Analysis of Fluxes on Depth of Penetration in Incoloy 800h Steel By Tig Welding

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Abstract*- A-TIG welding differs from conventional TIG welding process by the way of employing a thin layer of flux in the area to be welded. The flux can be a single component salt or a mixture of multiple salts. Usually these salts are of oxides, chlorides or fluorides. Use of these fluxes improves depth of penetration by two to three times in relation to the depth of penetration that can be achieved by conventional TIG welding. Though several mechanisms have been proposed for the improvement in depth of penetration, arc constrictions and/or reversal of Marangoni forces are considered as major influencing factors. The present aims to study the effect of single component fluxes viz., SiO_2, ZnO and a combination of SiO_2 and ZnO on the weld bead geometry in TIG welding of Incoloy 800H austenitic stainless steel. To study the effect of combination of these salts as flux mixture on the bead geometry several ternary flux mixtures were designed and used in producing autogenous TIG melt runs.*

Keywords- TIG welding, Multiple salts, Margoni force, Stainless steel

I. INTRODUCTION

The TIG welding is one of the main arc welding processes, in which the necessary heat for welding is generated by maintaining an arc between a refractory tungsten electrode and the base metal to be welded. The electrode, the arc, and the area surrounding the molten metal are protected from atmospheric contamination by an envelope of inert gas during heating and subsequent cooling. TIG welding is one of the cleanest and the most decorative weld joint surface producing welding procedure. Its carrier started during the Second World War, when it became a real mass production procedure. But the relations of that time had been changing by the second third of the century due to the introduction of new and higher productivity welding procedures (for example MIG/MAG, laser and electron beam welding). Low productivity results from a combination of the low welding speed and the multipass welding procedure for thick section plates or heavy wall pipe materials. Additional costs are incurred through edge preparation and substantially longer welding time because several passes with filler metal are required to fill the groove joints Apart from this the quality of TIG welding did not change any. Improvements in productivity in TIG welding technology have long been sought in the welding community. This demand has led to a so-called flux assisted TIG (TIG-flux)or A-TIG(Activated TIG) welding, a modified TIG welding process that uses flux compounds, such as oxide, chloride, or fluoride to overcome the limitations by increasing joint penetration using a single-pass operation without any edge preparation.

A BRIEF INTRODUCTION ABOUT A-TIG WELDING:

Activated flux assisted TIG (A-TIG) welding is a recently developed technology by E. O. Paton Welding Institute, Ukraine in the year 1960 where application of a special flux on the weld seam or groove of the base metal significantly increases the weld penetration.

The flux, also known as penetration enhancing compound, increases the weld penetration by as much as 300 % and produces consistent penetration regardless of heat to heat variations in base metal composition.

During welding activated flux changes the convection movement in the weld pool form centrifugal to centripetal type and there by deep penetration is achieved. Resulting depth of penetration is increased by a factor of 1.5 to 4 in comparison with the penetration depth of conventional process. The activating flux process can be applied in both manual and mechanized welding operations. However, because of the need to maintain a short arc length to achieve deep penetration, it is more often applied in mechanized applications.

In applications like nuclear power plants, petrochemical industries,jet-engine components, and rockets, generally nickel based alloys are considered as promising candidates, the reasons being their high strength and corrosion resistance at elevated temperature. Incoloy 800H, which comes under the family of austenitic nickel-chromium-based super alloys, exhibit high tensile strength, appreciable resistance to oxidation and carburization at elevated temperatures. The superior mechanical properties combined with resistance to high-temperature corrosion make these alloys exceptionally useful for many applications involving long-term exposure to elevated temperatures and corrosive atmospheres.

Generally Tungsten Inert Gas welding process is used for joining these super alloys. Limitations of TIG welding like its inferior joint penetration, its inability to weld thick materials in a single pass, and its poor tolerance to many material compositions, including cast-to-cast variations in the composition of certain impurities, as described byFujii and Huang and these limitations lower the productivity of the process. Researchers who worked on improving the joint penetration ,Fujii et al. HuangLeconte Liu and Sun , Xu , and Zhang eproposed one of the most notable technique is to use an activated flux in TIG welding process. Researchers at the Paton Welding Institute in Ukraine introduced the concept of using flux with TIG to increase joint penetration in the 1960s outlined by Gurevich. Sun and Pan reported that activated TIG welding can significantly increase penetration capability by as much as 300% compared with the conventional TIG welding.

Determining the effect of activating flux on joint penetration is essential in improving the performance of Activated TIG welding on Incoloy 800H super alloys. This study is focused on experimental investigation on effect of different oxide fluxes on welding of Incoloy 800H plates and carrying out the metallurgical analysis of the weldments.

1.2 PENETRATION MECHANISM THEORIES OF A-TIG

There are various theories about the explanation of the mechanism of the activating fluxes and they are as follows.

1.2.1 THEORY OF SAVITSKII AND LESKOV

This theory says that the activating fluxes decrease the surface tension of the weld pool, which makes able the arc pressure to invade deeper into the weld pool. This results is a deeper penetration.

1.2.2 THEORY OF SIMONIK

Simonik says that in the triggering fluxes there are oxide and fluorine molecules which have affinity to chain the free electrons at the edge of the arc's plasm. It is well known that the ions formed this way have substantially lower mobility than the free electrons. This leads to increase current density at the centre of the arc due to the higher movement of the free electrons. This results better focusing of the arc, which leads to the deeper penetration.

1.2.3THEORY OF HEIPLE AND ROPER

This theory says that the activating fluxes changes the gradient of the surface tension from negative to positive and causes the flowing of the molten metal to turn in the opposite direction and flow towards the center of the weld pool. This is how deep penetration is obtained by the reversed Marangoni-effect.

1.2.4THEORY OF LOWKE, TANAKA AND USHIO

They explain the deep penetration by the means of the higher electric insulation of the activating fluxes. Thus the arc is able to break through the surface (and the flux on it) over a narrower area. This means that the focus of the arc increases which leads to higher current density in the arc spot and this causes the deep penetration .However, the two mechanisms, Marangoni effect and Arc constriction effect are stated to play important role in enhancing the penetration in A-TIG welding.

1.3TUNGSTEN INERT GAS WELDING

Welding is the method of joining two or more metal pieces permanently, by melting both materials. The molten materials cool easily, and the two metals are permanently bound together. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the workpieces to form a bond between them, without melting the workpieces. Arc welding processes, which are very popular in welding techniques,maintains an electric arc between an electrode and the base m aterial to melt metals at he welding point, by utilising a welding power supply. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is sometimes protected by some type of inert or semi-inert gas, known as a shielding gas, and filler material issometimes used as well.Tungsten Inert Gas welding (TIG welding)or Gas–tungsten arc welding (GTAW) is a fusion welding process that melts and joins metals byheating them with an arc established between a non-consumable tungsten electrode and the metals. The chance of slag inclusions in the weld metal is eliminated as no slag is produced and the finished weld requires virtually no cleaning. The tungsten electrode is usually in contact with a water-cooled copper tube, called the contact tube, which is connected to the welding cable from the terminal.

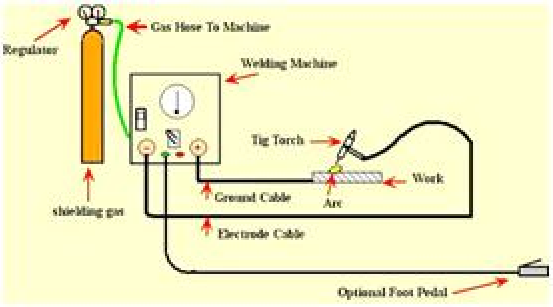


Figure.1.1 Schematic representation of the TIG

This allows both the welding current from the power source to enter the electrode and the electrode to be cooled to prevent overheating. The workpiece is connected to the other terminal of the power source through different cable.

Direct current is normally used with electrode negative polarity for welding most metals except aluminium ,magnesium and their alloys, because of the refractory oxide film on the surface which persists even when the metal beneath melts.GTAW welding torches are designed for either automatic or manual operation and are equipped with cooling systems using air or water.The angle between the centreline of the handle and the centreline of the tungsten electrode, known as the head angle, can be varied on some manual torches according to the preference of the operator. Air cooling systems are most commonly used for low-current operations while water cooling for high-current welding is needed

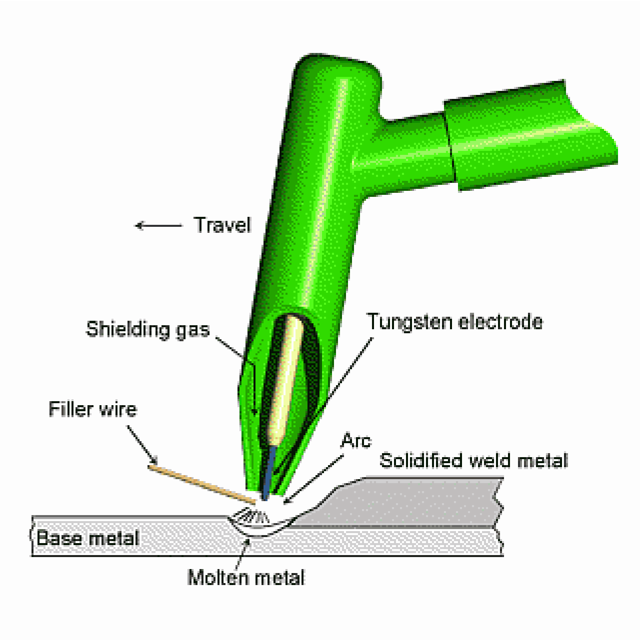


Figure 1.2 Schematic Illustration of the TIG Welding Torch

Gas tungsten arc welding uses a constant current power source, meaning that the current (and thus the heat) remains relatively constant, even if the arc distance and voltage change. This is important because most applications of GTAW are manual or semiautomatic, requiring that an operator hold the torch. Maintaining a suitably steady arc distance is difficult if a constant voltage power source is used instead, since it can cause dramatic heat variations and make welding more difficult.

The preferred polarity of the GTAW system depends largely on the type of metal being welded. Direct current with a negatively charged electrode (DCEN) is often employed when welding steels, nickel, titanium, and other metals. Direct current with a positively charged electrode (DCEP) is less common, and is used primarily for shallow welds since less heat is generated in the base material.

Alternating current, commonly used when welding aluminium and magnesium manually or semi-automatically, combines the two direct currents by making the electrode and base material alternate between positive and negative charge. This causes the electron flow to switch directions constantly, preventing the tungsten electrode from overheating while maintaining the heat in the base material.GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminium, magnesium, and copper alloys.

1.3.1 LIMITATIONS OFTIG WELDING

- TIG welding's key drawbacks are the small material thickness that can be welded in a single step, poor tolerance to certain material composition (cast to cast variations) and low profitability.
- Poor productivity in TIG welding results from a combination of low welding speeds and the high number of passes needed for filling the joint in thicker material.
- Variation in weld penetration due to variations in composition of base metal from one heat to another.

1.4ACTIVATED TIG WELDING

The EO Paton Institute of Electric Welding in the former Soviet Union first used A-TIG fluxes in the late 1950s. Because the weld shape is sensitive to microelements, such as sulphur, oxygen and selenium, a satisfactory weld joint with deep penetration can be obtained with smearing or pre-placing active flux within these microelements on the surface of the weldment in A-TIG welding. The use of fluxes in GTAW has been found to dramatically increase weld penetration in steels and stainless steels. Significant increases in the penetration capability of up to300 % compared with the conventional TIG process have been achieved when using activating flux consisting of oxides and halides. For the plate of 12 mm thickness, there is no groove preparation, which can be welded in a single pass. Therefore, A-TIG welding should bring about large benefits in terms of productivity. A thin layer of activating flux is covered on the surface of the joint to be welded by means of a brush or a spray before welding. The flux usually consists of oxides and halides, and it is mixed with acetone or the like to form a paste and painted as a thin coating over the area to be welded.

1.5SELECTION OF FLUXES

To study the effect of multi component fluxes, three oxide fluxes are selected. Studies on the effect of 32 oxide fluxes on A-TIG welding of stainless steel have shown that ZnO and SiO_2 are the best performing fluxes when considering depth of penetration.

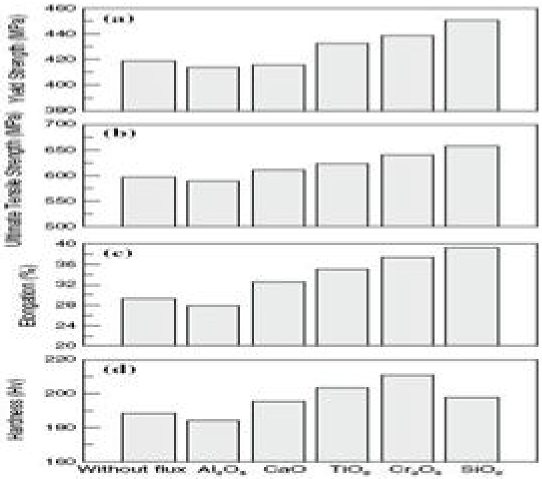


Figure1.4 Effect of oxide fluxes on mechanical properties.

Study of the Performance of Stainless Steel A-TIG Welds using five different oxide fluxes (Al2O3, Cr2O3, ZnO, SiO2 and CaO) shows that increases in weld depth and the decrease in bead width are significant with use of the ZnO and SiO2.A-TIG weldment exhibits better mechanical properties (including strength, ductility, and hardness) than those of TIG welding without flux as shown in the Fig.1.3.

When TIG welding with ZnOand SiO2 is used, the retained delta-ferrite content in weld metal is increased. A certain amount of retained delta-ferrite in austenitic stainless steel weld metals has a beneficial effect in reducing the hot cracking susceptibility. The result clearly indicates that the hot cracking susceptibility of stainless steel 304 as-welded can be reduced when certain flux was applied to TIG welding process.

1.6MECHANISM OF INCREASE IN JOINT PENETRATION

Many investigations on the mechanism and application technology of the A-TIG process have been made, and the two representative theories are the arc constriction and reversal of the Marangoni convection in the weld pool. However, there is still no commonly agreed mechanism for the increase in penetration depth. The two representative theories are discussed in depth in the sections that follow.

1.6.1THE REVERSED MARANGONI EFFECT:

This mechanism is based on the basic idea that the direction of fluid flow during the welding process can affect weld morphology. In studies related to molten fluid flow during welding Heiple et.al proposed that the temperature coefficient of surface tension is a factor in determining direction of molten fluid flow. He proposed that when a surface active agent is present in the liquid metal in a small but significant amount,$\partial\gamma / \partial T$ can be changed from negative to positive, thus reversing Marangoni convection and making the weld pool much deeper. This mechanism is termed as Reversed Marangoni convection. Surface reactive agents commonly used are oxides and halides. During activated TIG welding process it is applied as a layer of flux coating prior to welding. The mechanism has been explained more in detail as follows.

In the absence of a flux containing surface active agent, temperature coefficient of surface tension is negative. That means the outer edges would have a higher surface tension than the central region due to lower temperature.

The warmer liquid metal of lower surface tension near the center of the pool surface is pulled outward by the cooler liquid metal of higher surface tension at the pool edge. This induces a centrifugal Marangoni convection as shown in fig. It gives a wider weld bead width and shallower weld profile.

In the presence of a flux containing surface active agent, on the other hand, temperature coefficient of surface tension is positive. The cooler liquid metal of lower surface tension at the edge of the pool surface is pulled inward by the warmer liquid metal of higher surface tension near the centre of the pool .surface.

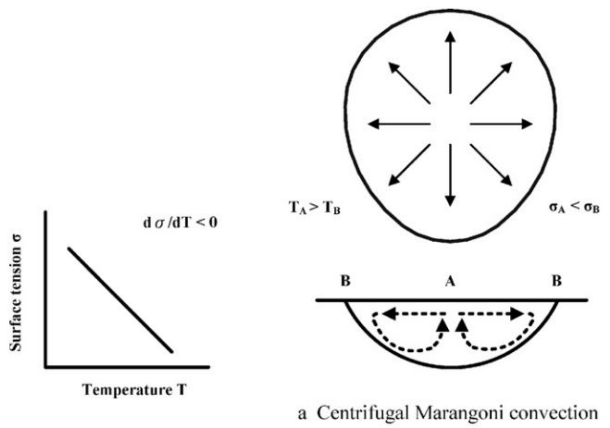


Figure 1.6: Schematic Representation of the Marangoni Flow When TIG Welding Is Carried Without the Presence of an Activating Flux

The flow pattern in favours convective heat transfer from the heat source to the pool bottom.In other words, the liquid metal carries heat from the heat source to the pool bottom more effectively, thus increasing the weld penetration.

1.6.2 ARC CONSTRICTION

It is based on Simonik (1976) principle of electron absorption. The cross-sectional view of an arc column normally appears round, as it consists of two concentric zones. Thesezones include an inner core and an outer region. The inner core of the arc carries the majority of the current, and has the highest temperature.

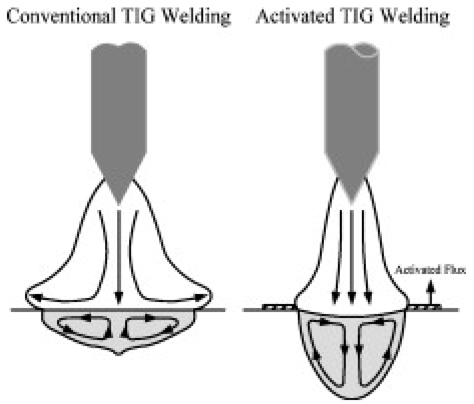


Fig1.6.2.TIG Welding

The outer region of the arc is much cooler, and tends to keep the arc plasma within the central region. For arcing with and without flux, that the inner core of the arc occupies almost the entire arc length. This zone is the arc column. Physically constricting the arc column can improve the concentration of heat energy in the anode root (Huang et al., 2005), and achieve a greater aspect ratio of the activated TIG welds compared with conventional TIG welds. That is, arc constriction gives higher depth of penetration and lesser bead width.

II. EXPERIMENTAL DETAILS

2.1 MATERIAL

2.1.1 WORK PIECE

Incoloy 800H of 4mm thick plates was cut into 80*50mm strips and the plates were polished with 600 and 400 grid silicon carbide paper to remove the surface contamination ,and then cleaned with acetone.The chemical composition is listed in Table 3.1. The Physical and Mechanical properties are listed in Table 3.2

Table 2.1. Chemical composition

C	Mn	S	Si	Cu	Cr	Fe	Al	Ti	Ni
0.065	0.688	<0.010	0.094	0.091	20.79	46.60	0.277	0.280	30.65

2.1.2 FLUXES

Three types of activated flux (SiO_2, ZnO, 50% SiO_2+50%ZnO) in powder form with nano particle size were selected. These powders were mixed with acetone to form a paste. A thin layer of flux was coated on the on the surface of the joint to be welded using camel hair brush before welding

Table 2.1.2 Physical and mechanical properties of Incoloy 800H

Physical properties	
Density	7.94 g/cm³
Melting Range	1357-1385 °C
Specific heat	460 J/kg °C
Mechanical properties	
Tensile strength	536 MPa
Yield Strength (0.2% offset)	150 MPa
Hardness	126 BHN

2.1.3.WELDING PARAMETERS:

Bead-on-plate welding was done using automated welding machine on specimens coated with different flux. All the specimens were welded under the same conditions and process parameters as listed . The welded specimens were cut in the weld cross section using an abrasive cutting machine and were polished with different grades of emery sheet followed by alumina polishing and diamond polishing to get 0.05 μm finishes.

Table 2.1.3 Process Parameters of Incoloy 800H

Weld current	100 A
Travel speed	0.83 mm/sec
Diameter of electrode	3.2 mm
Tip angle of electrode	45°
Shielding gas	argon
Gas flowrate	12.5 l/min

The welded specimens were cut in the weld cross section using an abrasive cutting machine and were polished with different grades of emery sheet followed by alumina polishing and diamond polishing to get 0.05 µm finishes.

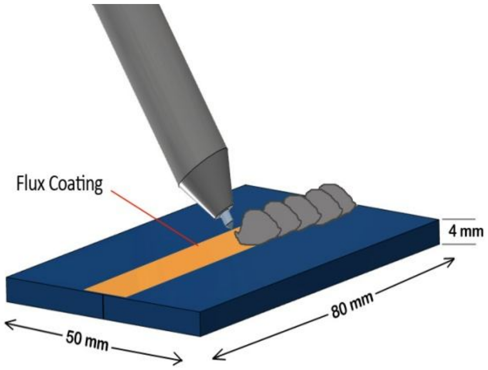


Figure 2.1 Schematic diagram of the welding process

2.2SAMPLE PREPARATION

Then the specimens were etched in a solution composed of15 ml HCl + 10 ml HAC + 10 ml HNO3 in order to use for metallographic analysis. Four such specimens were prepared from welded specimen using flux as well as without flux.

2.3 WELDING PROCEDURE:

To study the effect of flux assisted TIG welding experiments were carried out in the flat position with a torch angle of around 50 degree using LINCOLN CYBERWAVE 300S power source. The specimens were roughly polished with abrasive paper to remove surface impurities, and then cleaned with acetone. Flux combinations were prepared by using a precision weighing machine. In order to ensure uniform composition, thorough mixing was carried out. Just before welding, flux was mixed with ethanol in 1:1 ratio (paint like consistency) in a dish. This paste of activating flux was coated on the welding surface using a brush. Care had been taken to apply flux in a uniform layer and the coating width was made slightly larger than the weld bead width. After painting the flux, the ethanol was allowed to evaporate leaving flux on the surface before welding. The melt runs were made manually at a constant speed of 150 mm/minute.

2.4 MACROSTRUCTURAL AND MICROSTRUCTURAL STUDIES

After welding, small specimens of adequate size were cut from the weld bead in the transverse direction for macroscopic and microscopic analysis. The samples were ground and polished according to the standard metallographic practice with emery papers, alumina polisher and diamond paste polisher in the order. Polished specimens were etched with reagent of following composition,

Etchant- 30 g$FeCl_3$ +10 ml HCl + 3 ml HnO_3 + 20ml H_2O

Etchant time was taken as 15 to 20 seconds. The macrostructure of the weld beads were observed in a stereo zoom microscope and images were recorded using a digital image capturing facility. The profile of the beads was measured with the help of Image j software.

2.5 WELDING PARAMETERS

Table 2.5 Welding parameters

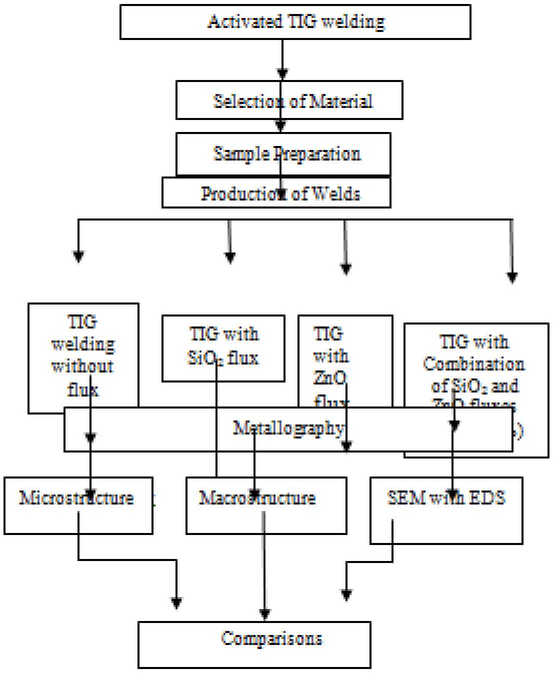
Welding speed	150 mm/min
Polarity	DCEN
Welding current	140 A
Shielding gas	99.9% Pure argon
Shielding gas flow rate	12 L/min
Electrode used	3.2mm diameter,2% thoriated tungsten
Arc length	2 mm
Electrode tip angle	55 degrees
Electrode tip	Taper

III. PROBLEM IDENTIFICATION

- Austenitic Steel require,
  - longer welding time
  - Higher filler metal consumption
  - Formation of residual stresses in conventional welded joints

  The risk of these burns in welded metal to form defects also increases. This can adversely impact the mechanical properties and durability of welded metal..
- Productivity is much lesser for conventional welding machines.

IV. METHODOLOGY



V. RESULTS

When SiO_2 activating flux was used for welding the specimen the depth of penetration was higher compared to the TIG welding without any flux.

The weld specimen welded using combination of SiO_2 and ZnO fluxes (50% each) showed a depth of penetration lower than that obtained using SiO_2 flux aloneZnO flux has a negative effect on the depth of penetration

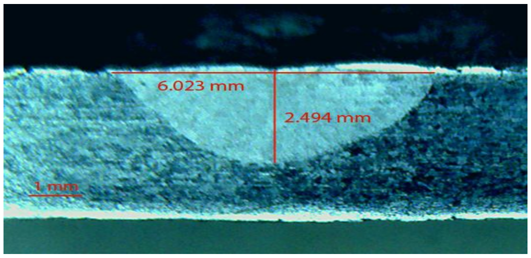


Fig.5.1macrostructure of welded specimen without using

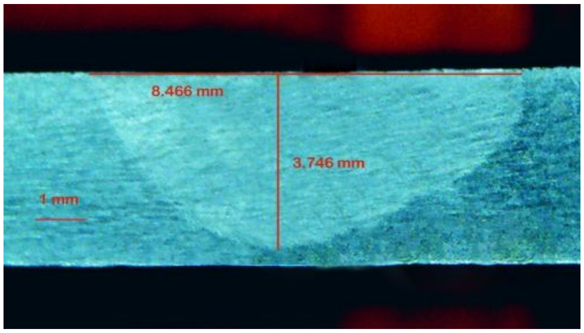


Fig.5.2macrostructure of welded specimen using SiO_2 flux

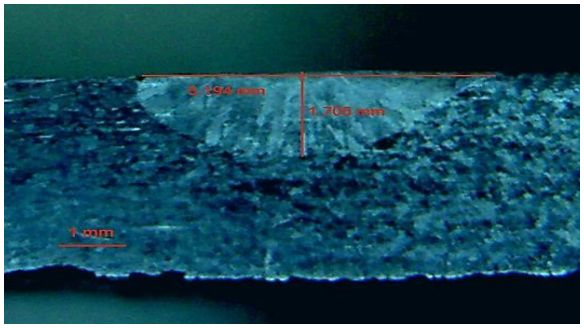


Fig5.3macrostructure of welded specimen using ZnO flux

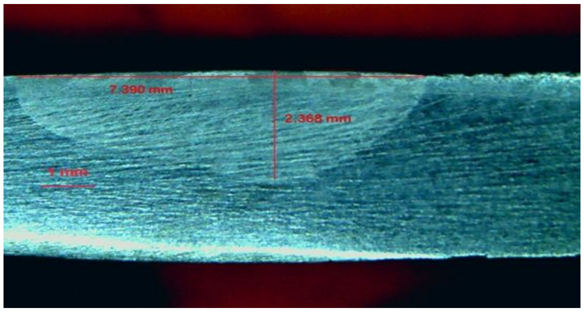


Fig 5.4.macrostructure of specimen using combination of SiO_2 and ZnO (50%-50%)

Specimen	Depth of penetration (mm)	Bead width (mm)
a) Without Flux	2.494	6.023
b) SiO_2	3.746	8.466
c) ZnO	1.706	5.194
d) SiO_2 + ZnO	2.368	7.390

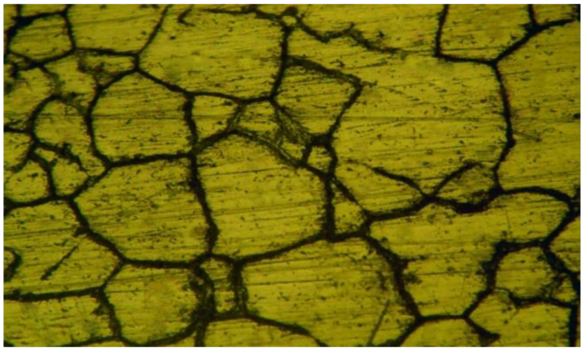


Fig 5.5 Microstructure of the base metal Incoloy 800H (magnification 200X)

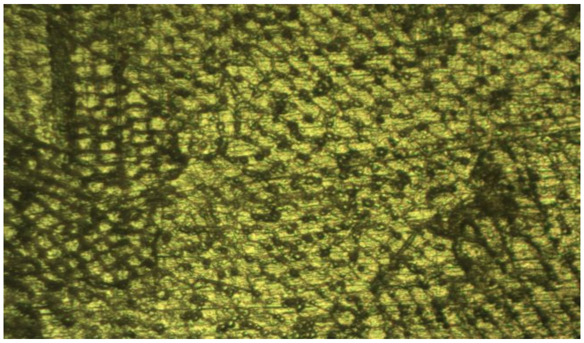


Fig 5.6 Microstructure of weld zone of the welded specimen without flux

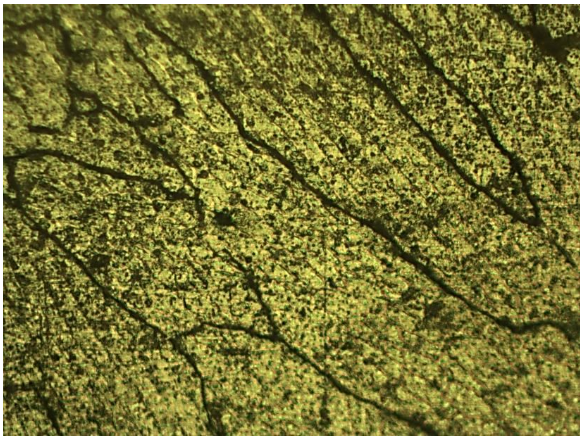


Fig 5.7 Microstructure of welded specimen using SiO_2 flux

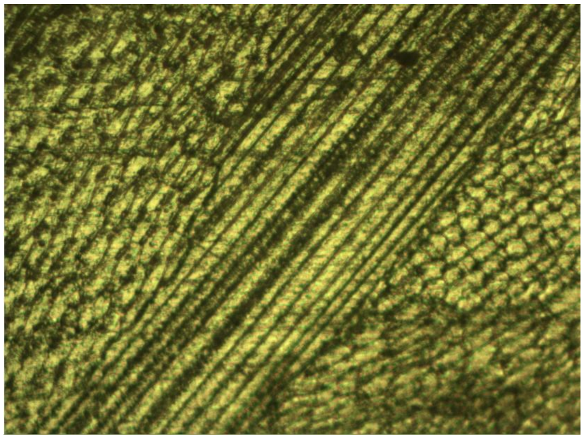


Fig 5.8 Microstructure of welded specimen using ZnO flux

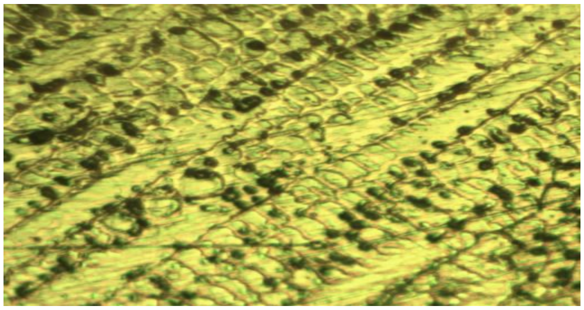


Fig 5.9 Weld zone microstructure of Weld specimen using SiO_2+ ZnO combination flux

VI. CONCLUSION

The Activated TIG welding process, which is proved to increase the depth of penetration in case of stainless steel, has been utilised for welding Incoloy 800H plates. Different type of fluxes like SiO_2 ,ZnO and Flux combination SiO2 and ZnO and the same parameters ,identified through trial and error methods,were used for all the experiments. Samples were prepared from the welded specimens using standard procedures and Metallurgical characterization of the weldments were analysed using SEM with EDS, Optical Macro and Microstructural Study. Macrostructure of the joints were studied under optical microscopy to identify the depth of penetration in each case.

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