B. TECH. PROJECT REPORT

On

Joining of Aluminium Alloy with Low Carbon Steel by using GMAW Process

BY

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DISCIPLINE OF MECHANICAL ENGINEERING
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Joining of Aluminium Alloy with Low Carbon Steel by using GMAW Process

A PROJECT REPORT

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

of
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INDIAN INSTITUTE OF TECHNOLOGY INDORE
December 2017

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Joining of Aluminium Alloy with Low Carbon Steel by using GMAW process"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr. Kazi Sabiruddin, Associate Professor, Department of Mechanical Engineering ,**IIT Indore is an authentic work.

Further, We declare that we have not submitted this work for the award of any other degree elsewhere.

Sarvjeet Bhambhu **Yash Dhabadgaonkar**

CERTIFICATE by BTP Guide

It is certified that the above statement made by the students is correct to the best of my knowledge.

Dr. Kazi Sabiruddin
Associate Professor
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Preface

This report on "**Joining of Aluminium Alloy with Low Carbon Steel by using GMAW process** " is prepared under the guidance of **Dr. Kazi Sabiruddin** .

In this report we have tried our best to present our research on Joining of Aluminium with Low carbon steel using GMAW process. We are hopeful that content presented in this report will be helpful to obtain good results in future on this research topic.

Sarvjeet Bhambhu , Yash Dhabadgaonkar
B.Tech. IV Year
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Acknowledgements

First, we would like to thank our supervisor **Dr. Kazi Sabiruddin** for his advices, kind support and valuable guidance for our project work.

We would also like to thank workshop welding operator **Mr. Rishiraj Chouhan** to train and help us in GMAW process. Our special thanks to PhD scholars **Mr. Vishal Sharma** and **Mr. Debajit Mishra** to help us in operating FE-SEM in SIC.

We also want to acknowledge SIC, IIT Indore to provide facility of FE-SEM and XRD.

Without their help and support, work on this project would not be this much.

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Abstract

Joining of Aluminium alloy and Low Carbon Steel often meats difficulties because of the large difference in their thermo-physical properties. Due to very less solid solubility of iron in aluminium, formation of brittle intermetallic phases known as intermetallic compounds (IMC) at high temperatures occurs which is the main reason for poor strength of Aluminium-Steel joint.

Gas Metal Arc Welding (GMAW) process was used to join 5mm thick sheets of Aluminium alloy and Low carbon steel in butt joint configuration using Al–5% Si, Al–12% Si filler wires at different welding parameters (i.e. Voltage and wire feed rate) . Coated (80-100 µm thick coating of Ni-Al) base material was also used to check the effect of Ni-Al coating.

The effects of using Si content filler wire and Ni-Al coating on base material on microstructure of weld zone were studied. Scanning electron microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDS) were used to study microstructure of different zones in a sample and to check the formation of intermetallic compounds (IMCs), X-ray diffraction (XRD) technique was used. Tensile test is also carried out to find strength of the weld joint by using Universal testing machine (UTM).

It was found that Si present in filler wire form compounds with some of the IMCs and Fe atoms which helps in lesser formation of IMCs, so the thickness of IMC layer could be controlled by using Si based filler wires. Thickness of IMC layer is lesser while using coated Al and normal steel base material as compare to normal Al and normal steel base material. This happens due to restriction of diffusion of Al from base material to Steel side which helps in reduction in formation of IMCs.

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Chapter 1

Introduction

Welded structures made of dissimilar metals like Aluminium alloy and Steel are getting important as it can be very helpful for weight reduction of vehicles. Considering the world wide crisis of available natural fuel it is important to save the fuel consumption. One such effective way to save fuel consumption is to reduce weight of the vehicles. Reducing weight is also a very effective way to improve a vehicle's efficiency and to reduce level of CO_2 gas emissions which is very harmful for environment. Materials such as aluminium alloy, magnesium alloy, plastics and carbon-fibre-reinforced plastic allow can be used to reduce the car bodyweight. Among different materials aluminium alloy seems to be the most promising one. Due to high cost of aluminium, it can't be used in every part of a vehicle , so joining of aluminium with steel at some parts can be very helpful. Therefore research on joining of Aluminium alloy with Steel has become essential. It is however very difficult to join them together due to the great differences in thermo-physical characteristics of these two metals, such as the melting temperature, thermal expansion and the poor metallurgical compatibility.

1.1 Welding is a process of joining similar or dissimilar materials with or without filler material, pressure but by the application of heat**.**

Weldability of a material refers to its ability to be welded. Many metals can be welded but some are easier to weld than others because it depends on melting point, thermal conductivity, thermal expansion, surface condition and micro structure of the base metals. These characteristics may be controlled or corrected by proper shielding atmosphere, fluxing material, filler material, welding procedure,etc.

Classification of welding process:

Welding Process is classified as shown in Figure 1.

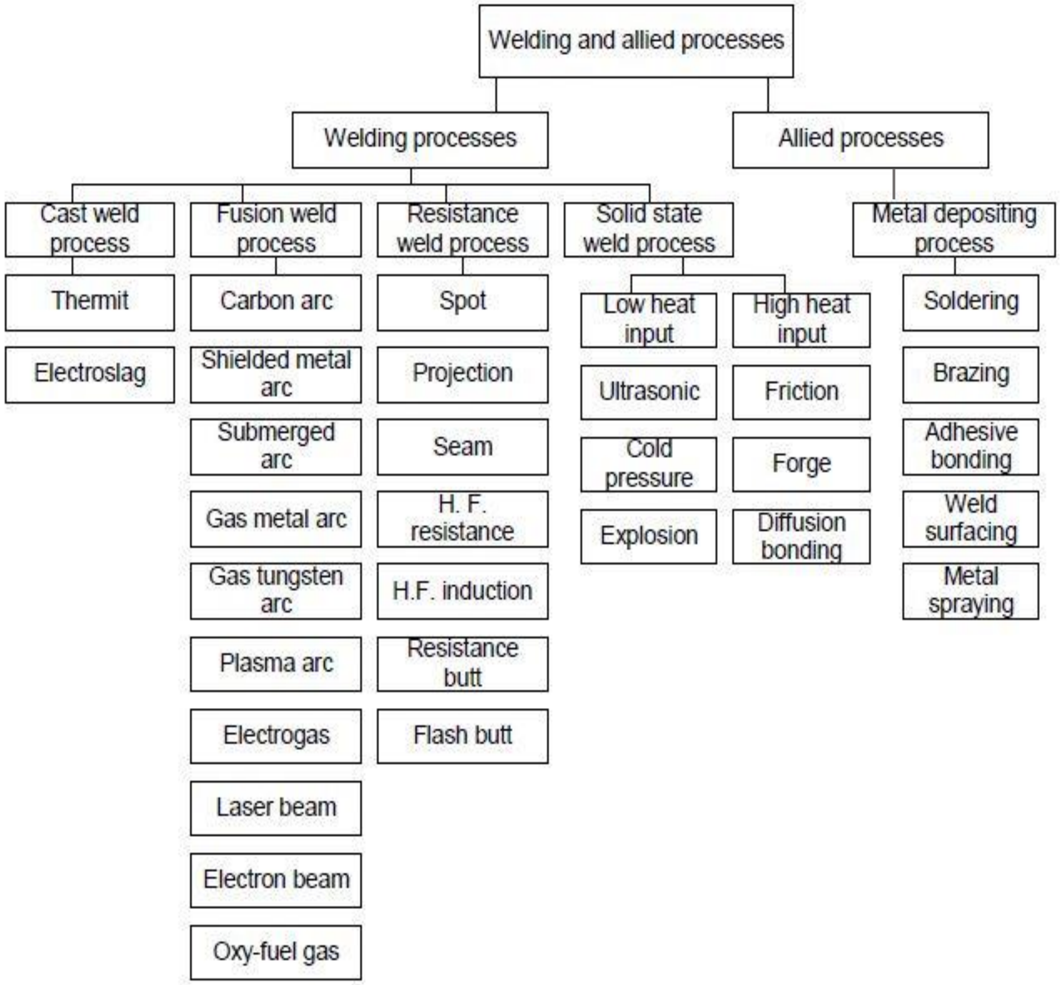


Fig: 1.1 Classifications of welding process [***Parmar R.S. (2007), Little R. (2001)***]

1.2 GMAW process :

Gas Metal Arc Welding (GMAW) also called as metal inert gas(MIG) or metal active gas(MAG), is an arc welding process in which base metals joins after melting due to heat formation from electric arc between filler wire electrode and workpiece. The process uses shielding from an externally supplied gases like Argon, CO_2, He to protect the molten weld pool. A constant voltage and DC power source is mostly used in this process. The GMAW process is flexible in its ability to provide sound welds for a very wide base material type and thickness range. The quality of weld joint in GMAW process depends on various parameters like voltage, current, wire feed rate, shielding gas, electrode diameter, etc.

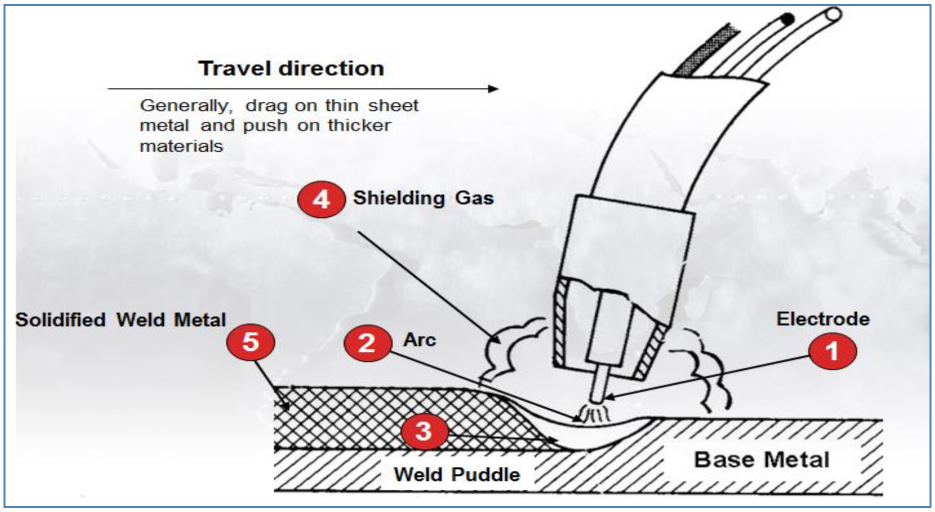


Fig. 1.2: Gas Metal Arc Welding (GMAW) process

1.3 Metal transfer modes in GMAW process :

Metal transfer refers to process of deposition of filler metal electrode on base metal to form the weld bead. Some common methods of metal transfer in GMAW process are short-circuit, globular, axial spray and pulsed spray transfer.

1.3.1 Short – Circuiting metal transfer:

In this mode transfer of a single molten droplet of filler metal occurs during the shorting phase of transfer cycle. The number of short-circuiting events can occur up to 200 times per second. The electromagnetic field, which surrounds the electrode, provides the force, which squeezes (more commonly known as pinch) the molten droplet from the end of the electrode. In this mode heat input is low as compare to other modes.

1.3.2 Globular metal transfer:

Globular transfer mode begins after the short-circuiting phase. It is considered as least desirable mode as it produce high heat input, poor weld surface, spatters, irregular and large molten droplets. It is useful in case of very high travel speed of torch.

1.3.3 Axial – Spray metal transfer:

It's the higher energy mode of metal transfer in which a stream of small molten droplets propelled axially across the arc. Excellent bead profiles and elimination of spatter are factors that make use of spray transfer desirable. Spray transfer mode welding is limited to use in the flat position for grooves horizontal positions for fillet welds.

1.3.4 Pulsed – Spray metal transfer:

It is a highly controlled variant of axial spray transfer, in which metal transfer occurs during the high energy peak level in the form of a single molten droplet. It provides excellent weld bead appearance.

1.4 Process parameters:

In GMAW process quality of weld joint depends on various parameters.

- **Arc voltage:** As the arc voltage increases, penetration increases, weld bead height decreases and bead width increases.
- **Wire feed rate:** How fast the electrode travels down the joint affects how much time the arc energy has to transfer into the base plate at any particular point along the joint. As travel speed decreases, the amount of time that the arc is over a particular point along the joint is greater and the resulting level of penetration increases and vice versa.
- **Electrode Extension:** The electrode extended from the end of the contact tip to the arc is properly known as electrode extension. it is also known as electrical stick out (ESO). Increasing electrode extension increases the resistance to the flow of current in the electrode and the current in the arc increases.
- **Electrode Diameter:** Generally more penetration is achieved with the smaller diameter electrode than with the larger diameter electrode at same current level.
- **Shield gas flow rate (f_s):** It is rate at which shield gas is supplied to protect the melt pool from atmospheric contamination. Lower values of the shield gas flow rate allow the atmospheric gases to react with the melt pool resulting in porous and oxidation of melt pool.

1.5 Advantages of GMAW process:

- The ability to join a wide range of material types and thicknesses
- All-position welding capability
- Excellent weld bead appearance
- Lower heat input when compared to other welding processes
- Easily adapted for robotic and automation welding application

1.6 Limitations of GMAW process:

- The use of argon based shielding gas for axial spray and pulsed spray transfer modes is more expensive than 100% carbon dioxide.
- The lower heat input characteristic of the short-circuiting mode of metal transfer restricts its use to thin materials.
- The higher heat input axial spray transfer generally restricts its use to thicker base materials.
- The higher heat input mode of axial spray is restricted to flat or horizontal welding positions.

1.7 Major Problems in Joining of Aluminium with Low Carbon Steel :

It is difficult to obtain joint between aluminium and low carbon steel with good strength due to following reasons:

- Very large amount of difference in melting temperature of both materials i.e. melting point of aluminium and steel is 660°C and 1510°C respectively.
- Thermal conductivity of aluminium i.e 250 W/m k is almost five times that of steel i.e. 50 W/m k.
- Poor metallurgical relation between aluminium and steel.
- Formation of brittle Intermetallic compounds between aluminium and steel.

Chapter 2 : Review of Past work and Research papers

2.1 Review of research papers on joining of Al with Steel

Following sections summarizes the review of research papers on work done using different welding processes for joining aluminium with steel.

Chen C.M. and Kovacevic R. (2004), joined 6-mm thickness 6061 Al to AISI 1018 steel by the Friction Stir Welding process. The main conclusion of their work was that the intermetallic phases $Al_{13}Fe_4$ and Al_5Fe_2 exist in the weld zone.

Zhang H.T. et al. (2007), made weld joint using 1mm thick 1060 aluminium and galvanized steel by a modified metal inert gas CMT welding brazing process in a lap joint configuration with 1.2 mm Al-Si filler wire.. They found that the thickness of IMC layer increases with increase in heat input.

Su Y. et al. (2007), joined 1mm thick sheets of 5052 aluminium alloy and galvanized mild steel in lap joint configuration by GMAW process with pure Al, Al–5% Si, Al–12% Si and Al–4.5% Mg filler wires having diameter of 1.2 mm. They found that the thickness of IMC layer varies along the cross-section of the joint and intermediate part of the IMC layer was thicker than the head and root parts which is due to cooling rate difference in the weld seam. Al-4.5%Mg filler wire is not suitable because of its high hot crack sensitivity, cracks generated at the root of joint made with Al–5% Mg filler, resulting in poor mechanical property.

Song J.L. et al. (2009), joined 3 mm thick 5A06 aluminium alloy and AISI 321 stainless steel plates by TIG welding–brazing with pure Al, Al-5%Si and Al-12%Si filler materials. Joint interface with pure aluminium consists of the θ-$FeAl_3$ phase in aluminium side and η- Fe_2Al_5 phase in steel side. They also found that with 5 wt.% of Si additions, the IMC layer has the optimum mechanical properties, and the max. tensile strength of the joint reaches 125.2 MPa.

Shao L. et al. (2015), joined 2 mm thick aluminium and galvanized mild steel by using GMAW process with filler wire ER5356 to investigate effect of joining parameters on microstructure of dissimilar metal joints between aluminium and galvanized steel. They found that joint between aluminium and galvanized steel contains a band of intermetallic Fe_2Al_5 compound in the steel side and the intermetallic $FeAl_3$ phase in aluminium side. After Metallographic studied it was found that the Fe_2Al_5 phase is in plate-like shape and $FeAl_3$ phase is in needle-like shape.

2.2 Literature Observations :

- Fe_xAl_y type intermetallic compounds form in both Al and Steel base metal side.
- Increasing Si content in filler material decreases the thickness of IMC layer.
- Increasing heat input increases the thickness of IMC layer.

2.3 Objectives of the Present Research Work :

- Joining of 1050 Aluminium with 1018 Low Carbon Steel in butt joint configuration by using GMAW process and Al-5%Si & Al-12%Si filler materials
- Selection of proper process parameters to obtain weld joint with high strength
- Microstructure study and XRD analysis of weld joint
- To study the effect of using coated (Ni-Al coating) base materials on Al-steel weld joint

Chapter 3 : Planning and Details of the Experiments

This chapter consists of details about the base and filler material selection, shielding gas, experimental setup and planning of experiments carried out for this work.

3.1 Base Material Selection :

In our work we used sheets 5mm thickness of 1050 Al and 1018 Steel ,as no work has been done on this grade of Al and steel using GMAW process. Table 3.1 and Table 3.2 present nominal composition of 1050 aluminium alloy and 1018 low carbon steel.

Table 3.1 : Nominal composition of 1050 Aluminium Alloy, (***in wt. %***)

Si	**Fe**	**Cu**	**Mn**	**Zn**	**Mg**	**Al**
0-0.25	0-0.40	0-0.05	0-0.05	0-0.07	0-0.05	Balance

Table: 3.2 Nominal composition of 1018 Low Carbon Steel, (***in wt. %***)

Si	**Mn**	**C**	**P**	**S**	**Fe**
0.020	0.60	0.16 - 0.20	0.010	0.020	Balance

3.2 Consumables Used :

3.2.1 Filler Material :

In this work Al-5%Si filler wire is used because many of the past work concluded that addition of Si content through filler wire helps in reducing the formation of intermetallic compounds. Table 3.3 and Table 3.4 represent nominal composition and physical properties of filler wire.

Table 3.3 : Nominal composition (wt%) of Al – 5%Si filler wire.

Si	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**	**Al**
4.5 – 5.0	0.80	0.30	0.050	0.050	0.10	0.20	Balance

Table 3.4 : Physical properties of Al – 5%Si filler wire.

Melting Temperature (ºC)	600 – 650 ºC
Filler wire Diameter (mm)	1.6 mm

3.2.2 Shielding Gas :

To protect the weld pool from surrounding gases, Argon is used as shielding gas in joining of aluminium with steel due to following reasons:

- Argon is a chemically inert gas.
- As Ionization energy of Argon (15.7eV) if low as compare to other gases, so argon facilitates better arc starting.
- High thermal conductivity levels result in more conduction of the thermal energy into the workpiece and Argon has low thermal conductivity as compare to helium and hydrogen.

3.3 Experimental Apparatus :

The experiments for this work were conducted using the **Fast MIG pulse 450 from KEMPPI, Finland.** GMAW machine is shown in Fig. 3.1 and Technical specifications of machine are shown by Table 3.5.

Table: 3.5 Technical specifiaction of KEMPPI FastMig 450.

Parameters	**Range**
Welding voltage	8-50 V
Welding current	10-450 A
Open circuit voltage	80 V
Wire speed	0.7-25 m/min
Power factor	0.9
Efficiency	88%

Fig. 3.1 : KEMPPI FastMig 450 machine

3.4 Experiment setup and arrangement :

Setup shown below in fig.3.2 is used for clamping arrangement of base materials to maintain proper position and root gap between aluminium and steel. In this setup both 1050 Aluminium allow sample and 1018 low carbon steel sample are placed according to the required root gap. Base plate is used to maintain flat surface for base materials for welding and clamping plates are used to avoid distortion.

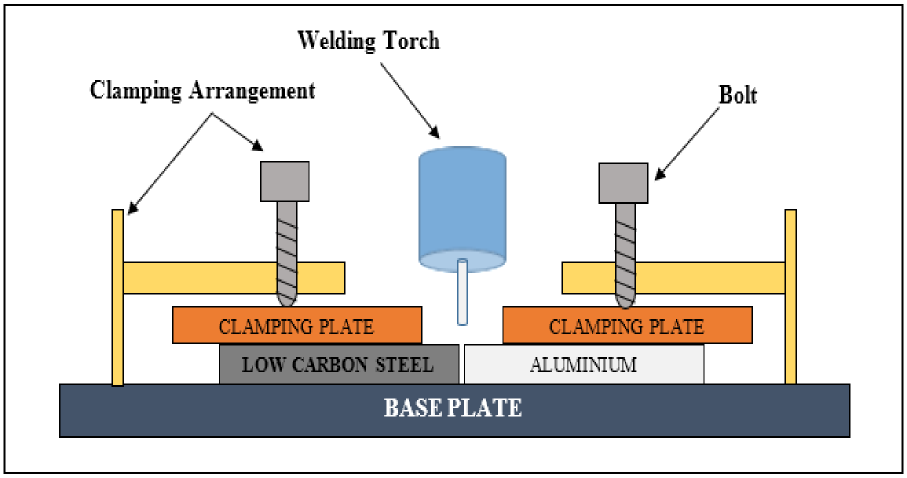


Fig. 3.2 : Clamping setup

3.5 Preliminary Experiments :

3.5.1 Parameter selection:

Various experiments of joining of Al with low carbon steel in butt joint configuration by varying two major GMAW process parameters (Voltage and Wire feed rate) were performed to find the suitable range of voltage and wire feed rate. Samples of aluminium and steel were prepared by using high speed cutter and bench top grinder. Table 3.6 shows the range of voltage and wire feed rate in which preliminary experiments were performed. This range of voltage and wire feed rate is used by considering optimum amount of heat input for both aluminium and steel base material.

Table 3.6 : Range of parameters used for preliminary experiments.

Parameter	Range
Voltage (V)	16 – 23 V
Wire feed rate (m/min)	2.0 – 4.0 m/min

3.5.2 Observations :

After performing experiments at selected voltage and wire feed rate combination from the above mentioned range, following observation is made:

- At low feed rate and low voltage combination, i.e. Wire feed rate < 3.0 m/min and Voltage < 17V, steel side is not melting properly due to low heat input.
- At high feed rate and high voltage combination i.e Wire feed rate > 3.8 m/min and Voltage > 19V, over heating and undercut welding defect is observed in Aluminium side due to very high heat input.
- At low feed rate and high voltage combination i.e. Wire feed rate < 3.0 m/min and Voltage > 20V, strength of joint observed very low as weld joint broke very easily by hands.
- At high voltage or high feed rate , lot of spatters were observed while welding the samples.
- A white oxidised layer was observed on weld bead which was due to very low rate of shielding gas input.

So suitable range of voltage and wire feed rate parameter to perform main experiments for tensile strength testing , microstructure study and XRD analysis is Voltage = 17 – 19 V and Wire feed rate = 3.0 – 3.8 m/min.

Table 3.7 shows the few examples of bad welding and good welding observed in preliminary experiments.

Table 3.7 : Few examples of bad welded samples and good welded samples.

Voltage (V)	Wire feed rate (m/min)	Al-steel weld joint using Al-5%Si filler wire	Remark
20.0	4.0		Bad weld due to Undercut defect
23.0	3.2		Bad weld due to Undercut defect
17.5	3.0		Good weld
18.0	3.2		Good weld
17.0	3.5		Good weld


3.6 Main Experiments :

By performing preliminary experiments it is found that suitable range of voltage and wire feed rate parameter is Voltage = 17 – 19 V and Wire feed rate = 3.0 – 3.8 m/min to avoid overmelting of aluminium due to high heat input and to provide appropriate amount of heat to steel side. During main experiments, welding of aluminium and steel samples were performed in selected range of parameters to test the tensile strength of samples welded at different voltage and wire feed rate. Microstructure study , XRD analysis and welding using coated sample was done on sample with best combination of voltage and wire feed rate.

3.6.1 Tensile strength testing :

1050 Aluminium and 1018 Steel samples were joined in butt joint configuration using GMAW process and Al – 5% Si filler wire at selected parameters shown in Table 3.7 .

Table 3.8 : Selected parameters for tensile strength testing

Voltage (V)	Wire feed rate (m/min)
17.5	3.0
	3.2
	3.4
18.0	3.0
	3.2
	3.4
18.5	3.0
	3.2
	3.4

Samples for tensile strength test was prepared according to ASTM E8 standard and was cut by wire EDM machine, like that the joint is in the middle of the tensile specimen. At each combination of voltage and wire feed rate 3 samples were tested to take the average value. The geometry of specimen used for tensile testing is shown in Fig. 3.3.

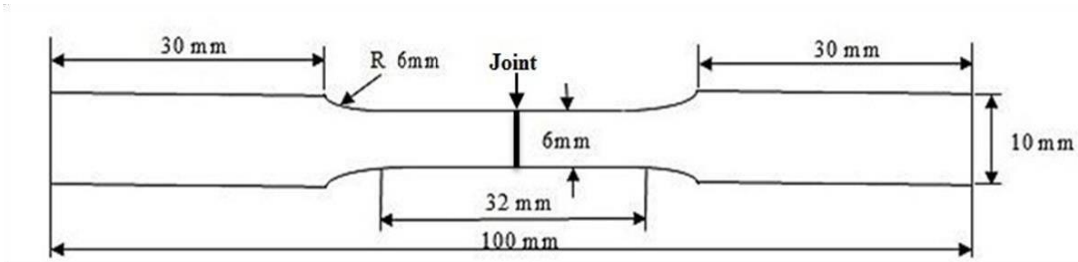


Fig: 3.3 Standard sample size for tensile strength testing

- Thickness: 5 mm
- Gauge length: 25.5 mm
- Radius of fillet: 6 mm
- Overall length: 100 mm
- Length of reduced section: 32 mm
- Length of grip section: 30 mm
- Width of grip section: 10 mm

Fig: 3.4 Tensile Testing Machine

Tensile strength was determined using a universal testing machine (***Tinius Olsen H50KL, USA***) as shown in Fig. 3.4.

3.6.2 XRD (X-Ray diffraction) analysis :

A weld sample prepared at optimal combination of voltage and feed rate was cut into 15mm*15mm (consisting equal portion of base steel, weld bead and base aluminium) using wire EDM machine and was flattened using surface grinder. It was then cleaned using acetone and Ultra sonic cleaner. XRD experiment was performed on this sample in SIC, IIT Indore.

3.6.3 Microstructure study :

Study of microstructure of optimal joint is important to understand the phase transformation across different zone (Base material, Fusion Zone, HAZ). Weld sample was prepared at optimal combination of voltage and wire feed rate and from this a sample (dimension 10 mm x 6 mm) was cut using Wire EDM process. Sectioned samples were mounted using cold setting resin to facilitate holding the samples during polishing. Cross section side of sample was then polished on the polishing machine (**Buehler 250**) using polishing papers of different grades, starting from 600, 800, 1000, 1500, 2000 and 2500 and with diamond paste of 1 μm using selvet cloth to get a mirror finish. Polished sample was then cleaned with acetone using Ultra sonic cleaner to remove any dirt or diamond paste sticked to the sample . The sample was then observed under the inverted optical microscope and FE-SEM (Field Emission Scanning Electron Microscope).

3.6.4 Welding of Coated samples:

Welding of coated aluminium with normal steel and normal aluminium with coated steel was performed at optimal combination of voltage and wire feed rate. **Ni-Al** coating of thickness 80 – 100 μm was applied on cross-section of base aluminium and base steel because Ni has good computability and good bonding with both aluminium and steel.

Coating method: Ni – Al coating was applied on base materials using D – gun thermal spray coating method from **SVX Pvt. Ltd. , Noida**. In Detonation gun, Oxygen and fuel(acetylene) is fed into the barrel with a charge of powder. Gas is then ignited by spark and powder is accelerated at super sonic velocity due to very high heat. High kinetic energy of hot powder particles on impact with base material results in formation of very strong coating.

Chapter 4 : Results and Discussion

This chapter consists of results and summary of observations in tensile strength testing at selected parameters, microstructure study, XRD analysis and welding of coated samples.

4.1 Tensile Strength Testing :

Tensile strength of samples welded at selected parameters give in Table 3.7 was evaluated using Universal Testing Machine (UTM). Table 4.1 shown below consists the value of Ultimate tensile strength (in MPa) of joint of samples welded at each selected parameter.

Table 4.1 : Value of Ultimate Tensile strength(in MPa) at selected parameter.

Filler Wire	Parameter		Tensile Strength (MPa)
	Voltage(V)	Wire feed rate(m/min)	
Al – 5%Si	17.5	3.0	3.13
		3.2	3.43
		3.4	11.5
	18.0	3.0	15.4
		3.2	17.1
		3.4	9.21
	18.5	3.0	2.10
		3.2	2.17
		3.4	1.23

Result:

- The best value of ultimate tensile strength was found for sample prepared at Voltage of 18.0V and Wire feed rate of 3.2 m/min , Ultimate tensile strength = 17.1 MPa.
- In each sample every time joint breaks from steel side which is due to higher quantity of brittle IMCs near steel side.

4.2 XRD analysis :

After performing XRD experiment on a welded sample prepared at best combination of voltage and wire feed rate i.e. Voltage = 18.0V and Wire feed rate = 3.2 m/min , XRD data was analysed using X-pert High Score software in which JCPDS and ICDD data files are stored. The analyses of graph obtained software is shown in Fig.4.1.

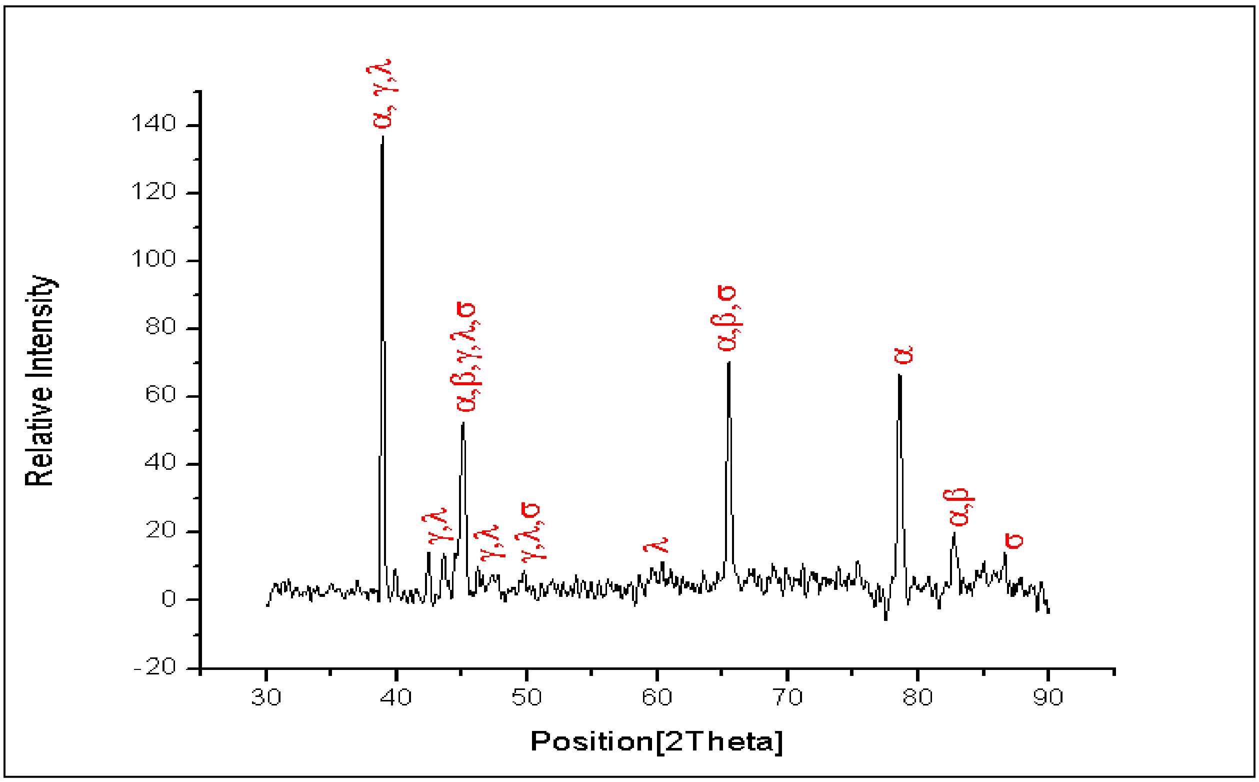


Fig.4.1 XRD analysis graph

Where α,β,γ,λ,σ denotes:

α – Al β – Fe σ - FeSi

γ – $FeAl_{3.2}$ λ – $Fe_2Al_3Si_3$

Results :

- Using JCPDS/ICDD data files the significant peaks of the XRD data are identified to be the phases of **Al , Fe, FeSi, $FeAl_{3.2}$ and $Fe_2Al_3Si_3$**.

4.3 Mircrostructure study :

Microstructure study has been conducted on the weld sample prepared at voltage of 18V and wire feed rate of 3.2 m/min by using Al – 5% Si wire.

Fig.4.2 - image captured by Optical zoom microscope, shows the cross section view of sample prepared for microstructure study. Fig.4.2 (a) and fig.4.2 (b) – images captured by inverted microscope shows the boundary between Al & weld pool and Steel & weld pool.

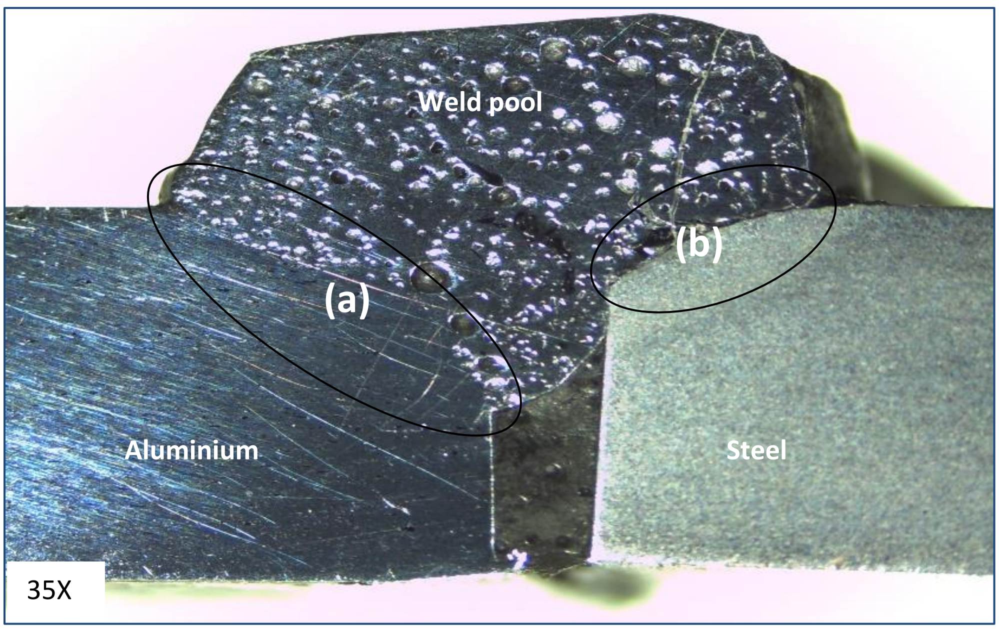
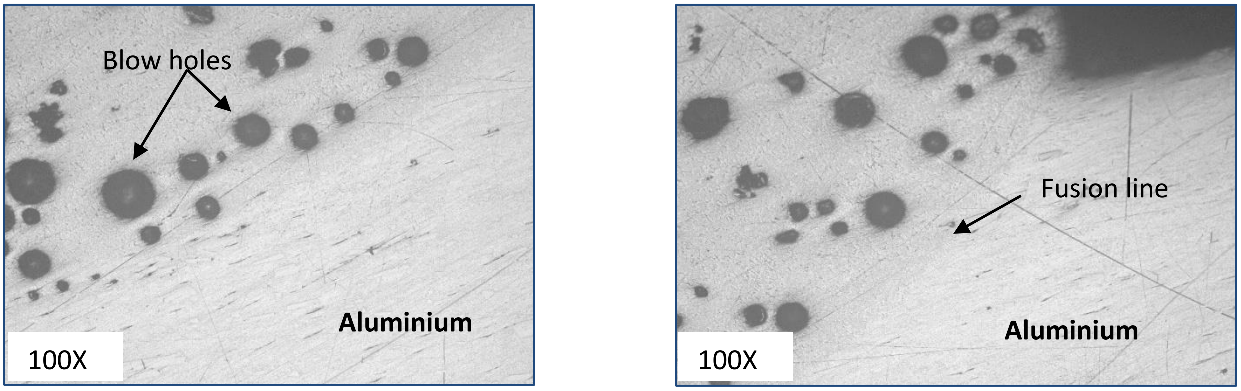
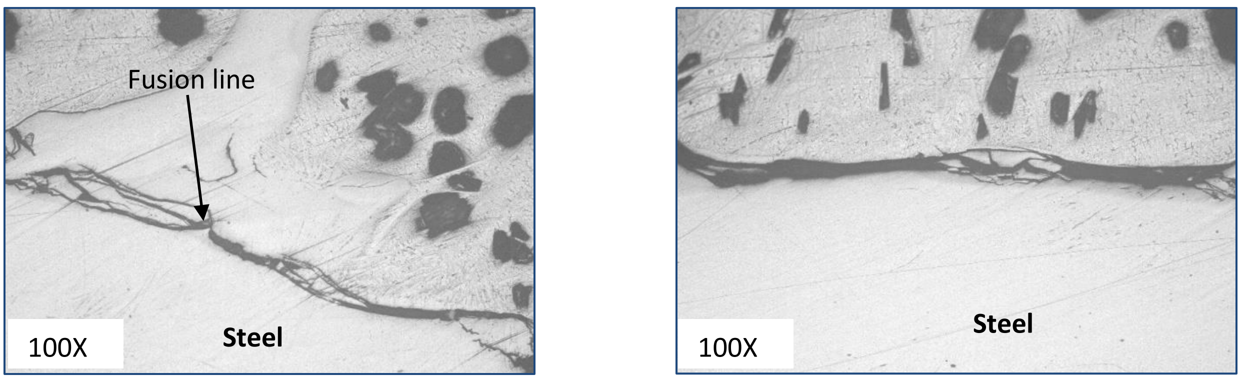


Fig. 4.2 Cross sectional view of sample



(1) (2)

Fig. 4.2(a) : Aluminium and weld pool interface



(1) (2)

Fig. 4.2(b) : Steel and weld pool interface

fig. 4.3 and fig. 4.4 (image captured by FE-SEM) shows the needle shape structures formed in weld pool.

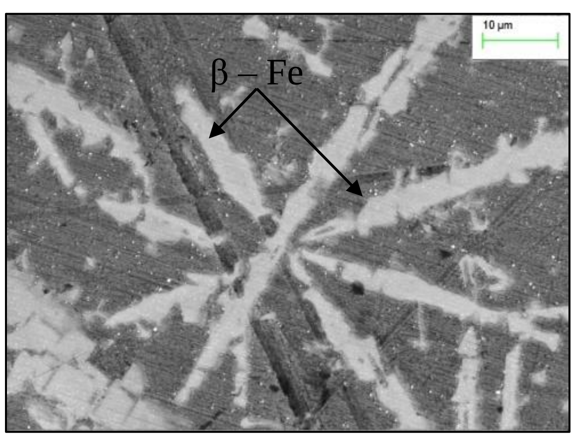


Fig. 4.3(a) : Needle shape structure of β – Iron

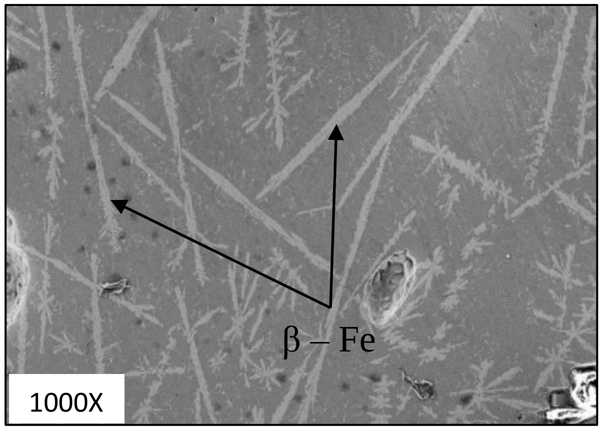


Fig. 4.3(b) : Needle shape structure of β – Iron

EDS (Energy Dispersive X-Ray Spectrum) analysis on needle shaped structures shown in fig.4.3 (a) & (b) results these needle as β phase of iron.

Fig. 4.4 (image captured by FE-SEM) shown below consists enlarged view of cracks formed in interface between steel and weld pool. EDS analysis of these cracks concluded it as layer of brittle intermetallic compound $FeAl_{3.2}$.

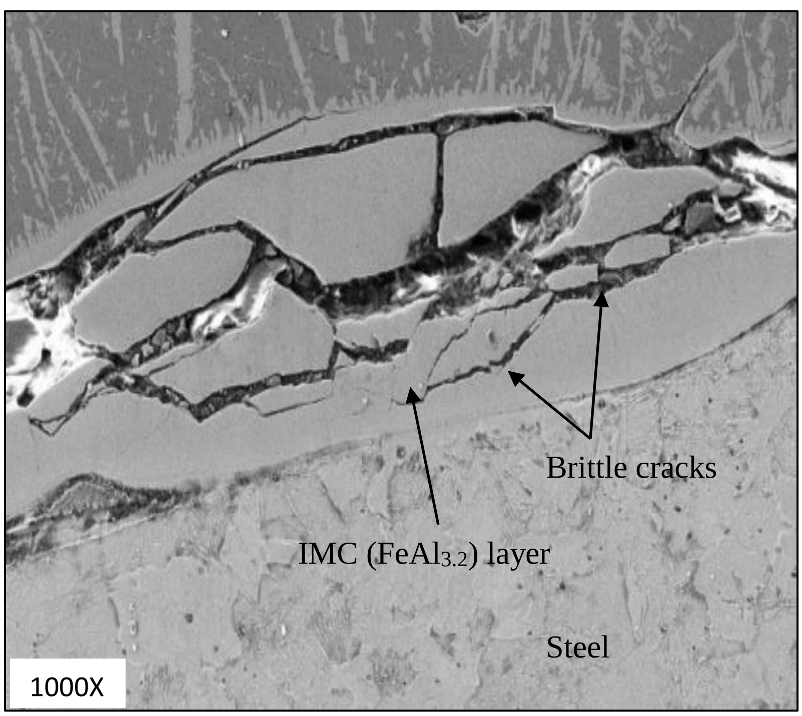


Fig. 4.4: IMC layer at steel-weld interface

Results:

- Microstructure study shows a fine interface between aluminium & weld pool and improper fusion between steel & weld pool.
- Lot of cracks are observed at steel – weld pool interface which is due to the formation of brittle IMCs at steel side.
- Due to very high temperature in weld pool, α phase of Iron transforms into β phase of iron that are of needle like shape.

4.4 Welding of Ni – Al coated sample :

Coated Al with normal steel and normal Al with coated steel were joined by GMAW at voltage = 18.0V and wire feed rate = 3.2 m/min using Al-5%Si filler wire to see the effect of application of Ni – Al coating on base material.

Joining of normal aluminium with coated steel was not successful as Ni-Al coating on steel restricts enough input of heat for melting of steel while joining of coated aluminium with normal steel was successful with good strength. Fig. 4.5 shows the interface between coated aluminium & weld pool and fig. 4.6 : (a) , (b) , (c) shows the interface between normal steel & weld pool. If we compare thickness of IMC layer in fig.4.2(b) and fig.4.6(a) , we can see thickness of IMC layer in sample with coated aluminium is lower than with normal aluminium. The reason for decrease in IMC layer with application of Ni – Al coating on aluminium could be that Ni – Al coating restricts the diffusion of aluminium from base material to steel side which reduces the formation of IMCs.

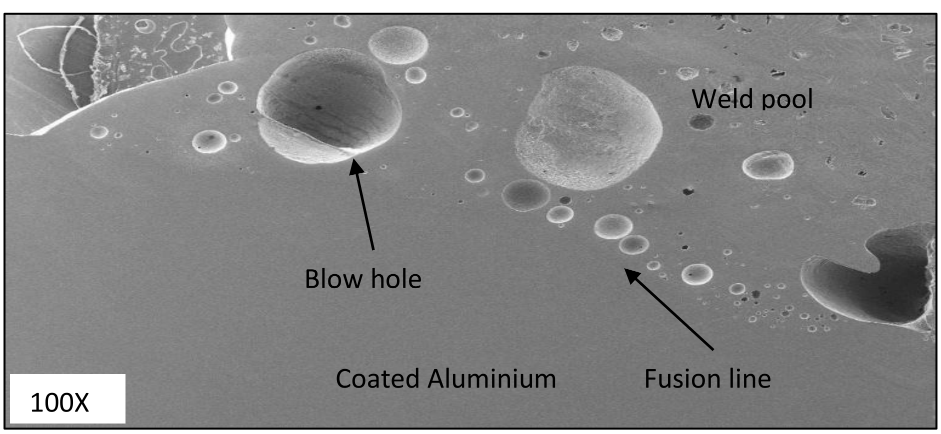


Fig. 4.5: Interface between coated aluminium and weld pool

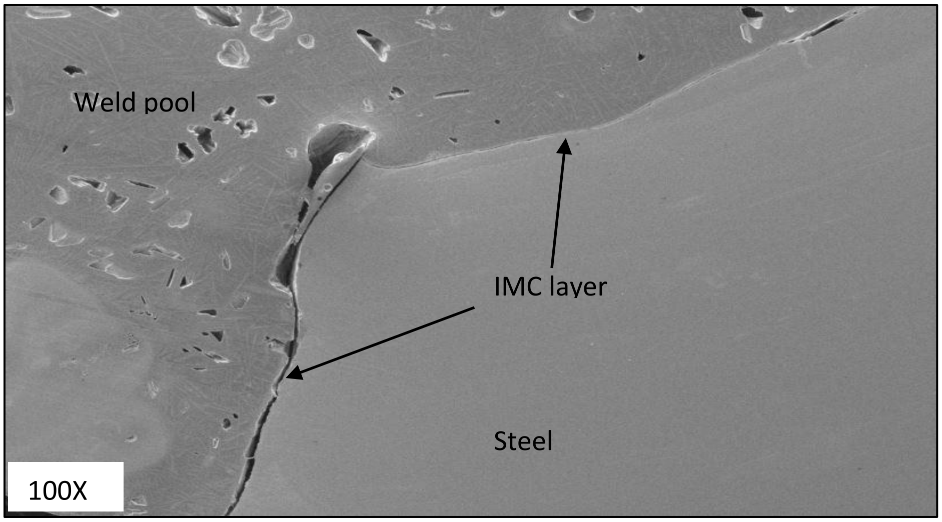


Fig. 4.6 (a) : Steel – weld pool interface

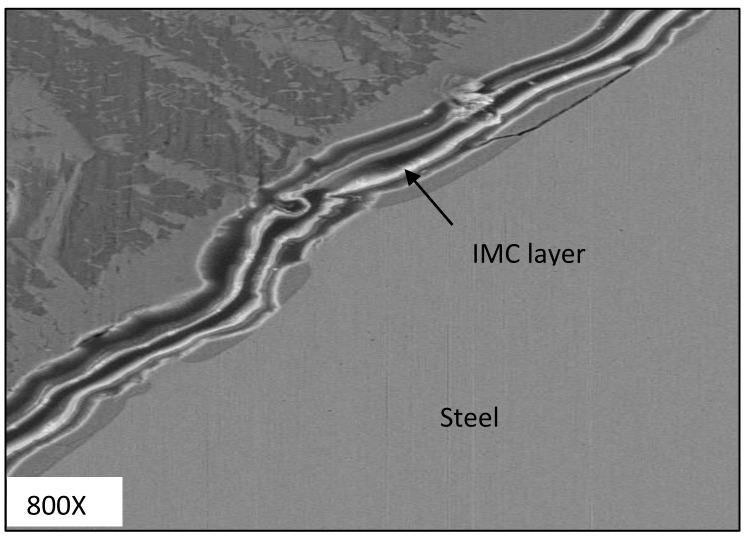


Fig. 4.6 (b)

Chapter 5 : Conclusions and Scope for Future Work

5.1 Conclusions :

The major conclusions of our project work on joining of 1050 Al and 1018 Steel using GMAW process and Al – 5% Si filler wire which consists tensile strength testing , XRD analysis, microstructure study and effect of application of Ni – Al coating on base materials are as follows:

- Optimal range of Voltage and Wire feed rate is necessary to avoid overheating defects in aluminium and to provide good amount of heat to steel for proper fusion.

- Maximum tensile strength of joint observed was around 17.1 MPa , at voltage of 18.0 V and wire feed rate of 3.2 m/min.

- In tensile testing, all the joints fail from steel side, which indicates weaker side of the joint to be the steel-weld pool interface.

- From XRD analysis, the phase of IMC layer is found to be $FeAl_{3.2}$.

- In microstructure study, needle like structure of β phase of Iron is found in the weld pool.

- Using of Ni – Al coated aluminium and steel as base materials, thickness of IMC layer can be decreased. However, joint with coated Al-Steel is successfully prepared as the other combination is not been successful.

- To obtain high strength Al-steel weld joint by GMAW process along with proper parametric combination, proper filler wire with higher Si content and coated base material may be used.

5.2 Scope for the Future Work :

- To obtain desired result more experiments can be carried out with more metallographic study. Combination of optimum process variables, filler wire and proper coating application to base materials may result in a very strong Al-steel weld joint by GMAW. Other than GMAW different types of joining technologies may be tried to compare the effects on the joint strength by different technologies.

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