INVESTIGATION OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF NICKEL BASED SUPER ALLOY (INCONEL-600) USING GAS TUNGSTEN ARC WELDING

Dissertation- II

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

Of

Master of Technology

IN

MECHANICAL ENGINEERING

By

Vikas kumar

(11502494)

Under the guidance of

Mr. Kamlesh Kumar Mishra

(Assistant Professor)

(14703)

LOVELY PROFESSIONAL UNIVERSITY

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DEPARTMENT OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY PUNJAB

CERTIFICATE

I hereby certify that the work being presented in the thesis entitled **"Investigation of Microstructure and Mechanical properties of Nickel based super alloy (Inconel-600) by using gas tungsten arc welding** in partial fulfillment of the requirement of the award of the Degree of master of technology (Spl. in Manufacturing Technology) and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **(Kamlesh Kumar Mishra, Assistant professor)** Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this Thesis has not been submitted in part or full of any other University or Institute for the award of any degree.

(Date) (Vikas Kumar)

Regd. no. 11502494

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

(Date) (Kamlesh Kumar Mishra)

(U.ID-14703)

HOD (ME)

The external viva-voce examination of the student was held on successfully ________________

Signature of Examiner

APPROVAL PAGE

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SR.NO.	NAME OF STUDENT	REGISTRATION NO	BATCH	SECTION	CONTACT NUMBER
1	Vikas Kumar	11502494	2015	M1572	9855128216

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PAC Member 2 Name: Ankur Bahl	UID: 11108	Recommended (Y/N): NA
PAC Member 3 Name: Jasvinder Singh	UID: 15854	Recommended (Y/N): Yes
PAC Member 4 Name: Anil Kumar	UID: 20296	Recommended (Y/N): Yes
DAA Nominee Name: Kamal Hassan	UID: 17469	Recommended (Y/N): Yes

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ABSTRACT

Experimental Investigation was carried out to study the mechanical and microstructural properties of Nickel based super alloy of GTAW welding. We use butt weld 3 mm thickness of the plate. The process was applied to different specimen in which we vary the heat input and welding parameters. For mechanical testing we was used the two different sample. In the first one we was tested the impact test by charpy v-notch test and then co-relating with metallurgical studies. The micro hardness results of Rockwell hardness and brinell hardness tester have maximum strength at weld metal. AFM results of the welding joint have maximum peak values at the interface where the welding are done. Maximum peak values at the welding zone because of the faster cooling rate of the joint to microstructural indicates that coarse grain structure and powder XRD is used for idenfication of phase of crystalline material and for finding the unit cell dimensions. Face cubic centre types unit cell structure are found in that types of analysis.

Keywords: Inconel 600, TIG, AFM, Powder XRD, Micro Hardness tester, Impact test etc.

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Chapter 1

1. INTRODUCTION

Welding is the another type of joining process, is this type of process several similar or dissimilar materials like metals, alloys or plastics, to each other with the application of heat or pressure at the two mating surfaces. During the perform of welding, An arc is generated between the workpiece and the electrode melting of metal takes place at the interface and permanent joint achieved after the solidification of melting material. Sometimes a filler material is provided for joining the metals those materials introduce a strong bond between the materials. Filler metals are characteristically added to strengthen of joint. During the process of welding various physical changes are found at the weld metal surface. These changes are also affecting the capability of the material of weld. Physical changes are found during the process of welding are metallurgical , due to the rate of solidification, changes in weld zone is occurred in hardness, other changes is also occurred at the position of joint due to the reaction of material with atmospheric oxygen and then tendency of crack configuration is found.

1.1 Classification of different welding processes

Welding processes are classified on the basis of heat as follows:

1.1.1 Arc Welding

An arc welding process is also recognized as the shielded metal arc welding. The process of an arc welding, it produced an arc between the workpiece and an electrode by applying an electric power supply. However, melting of metal takes place at the interface and welding could be prepared. The process of welding used AC as well as a DC type power source for welding performance. Generally, consumable and non-consumable types of electrode are used in arc welding according to their requirement.

1.1.2 Gas Welding

In Gas welding, coalescences of two or more metals by the application of heat which are produced by the oxyacetylene gas. It usually focused, at elevated temperature flame which is made up of combination of gases and combustion of gas are required for joining the workpiece by melting of external filler materials. Oxyacetylene gas welding is the important type of gas welding process in which reaction of oxygen is takes place with the acetylene and large amount of heat is produced.

1.1.3 Resistance Welding

In this type of welding process, heat is produced by passing of large amount of electric current (10^3 – 10^5) A and the application of pressure resistance is produced between the two mating surfaces. Spot-welding is other types of resistance welding; the pointed electrode is used for the operation. The wheel-shaped electrode is used for seam-welding.

1.1.4 High Energy Beam Welding

A high intensity of energy beam is used for melting the workpiece and also joins the both workpiece by the application of pressure. Laser beam and electron beams are the type of energy beam which is used in this type of welding. HEB welding, welding of highly developed material or occasionally welding of different materials, which is not achievable through the traditional welding process.

1.1.5 Solid-state Welding

In these process, melting of workpiece materials are not required for welding or joining the workpiece. In which the heat is produced by rubbing action between the workpiece or by application of hammering operation at the joint. Broad types of solid-state weldings such as diffusion welding, explosive welding, electromagnetic pulse welding, ultrasonic welding, friction-stir-welding etc.

1.2 Arc Welding

In all the different types of welding processes, arc welding is broadly classified on the basis of types of different material are used. Different types of welding processes are:

1.2.1 Manual Metal Arc Welding (MMAW)

MMAW is that welding process in which we used consumable electrode which is flux coated at the outer surface. When electrode melts, the flux break up and generate shielding gas for the weld zone and intercede the region of weld from the harmful gases and atmospheric oxygen. The weld is protecting from the atmosphere due to the floating of slag at the surface of the pool of weld. These shielded gases produces the slag at the surface of electrode or filler metal.

1.2.2 Metal inert gas welding (MIG/MAG)

MIG welding is also known by the name of gas metal arc welding GMAW process, in this process of welding continuous wire is used for joining the metal or consumable electrode for welding. At weld region, the welding gun is used for entering the combination of carbon dioxide gas and argon gas to the shielding gas of argon. Here application of pressure is not required for welding.

1.2.3 Tungsten Inert gas welding (TIG)

TIG welding process also known by the gas tungsten arc welding process GTAW. In this process, a tungsten electrode is created for welding purpose which is in non-consumable in nature. Welded region is protected from the atmosphere with a Argon or Helium of shielding gas or occasionally a combination of both the gases. A filler metal may also introduce physically for suitable welding application. During the Second World War TIG welding was developed. After the developing of TIG welding process welding is feasible for those materials whose welding is complicated. The application of TIG nowadays extend to a multiplicity of different metals like nickel alloy, nickel-chromium alloy, alloy of steel like SS, MS and HTS, Al alloy etc. Similar to various system of welding, supply of power sources have well improved from the crucial type of transformer to the peak controlled electronic power source.

1.3 Principle of operation of TIG

Supply of welding current, water for cooling and inert gas is turned on. An Arc is produced between tungsten electrode which is non-consumable in nature and the workpiece by touching the electrode with the workpiece or applying the high unit of frequency. In first method, arc is initially struck on the scrap metal piece and then broken by the length of arc is increasing. In second method, a frequency which has high current is super-imposed or lay over the welding current. Shielding gas protect the weld zone and the tungsten electrode from the atmospheric air. Up to 20,000oC temperatures may be obtained by the electric arc and produced heat which is focused for the melting the material and for joining the materials. The weld pool is also used for joining the base metal with the application of filler materials or without it.

Principle of operation of tig welding and schematic diagram of process is given in fig. 1 & fig. 2 correspondingly.

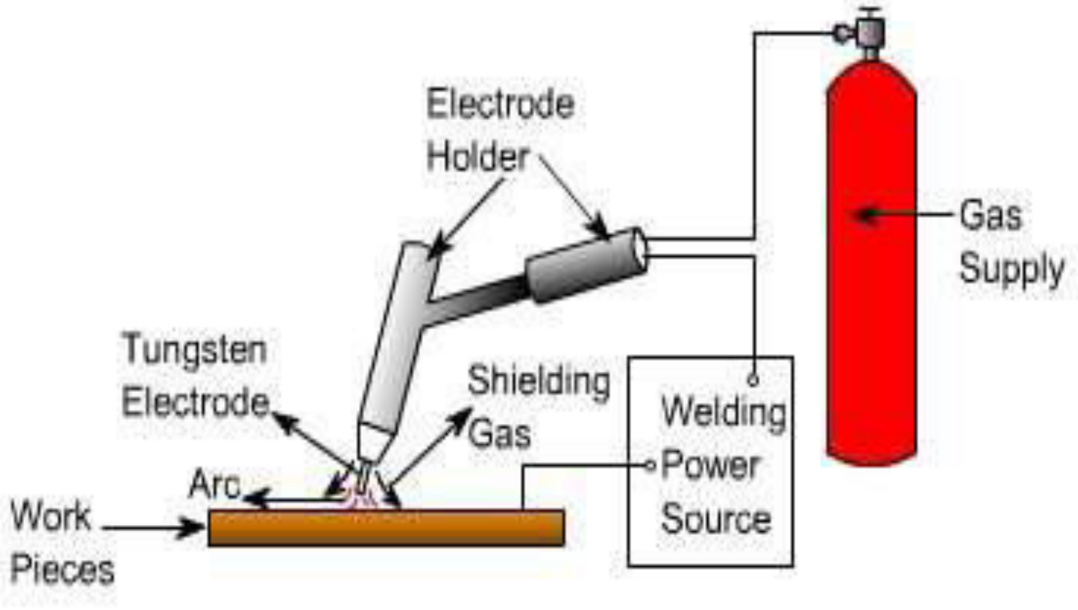


Figure 1 Schematic diagram of TIG welding setup

Generally the tungsten electrode have 150 to 200 mm in length and diameter range between the 0.5 mm to 6.4 mm. different size of electrodes having their different current carrying capacity which depends on DC power sources whether the connection is positive or negative. The source of power is required to sustaining the arc has a drooping or a constant current characteristic which provides a basically output of constant current when the length of arc is diverse over a number of mm. power source of open circuit voltage is between the range of 60- 80V.

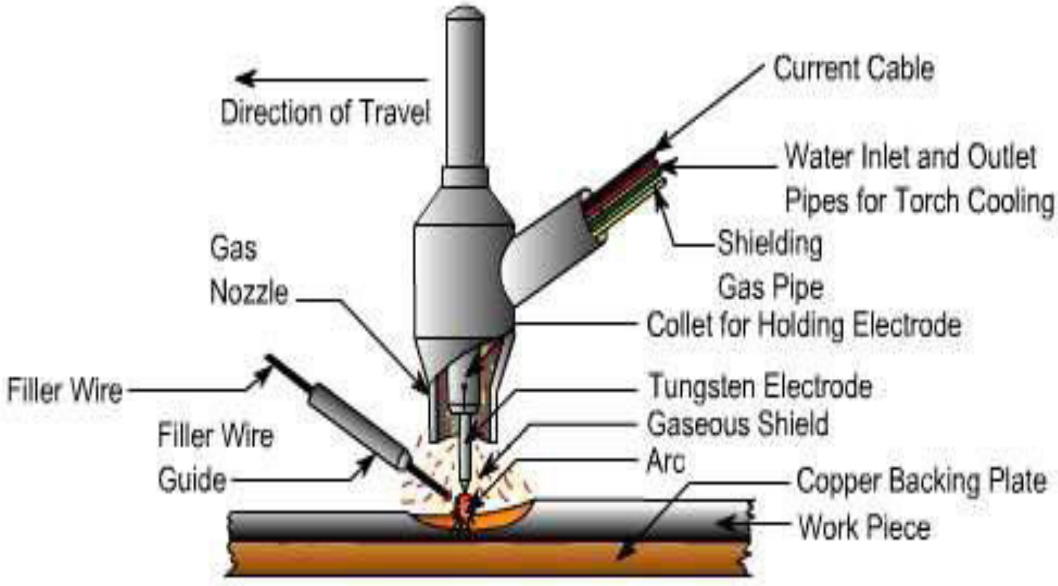


Figure 2 Principle of TIG welding

1.4 Types of welding current used in TIG welding

1.4.1 DCSP (Direct Current Straight Polarity)

Direct current is used in TIG welding process. An electrode of tungsten is associated with the negative pole of the power source. In DC welding process connection is required is most ordinary. When the tungsten electrode is attached with the negative terminal of the power supply that time it will only customized the 30% of the heat or welding current. Narrow profile and good penetration properties are found when the resulting weld is shown.

1.4.2 DCRP (Direct Current Reverse Polarity)

In this type of welding system, the tungsten electrode is joined with the positive terminal of the power source. DCRP type of connection is required infrequently because more heat is generated at the tungsten electrode due to this reason the electrode is burn up and overheated. DCRP type of connection provides a profile of shallow and wide. It is also essentially used for very light materials at low ampere.

1.4.3 AC (Alternating Current)

Alternating currents are used for the whitest metal like aluminium and magnesium for the welding current. The heat input to the electrode is carried out as the wave of AC passes through the one side to the other side of the wave. Tungsten electrode is positive on the half of the cycle due to this electron will scuttle from base metal surface to the electrode. Due to the transfer of electron from the base metal surface to the electrode lifting of oxide skin on the base materials is resulting. The sided waveform is known by the cleaning half of the side.

1.4.4 Alternating Current with Square Wave

The beginning of modern electricity, AC welding machines can at the moment be produced by a wave form called Square Wave. The square wave has improved control and each side of the wave can provide a more cleaning half of the welding cycle and more penetration. [2]

1.5 Advantages of TIG welding

TIG welding method has various advantages over the other welding processes are as follows:

I. Narrow concentrated arc is formed in welding.
II. In this types of process no need of flux because shielding gas is used for preventing the electrode and weld pool.
III. In TIG welding process spatter and fumes are not leave.
IV. By the application of tig welding process thin plates are also welded.

1.6 Applications of TIG Welding

This type of process is optimally proper for the base metal plate having thickness range between the 5 to 6 mm. That materials whose plate is thick in nature can also be join by the muti passes of high inputs of current and leading to distortion and it also decrease the mechanical properties of base metal. During the welding process the high quality of welds is achieved by the suitable control over the heat inputs and addition of filler metals individually. This process is suitable for every position of welding and it also useful for welding of hollow shaped pipes joints and tube etc. This process is eco-friendly with atmosphere because it does not leave any spatter and fumes after or during the process of operation so, we also say that this process is convenient and cleaning process or sometimes no required any finishing. TIG welding method is working with both manual as well as automatic operations.

This welding process is mostly used in the different industrial applications such as,

- In the nuclear thermal power plants
- Aircraft aviation
- Application in food processing industries
- Industrial maintenance and repair work
- It is mostly used in the automobile industry

1.7 Process parameters of TIG welding

Different parameters are considered during the process of welding in a given below:

1.7.1 Welding Current

When the flowing current is higher than normal that time splatter surface is formed at the mating of base metals by the increasing of current in this process workpiece surface is damaged. Once more lesser current settled in welding process it leads to stricking of electrode to the filler wire. The fixed amount of current approach will varies the voltage in order to sustain a constant arc current.

1.7.2 Welding Voltage

TIG welding machine equipment is dependable at the welding voltage which may be fixed or adaptable. A high preliminary voltage are allows for effortless arc initiation and a better variety of operational tip distance. If the voltage is too high that time quality of welding may guide to large variable.

1.7.3 Inert Gases

There are various factors for the selection of shielding gas whose effects on the cost of welding parameter, temperature of weld, arc stability, splatter, life of electrode etc. These gases also influences the complete weld penetration depth and surface profile, permeable, resistance of corrosion, physical properties of the weld materials. Combination of argon (Ar) or Helium(Hi) gas may be effectively used for TIG welding processes. Pure Argon is used for the welding of very thin materials. It also provides a good arc for smooth or quite working of process. The diffusion of arc produced in Argon is less than as compare to the arc produced in helium. For the welding of the different alloys like structural steels, Al, Cu and titanium and magnesium alloy are welded by the pure argon and for welding of those materials whose have high conductivity like Aluminium and copper, helium gas are used for welding.

1.8 Inconel alloy and their properties

Inconel alloy is the alloy of nickel-chromium iron. Its have good mechanical properties and they are oxide and corrosion resistance in nature which is helpful for working in that environments where high pressure and K.E are subjected. When we heated the Inconel alloys at high temperature they are forms a thick and stable layer which protect the surface from additional attack. These types of materials retain its strength over a best range of temperature, Inconel alloys are used at that places where high temperature is applied. In these alloy the high contains of nickel alloy gives it corrosion resistance behaviour by many organic and non-organic compound. During the solid solution strengthening the strength characteristics is depends on the high temperature. Intermetallic compound (Ni3Nb) is formed by the reaction of some amount of niobium with nickel all process is run in age-hardening. They forms a small cubic crystals that affects the creep behaviour of surface due to raising its temp. For joining of Inconel alloy we also add some filler materials at their applications. Inconel alloys are present in different grade like Inconel-600, Inconel-625, and Inconel-718 etc. [3]

Chapter 2

2.1 Review of Literature

Y.S. Sato et.al [1] studied about the FS welding of the joints of Inconel-600 alloy base metal and researchers were checking their physical properties. Researchers formed a defect free weld by applying the partially penetration of FS welding of the use of tool of polycrystalline cubic boron nitride(PCBN).and the conclusions of this study is friction stir welding made a noise weld lacking any defects in this alloy. The stir zone consisted of the finer grain structure than the base material.

K.H. Song et.al [2] evaluated the dissimilar alloy of Inconel 600 and SS 400 of lap joint by the welding of friction stir and they were examined the properties of weldments by different testing methods. Researchers were used scanning electron microscopy (SEM) & (EDS) method for studying the microstructure of weld part and electron backscattering diffraction system used for assessment of grain size, shape and also carried out the grain misorientation of weld. They concluded that friction stir weld joints successfully obtained at dissimilar metal without any voids and crack, types of defects.

Young Su Park et.al [3] optimize welding of nickel based super alloy, they used TIG welding at the alloy of nickel which is alloy 617. Alloy 617 has its corrosion resistance properties was optimized the study microscopic structure and mechanical properties and they concluded that Alloy 617, they are in reliable in nature for welding.

H. Tanigawa et.al [4] has studied about the ITER blanket coneection of Hydraulic by the laser and TIG welding. Shield blanket are used in ITER has an active cooling structure these is important to the cooling water manifold. And the researcher had concluded that the welding of horizontal pipes are linear misalignments with respect 0.7 and 1.0 mm for the TIG welding and laser. Inputs of heat for the laser is 1.7 kj/m and for TIG welding is 5.5 kj/m.

Jon Lambarri et.al [5] has studied about cladding technique to produce and repair on Inconel 718. The purpose of this study to evaluate the coatings which applied on specimen which is more preferable for any manufacturing industries.

R. Arabi Jeshvaghani et.al [6] studied about the TIG welding of Ni based super alloy after the welding coating of 1 to 2 mm thickness material was deposited over the specimen. After these coating and welding the structure is measured by scanning electron microscopy and identification of crystalline phase by powder XRD. And they concluded that the dendrites structure are formed over the coating surgace of material and m23c6 layer is formed over the specimen. The mixture of weld or unweld zone had the structure of eutectic ledeburit with the martensite microstructure.

S. Raju et.al [7] has studied about the characteristics of Inconel 600 in terms of thermal expansion by using X-ray diffraction method. They have concluded that the temperature success full measured accurately during the experimental work.

M. Shakil et.al [8] has studied about the welding of Inconel 600 and SS 304L with using of electron beam welding. SEM, EDS and XRD techniques used for the detect the characteristics of the joint of weld. They have observed that on microstructure the segregation of S element due to locality of end crater.

V.Anand Rao et.al [9] has studied the welding of same two pieces stainless steel by using TIG welding techniques. Current, welding speeds and filler materials are taken in this study. They work carried out high accuracy with minimum error. The using filler metal provided better results.

Xin Ye et.al [10] studied that the pre-welding condition of the base metal, the welding heat input, and the state of the interlayer in multi-layer welding are examined to identify means of controlling the hot cracking in Inconel-718 cast sheets during tungsten inert gas (TIG) welding Concluded that Weld metal center longitudinal solidification cracks, weld metal toe transversal solidification cracks, and heat-affected-zone liquid cracks were found in the welding joints of theInconel-718 superalloy.

Ravindra I. Badiger et.al [11] has studied that the Joining of bulk metals using microwave energy is being explored as a new processing method in the era of high technology applications. They have concluded that Inconel-625 alloy has been effectively created microwave hybrid heating with using of nickel powder..

Vaishal J. Banker et.al [12] has studied that the wear action of Inconel 600 alloys by experimental examination in dry sliding by using Taguchi and regression analysis methods and conclusions of this study is the wear of Inconel 600 raises with enlarge of load and diminish as the pin-heating temperature increases and Regression model gave very accurate results.

Paolo Ferro et.al [13] optimized the experimental and numerical analysis of wrought Inconel-706 super alloy after the welding of electron beam welding**.** Researchers used the XRD technique for the study of mechanical properties of the welded specimen. At the basis of experimental data, analysis the numeric model whole method has developed. FEM analysis used for analysis of numerical data which is taken from the experiments. They concluded that high reliability represent the joints which have introduced by electron beam weldability provides better results.

Sivaprasad et.al [14] has studied about TIG welding of Nickel based alloy using welding varying voltage and current ranges. They found influence behaviour of fatigue and analyse different post weld treatment.

Qinglei et. al [15] analysed microstructure, element sharing, phase constituents and micro hardness for welding joint of Mo-Cu composite and 18-8 stainless steel plates of thickness 2.5 mm carried out by TIG welding process with Cr-Ni fillet wires. Welding has done with speed (49.8-64.2)mm/min, gas flow rate-8 l/min, arc voltage-(28-32) V and welding current -90 A. creation of γ-Fe(Ni) phases and $Fe_{0.54}Mo_{0.73}$ compound must contributed to the high micro hardness. The results point out that austenite and ferrite phases were obtained in the weld metal. The micro hardness near the fusion zone at Mo–Cu composite side enlarged from weld metal to fusion zone, and the zenith value appeared near the limit between fusion zone and Mo–Cu composite.

Ahmet durgutlu et.al [16] has studied the welding of 316L, the using of TIG welding with shielding gas. They have concluded that weld metal hardness is comparatively low the region of HAZ and base metal. Shielding gas provided the maximum tensile strength.

Raveendra et. al [17] has studied the influence of pulsed current the purpose of enhance the weld joints, by using of GTAW. They have concluded that ultimate tensile and yield strength was measured more than the pulsed current weldments.

Song et. al [18] has studied of the welding possibility of two different alloy of 5A06 Al and AISI 321. Ac current was used throughout the operation. The welding parameters were taken current arc length, welding speed and gas flow rate. They investigate Si protected the layer of IMC layer.

Kumar and Sundarrajan et.al [19] has studied pulsed TIG welding on AA5456 Al's alloy. The optimization of pulsed TIG welding by Taguchi techniques. They observed that by these techniques obtained high mechanical properties.

Akbar Mousavi et.al [20] has studied the influenced of geometry formation on the allocation of residual stresses in TIG. The obtained data by XRD method compared with the predicted data. The residual stresses were found design modelling techniques.

Indira Rani et. al [21] has studied about the mechanical properties of AA6351of weldments. GTAW with non-pulsed or pulsed method were employed. They have concluded that the base metal strength closer to the weldments and optimized the failure regions of weldments found near HAZ.

Sakthivel et.al [22] studied creep rupture behavior of 3 mm thick 316L austenitic stainless steel weld joints fabricated by single pass activated TIG and multi-pass conventional TIG welding processes. Welding was completed by using current in the range of 160-280 A, and welding speed of 80-120 mm/min. Experimental outcome shows that weld joints possessed lower creep rupture life than the base metal. It was also found that, single pass activated TIG welding process increases the creep rupture life of the steel weld joint over the multi-pass TIG weld joints.

Yatender Gupta et.al [23] had investigates the methods used for welding the alluminium 6062 alloy. Researchers had done their work by comparing the mechanical and microstructure, properties of specimen by using TIG and MIG welding techniques and it was found that the MIG welding is better than other welding techniques. Microstrtural and mechanical properties of welded specimen was good in MIG welding.

Rajiv suman et.al [24] evaluated the yield strength, hardness and microstructure, properties of aluminium 31000-H2 alloy by using single pass of tungsten gas welding. Researchers had done microstructural analysis of welded specimen by using SEM and other properties also calculated by Rockwell hardness tester and UT Machine and they concluded that the strength of the parent material is higher than the heat affected zone and fusion zone. The ductility of the parent material is decreased as compared to fusion zone and heat affected zone.

2.2 Research Gap

By doing the literature survey, it has been observed that No. Of Researchers had done a lot of work on Inconel 600 with dissimilar materials like stainless steel, mild steel but welding of similar Inconel material is not done by any other researchers. Friction stir welding had used for welding of Inconel 600 with SS 400. But no efficient work is practical on Inconel 600 with mechanical properties of similar material and micro structural property of weld joint specimen had been reported. By the survey of literature also reveal that there is a possibility of working in the way because of the critical application (like in nuclear industry, chemistry industry etc.) and to make safer for further used.

2.3 Scope of the study

Detail study of the weld of the material required because welding alters the microstructure of the material and produces tensile stress at the region of welding and heat affected zone, which can cause of unfavorable behavior of corrosion in the welding material. due to the high burn-up of FBR fuels, the concentration of fission products is much higher in the High Level Waste generated from the reprocessing of FBR spent fuels. Hence, studying the corrosion behaviour of nickel base alloys in the HLW of spent fuels of FBRs and identifying lucrative corrosion resistant materials for the long term storage of waste in acid medium solutions of different concentrations are required.

2.4 Objective of the study

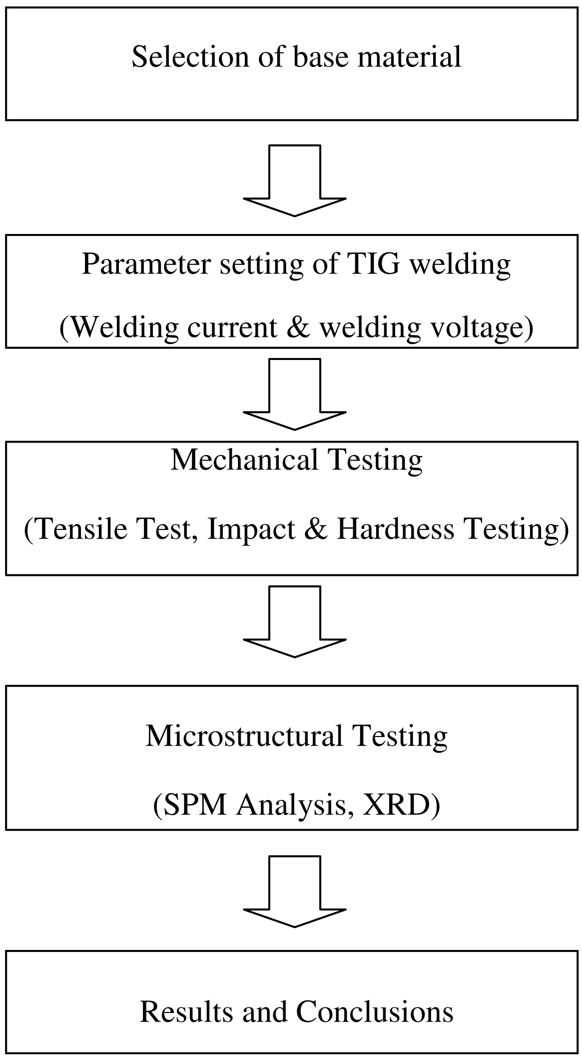
In this work we will perform welding of 3mm thick Inconel-600 similar alloy, for welding of Inconel-600 alloy TIG welding machine setup is used. We will also investigate that Inconel-600 alloy is feasible or not by doing welding of TIG. If welding is done at the interface of Inconel-600 that time we check the mechanical properties and microscopic structure. Effect of welding speed and applied current on the tensile strength of weld joint, micro hardness of weld pool and microstructure of joint will investigate.

Chapter 3

Experimental and Testing

In this chapter, we discuss the experimental procedural of TIG welding on the similar Inconel 600 plates after the welding procedure we cut the specimen into no. of sample for mechanical testing (viz. tensile test, hardness test & impact test) another sample are used for micro structural analysis over Scanning Probe Microscope and Powder XRD is also used for identification of phase of crystalline material.

3.1 Plan of Experimentation



3.2 Base Metal

In our investigation, the work plate of nickel chromium alloy (Inconel 600) will cut to length from the flats and each plates having a length 50 mm , width 50 mm and thickness of plate is 3 mm.

3.2.1 Inconel 600

Inconel alloy is the alloy of nickel-chromium iron. Its have good mechanical properties and they are oxide and corrosion resistance in nature which is helpful for working in that environments where high pressure and K.E are subjected. When we heated the Inconel alloys at high temperature they are forms a thick and stable layer which protect the surface from additional attack. These types of materials retain its strength over a best range of temperature, Inconel alloys are used at that places where high temperature is applied. In these alloy the high contains of nickel alloy gives it corrosion resistance behaviour by many organic and non-organic compound. During the solid solution strengthening the strength characteristics is depends on the high temperature. Intermetallic compound (Ni_3Nb) is formed by the reaction of some amount of niobium with nickel all process is run in age-hardening. They forms a small cubic crystals that affects the creep behaviour of surface due to raising its temp. For joining of Inconel alloy we also add some filler materials at their applications. Inconel alloys are present in different grade like Inconel-600, Inconel-625, and Inconel-718 etc.

These types of nickel chromium alloy having good application in those industries where the requirement of corrosion and high temperature resistance properties is needed.

Element	Nickel + Cobalt	Chromium	Iron	Carbon	Manganese	Sulfur	Silicon	Copper (Cu)
%	72	14.0 to17.0	6.00 to10.0	0.15	1.00	0.015	0.50	0.50

Table 1 Chemical composition of Inconel 600 alloy

3.3 Welding Equipment

3.3.1 Equipment used in TIG welding

- Welding torch, tungsten electrode and filler rod.
- Welding power source, DC power supply and cables, high frequency unit.
- Cylinder for inert gas which is used for shielding purpose, pressure regulator valve, flow measuring meter.
- Solenoid valve for gas and water.

3.3.2 Welding torch

Welding torch used in TIG welding cooled by the water or air cooled. Collet is used for holding the electrode of tungsten and feeds the shielding gas to the puddle. Water cooled puddle is preferred when the current is beyond the 150 A. tungsten electrode are used in welding process is off two types thoriated tungsten or zicronated tungsten. Tungsten electrode can resist high temp. so, they are mostly used in welding as a electrode. Nitrogen attacks liquid tungsten when copper is welding in atmosphere of nitrogen that time alloy tungsten is used.

3.3.3 Power source

In GTAW process, we used AC or DC both type of power source but DC is most preferred at the place of AC for the welding of different alloys like nickel, copper, stainless steel and its alloy on the other hand, AC type power supply used for welding of mildsteel, aluminium, magnesium and their alloys reverse polarity removes oxide film on aluminium and magnesium, for the ignited arc we used high frequency unit and stabilized while using AC source. A typically GTAW power source rated from range 3-200 A or 5-300 A with a range of voltage of 10-35 V with 60% duty cycle.

3.3.4 Inert gas

Different types of inert gases can be used in TIG welding

Argon(Ar), Helium (He), Mixture of argon(Ar) and helium(Hi), mixture of oxygen and argon (ar) and mixture of hydrogen or argon.

Pressure regulator and flow meter are used to stepdown the pressure of inert gas from cylinder that is 140 kg/cm^2 to 150 kg/cm^2 and feed the same at definite flow rate for mild steel, Al and its alloys, Cu, Ni and its alloy and stainless steel welding generally Ar-He or its mixture is used.

3.4 Welding Procedure

In Experimentation study of welding sample of Inconel 600 alloy we was selected the plate having thickness 3mm. the nickel- chromium alloy are cut into the dimension of 50 mm in length, 50mm in width and having thickness of plate is 3mm by the help of band saw after the cutting of sample grinding was done over the Inconel plate for edge preparation and for removing the unwanted material over the Inconel plate. After the preparation of edge and removing the unwanted material from the plate we polished the surface with used the emery paper for removing the unwanted material or for proper surface finish we used the emery paper.

After the preparation of sample, the specimen is fixed over the working table for preparing the butt joint between the Inconel 600 plates.

Figure 3 Sample after TIG welding

In this experimentation we were used the setup of TIG welding machine with alternating current whose is concentrates the area of heat and welding part. Electrode used in this welding is made up of zirconiated material and having a thickness of 3.4 mm. the end part of electrode is reduced by 2/3 from their original dimension by the use of grinding and after this arc is stricking over the waste material.

For the welding parameters we take the numbers of trail. After doing the trail of TIG welding over Inconel 600 plate the welding parameters are given below in table 2. The welding parameter are welding current, welding voltage, type of electrode, gas, distance between the electrode tip from the centre of weld etc.

Welding parameters	**Range**
Current	60-80 amp
Voltage	25 v
Welding speed	(3-4) mm/s
Flow rate of Gas	(8- 10) l/ mm
Distance between the electrode tip from centre of weld	3 mm
Current type	AC
Dimension	(50 * 50 * 3) mm

Table 2 Different welding parameters used for Experimentation

3.5 Testing

Mechanical and microstructure testing are important for welded specimen because these types of

3.5.1 Specimen Sampling

In mechanical testing method we find the mechanical properties of material by using their different method like we can find the resilience by impact tester, hardness by different hardening tester Machine. we will also find the yield strength, tensile strength, percentage of elongation by using ultimate testing machine. For different testing method, ASTM had decided some imperative for the testing of specimen. By the use of ASTM standard A370 the standard specimen size dimension is (55*10*2.5) mm. the specimen dimensions with its dimensions are shown in fig. 5.

Chapter-4

Mechanical testing and microstructure Studies

In these chapter we discuss the procedural details of mechanical properties (viz. impact test, micro hardness testing) and microstructure studies (viz. Xrd analysis, Atomic Force Microscope analysis) as weld specimen will be subjected with an aim of generating data for further analysis.

4.1 Mechanical testing of welding joint

Mechanical testing of the welding joint had been carried out by the use of ASTM standard for testing the welding joint. Fabrication of joint is discuss in earlier chapter 3. Now, in these chapter we detail study about the testing sample. Here in mechanical testing we only study about the impact test and hardness of the specimen. Impact test was carried out over charpy impact test and hardness of the welding joint was carried out by two different method of hardness testing i.e. Rockwell hardness tester and brinell hardness.

4.2 Impact test

The specimen will be carried out from each welding plate and prepared accordance of the ASTM standard A370 which is charpy v notch test for metallic materials. For better assessment of welding joint notch are prepared over the specimen. The study of specimen mainly focused over the heat affected zone or heat input parameters. So, these will be important to study changes in the toughness of weld metal by changing the welding conditions. The absorption of energy are shown in charpy v notch tester.

Figure 4 Charpy impact tester machine

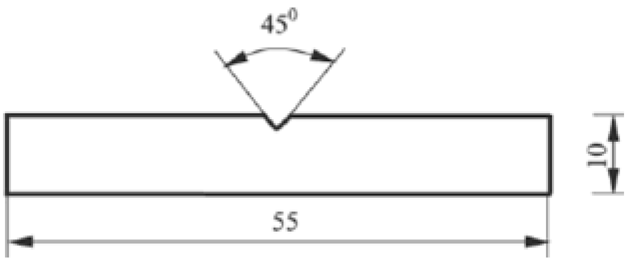


Figure 5 ASTM standard specimen

4.3 Micro- hardness studies

For micro hardness studies we will firstly etching the specimen because it removes unwanted material from the surface of plate after etching process we polishing the plate. Due to the process of etching and polishing the standard specimen are prepared for hardness testing. Etching will be done of emery paper have 2500 grit size. Etching helping for removing oxide layer of fine size and coarse as well as scratches on the surface that are to be metal analyzed.

Figure 6 Brinell and Rockness hardness tester

Micro hardness can be measured with the help of micro hardness tester at various zone of interest in different weldments. Testing of micro-hardness of sample will be carried out transversely as well as longitudinally direction. Hardness of the specimen will be carried out brinell hardness tester as well as Rockwell hardness tester. Fig. shows the different types of hardness tester.

4.4 Micro structural Studies

To investigate the effect of heat at the interface of specimen, weld zone and heat affected area i.e. HAZ microstructure analysis is important. In this experiment we were studied about the structure of the welding plate by using SPM. AFM is the type of SPM with confirmed pledge on the order of fraction of a nanometer, more than thousand times as compare to the diffraction of limit of optical.

In force measurement, force can be measured between the mechanical probes of the instrument to the specimen which surface has been measured. For better imaging, the images are formed in three dimensional by the sample imposed to that surface at which the structure can be measured with high resolution. Three dimensional images are achieved by scanning of raster of the position of the sample with the respect of tip and height between the probe and sample and the topographic images are formed in AFM analysis. Apseudocolor plot are helped for ploting the topography surface in AFM.

We were also used powder Xrd for the identification of crystalline phase of the material and it also provides a dimensions of unit cell of the matter. The analyzed material is finely ground, homogenized, and average bulk composition. X-ray diffraction is very commonly technique for the study crystal structures and it also finds the space between the atoms. It is based on the principle of monochromatic interference X-ray. Cathode ray tube is used for generating X-rays. It satisfied bragg's law when the incident rays is interacted with the sample or specimen. These diffraction can be detected processed and counted. In this investigation we used Xrd analysis for determination of unit cell dimensions, fine grained structure of the material. Xrd Analysis of welding joint is briefly explained in the next chapter.

In this part of the study we have done mechanical testing and metallurgical studies on the TIG welding of Inconel 600 joints. First of all charpy test V-notch impact test specimen were prepared by wire cut EDM and then impact test was performed. Similarly in metallurgical studies we have done micro hardness and observe the microstructure of the welded specimen. The value of different test was recorded and different result is obtained.

Chapter 5

Result & Discussion

5.1 Mechanical Testing for Welding Joint

Mechanical testing like impact test and micro- hardness test was carried out on different specimen following the standard procedure.

5.1.1 Analysis of charpy impact testing results

the charpy test was performed on different welding specimen by varying heat input and result obtained are summarized in table . the result shows the specimen which is welded at low heat input posses maximum impact strength about 29 joule by using TIG welding. And the impact strength of base parent material is 110 joule. As welded specimen of Inconel 600 alloy have less strength as compare to parent material when the sample are break and the value of impact strength is given in the table 3.

Weld/ Material	Energy absorbed in Joule	Effect
Parent material	83.3 joule	Non break
Weld material	26 joule	Break

Table 3 Charpy impact test results

These type of test are used for finding the toughness of the welded specimen by the use of strain rate test. And these types of test are also find amount of energy absorption during the fracture of material. This absorbed energy measured of a given material's notch toughness and act as a tool to study the temperature dependent ductile brittle transition.

For analysis the charpy test over welded joint we will used the ASTM standard A370. According to this standard the sample have the dimensions 55mm * 10mm* 2.5mm, thickness of the specimen is 2.5 according to the standard of A370. Experimental setup of the impact test explained into pervious chapter in details and the result of the impact test is shown in table on the basis of their parent material and welded specimen. Impact tested specimen is shown in the figure. Effect of the test are shown in table with the form of absorption of energy is breakable or non break.

Figure 7 Specimen after charpy impact test

5.1.2 Micro-Hardness studies

In this investigation Micro hardness analysis will be done by two different method of hardness testing machine first is Brinell hardness tester and other is Rockwell hardness machine. Hardness is defined as to fight to indentation and it normally used to calculate of fight to scratching. Resistance to the pointer indent into the softer one depends on the hardness of the sample at which load is applied through the indenter.

In Brinell hardness tester, the indenter used in that machine is made up of steel bar of varying diameter (D) according to their used and the indentation effect over the material is known as x =the diameter of indentation is denoted by d. BHN results always shows in the term of load (P). BHN is defined as the ratio of Load applied to the projected contact area. Load are applied to the indentation is always lies between the 500 kg to 3000 Kg are depends upon the materials which are used for testing. More loads is applied for hard material as compare to soft materials. The formula of Brinell hardness tester is shown in below

$$\mathrm{BHN} = \frac{2\mathrm{P}}{\pi \mathrm{D}[\mathrm{D} - (\mathrm{D}^2 - \mathrm{d}^2)]^1/2}$$

P = applied load

D = Diameter of the ball indenter

d = diameter at the circumference of the enduring impression

Brinell Hardness testing of the welding specimen are shown in the table . the indentation of steel ball create the diameter or circumferences on the welded specimen. Load are applied for hardness testing are 3000 kg and the steel ball diameter D is 10 mm. after the indentation impression of the ball are come out over the plate in the form of rim. The rim diameter are varies on the basis of material surface their are different-2 values of indentation diameter are shown in table 4.

Types of materials	Indentation impression in diameter (mm)	Load in Kg	Hardness HB
BM	5.1 mm	3000 Kg	136.58
WM	4 mm	3000 kg	228.76
HAZ	4.5 mm	3000 kg	178.54

Table 4 Brinell Hardness Test results at different welding zone

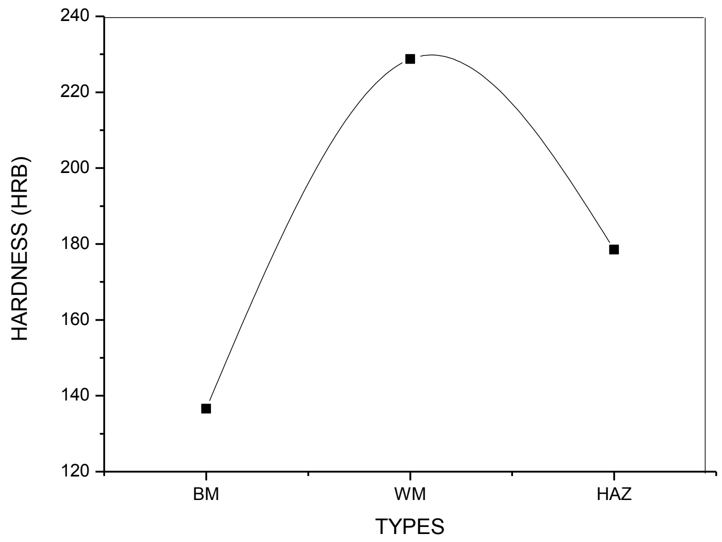


Fig. 9: Brinell hardness values from base metal to weld metal

In Rockwell Hardness test the first minor load is applied 10 kg and then major loads which is varies between the 50 to 150 kg on the surface of body where the hardness will be measured. Indenter and load are applied on the basis of scale (A, B, C, D) load and indenter diameter are dependents on the scale. In our experimentation we were used scale B, for these types of scale load are often is generally used 100 Kgf and indenter dimensions are 1/16 inch. Dia. Or 1.588 mm of steel sphere.

Rockwell hardness tester is discussed in briefly in the previous chapter and the Rockwell hardness equation is shown as

$$HR = N - d/s$$

These types of equation have no unit so these are a unit less quantity. All the value of N and S are given in table on their basis of types of scale is used. Here we used the B types scale and these types of scale value are given that

Scale	Abbreviation	Load	Indenter	N	S
B	HRB	100 kgf	1/16 inch. Dia. (1.588mm)	130	0.002 mm

Table 5 Rockwell hardness testing scale

Types of material	Load in kgf	Hardness in HRB
BM	100 kgf	65 HRB
WM	100 kgf	71 HRB
HAZ	100 kgf	68 HRB

Table 6 Results of Rockwell hardness at different welding zone

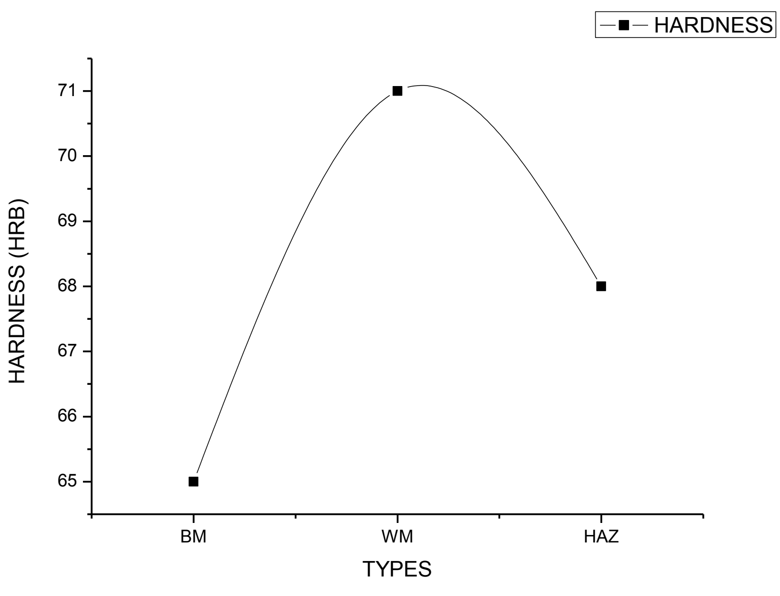


Figure 8 Rockwell hardness value from base metal to weld metal

5.2 Microstructure studies

In our investigation, we were analysed the surface of welding plate by the help of atomic force microscopy and powder Xrd analysis. Atomic force microscopy is also known as the scanning probe microscopy (SPM) in these types of analysis we analysis the surface of materials. These types of atomic resolution help to investigates the possible solid surface with better accuracy that has not be find before or out before. These types of studies are mostly helpful for insulators. Atomic force microscopy is differ from the other types of microstructure analysis instrument like SEM. AFM is time consuming process as compare SEM analysis. It gives the colored images of the tested specimen.

Very weak physical forces are utilized in the AFM is large caused by the vandar waal potentials. The dominations of repulsive part is taken when the distance between the tip and surface is so small that times the working of AFM is in contact mode.

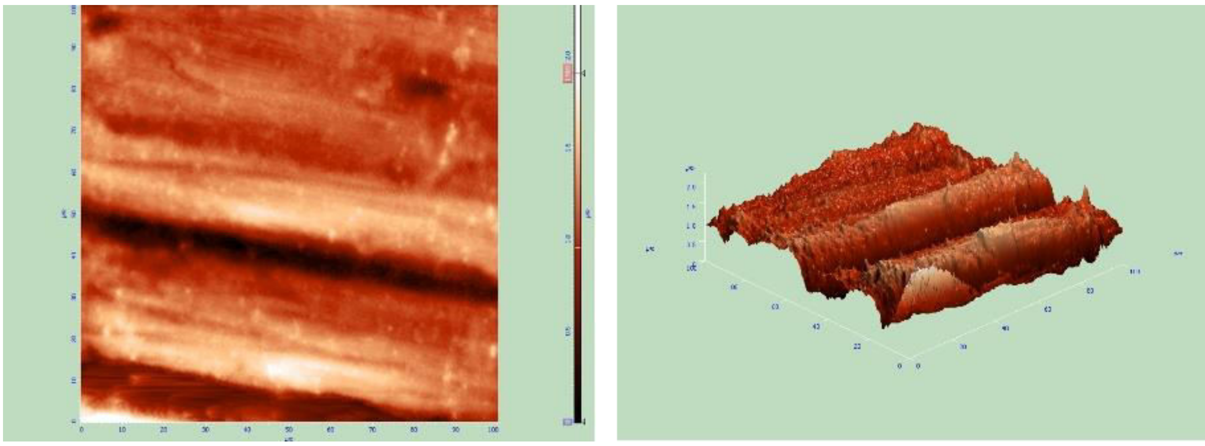


Figure 9 AFM 2D & 3D image at weld zone

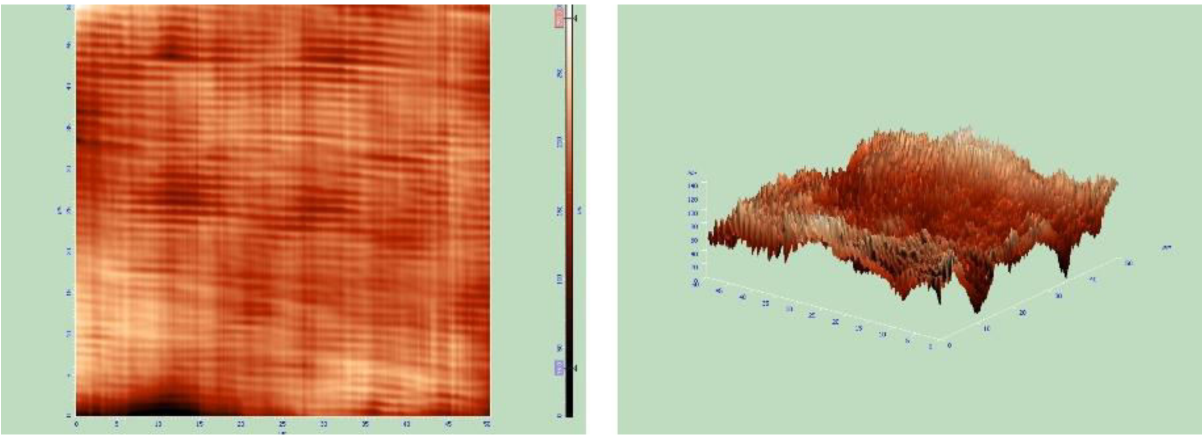


Figure 10 AFM 2D & 3D Image at base metal

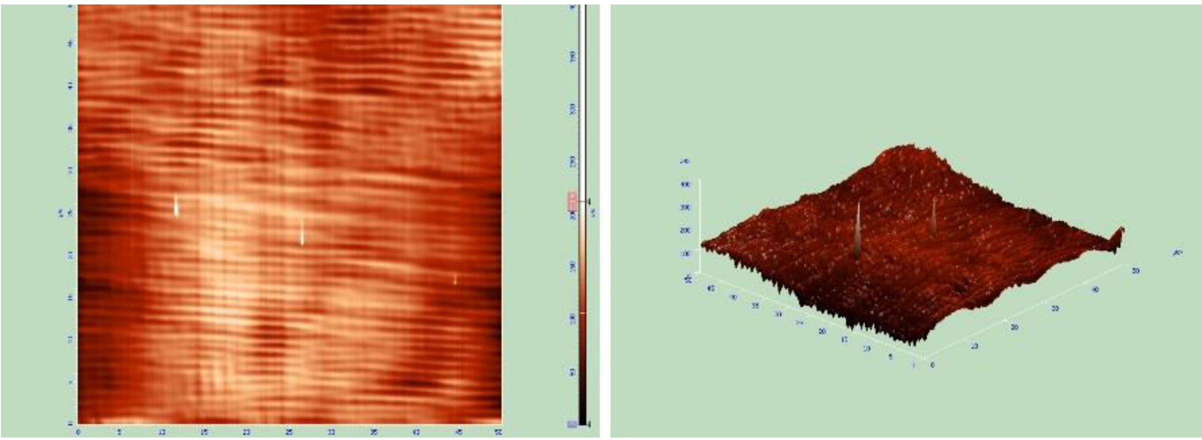


Figure 11 AFM 2D & 3D Image at HAZ

In order to study the heat input on the fusion zone, weld zone, heat affected zone and base metal micro structural studies are to be carried out on the welding specimen. That specimen whose are use for micro hardness testing that samples are used for AFM analysis and powder Xrd analysis. First of all the surface of specimens will be electrolytically etched with emery paper and polished by acetone after these polishing and etching of the plates the plate is going to for AFM analysis there are different images are shown in fig.11- 13. They are all the different -2 AFM images of welding zone like weld zone, haz and base metal. First of all we discussed the analysis of AFM image at fusion zone in that surface welding of Inconel 600 material are considered the two dimensional and three dimensional images are shown in fig. 11 in these analysis the average surface roughness is 218.019 nm, AFM images of parent material and heat affected zone also given in fig. 12, 13. In all these two figures the 2d & 3d images are shown. In heat affected zone average roughness is 20.1683nm and the average roughness of parent material is 17.1595 nm. By the analysis of these results we can say that the roughness of welding joint is not better than parent material or heat affected zone. All the data about the average roughness is discussed above.

5.3 Powder XRD analysis

Powder XRD is that types of analysis in which detection of phase of crystalline material and it can also provides the in sequence about the unit cell geometry. The average material is delicately view and homogenized, this analyses help for determination of bulk phases or composition is determined. Powder XRD analysis based on the principle of constructive interference of monochromatic X-rays and crystalline structure. Powder XRD is based on the principle of bragg's law

$$(n\lambda = 2d \sin \theta)$$

The X-ray can be detected and counted. when we will scan the data by the limits of 2 theta Angle all the possible path of diffraction of the pattern should be attain due to unsystematic point of reference of powder material. all mineral deposits have their own distinctive d-spacing because due to the conversion of diffraction of peak into d spacing is allocate due to these identification of phase are required.

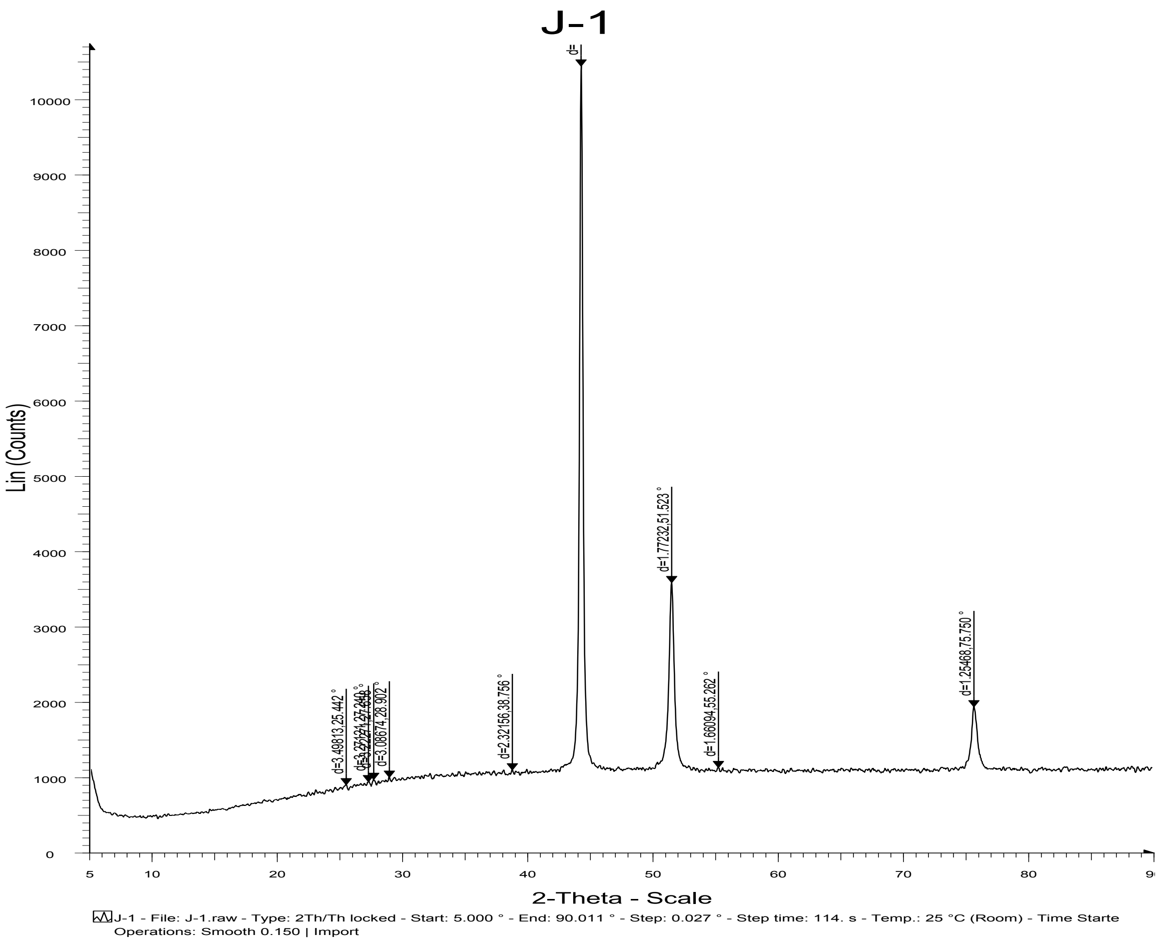


Figure 12 XRD profile obtained at room temperature

The room temperature powder XRD profiles are shown in above figure with the given scale 2 theta. The relative parameter change as estimated by angle 2 theta. The lattice parameter is shown in three fcc reflections, namely (1 1 0), (2 0 0), & (2 1 1) finally all the the value of m is given by m = H^2+ k^2+l^2 and miller indices are (h,k,l) all the values of given xrd data are shown in table.

2θ	**Theta in deg.**	**Theta in rad.**	**Sinθ**	**Sin^2θ**	**Ratio**	**k-factor**	**H^2+k^2+l^2**	**(h,k,l)**
44.283509	22.141754	0.3864	0.61419	0.3772	1	2	2	(110)
51.521998	25.760999	0.4495	0.43460	0.1888	2	4	4	(200)
75.786337	37.893168	0.6613	0.37689	0.1420	3	6	6	(211)

Table 7 Results of XRD data analysis

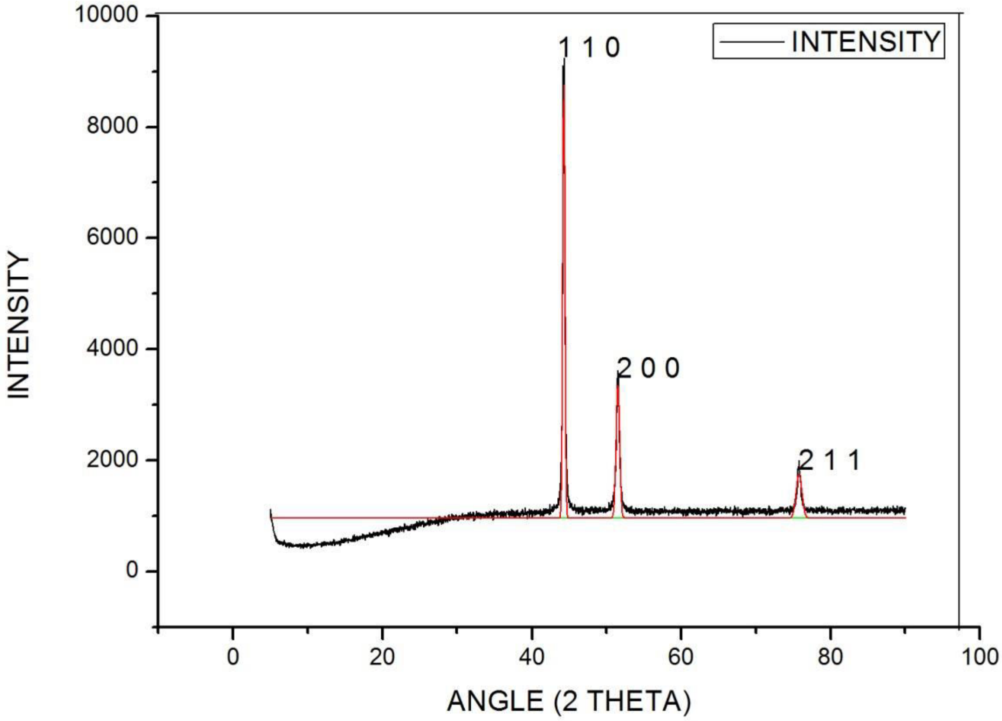


Figure 13 Representation of unit cell in XRD image

Chapter 6

6.1 Conclusions

After the TIG welding of nickel based super alloy (Inconel-600) mechanical and microstructural properties of weld have been studies and following conclusions can be drawn.

- Welding of similar Inconel 600 alloy is possible with the range of voltage 60-80 v without the use of filler materials.
- Mechanical properties of welding specimen are better than parent material, Roughness of the welded joint is less than the impact strength at base metal or in other the toughness of the welded joint is less than base metal.
- In our investigation, it also found that the hardness of weld metal is maximum as compare to parent metal & heat affected zone in both the hardness testing machine. The maximum hardness is 228.76 HB in Brinell hardness tester and 136.58 in base metal.
- AFM results of welding of similar Inconel 600 plates are that in which the maximum no. of peaks are occurred at the weld zone as compare to base metal. The average roughness of the joint is maximum to the roughness at HAZ & base metal.
- Powder XRD analysis was helped for indentifying the phase of crystalline material. In this investigation face cubic centre structure are found on the welding joint the unit cell of welding joints are (110), (200) & (211) are found due to the XRD analysis.

6.2 Future Scope

- Welding parameter studies are also done of these Inconel- 600 alloy with the use of filler materials or without it.
- Comparatively studies of the Inconel-600 alloy have been done with the use of filler material and without the use of filler material.
- Mechanical and microstructural properties are also tested for comparatively studies.
- Scanning Electron Microscopy Techniques and TEM analysis can be performed on the welded specimen for enhancing the material properties.

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