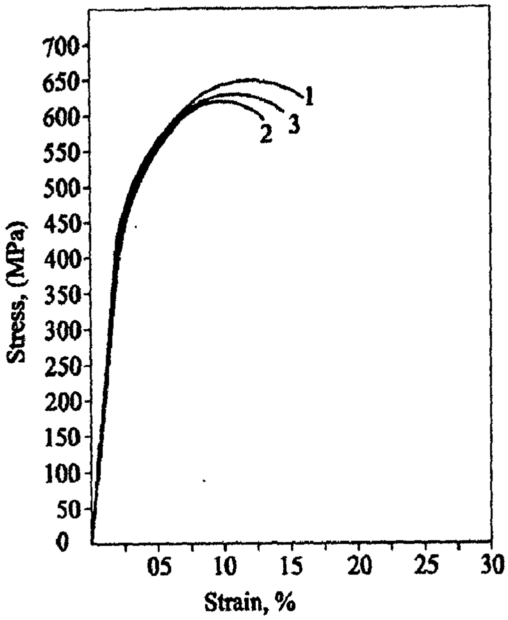

Fig. 5.2 Weldment with flux 1

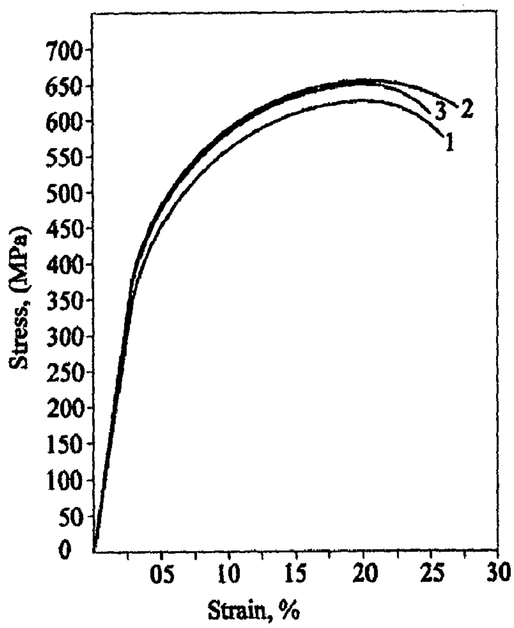

Fig. 5.3 Weldment with flux 2

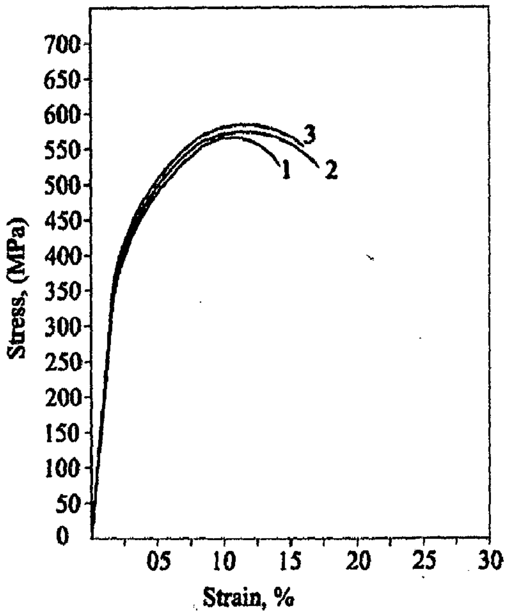

Fig. 5.4 Weldment with flux 1 heat treated

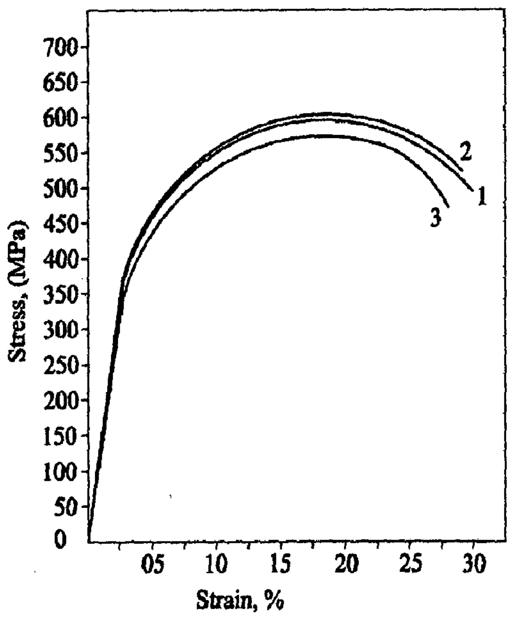

Fig. 5.5 Weldment with flux 2 heat treated

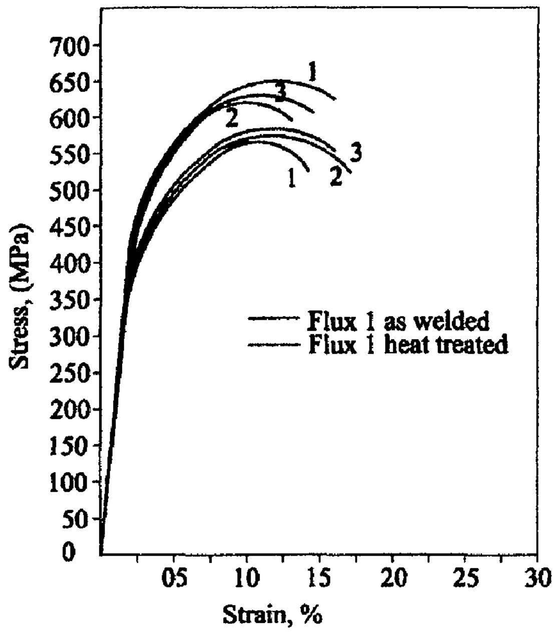

Fig. 5.6 Comparison 1

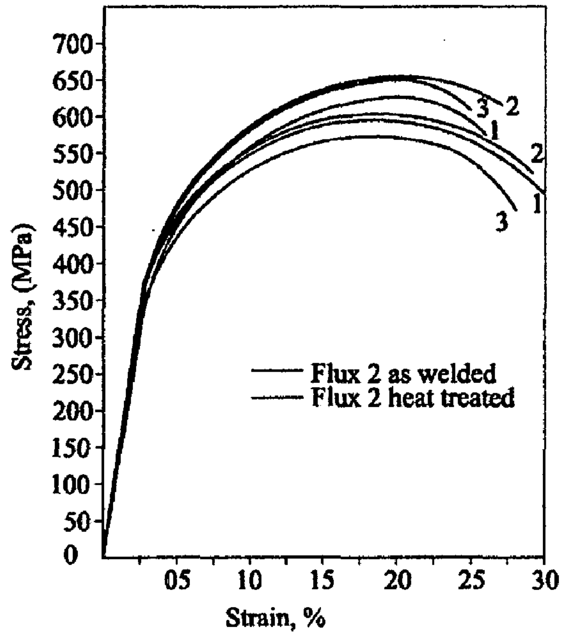

Fig. 5.7 Comparison 2

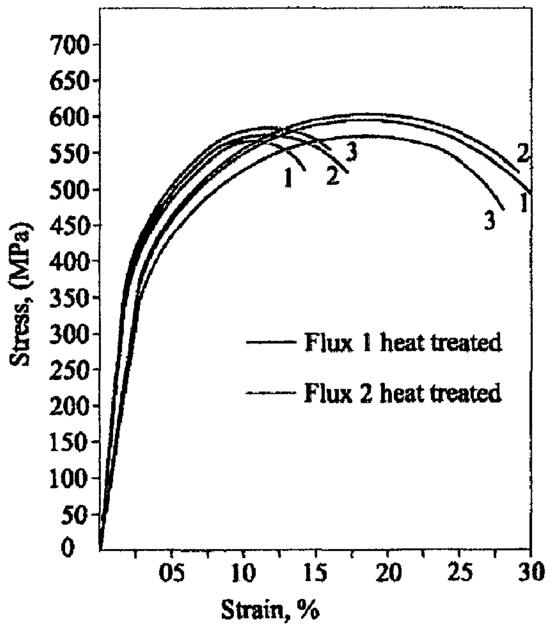

Fig. 5.8 Comparison 3

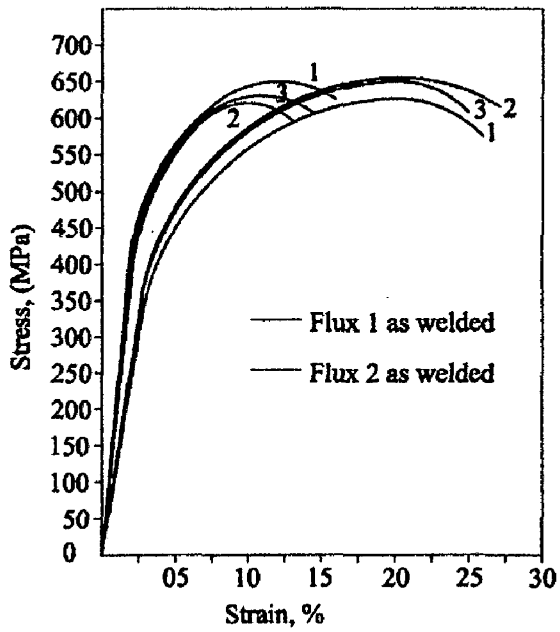

Fig. 5.9 Comparison 4

From the above results we conclude that the tensile strength is decreasing while the ductility is increasing after heat treatment. And weldment with flux 2 is more ductile in nature as compare to weldment with flux 1.

5.2 Impact Testing

Table 5.7 Impact Toughness of weldment with flux 1

Material	Energy absorbed in **joule** at room temperature	
	Orientation of Notch	
	Along the welding direction	Along the transverse of weld
Specimen 1	76	166
Specimen 2	66	140
Specimen 3	70	150

Table 5.8 Impact Toughness of weldment with flux 2

Material	Energy absorbed in **joule** at room temperature	
	Orientation of Notch	
	Along the welding direction	Along the transverse of weld
Specimen 1	74	206
Specimen 2	96	210
Specimen 3	80	200

Weldment with flux 2 has more toughness value than that of weldment with flux1. This might be due to the more SiO_2 and TiO_2 content present in the flux 2, because SiO_2 improve slag detachability with good bead appearance and TiO_2 improves the stability and impact properties.

5.3 Micro-hardness Testing

Results of micro-hardness tests are described in **Table 5.9 to 5.12**. These were taken along a line on the thickness of the welded plate including the base metals, heat-affected zones and weld metal. The distributions of micro-hardness are graphically, represented in **Fig. 5.10 to Fig. 5.17**.

Table: 5.9 Micro-hardness values across weldment with flux 1 as welded

Zones in weldment	Hardness (HV)
Base Metal 20MnMoNi55 steel	224.5 – 322.0
HAZ (20MnMoNi55 Side)	232.5 – 383.0
Fusion Line (20MnMoNi55 and Weld)	73.1
Weld Metal	227.0 – 345.0
Fusion Line (SS 304 and Weld)	130.0
HAZ (SS 304 Side)	253.0 – 274.0
Base Metal SS 304 Steel	259.0 – 274.0

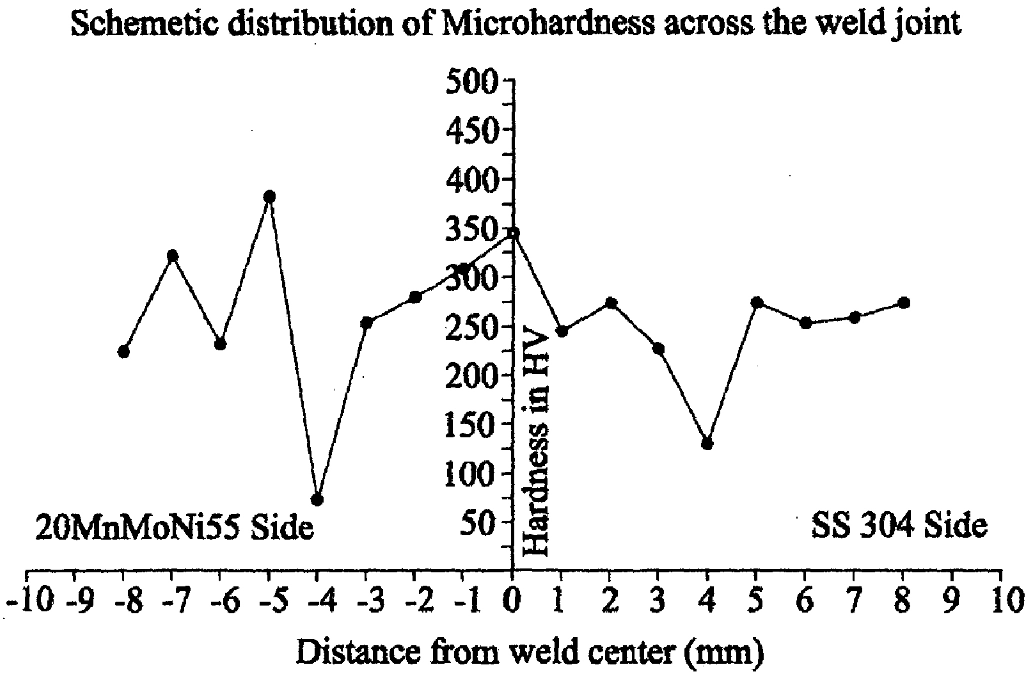

Fig. 5.10 Micro-hardness across weldment with flux 1 as welded

Table: 5.10 Micro-hardness values across weldment with flux 2 as welded

Zones in weldment	Hardness (HV)
Base Metal 20MnMoNi55 steel	149.5 – 245.0
HAZ (20MnMoNi55 Side)	297.0 – 464.0
Fusion Line (20MnMoNi55 and Weld)	237.0
Weld Metal	241.0 – 464.0
Fusion Line (SS 304 and Weld)	297.0
HAZ (SS 304 Side)	209.5 – 243.0
Base Metal SS 304 Steel	259.0 – 260.0

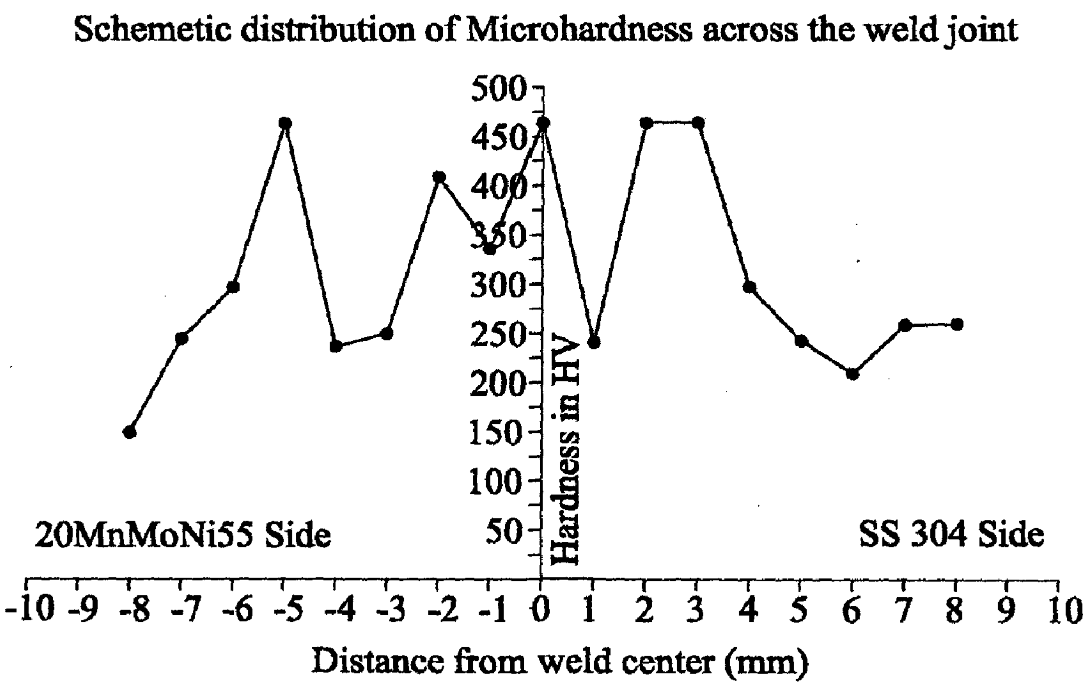

Fig. 5.11 Micro-hardness across weldment with flux 2 as welded

Table: 5.11 Micro-hardness values across weldment with flux 1 after heat treatment

Zones in weldment	Hardness (HV)
Base Metal 20MnMoNi55 steel	401.0 – 431.0
HAZ (20MnMoNi55 Side)	387.0 – 413.0
Fusion Line (20MnMoNi55 and Weld)	351.0
Weld Metal	319.0 – 514.0
Fusion Line (SS 304 and Weld)	297.0
HAZ (SS 304 Side)	328.0 – 358.5
Base Metal SS 304 Steel	224.0 – 254.0

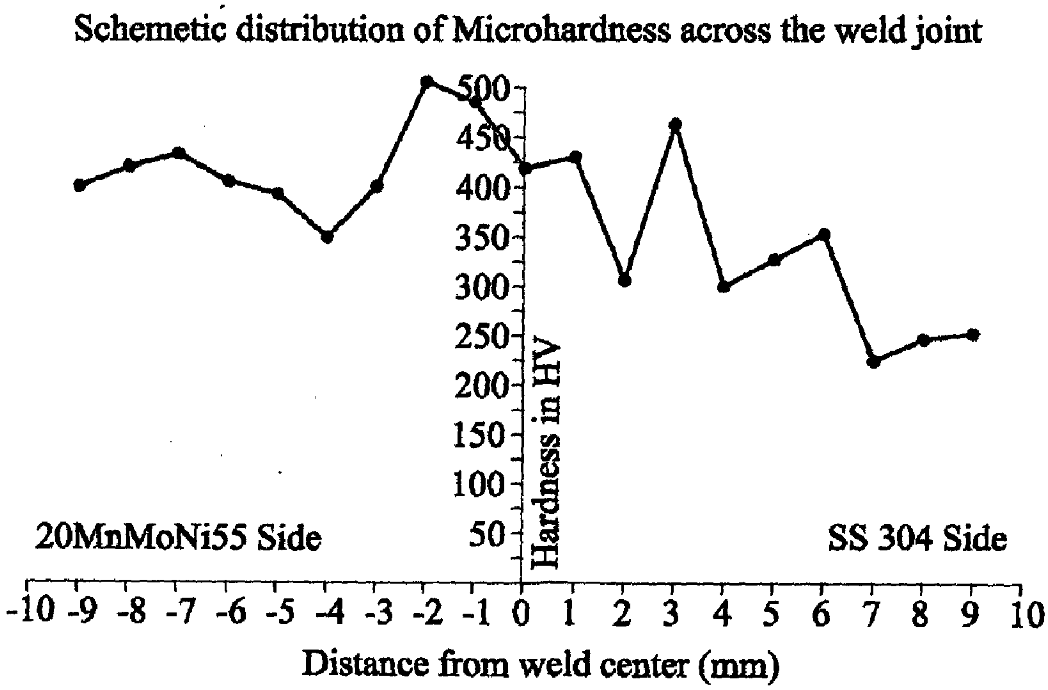

Fig. 5.12 Micro-hardness across weldment with flux 1 after heat treatment

Table: 5.12 Micro-hardness values across weldment with flux 2 after heat treatment

Zones in weldment	Hardness (HV)
Base Metal 20MnMoNi55 steel	383.0 – 464.0
HAZ (20MnMoNi55 Side)	464.0 – 514.0
Fusion Line (20MnMoNi55 and Weld)	322.0
Weld Metal	328.5 – 441.0
Fusion Line (SS 304 and Weld)	184.0
HAZ (SS 304 Side)	201.0 – 206.0
Base Metal SS 304 Steel	196.0 – 268.0

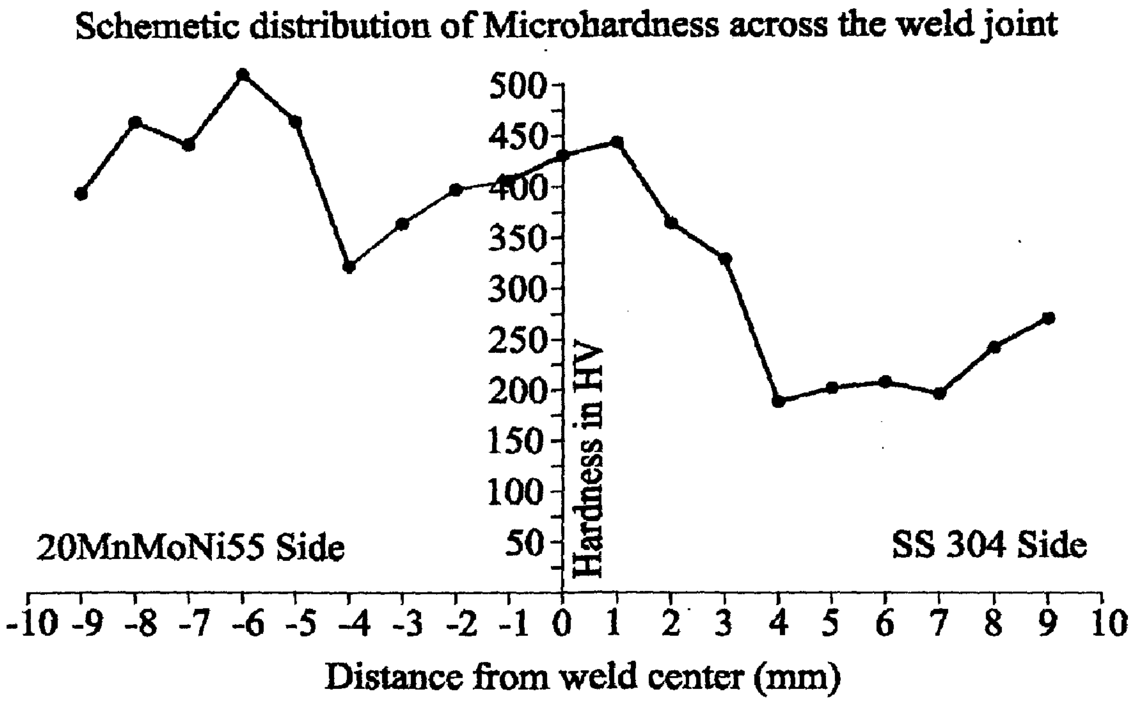

Fig. 5.13 Micro-hardness across weldment with flux 2 after heat treatment

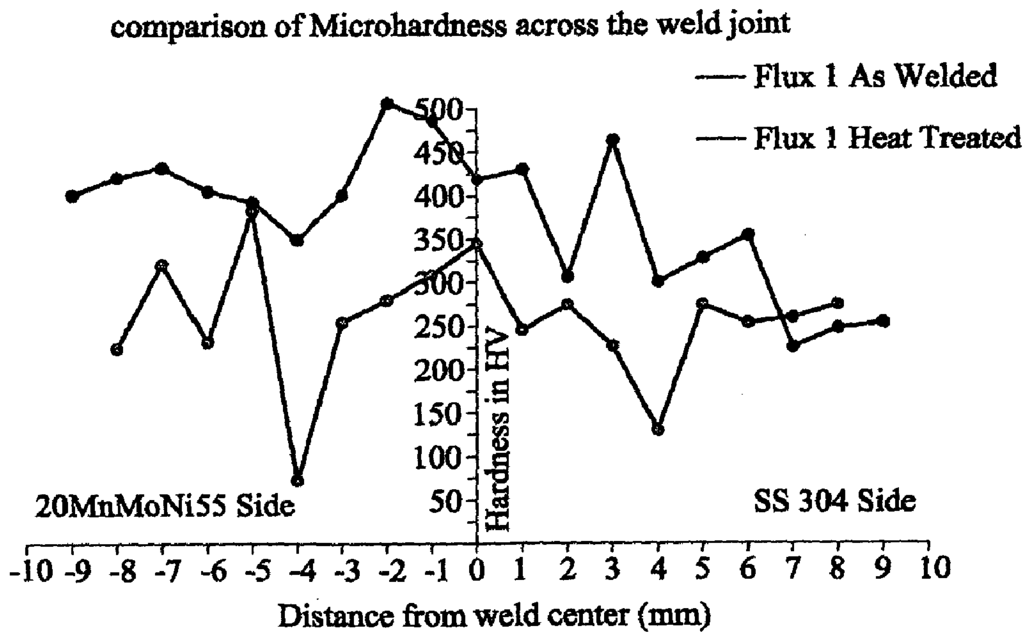

Fig. 5.14 Micro-hardness comparison 1

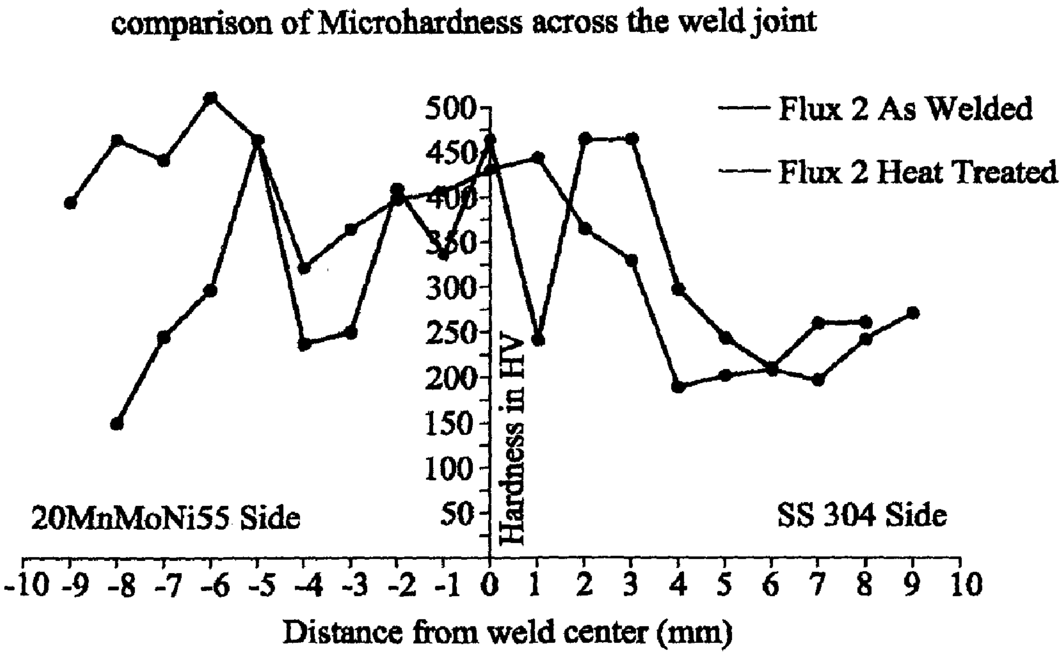

Fig. 5.15 Micro-hardness comparison 2

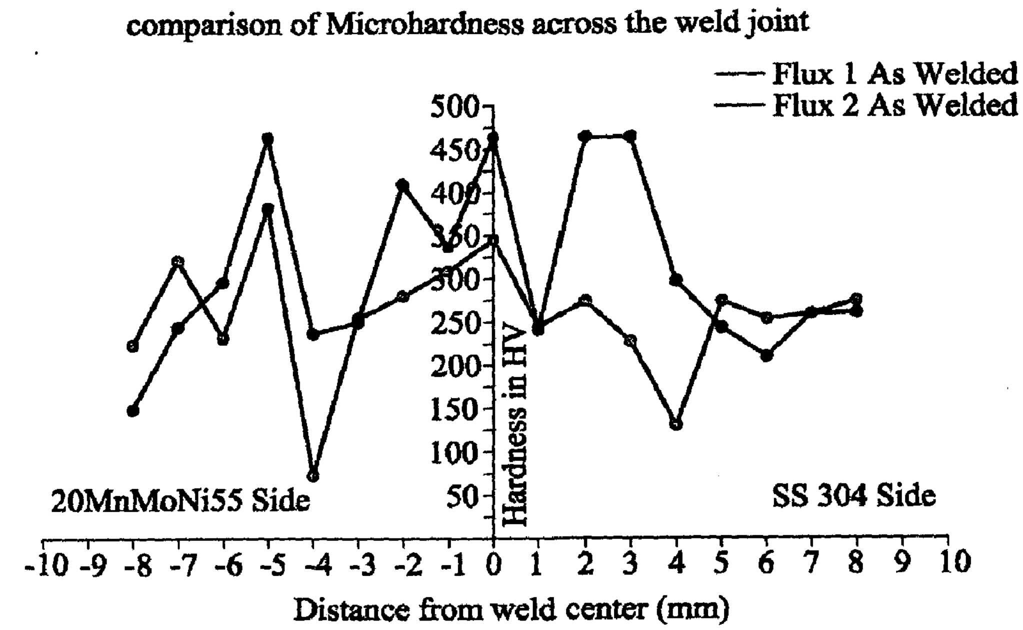

Fig. 5.16 Micro-hardness comparison 3

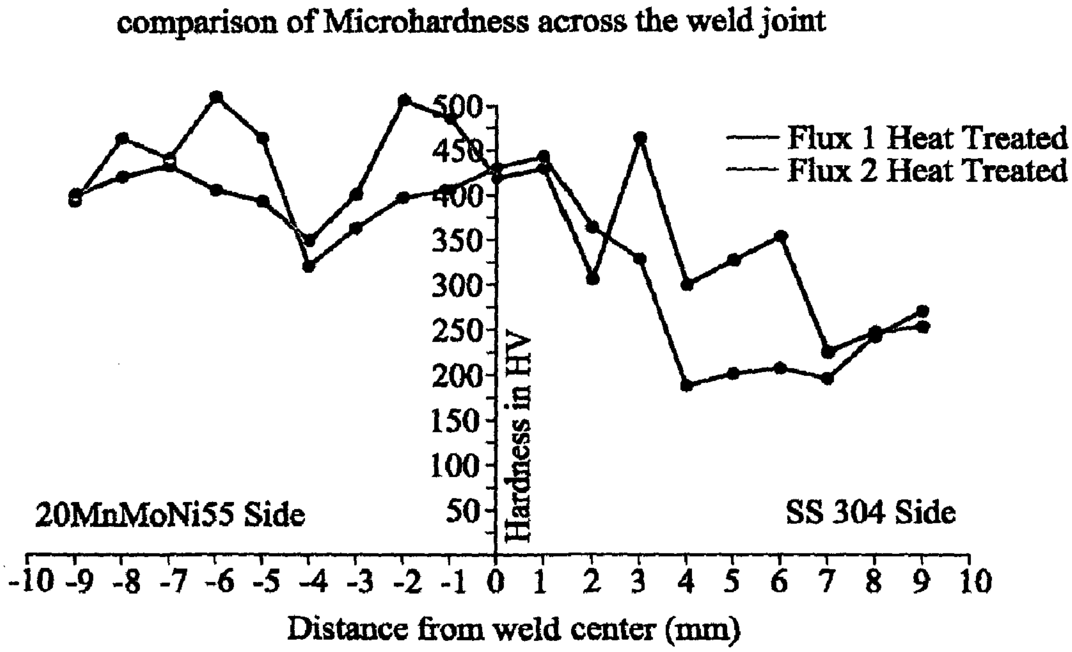

Fig. 5.17 Micro-hardness comparison 4

5.4 Micro-structural Studies

Studies were carried out on metallographic specimens with magnification 25 X, 50 X and 100 X magnifications. Specimens were prepared first polishing with grade 120 to grade 1200 then cloth polished, after that etching was done.

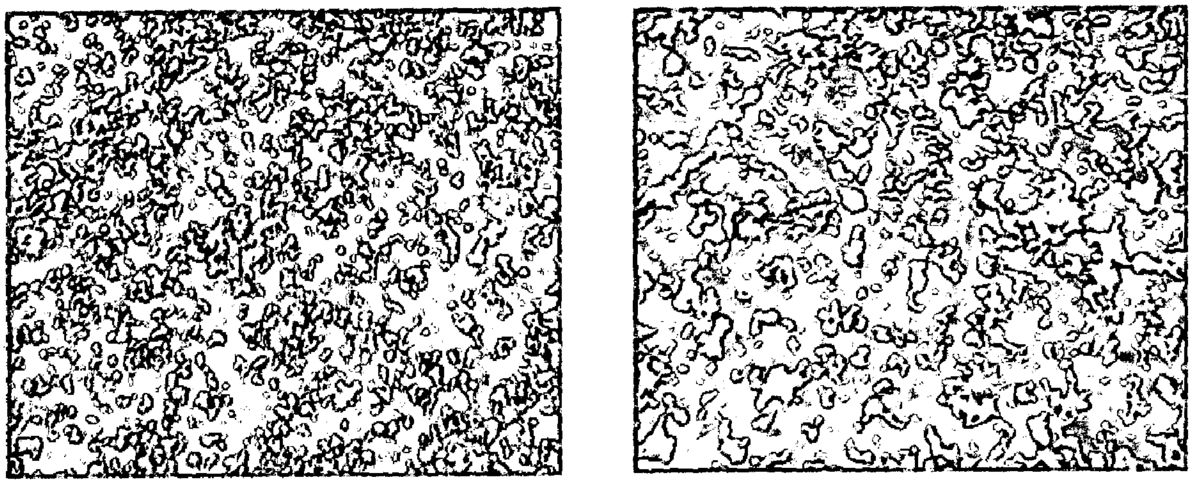

Fig: 5.18 Microstructures of base metal 20MnMoNi55 at 25X and 100X

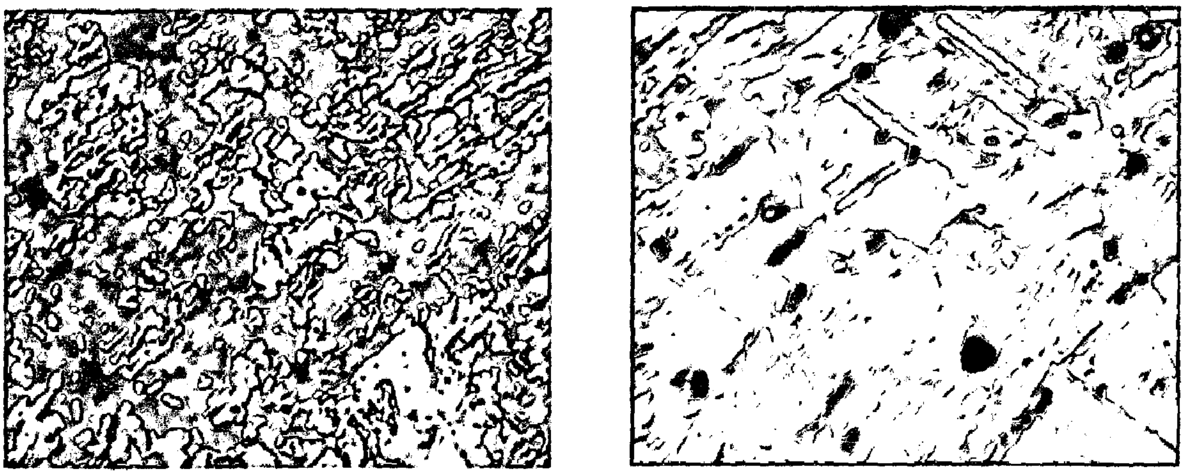

Fig: 5.19 Microstructures of base metal SS 304 at 25X and 100X

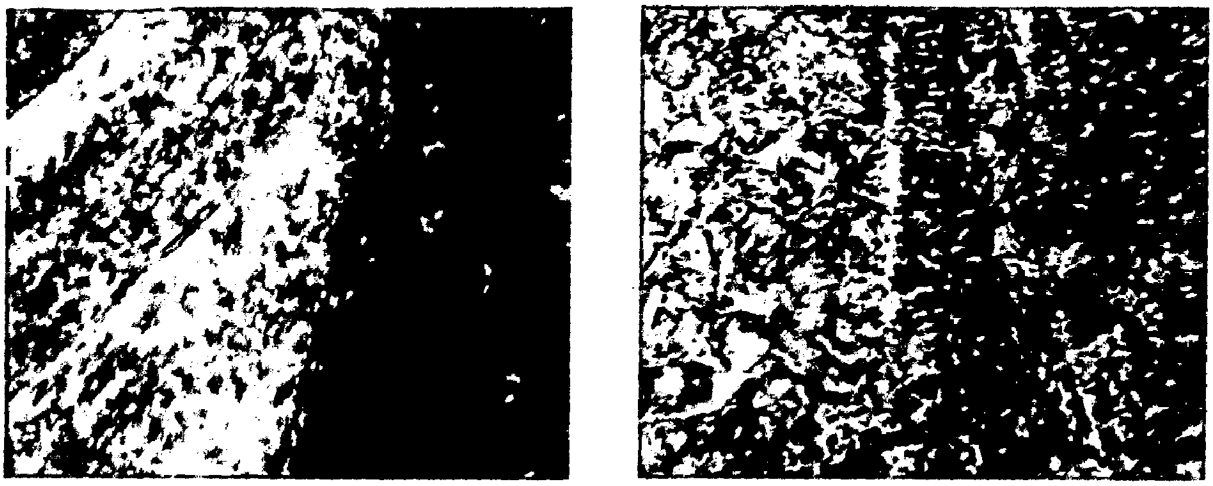

Fig: 5.20 Microstructures of HAZ 20MnMoNi55 side with flux 1 at 25X and 100X as welded

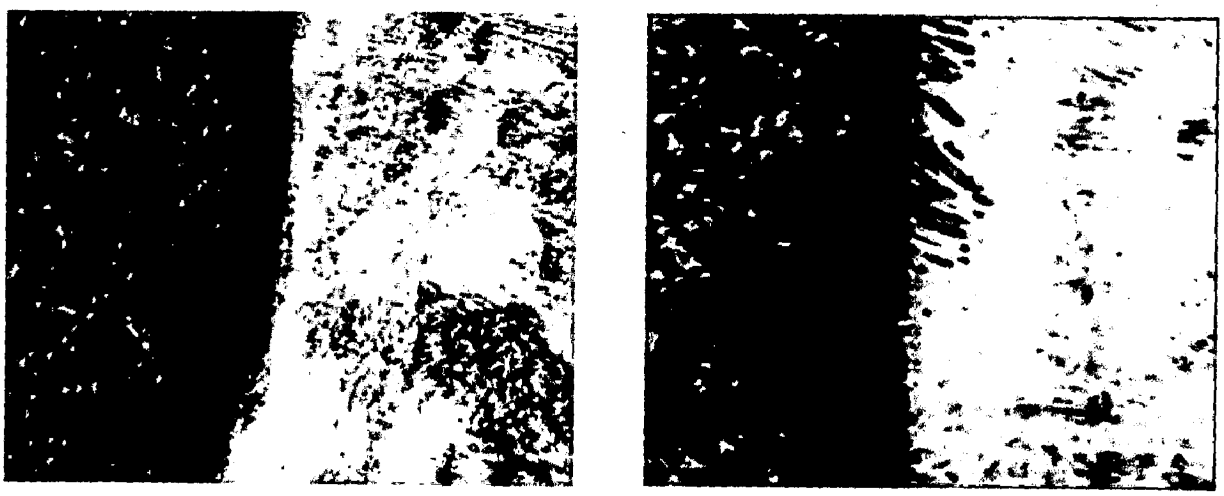

Fig: 5.21 Microstructures of HAZ 20MnMoNi55 side with flux 2 at 25X and 100X as welded

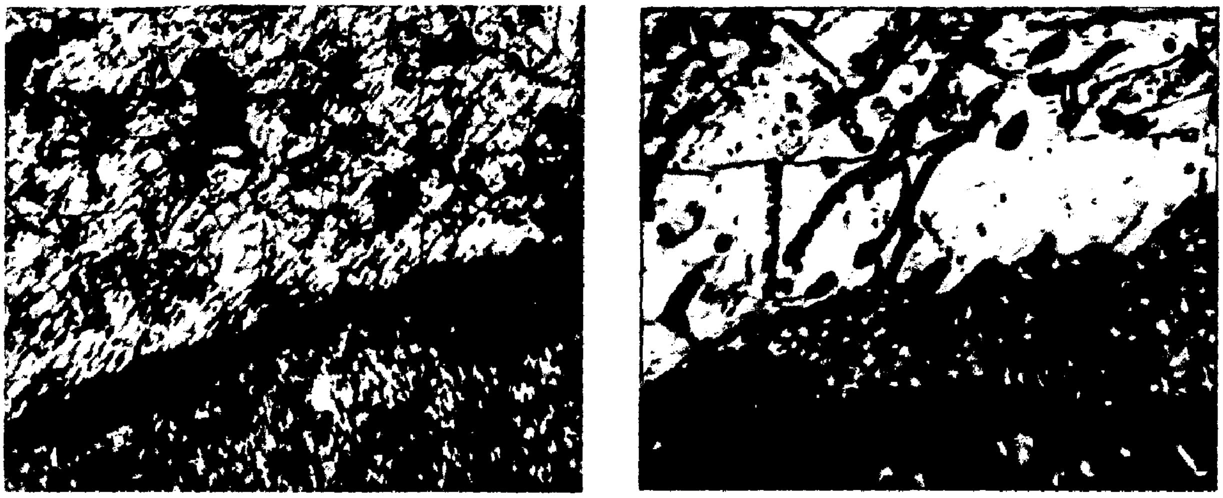

Fig: 5.22 Microstructures of HAZ SS304 side with flux 1 at 25X and 100X as welded

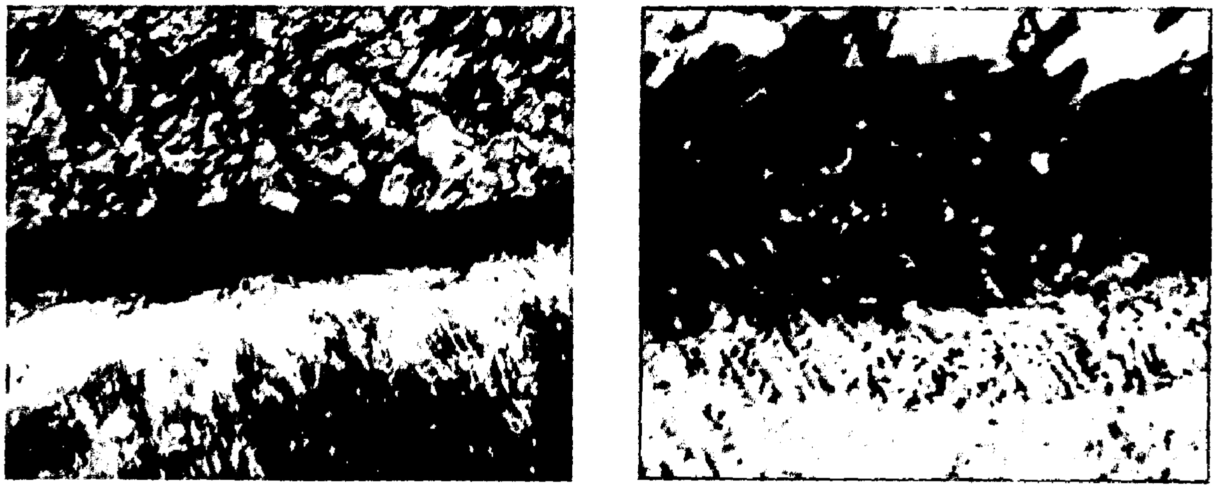

Fig: 5.23 Microstructures of HAZ SS 304 side with flux 2 at 25X and 100X as welded

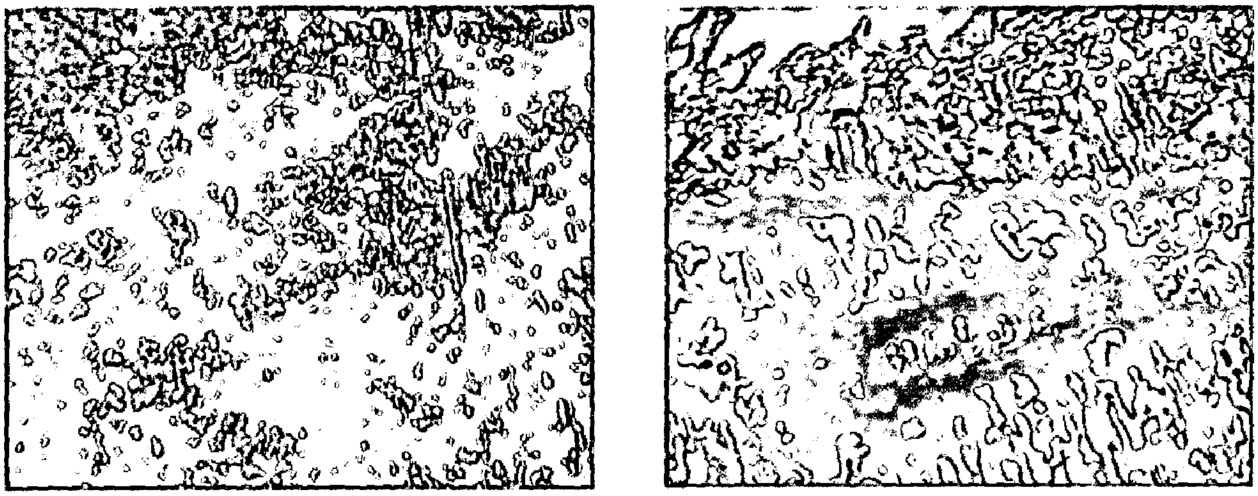

Fig: 5.24 Microstructures of weldment with flux 1 at 25X and 100X as welded

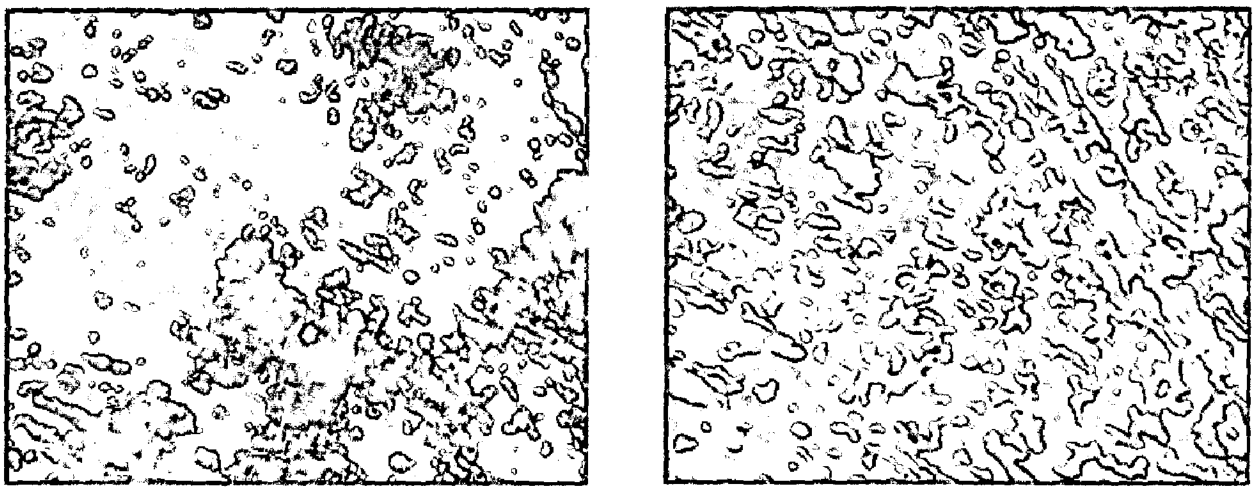

Fig: 5.25 Microstructures of weld with flux 2 at 25X and 100X as welded

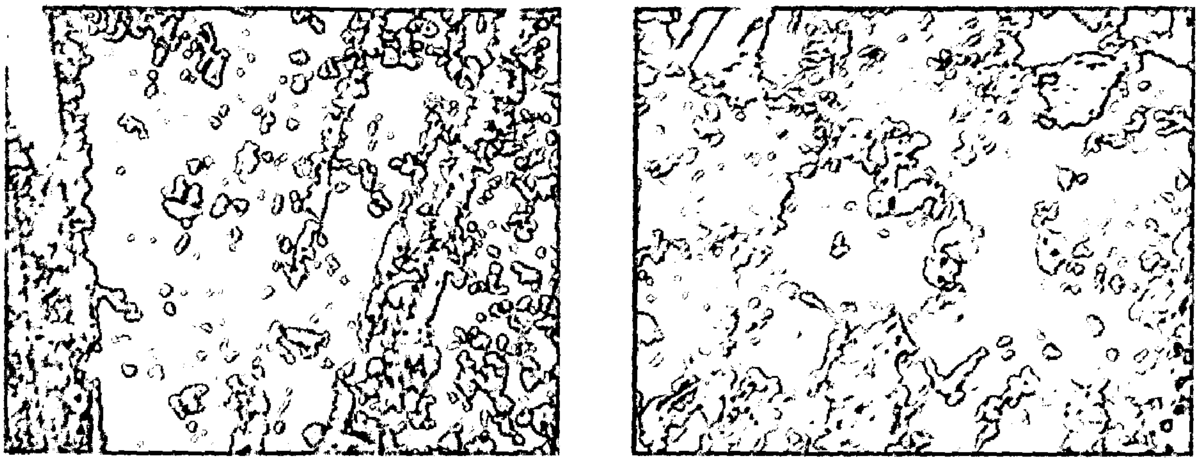

Fig: 5.26 Microstructures of HAZ 20MnMoNi55 side with flux 1 at 25X and 100X heat treated

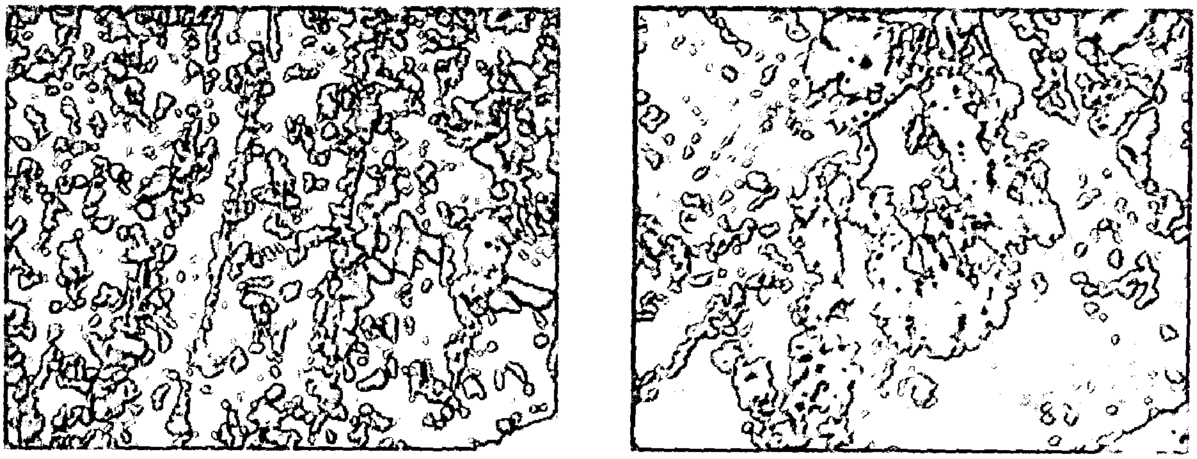

Fig: 5.27 Microstructures of HAZ 20MnMoNi55 side with flux 2 at 25X and 100X heat treated

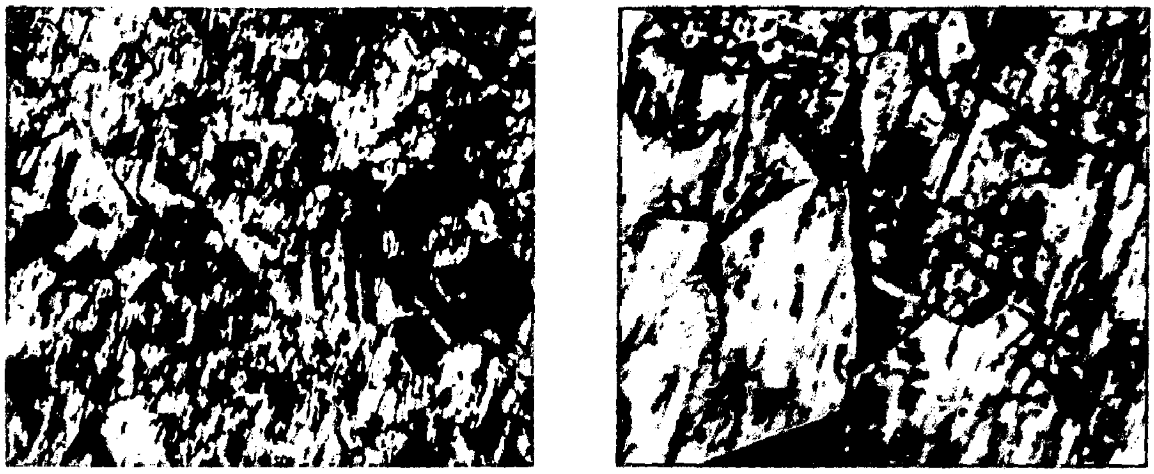

Fig: 5.28 Microstructures of HAZ SS304 side with flux 1 at 25X and 100X heat treated

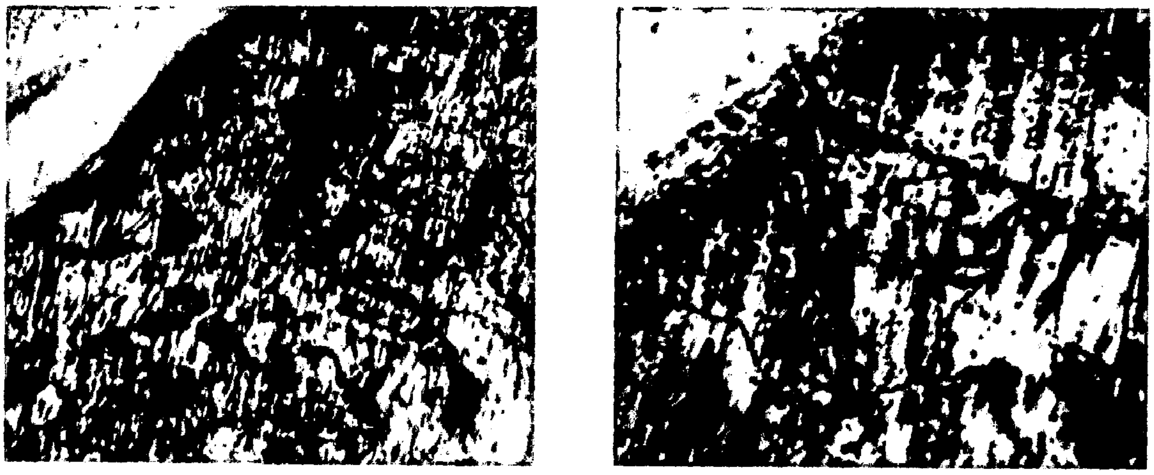

Fig: 5.29 Microstructures of HAZ SS304 side with flux 2 at 25X and 100X heat treated

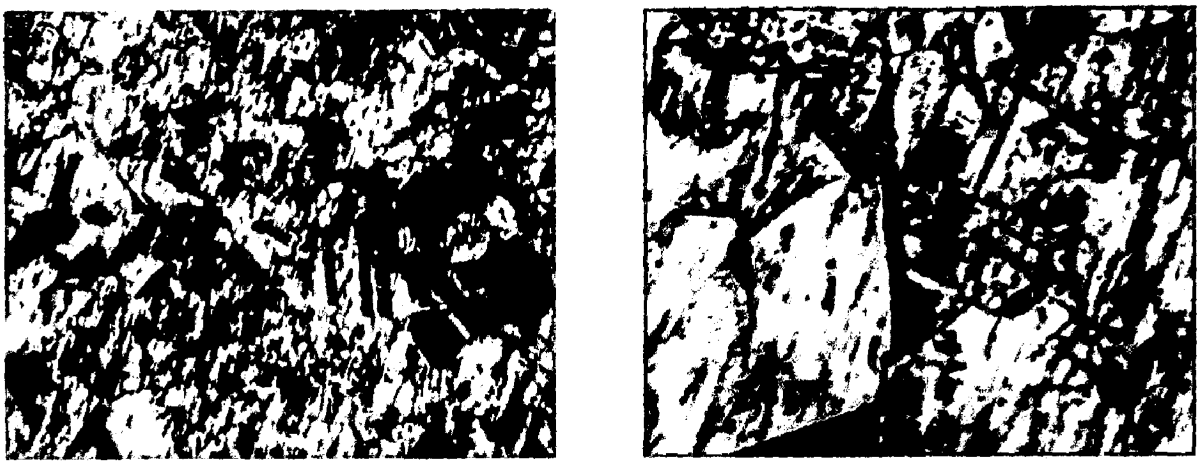

Fig: 5.28 Microstructures of HAZ SS304 side with flux 1 at 25X and 100X heat treated

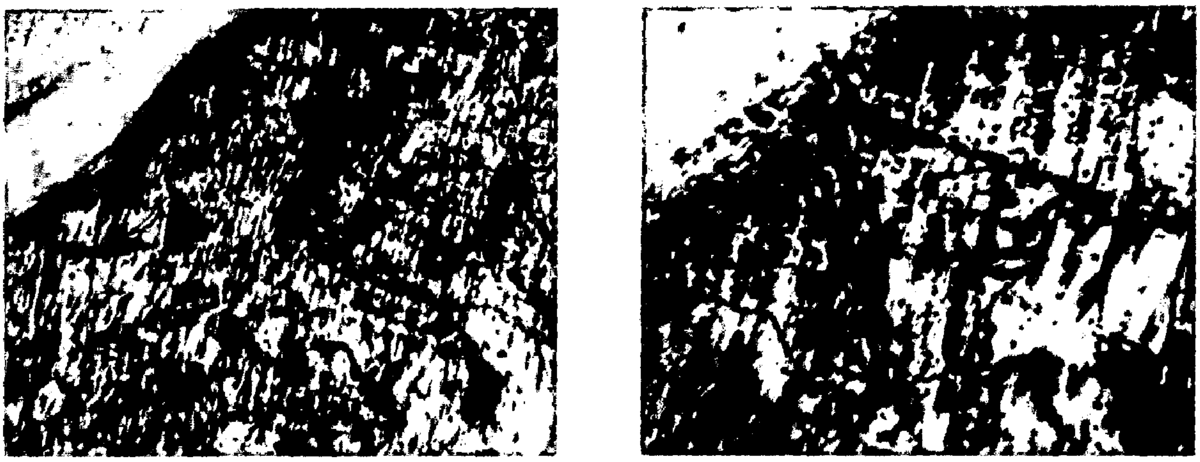

Fig: 5.29 Microstructures of HAZ SS304 side with flux 2 at 25X and 100X heat treated

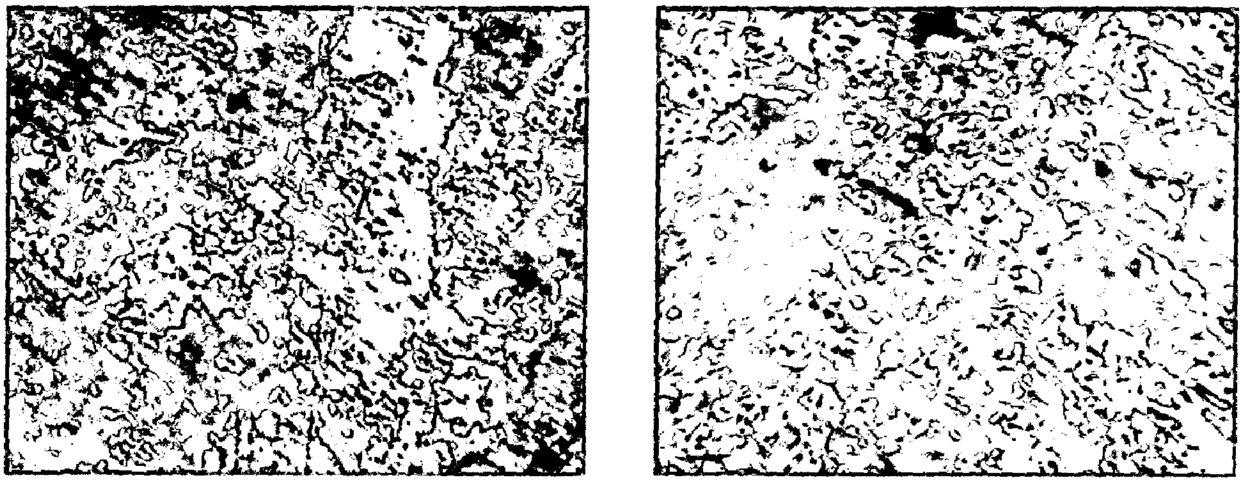

Fig: 5.30 Microstructures of weldment with flux 1 at 25X and 100X heat treated

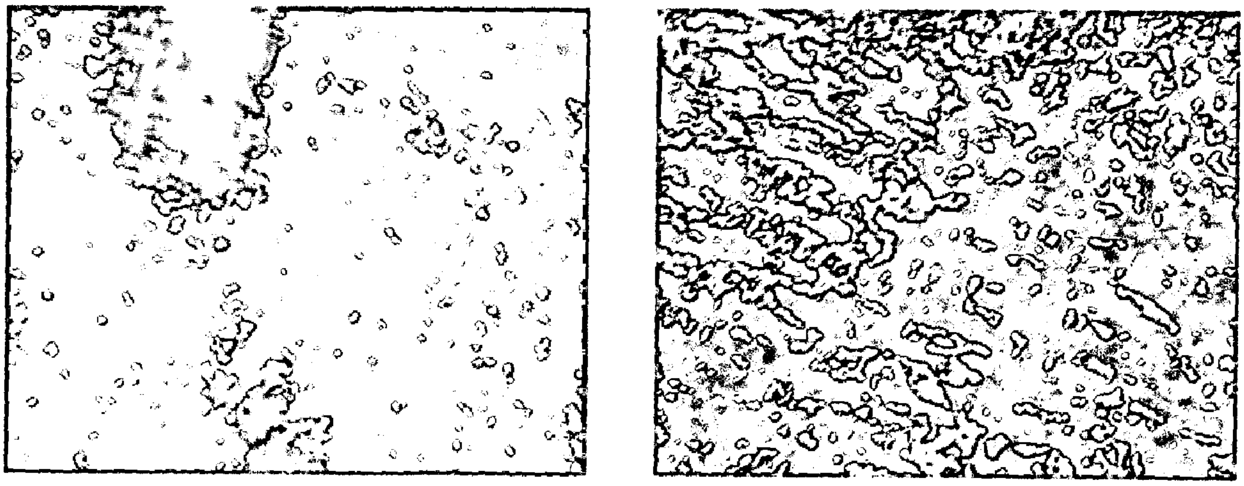

Fig: 5.31 Microstructures of weldment with flux 2 at 25X and 100X heat treated

The microstructure of base metal 20MnMoNi55 steel is shown in **Fig.5.18**. Major constituent are ferrite (white) and pearlite. The microstructure of base metal austenitic stainless steel 304 is shown in **Fig.5.19**. Black portion indicates the presence of carbides and major constituent is austenite. Dissimilar weld joint is inhomogeneous in nature as shown in **Fig. 5.24** and **Fig. 5.25**.

The microstructure of 20MnMoNi55 steel side is major in ferrite and pearlite. On the SS304 side it shows twins structure. Depending on the degree of the dilution from each side, various mixtures of austenitic and ferrite phases might be found in the microstructure. HAZ of both sides is shown in **Fig. 5.20** and **Fig. 5.21**. A darkly etched area with an adjacent decarburized narrow band was observed. This also revealed lot of carbide precipitation; this indicates the fact that the austenitic steel has relatively low carbon content. Carbide precipitation observed in HAZ of austenitic stainless steel. After heat treatment the microstructures of weldment are shown in **Fig. 5.26** to **Fig. 5.31**.

5.5 SEM Analysis

SEM of fractured surface of tensile test fractured specimens was conducted. It is observed that fractured surface of tensile specimen of weldment with flux 1 and flux 2 has dimples. After heat treatments it is observed the increase in size of dimples, so increase in ductility.

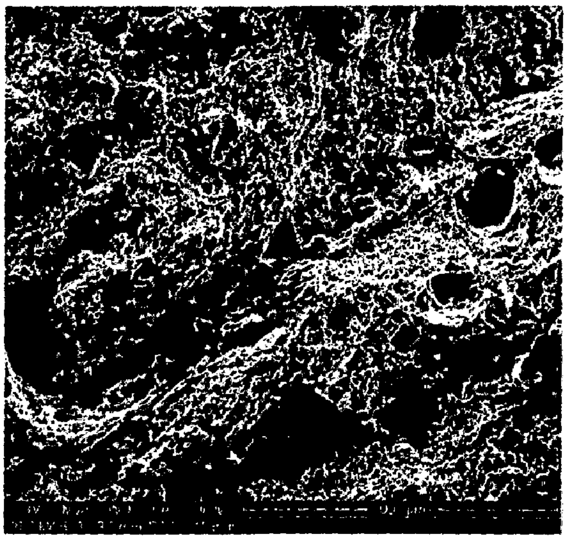

Fig. 5.32 Fractured surface of tensile specimen of weldment with flux 1

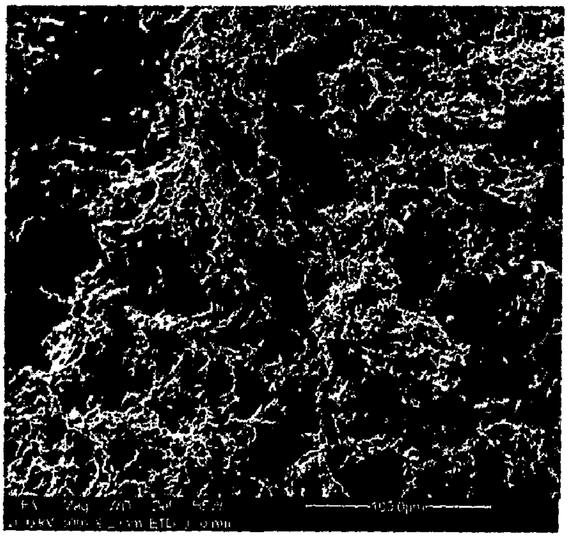

Fig. 5.33 Fractured surface of tensile specimen of weldment with flux 1 Heat Treated

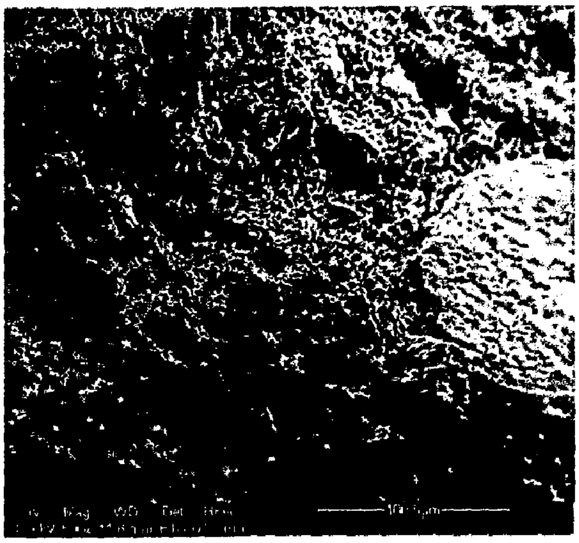

Fig. 5.34 Fractured surface of tensile specimen of weldment with flux 2

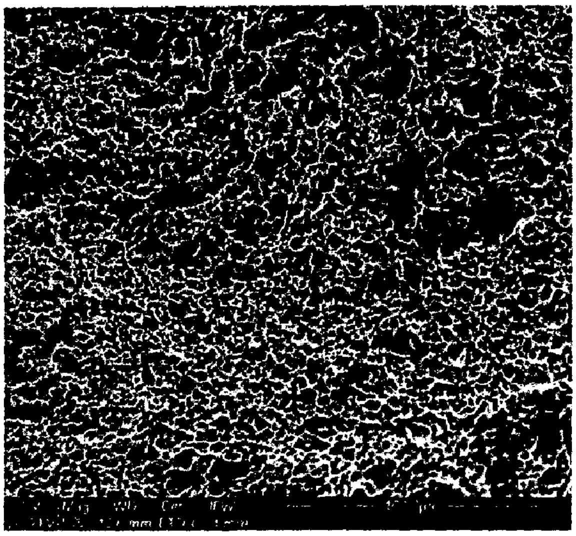

Fig. 5.35 Fractured surface of tensile specimen of weldment with flux 2 Heat Treated

Chapter 6

CONCLUSIONS

After concluding the experiments the following conclusions can be made on the bimetallic welding of German steel and SS 304.

- The Yield Strength and Ultimate Tensile Strength of weldment with flux BB202 (Flux 1) is less than that of weldment with flux Supershield SS (Flux 2). As compare to base metals both weldments have greater Yield Strength but low Ultimate tensile Strength.
- After heat treatment both weldment shows reduction in YS and UTS and a slight increase in % elongation as compare to as-welded samples.
- Micro-hardness of weldment with flux BB202 (Flux 1) is less than that of weldment with flux Supershield SS (Flux 2).
- After heat treatment hardness increase for both the weldment.
- SEM analysis shows that weldment of Supershield SS (Flux 2) is more ductile in nature as compare with weldment of BB202 (Flux 1).

Chapter 7

SCOPE FOR FUTURE WORK

- As submerged arc welding is a versatile to join thick plates. The present work can be carried out after optimizations of parameters with SAW process.
- Other different fluxes combination can be used to find their effect on mechanical properties of bimetallic welding of German steel and SS 304.
- Mechanical properties can be obtained with heat treatment process at different temperatures for different time period.
- The impact properties were testes at room temperature; these can be tested at different temperatures and with different corrosive medium.
- The process can be carried out for different groove angles.

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