Chapter 2

Literature Review

Chapter 2 reviews the various literatures of GMAW pertaining to the present investigation. A brief survey is carried out on the welding of AA6061 and AA6063 aluminum alloys. Based on the available literature effect of process parameters on bead profile characteristics have been reviewed. Further, literatures related to optimization and prediction techniques of bead profile characteristics have been reviewed and presented. Literatures related to the discussion of the scope and objectives of the present investigation on GMAW joints have been discussed.

2.1 Literature Review

The present research aims to investigate the effects of Gas Metal Arc Welding (GMAW) on the mechanical properties of different grades of aluminum alloys. GMAW is the most common method of joining aluminum alloys used in various industrial processes. It replaces the Tungsten Inert Gas (TIG) method of providing equally high quality of joints with a much higher performance. Aluminum alloys under consideration for this experiment will be from 6XXX series, consisting of silicon and magnesium as main alloying elements. Weld joints will be produced with the help of a Gas Metal Arc Welding (GMAW) process. The Hardness, Tensile strength, yield stresses and elongation will be the mechanical properties to be obtained. As aluminum alloys show large micro structural changes after welding it is necessary to know about the effect of welding parameters on the mechanical properties of weldments as too high welding current and too high welding speed will result in high heat input and weakening of weld profile so a balance is need to be struck between welding parameters and mechanical properties. Scanning Electron Microscopy (SEM) technique will be used to analyze micro structural changes.

C. L. Lin et al. (2004), Used the Taguchi Method and Grey Relational Analysis to Optimize Turning Operations with Multiple Performance Characteristics. Cutting experiments were carried out on an engine lathe using a P20 tungsten carbide for the machining of S45C steel bars. Each of three factors cutting speed, feed rate and depth of cut were taken in three levels. Interaction of input factors namely cutting speed (135m/min, 210m/min, 285m/min), feed rate(0.08mm/rev, 0.2mm/rev, 0.32 mm/rev) and depth of cut (0.6mm, 1.1mm, 1.6mm) was done with multiple performance characteristics which were tool life, cutting force and surface roughness using Taguchi and Grey relational analysis. L9 orthogonal array was prepared for factors at three levels each. Grey relational grade was obtained from multiple performance characteristic which predicted the optimized set of process parameter. Cutting speed 135m/min, feed rate 0.8mm/rev and depth of cut 0.6mm was the optimized set of parameters. Later ANOVA was also applied to analyze the contribution of each factors at three levels on multiple performance characteristics.

N. Ghosh et al. (2016), optimized the process parameters of MIG welding on 316L austenitic stainless steel on basis of the yield strength, ultimate tensile strength and percentage elongation. They varied three process parameters at three levels which are welding current (100 A, 112 A, 124 A), gas flow rate (10 l/min, 15 l/min, 20 l/min) and nozzle to plate distance (9 mm, 12 mm, 15 mm). They used L9 Taguchi orthogonal array design of experiment, so they performed 9 experiments. They analyzed the yield strength, ultimate tensile strength and percentage elongation and on the basis of these properties, they optimized the process parameters. They also applied the ANOVA which tells percentage contribution of process parameters on mechanical properties and their optimized welding current was 100 A, gas flow rate was 20 l/min gas and nozzle to plate distance was15 mm.

G. Nabendu et al. (2017), optimized the process parameters of gas metal arc welding on AISI 409 ferritic stainless steel on basis of the ultimate tensile strength and percentage elongation. They varied three process parameters at three levels which are welding current (100 A, 112 A, 124 A), gas flow rate (10 l/min, 15 l/min, 20 l/min) and nozzle to plate distance (9 mm, 12 mm, 15 mm). They used L9 Taguchi orthogonal array design of experiment, so they conducted 9 experiments. They analyzed the ultimate tensile strength and percentage elongation and on the basis of these properties, they optimized the process parameters. They also applied the ANOVA which tells percentage contribution of process parameters on mechanical properties. They also performed the visual inspection. On the basis of grey relational grade value, the optimized welding current was 124 A, gas flow rate was 10 l/min and nozzle to plate distance was 9 mm.

M. V. Patil et al. (2017), optimized the parameters of gas tungsten arc welding on SS 304 austenitic stainless steel on the basis of the tensile strength and hardness. They varied the root gap (1.6 mm, 3.2 mm), filler diameter (1.6 mm, 2.4 mm), welding current (90 A, 140 A), gas flow rate (8 l/min, 12 l/min), plate thickness (5 mm, 10 mm) and electrode diameter (1.6 mm, 3.2 mm). They performed 22 experiments. On the basis of the design of experiment maximum tensile strength was 618.7226 MPa and maximum hardness was 87.9256 HRB at root gap was 2.83 mm, filler rod diameter was 1.76 mm, welding current was 140 A, plate thickness was 5.48 mm, electrode diameter was 3.2 mm and the gas flow rate was 11.92 l/min.

K. Pal et al. (2011), optimized the weld deposition efficiency in pulsed MIG welding. They varied six process parameters at five levels which are torch angle in degree (-35, -15, 0, 15, 35), welding speed in mm/s (4.6, 5.8, 7.7, 8.8, 9.9), wire feed rate in m/min (6.3, 7.3, 8, 8.7, 9.7), peak voltage in volt (27, 30.4, 33, 35.6, 39), pulse frequency in Hz (80, 105, 124, 144, 172) and pulse on time in ms (2.6, 3.4, 4, 4.6, 5.4). They performed 53 experiments. On the basis of coded design matrix process parameters are optimized.

K. Srinivasan et al. (2011), analyzed the effect of heat on fume generation and joint properties of gas metal arc welding on austenitic stainless steel AISI 316. They examined mechanical properties such as yield strength, ultimate tensile strength, percentage elongation, join efficiency, impact toughness and microhardness of weld zone and heat affected zone at different heat input which are 0.96 kJ/mm, 1.03 kJ/mm, 1.15 kJ/mm, 1.26 kJ/mm and 1.32 kJ/mm. They also analyzed the microstructure of heat affected zone at these heat input levels. They concluded that The fume generation rate and fume percentage show a directly proportional relationship with wire feed rate of gas metal arc welding process and superior mechanical properties such as yield strength, tensile strength, percentage of elongation, impact toughness, and microhardness are exhibited by the joints fabricated at 1.15 kJ/mm heat input and welding fume produced at moderate level.

S. V. Sapakal et al. (2012), optimized the parameters of MIG welding on MS C20 on the basis of the depth of penetration. They varied the three process parameters at three levels which are welding current (60 A, 90 A, 120 A), welding voltage (15 volt, 22.5 volt, 30 volt) and welding speed (20 cm/min, 40 cm/min, 60 cm/min). They used L9 Taguchi orthogonal array design of experiment, so they conducted 9 experiments. They analyzed the depth of penetration and on the basis of this dimension, they optimized the process parameters. They also applied the ANOVA which tells percentage contribution of process parameters on the depth of penetration.

V. Chauhan et al. (2015), optimized the process parameters of MIG welding for welding of stainless steel SS 304 and low carbon steel. They varied the three process parameters at three levels which are welding current (80 A, 100 A, 120 A), welding voltage (16 volt, 19 volt, 22 volt), welding speed (30 cm/min, 40 cm/min, 50 cm/min) and other variables was constant. They analyzed the ultimate tensile strength and on the basis of this property, they optimized the process parameters. They also applied the ANOVA which tells how much significant the process and percentage contribution of process parameters on ultimate tensile strength. The effect of welding current on the ultimate tensile strength is more, followed by welding speed and welding voltage.

D. M. Arya et al. (2013), optimized the process parameters of MIG welding on alloy steel. They varied five process parameters at four levels which are welding current (80 A, 90 A, 100 A, 110 A), gas flow rate (10 l/min, 13 l/min, 14 l/min, 15 l/min), wire diameter (0.8 mm, 0.9 mm, 1 mm, 1.2 mm), arc voltage (18 volt, 18.5 volt, 19 volt, 19.5 volt) and welding speed (45 cm/min, 48 cm/min, 51 cm/min, 55 cm/min). They used L16 Taguchi orthogonal array design of experiment, so they performed 16 experiments. They analyzed the tensile strength, bead width, bead height, depth of penetration and heat affected zone. On the basis of these properties and dimensions they optimized the process parameters. They also applied the ANOVA which tells how much significant the process and percentage contribution of process parameters on the tensile strength, bead width, bead height, penetration and HAZ.

R. Kumar et al. (2015), optimized the process parameters of gas metal arc welding for welding of austenitic stainless steel AISI 304 and low carbon steel. They varied the three process parameters at three levels which are welding current (100 A, 150 A, 200 A), welding voltage (23 volt, 25 volt, 30 volt), gas flow rate (20 l/min, 23 l/min, 25 l/min) and other variables are constant. They used L9 Taguchi orthogonal array design of experiment, so they conducted 9 experiments. They analyzed the hardness and on the basis of this property, they optimized the process parameters.

Jing Zhang et al. (2017), examines the effect of initial microstructure on the deformation behaviour of A2219 alloy. They found that as-solutionized microstructure showed the highest deformation resistance and as-aged microstructure shows lowest under the same deformation conditions

Yi Han et al. (2014), investigate microstructure and mechanical properties of Al–Mg–Si–Cu alloy with high manganese content. The yield strength of the examined alloys with high manganese content was found to be about 52–65% higher than that of commercial 6061 alloy

Wu Dafang et al. (2017), investigate weldability of Alloy (Al–Cu–Mg) alloy. They showed that aluminium alloy strengthened by heat treatment since Because of its higher strength, finer weldability of alloy.

R. Kumar et al. (2014) analyzed the effect of welding current, arc voltage and root gap on the mechanical properties during the MIG of A5052 grade by microstructure, hardness and tensile strength of welded specimen. Root gap has greatest effect on tensile strength followed by welding current and arc voltage. Arc voltage has greatest effect on hardness followed by root gap and current.

Haragopal et al. (2011) studied the Taguchi method of design process parameters to optimize mechanical properties of weld specimen for aluminium alloy Al-65032, which is used for construction of aerospace wings. Main process parameters considered are gas pressure, current, groove angle and pre-heat.

A. Ibrahim et al. (2012) suggested that GMAW process is leading in the development of arc welding process which has higher productivity and good in quality. Effects of parameters on weld penetration, microstructure and hardness on A2021 was studied on 6mm thickness base metal by using MIG welding

Fuheng Nie et al. (2016) studied the microstructure and mechanical properties of pulse metal inert-gas (P-MIG) welded dissimilar joints between 4 mm thick wrought 6061-T6 and cast A356-T6 aluminum alloy plates. In testing the tensile strength of the joints reached 235 MPa, which is 83% of that of A6061 alloy, and then decreased with the increase of travel speed while keeping other welding parameters constant.

Indira Rani et al. (2012) investigated the mechanical properties of the weldments of AA6351 during the GTAW/TIG welding without pulsed and with pulsed current at different frequencies. Experiment carried out on 6mm thick plate and welding was performed on current 70-74amp, arc travel speed 700-760 mm/min, and pulse frequency

3 and 7 Hz. From the experimental results it was concluded that the tensile strength and YS of the weldments is closer to base metal. Defect-free welds were produced on 0.25 inch thick mild steel (AISI 1018) using tools made up of molybdenum and tungsten based alloys. Same types of work done to add two types of plain carbon steel.

Yao Liu et al. (2012) investigated the mechanical properties and microstructure of aluminium 5083 weldment by TIG and MIG welding. Weldment produced by both is mechanically softer than the base metal. It is revealed that AA5083 weldment processed by TIG is mechanically more reliable than those by MIG welding.

P Kumar et al. (2011) demonstrated the increase of mechanical properties and effective optimization of pulsed GTAW process parameters on aluminum alloy A6061. Welding was done with input parameters as base current (80-110) Amp, pulse frequency (50-125) HZ and pulse duty cycle 30-75%. Taguchi method was employed to calculate experimental structure and to study process optimization parameters on mechanical properties of the joints. Result of the experiment showed that pulse current, base current, pulse duty cycle and frequency plays significant role on microstructure and mechanical properties of weld, but pulse current plays the greater role i.e. 52.55 %. In this investigation, pulse current of 120A, background current of 80A, pulse frequency of 50Hz and pulse duty cycle of 75% resulted in the maximum values of mechanical properties.

Lakshman Singh et al. (2013) Performed TIG welding process to analyze the data and evaluate the influence of input parameters on tensile strength of 5083 Al-alloy specimens with dimensions of 100mm long x 15mm wide x 5mm thick. Welding current (I), gas flow rate (G) and welding speed (S) are the input parameters which effect tensile strength of 5083 Al-alloy welded joints. As welding speed increased, tensile strength increases first till optimum value and after that both decreases by increasing welding speed further. Results of the study show that maximum tensile strength of 129 MPa of weld joint are obtained at welding current of 240 Amps, gas flow rate of 7 lit/min and welding speed of 98 mm/min. These values are the optimum values of input parameters

Hui. Li. et al. (2017) perform TIG welding techniques and studied the effect on microstructure, properties and porosity of the welded joint of 2219 aluminum alloy. They optimized the process parameter on the basis of heat input to reduce the porosity and analyze its effect on microstructural feature. Although a lot of work has been done on friction stir welding of aluminum and its alloys, work on steels has been very limited.

W Xu et al. (2004), performed an experiment to investigate quasi-static and dynamic material behaviour for the parent material, weld metal and HAZ of MIG welds. The parent material used was 6005A aluminium alloy in the solution treated and artificially aged condition. The filler wires selected were 4043(aluminium-5%silicon) and 5356(aluminium-5%magnesium). The testing programme included hardness surveys, tensile, Charpy impact and fracture resistance tests. These tests were carried out in dynamic servo-hydraulic testing machines and in a 10 m drop-weight tower. The quasi-static crush tests were carried out using a servo-hydraulic testing machine with a maximum load capacity of 1,800kN. The specimen was subjected to an axial compressive load applied under a slow displacement rate of 6mm/min. The dropweight impact tests were performed using a dropweight testing machine. A total mass of 102kg can be dropped from a maximum height of 9.8m. The conclusions drawn from the experimental work was that the aluminium-silicon weld metal in the extruded plates was poorer than the weld metal made using aluminium-magnesium filler metal in terms of strength, ductility and fracture resistance. Moreover under quasi-static loading, the aluminium-magnesium weld metal in the extruded plate outperformed the parent material in terms of the ultimate strength, ductility and fracture toughness, but its 0.2% proof strength was lower than the parent material. In terms of the ability to sustain uniform plastic deformation, the HAZ was the worst zone, as indicated by the smallest amount of elongation at the maximum load. This, coupled with the lower strength than the parent material, will cause strain localization in the HAZ. [4]

Krzysztof Dudzik (2011) (performed an experiment on 5083, 5059 and 7020 Al alloy pieces joined by MIG welding to know about their mechanical properties. The study was aluminum alloy EN AW-7020 T6. For a comparative study was carried out using aluminum alloy EN AW-5083 and AW-5059 ALUSTAR (AlMg5Mn0, 7). For the 7020 alloy welding wire used alloy AlMg5 (5356)-Nertalic AG5 SAF. For the 5083 alloy welding wire used 5383 alloy and 5059 alloy welding wire alloy 5183. Wire electrodes immediately prior to welding was etched. Argon shielding gas was used with a purity of 99.99%.In order to determine the mechanical properties were carried out static tensile test. The study was performed at ambient temperature, i.e. 20°C ± 2 Tensile testing was carried out on samples with flat-type testing machine EU-40 on the strength of 200 kN ± 1 During the study determined parameters such as ultimate tensile strength UTS, yield stress YS, and elongation EL. The conclusions drawn from the study included that using a static tensile test on flat specimens of alloys 7020, 5083 and 5059 showed that the alloy 7020 is characterized by the highest strength properties. Both the alloy 7020 and 5059 had higher strength properties but low ductility of welded joints can be a big problem.[6]

H. Guo, et al. (2009) (performed an experiment to know about formation of the crater formed in a GMAW of aluminum alloy 6005-T4. Transient weld pool shape and the distributions of temperature and velocity were calculated by a three-dimensional numerical model. The final weld bead shape and dimensions were obtained. Corresponding experiments were conducted and in good agreement with modeling predictions. Metallurgical characterizations were also performed on the experimental samples. Weld pool and weld bead shapes, temperature field, and velocity distribution were obtained for the terminating stage of the welding process. Experiments were conducted on the formation of the stopping end of the weld. The conclusions drawn from the experiments were as: (a) It was found that the crater is formed because of the depression at the weld pool center as a result of droplet impingement effect and arc pressure. (b) The weld pool solidifies very quickly once the weld process stops. Due to the rapid heat dissipation, there is no time for the molten metal to flow back towards the weld pool center and close up the crater. Thus, a crater is formed at the end of the weld bead. [7]

P.M.G.P. Moreira et al. (2009) (experimented on two age hardenable Al alloys weldments to know about their fatigue beaviour using MIG and FSW techniques. In the MIG welding process, the arc and the weld are protected from atmospheric contamination by a gas shield, and an electric potential is established between the electrode and the work piece causing a current flow, which generates thermal energy in the partially ionized inert gas. A study of the fatigue behaviour of Metal Arc (MIG) butt welds of two 3 mm thickness age hard enable aluminium, 6082-T6 and 6061-T6 alloys, was carried out. Tensile tests and micro hardness measurements of weld joints and base materials were performed in order to determine the influence of each welding process in the mechanical properties. Main conclusion drawn from the experiment was Yield and rupture stress of MIG welded specimens are lower than for base material. The MIG welded 6061-T6 specimens presented higher fatigue lives than the MIG 6082-T6 specimens.[8]

R. Kumar et al. (2014), performed an experiment to know about the micro-structure, weld bead geometry, dilution rate and mechanical properties of Welding results with this process showed good process stability in the welding of thin sheets of aluminium. This process variant permits a higher deposition rate, a lower energy input and fair gapbridging capacity than the conventional GMAW process with round filler wire. Weld mismatch was found to increase with the increase in heat input primarily due to greater differential thermal expansion in HAZ and the basemetal. Weld bead geometry parameters such as weld size, throat and weld convexity increases with an increase in heat input. Lap joints required more heat input than butt weld joints for the same thickness. The dilution in case of lap joints (10–25%) was less than that of butt joints (60–80%). [9]

John C. et al. (2005), recent developments in weldability testing for advanced materials. The term “weldability” has been used to describe a wide variety of characteristics when a material is subjected to welding. These include the physical and mechanical properties of the welded structure, the ease with which welding can be accomplished from a practitioner’s standpoint, the ability of the material to avoid metallurgical degradation (usually assessed by its susceptibility to cracking during welding or subsequent heat treatment), and the ability of the welded structure to perform in its intended service environment. A number of weldability tests have been developed over the years to evaluate and quantify material weldability. Many of these test techniques have focused on the phenomenon known as “hot cracking”. This paper will review the basic concepts associated with hot cracking and other forms of elevated temperature cracking and describe some recent advances in the use of testing approaches to quantify susceptibility to these forms of cracking.

A.L. Dhobale et al. (2016), effect of arc voltage, welding current and welding speed on tensile strength, impact energy and hardness of aa6063 joints produced by MIG welding” metal inert gas welding is one of the widely used techniques for joining ferrous and nonferrous metals. MIG welding process offers several advantages like joining of unlike metals, low heat effected zone, absence of slag etc compared to TIG welding.

Metal inert gas (MIG) welding, in which argon, helium CO_2 are used as shielding gas. The accuracy and quality of welded joints largely depends upon type of power, welding speed, type of inert gas used for shielding, heat input. This study deals with the investigation of effect of welding heat input on the mechanical properties of the welded joint. Experiments are conducted on specimens of single v butt joint. The material selected for preparing the test specimen is Aluminium AA6063 Alloy. The strength of the welded joint is tested by a universal tensile testing machine and the results are evaluated. The higher ultimate tensile strength 0.22 KN/mm^2 produced at 120A Current, 24V Voltage, 60˚Cm/min. The higher micro hardness 78RC produced at 140A Current,24V Voltage, 60Cm/min Speed in MIG Welding and Lower micro hardness 70RC produced at 120A Current, 24V Voltage, 60Cm/min Speed. In the aluminium hardness should be because if hardness increased then material becomes brittle in nature. The higher Impact Energy 48J produced at 120A Current, 24V Voltage, 60Cm/min Speed in MIG Welding. The MIG welding process shows good result at 120A Current, 24V Voltage, 60cm/min Speed. So this is best suitable parameter to weld Aluminium alloy (AA6063) with filler material (AA5356) with MIG Welding process.

P.K. Palani et al. (2006)**,** Selection of parameters of pulsed current gas metal arc welding Pulsed welding is a controlled method of spray transfer, in which the arc current is maintained at a value high enough to permit spray transfer and for long enough to initiate detachment of a molten droplet. Once the droplet is transferred the current is reduced to a relatively low value to maintain the arc. These periods of low current allow the average arc current to be reduced into the range suitable for positional welding, while periodic injection of high current pulses allows metal to be transferred in the spray mode. Parameters of these current pulses, such as I_p I_b, T_p and T_b have a distinct effect on the characteristics *viz*., the stability of the arc, weld quality, bead appearance and weld bead geometry. Improper selection of these pulse parameters may cause weld defects including irregular bead surface, lack of fusion, undercuts, burn-backs and stubbing-in.

2.1 Observation from literature review/ Research gap

It is observed from the literature review that different combination of welding process parameters is varied. In some cases welding current, gas flow rate and travel speed are varied and in some cases welding voltage, wire feed rate and travel speed are varied, in some cases welding current, gas flow rate and nozzle to plate distance are varied and in some cases welding current, gas flow rate and electrode diameter are varied. Very few investigations are carried out to assess the weldability of A6061 and A6063 aluminium alloy via Metal Inert Gas (MIG) Welding. Metal Inert Gas (MIG) Welding has not been explored exclusively for welding of A6061 and A6063 aluminium alloy in terms of different welding parameters.

During experimental work welds will be prepared using Gas Metal Arc Welding (GMAW) technique of AA6061 and AA6063 alloys. In the experiment welding parameters Arc Voltage, Welding current, will be altered suitably and their effect on microstructural and mechanical properties which include Optical Microscopy, Scanning Electron Microscopy, Hardness, Ultimate Tensile Strength, Yield Stress and elongation will be investigated. Phase detection will be observed via XRD analysis also.