CHAPTER 1

INTRODUCTION

Welding is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar and dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filler metal is used during welding, then it is termed as “Autogenous Arc Welding”.

During ‘Bronze Age’ parts were joined by forge welding to produce tools, weapons and ornaments etc., however present-day welding processes have been developed within a period of about century.

First application of welding with carbon welding was developed in 1885 while metal arc welding with bare electrode was patented in 1890. However, these developments were more of experimental value and applicable only for repair but proved to be the important base for present day Manual Metal Arc (MMAW) welding and other welding processes. In the meantime Resistance Arc Welding was developed in USA in the year 1886. Other resistance welding processes like Spot and Flash welding with manual application were developed in the year 1905. With the production of cheap Oxygen in 1902, Oxy-Acetylene welding became feasible in 1903. When the coated electrodes were developed in 1907, the manual metal arc welding process became viable for production/fabrication of components and assemblies in the industries in large scale.

In the present investigation MIG arc welding has been performed on low carbon steel C20 with Electrode ER70S-4 which is a kind of mild steel copper coated welding wire, suitable for CO2 gas protective. For the selection of the input process parameters of the welding, various papers has been studied and the following parameters were chosen as the variable input parameters (Kumar. Et al., 2014) : Current, Voltage, Gas flow rate for optimization of welding characteristics (Hardness **(**Patel, C. et al. (2013), and Tensile strength).

The experiments were performed with the various combinations of levels of the parameters and optimum level of the parameters was found out from the main effect plot and the results were analyzed using Raw Data ANOVA and S/N ANOVA. The optimum level of the factors has been determined for each of the experiments. Estimated average values of the response has been calculated and hence Confidence Interval and Range of each response also be found out.

In most of the products, they should have several quality characteristics of interest. A single setting of process parameters may be optimal for one quality characteristic but the same setting may yield detrimental results for other quality characteristics. In such cases, a need arises to obtain a setting of the process parameters so that the product can be produced with multi-optimum or near multi-optimum quality characteristics.

1.1 Objective of the Project

Keeping in view of the discussion made in this chapter, the focus of the present study has been to “A STUDY, ANALYSIS AND OPTIMIZATION OF MIG WELDING PROCESS PARAMETERS FOR MINIMISATION OF HEAT EFFECTED ZONE (HAZ)”. In order to accomplish this following steps have been identified:

- Investigation of working range of process parameters viz. welding current, voltage, carbon dioxide as shielding gas affecting welding quality characteristics.
- Investigation on the effect of welding current, voltage carbon dioxide as shielding gas on the hardness (ROCKWELL HARDNESS NUMBER) of the welded joint.
- Setting of optimal level of parameter using One-Factor-At-a-Time (OFAT) Experiment and finding out the levels of the factors for the experiment.
- Optimization of process parameters: current, voltage and gas flow rate and welding quality characteristics (hardness) using Taguchi technique and prediction of Confidence Interval at 95%
- Experimental verification of optimized individual quality characteristics.
- Microstructure comparison of parent metal and welded metal at optimized setting.

CHAPTER 2

LITERATURE REVIEW

Many research workers have investigated and demonstrated the effect of various process parameters viz. current, voltage, electrode diameter, shielding gas like CO_2, He, Ar etc. on the hardness and the tensile strength in Arc welding. The literatures describing the effect of above mentioned variable has been discussed below:

Satyaduttsinh P. et al.(2014) Investigated and demonstrated the effect of welding parameters like welding current, welding voltage, Gas flow rate, wire feed rate, etc. on weld strength, weld pool geometry of Medium Carbon Steel material during welding. By using DOE method, the parameters can be optimize and having the best parameters combination for target quality. The advantages of using Taguchi orthogonal array on design of experiments have also been discussed.

Kumar.et al. (2014) Optimization of the process parameters in GMAW by Taguchi's experimental design method has been performed. An L9 Orthogonal Array was selected to study the relationships between the tensile strength and the three controllable input welding parameters such as voltage, current and gas flow rate. The optimized values so obtained for better tensile strength are current of 220 A, voltage of 40V and gas flow rate of 17 1pm. Base metal used was 1018 Mild Steel.

Verma, S. et al. (2014) They performed experiments for obtaining better bead height and bead width separately. The optimal parameters combination of bead height for CRC steel 513 GR-D was welding current 170 amps, the Welding voltage 26 volts and the wire extension 10 mm. Welding current is significantly affects the bead height with contribution of 54% followed by wire extension with contribution of 40% and welding voltage with contribution of 02%. And the optimal parameters combination of bead width for CRC steel 513 GR-D was welding current 190 amps, the Welding voltage 22 volts and the wire extension 10 mm. Wire extension is significantly affects the bead width with contribution of 71% followed by welding current with contribution of 21% and welding voltage with contribution of 08%.

Kadani, M. et al. (2014) it can be concluded from the research work that Taguchi's robust orthogonal array design can be successfully used to develop simple bead geometry based criterion for selection of MI welding process parameters to obtain the desired responses. The conclusions are based on bead-on-plate studies; they are suitable for hard facing work.2-factor interactions must be considered to predict the best combination of process parameters to get the optimum condition for best responses. Further, this it may be necessary to include type of shielding gas, etc. They took wire feed rate (3-6m/min), arc voltage (14-18volt), welding speed (1.5-1.9mm/min) , gas flow rate (8-16lit/min) and plate thickness(6-8mm.) as the input process parameters.

Patel, C. et al. (2013) In this dissertation work, various cutting parameters like, welding current, wire diameter and wire feed rate have been evaluated to investigate their influence for MIG welding and TIG welding. By use of GRA optimization technique, the optimal parameter values for better hardness for MIG are 100amp current, 1.2 mm wire diameter and 3m/min wire feed rate. Similarly the values obtained for TIG are 80amp current and 0.8mm wire dia. Base metal used was Carbon Steel (plain).

Vishwakarma ,B. et al.(2013) Studied the effect of welding current, electrode diameter, voltage and welding techniques on mechanical properties of mild steel. The test pieces of welded work pieces were made for tensile, hardness and impact tests. Specimens for microstructure examination were also prepared. It was observed in microstructure examination that with increasing current and voltage the grains tends to be coarser, while with increasing electrode diameter it tends to be finer. The experiments were performed between current range100Ato200A and voltage in between 10Vto30V

Boob, A.N. et al. (2013) Performed experiments for obtaining better microstructure. Took input process parameters as welding current (150-200amp), welding voltage (30volt) and welding speed (156-276mm/min) and after performing certain conformational experiments they came with the conclusion that increase in welding speed decreases the width of heat affected zone.

Singh, V. (2013) Taguchi optimization method was applied to find the optimal process parameters for Tensile Strength. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method. The optimized values thus found for better tensile strength are 40 CFH gas flow rate, 35V voltage and 1.5mm welding position gap.

Patil, U.S. Et al. (2013). In this paper, the optimization of the process parameters for MMA welding of stainless steel and mild steel with greater weld strength and optimum metal deposition has been reported. The higher-the-better quality characteristic is considered in the weld strength prediction. The Artificial Neural Fuzzy Interface system is used to solve this problem. The experimental result shows that the weld strength can be controlled, according to demand by setting the input value predicted by ANFIS system.

Olawale J. O. et al. (2012). The investigation was conducted to correlate process variables in shielded metal-arc welding (SMAW) and post weld heat treatment on some mechanical properties of low carbon steel weld. The samples were welded together using AWS E6013 electrodes with DC arc welding process. Varying welding currents of 100 A, 120 A, 140 A were used with a terminal voltage of 80 V. The weld samples were prepared for hardness, tensile and impact test. The prepared samples were then subjected to normalizing heat treatment operation at temperatures of 590°C, 600°C, 620°C, 640°C, 660°C, 680°C, and 700°C. It was observed that increase in welding current led to an increase in hardness and ultimate tensile strength values of as-weld samples while impact strength decreases. After post heat treatment operation the hardness and ultimate tensile strengths decreases while impact strength increases.

S.V Sapakal. (2012) Presented study and optimization of influence parameters current, voltage and welding speed on penetration depth of MS material with the help of Taguchi's design. The predicted parameters were analyzed by analysis of variance (ANOVA). A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method. The improvement of S/N ratio is 2.13. The experiment value that is observed from optimal welding parameters, the penetration is 5.25mm. & S/N ratio is 14.40.

Satish, R. et al. (2012) Variation in heat input resulted in significant changes in the mechanical properties of the weld. Results show that lower heat input resulted in lower tensile strength and too high heat input also resulted in reduced tensile strength. An intermediate value of average heat input in the range of 1500 to 1600 J/mm gave the highest tensile strength. Gas flow rate is the factor that significantly contributed to a higher percentage and has greater influence on the tensile strength followed by contributions from current and bevel angle. The optimum range includes current of 110 to 115 amperes, shielding gas flow rate of 12.5 LPM, and bevel angle of 45 degrees. It was also found that the weld and the SS base metal was free from susceptibility to IGC and also gave higher tensile strength for the heat input range mentioned above.

CHAPTER 3

WELDING PROCESSES

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work pieces 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 work pieces to form a bond between them, without melting them.

3.1 Classification of Welding Processes

There are about 35 different welding and brazing process and several soldering methods, in use by the industry today. There are various ways of classifying the welding for example; they may be classified based on source of heat (flames, arc etc.)

In general, various welding processes are classified as follows.

3.1.1 Gas welding

Gas welding is widely used in sheet metal works. Depending on combustion mixture of gas, it may be classified as:

a) **Oxyacetylene welding:** It is a Gas Welding process using a combustion mixture of acetylene (C_2H_2) and oxygen (O_2) for producing gas welding flame. Oxyacetylene flame has a temperature of about 6000°F (3300°C). Combustion of acetylene takes place in two stages-

    1. Inner core of the flame. $C_2H_2 + O_2 = 2CO + H_2$
    2. Outer envelope of the flame: $CO + H_2 + O_2 = CO_2 + H_2O$

    Acetylene is safely stored at a pressure not exceeding 300 psi (2000 kPa) in special steel cylinders containing acetone. Outside of cylinder acetylene is used at an absolute pressure not exceeding 30 psi (206 kPa). Higher pressure may cause explosion.

b) **Oxyhydrogen welding(OHW)**:Oxyhydrogen Welding is a Gas Welding process using a combustion mixture of Hydrogen (H_2) and oxygen (O_2) for producing gas welding flame

Oxyacetylene flame has a temperature of about 4500°F (2500°C). Combustion reaction is as follows: $2H_2 + O_2 = 2H_2O$

Oxyhydrogen Welding is used for joining metals with low melting points, like aluminium, magnesium, etc.

c) **Pressure gas welding (PGW)**:Pressure Gas Welding is a Gas Welding, in which the welded parts are pressed to each other when heated by a gas flame. The process is similar to Resistance Butt Welding. Pressure Gas Welding does not require filler material. Pressure gas welding is used for joining pipes, rods, railroad rails.

3.1.2 Arc welding

Arc welding is most widely used in fabrication industries. In general, various arc welding processes are classified as follows.

a) **Carbon arc welding:** Carbon arc welding (CAW) is a process which produces coalescence of metals by heating them with an arc between a non-consumable carbon (graphite) electrode and the work-piece. It was the first arc-welding process ever developed but is not used for many applications today, having been replaced by twin-carbon-arc welding and other variations. The purpose of arc welding is to form a bond between separate metals. In carbon-arc welding a carbon electrode is used to produce an electric arc between the electrode and the materials being bonded. This arc produces extreme temperatures more than 3000°C. At this temperature the separate metals form a bond and become welded together.

b) **Plasma arc welding:** Plasma arc welding (PAW) is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the work piece. The key difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 28,000 °C (50,000 °F) or higher. Arc plasma is the temporary state of a gas. The gas gets ionized after passage of electric current through it and it becomes a conductor of electricity. In ionized state atoms break into electrons (-) and ions (+) and the system contains a mixture of ions, electrons and highly excited atoms. The degree of ionization may be between 1% and greater than 100% i.e.; double and triple degrees of ionization. Such states exist as more number of electrons is pulled from their orbits. Welding (MMA or MMAW), flux shielded arc welding (Kumar, D. et al.,2014) or informally as

Shield metal arc welding**.** Shielded metal arc welding (SMAW), also known as manual metal arc stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapours that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.

c) **TIG (Tungsten inert gas welding):** Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inertshielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapours known as plasma.

d) **MIG (Metal inert gas welding)**: MIG is currently one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. In MIG, however, the electrode wire does not have a flux coating, and a separate shielding gas is employed to protect the welding from oxidation. The basic technique for GMAW is quite simple, since the electrode is fed automatically through the torch (head of tip). GMAW requires only that the operator guide the welding gun with proper position and orientation along the area being welded.

3.1.3 Resistance welding

The various types of resistance welding are discussed below:

a) **Spot welding:** Resistive spot welding (RSW) is a process in which contacting metal surfaces are joined by the heat obtained from resistance to electric current.

b) **Seam welding:** Resistance seam welding is a process that produces a weld at the faying surfaces of two similar metals. The seam may be a butt joint or an overlap joint and is usually an automated process. It differs from butt welding in that butt welding typically welds the entire joint at once and seam welding forms the weld progressively, starting at one end.

c) **Projection welding:** Resistance projection welding (RPW) is a variation of resistance welding in which current flow is concentrated at the contact surfaces of interest by an embossed, cold headed, or machined projection. The projection(s) effectively localize the current, forcing the parts to heat predominately at the mating surfaces.

d) **Resistance butt welding**: Commonly used for joining wires. End-to-end positioning of work piece surfaces. When welding pressure between the two surfaces has built up, the welding current is turned on, the joint surfaces are heated, and the welding cycle will result in even upset metal.

e) **Flash butt welding:** Flash welding is a type of resistance welding that does not use any filler metal. The pieces of metal to be welded are set apart at a predetermined distance based on material thickness, material composition, and desired properties of the finished weld. Current is applied to the metal, and the gap between the two pieces creates resistance and produces the arc required to melt the metal.

3.1.4 Solid state welding

The various types of solid state welding are discussed below:

a) **Cold welding:** Cold or contact welding is a solid-state welding process in which joining takes place without fusion/heating at the interface of the two parts to be welded. Unlike in the fusion-welding processes, no liquid or molten phase is present in the joint.

b) **Diffusion weldin**g: Diffusion welding (DFW) is a solid state welding process by which two metals (which may be dissimilar) can be bonded together. Diffusion involves the migration of atoms across the joint, due to concentration gradients. The two materials are pressed together at an elevated temperature usually between 50 and 70% of the melting point.

c) **Forge welding:** Forge welding is a solid-state welding process (Kumar,D. et al.,2014) that join two pieces of metal by heating them to a high temperature and then hammering them together. The process is one of the simplest methods of joining metals and has been used since ancient times. Forge welding is versatile, being able to join a host of similar and dissimilar metals.

d) **Hot pressure welding:** Hot-pressure-welding is a solid-state process that produces joints between the faying surfaces of two bodies. It is done by application of heat and pressure.

e) **Roll welding:** Roll-welding, also called Roll Bonding, is a process that joins together a stack of sheets or plates. The stack is fed through a cold rolling mill under sufficient pressure to produce significant deformation and solid-state welding.

3.1.5 Thermochemical welding

There are two types of thermo chemical welding viz. thermic welding and atomic welding as discuss below:

a) **Thermite welding:** Exothermic welding, also known as exothermic bonding, thermite welding (TW), and thermite welding, is a welding process for joining materials that employs molten metal to permanently join the conductors. The process employs an exothermic reaction of a thermite composition to heat the metal, and requires no external source of heat or current. The chemical reaction that produces the heat is an aluminothermic reaction between aluminium powder and a metal oxide.

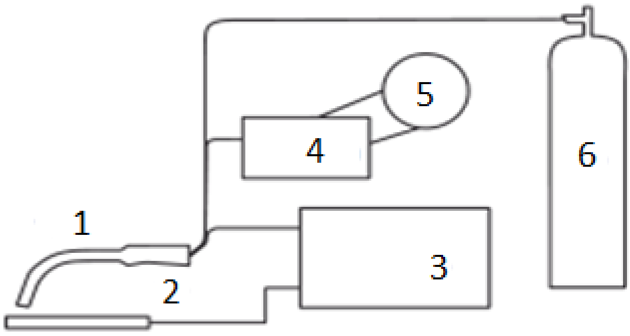
b) **Atomic welding:** Atomic hydrogen welding (AHW) is an arc welding process that uses an arc between two metal tungsten electrodes in a shielding atmosphere of hydrogen. The process was invented by Irving Langmuir during his studies of atomic hydrogen. The electric arcefficiently breaks up the hydrogen molecules, which later recombine with tremendous release of heat, reaching temperatures from 3400 to 4000 °C. Without the arc, an oxyhydrogen torch can only reach 2800°C (Kumar, D. et al. (2014). This is the third hottest flame after dicyanoacetylene at 4987 °C and cyanogen at 4525 °C. An acetylene torch merely reaches 3300 °C.

3.2 MIG Welding Equipment, Operational Technique and Safety

MIG is currently one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. There, the method is often used for arc spot welding, thereby replacing riveting or resistance spot welding. It is also popular for automated welding, in which robots handle the work pieces and the welding gun to speed up the manufacturing process (Verma, S. et al., 2014). Generally, it is unsuitable for welding outdoors, because the movement of the surrounding air can dissipate the shielding gas and thus make welding more difficult, while also decreasing the quality of the weld. The problem can be alleviated to some extent by increasing the shielding gas output, but this can be expensive and may also affect the quality of the weld. In general, processes such as shielded metal arc welding and flux cored arc welding are preferred for welding outdoors, making the use of GMAW in the construction industry rather limited. Furthermore, the use of a shielding gas causes GMAW to be unpopular for underwater welding.

3.2.1 Equipment

To perform gas metal arc welding, the basic necessary equipment is a welding gun, a wire feed unit, a welding power supply, an electrode wire, and a shielding gas supply. The Circuit diagram of MIG machine is shown in Fig 2.1



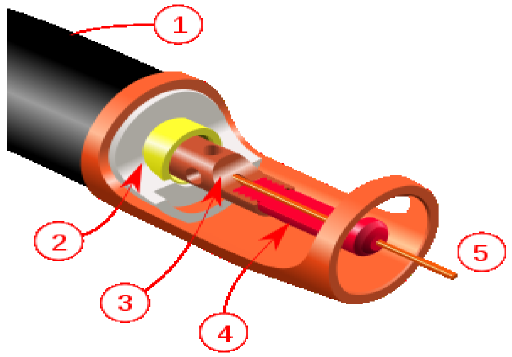
(1) Welding torch
(2) Work piece
(3) Power source
(4) Wire feed unit
(5) Electrode source
(6) Shielding gas supply

Fig 3.1: MIG Circuit diagram.

3.2.2 Welding gun and wire feed unit

The typical GMAW welding gun has many key parts—a control switch, a contact tip, a power cable, a gas nozzle, an electrode conduit and liner, and a gas hose. The control switch, or trigger, when pressed by the operator, initiates the wire feed, electric power, and the shielding gas flow, causing an electric arc to be struck. The contact tip, normally made of copper and sometimes chemically treated to reduce spatter, is connected to the welding power source through the power cable and transmits the electrical energy to the electrode while directing it to the weld area. It must be firmly secured and properly sized, since it must allow the electrode to pass while maintaining electrical contact. On the way to the contact tip, the wire is protected and guided by the electrode conduit and liner, which help prevent buckling and maintain an uninterrupted wire feed. The gas nozzle directs the shielding gas evenly into the welding zone.

The wire feed unit supplies the electrode to the work, driving it through the conduit and on to the contact tip. Most models provide the wire at a constant feed rate, but more advanced machines can vary the feed rate in response to the arc length and voltage. Some wire feeders can reach feed rates as high as 30.5 m/min (1200 in/min) (Patil, U.S. et al., 2013) but feed rates for semiautomatic GMAW typically range from 2 to 10 m/min (75–400 in/min). Different parts MIG torches (nozzle cutaway image) are shown in Fig2.2 below:



(1) Torch handle

(2) Molded phenolic dielectric (shown in white) and threaded metal nut insert (yellow)

(3) Shielding gas diffuser

(4) Contact tip

(5) Nozzle output face

Fig 3.2 MIG Torch.

3.2.3 Power supply

Most applications of gas metal arc welding use a constant voltage power supply. As a result, any change in arc length (which is directly related to voltage) results in a large change in heat input and current. A shorter arc length causes a much greater heat input, which makes the wire electrode melt more quickly and thereby restore the original arc length. This helps operators keep the arc length consistent even when manually welding with hand-held welding guns. To achieve a similar effect, sometimes a constant current power source is used in combination with an arc voltage-controlled wire feed unit. In this case, a change in arc length makes the wire feed rate adjust to maintain a relatively constant arc length. In rare circumstances, a constant current power source and a constant wire feed rate unit might be coupled, especially for the welding of metals with high thermal conductivities, such as aluminium. This grants the operator additional control over the heat input into the weld, but requires significant skill to perform successfully.

3.2.4 Electrode

Electrode selection is based primarily on the composition of the metal being welded, the process variation being used, joint design and the material surface conditions. Electrode selection greatly influences the mechanical properties of the weld and is a key factor of weld quality. In general, the finished weld metal should have mechanical properties like those of the base material with no defects such as discontinuities, entrained contaminants or porosity within the weld. To achieve these goals a wide variety of electrodes exist. All commercially available electrodes contain deoxidizing metals such as silicon, manganese, titanium and aluminium in small percentages to help prevent oxygen porosity. Some contain de-nitriding metals such as titanium and zirconium to avoid nitrogen porosity. Depending on the process variation and base material being welded the diameters of the electrodes used in GMAW typically range from 0.7 to 2.4 mm (0.028–0.095 in) but can be as large as 4 mm (0.16 in). The smallest electrodes, generally up to 1.14 mm (0.045 in) (Satyaduttsinh P. et al.,2014) are associated with the short-circuiting metal transfer process, while the most common spray-transfer process mode electrodes are usually at least 0.9 mm (0.035 in).

3.2.5 Shielding gas

Shielding gases are necessary for gas metal arc welding to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. This problem is common to all arc welding processes. In MIG, however, the electrode wire does not have a flux coating, and a separate shielding gas is employed to protect the weld. This eliminates slag, the hard residue from the flux that builds up after welding and must be chip off to reveal the completed weld(Boob, A.N. et al.,2013). The choice of a shielding gas depends on several factors, most importantly the type of material being welded and the process variation being used. Pure inert gases such as argon and helium are only used for nonferrous welding; with steel they do not provide adequate weld penetration (argon) or cause an erratic arc and encourage spatter (with helium). Pure carbon dioxide, on the other hand, allows for deep penetration welds but encourages oxide formation, which adversely affect the mechanical properties of the weld. lts low cost makes it an attractive choice, but because of the reactivity of the arc plasma, spatter is unavoidable and welding thin materials is difficult. As a result, argon and carbon dioxide are frequently mixed in a 75%/25% to 90%/10% mixture (Satyaduttsinh P. et al. 2014). Shielding gas mixtures of three or more gases are also available.

3.2.6 Operation

For most of its applications gas metal arc welding is a simple welding process to learn to require no more than a week or two to master basic welding technique. Even when welding is performed by well-trained operators weld quality can fluctuate since it depends on a number of external factors. All GMAW is dangerous, though perhaps less so than some other welding methods, such as shielded metal arc welding.

3.2.7 Technique

The basic technique for GMAW is quite simple, since the electrode is fed automatically through the torch (head of tip). GMAW requires only that the operator guide the welding gun with proper position and orientation along the area being welded. Keeping a consistent contact tip-to-work distance (the *stick out* distance) is important, because a long stick out distance can cause the electrode to overheat and also wastes shielding gas. Stick out distance varies for different GMAW weld processes and applications. The orientation of the gun is also important (Patil, U.S. et al.2013), it should be held to bisect the angle between the work pieces; that is, at 45 degrees for a fillet weld and 90 degrees for welding a flat surface. The travel angle, or lead angle, is the angle of the torch with respect to the direction of travel, and it should generally remain approximately vertical. However, the desirable angle changes somewhat depending on the type of shielding gas used (with pure inert gases); the bottom of the torch is often slightly in front of the upper section, while the opposite is true when the welding atmosphere is carbon dioxide.

3.2.8 Safety

Gas metal arc welding can be dangerous if proper precautions are not taken. Since GMAW employs an electric arc, welders wear protective clothing, including heavy leather gloves and protective long sleeve jackets, to avoid exposure to extreme heat and flames. In addition, the brightness of the electric arc is a source of the condition known as arc eye, an inflammation of the cornea caused by ultraviolet light and, in prolonged exposure, possible burning of the retina in the eye. Conventional welding helmets contain dark face plates to prevent this exposure.

Welders are also often exposed to dangerous gases and particulate matter. GMAW produces smoke containing particles of various types of oxides, and the size of the particles in question tends to influence the toxicity of the fumes, with smaller particles presenting a greater danger. Additionally, carbon dioxide and ozone gases can prove dangerous if ventilation is inadequate. Furthermore, because the use of compressed gases in GMAW pose an explosion and fire risk, some common precautions include limiting the amount of oxygen in the air and keeping combustible materials away from the workplace.

CHAPTER 4

DESIGN OF EXPERIMENTS APPROACH & ANOVA

DESIGN OF EXPERIMENTS APPROACH &ANOVA

CHAPTER 4

The technique of defining and investigating all possible conditions in an experiment involving multiple factors is known as Design of Experiments. It is sometimes also referred as factorial design. The concepts of DOE have been in use since Fisher's work in agricultural experimentation, approximately half a century ago. Numerous application of this approach have been used in the various field of engineering. Initially it started with considering all possible combinations of factors (or trials), which is known as Full Factorial Experiment. But as number of factor increases and their level increases, number of experiments also increases tremendously. Number of experiments in a Full Factorial Experiment is equal to L^m, where L is the number of level of a factor and m is the number of factor in the experiment. Later to decrease the number of experiments Fractional Factorial Experiment design is developed, where an experimenter chooses to include important factors only from his past experience. But the problem with this approach is that two different experimenter working on the same problem may come up with two different experiment design and have different solutions for the same problem. To standardize Fractional Factorial Experiment Design, Dr. Genichi Taguchi developed a new method called Taguchi Method. Taguchi designed a number of arrays called Orthogonal Array (OA), which can be used as a template to design experiments.

In the present investigation Taguchi Method has been used for analysing process parameters affecting on quality of welding.The details of these experiment method and their analysis method is discussed below:

4.1 Taguchi Method

A Japanese electrical engineer, Dr .Genichi Taguchi developed a statistical method to standardize Fractional Factorial DOE methodology. He designed numbers of orthogonal arrays (OA) and developed mathematical formulation for the same. The goal of the Taguchi Method is to produce robust design of industrial products, which are insensitive to uncontrollable environmental noise factors. For that he introduced the concept of Signal to Noise (S/N) ratio.

4.1.1 Orthogonal Array (OA)

Taguchi developed a number of arrays which can be used as a template to design an experiment (Roy, R.K.,1990). Depending on the number of trial condition each arrays are named, for example Orthogonal Array L9 has nine trial conditions. The rows represent trial condition whereas columns represent factor assignments. These arrays are called orthogonal because a level occurs same number of time in each column. The main advantage of OA is that it greatly reduces number of experiment and hence reduces time and cost of experimentation.

1) Selection of orthogonal array:

Selection of OA is done on the basis of Degree of Freedom (DOF) of the experiment. The DOF of the experiment should be less than equal to DOF of the array.

The DOF of an experiment is the summation of DOF of all factors and Interaction under study. For an experiment having four, three level factors then total DOF is

$DOF_{exp} = (3-1) + (3-1) + (3-1) + (3-1) = 8$

The DOF of an array is the summation of DOF of all columns; e.g. Oa L9 has four columns and each column has three levels (i.e. two levels) total DOF of L9 is:

$DOF_{L9}= (3-1) + (3-1) + (3-1) + (3-1) +8$

Another point to be noted that level of the factors of the experiment should be equal to the level of the OA. Examples of two level arrays are L4, L8, and L16 etc. And three level arrays are L9, L27 etc. A two level array can handle factors having two level only, a three level array can handle three level factors and two level factors (with minor modification).

As the goal is to minimise number of experiments, the smallest array that satisfies above condition should be selected for the design.

2) Column assignment:

In Taguchi OA effect of every column is compounded with effect of other columns. For designing a simple experiment without interaction, one can assign factor to any column but in case of an experiment with interaction study, one should consult Linear Graph or Triangular table.

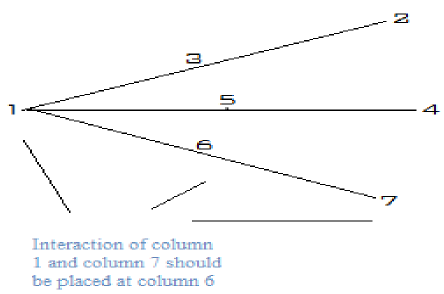


Fig 4.2 Linear Graph of L8 OA

In the figure the number the middle of the straight lines indicate the column number of the interaction column of the columns number given at the ends, For example interaction of column 1 and column 7 can be placed at column number 6.Another method of column assignment is use of triangular table as shown Table 4.1.

Table 4.1 Triangular Table of 3 level Orthogonal Array

1	2	3	4	5	6	7	8	9	10	11	12	13
[1]	3 4	2 4	2 3	6 7	5 7	5 6	9 10	8 10	8 9	12 13	11 13	11 12
	[2]	1 4	1 3	8 11	9 12	10 13	5 11	6 12	7 13	5 8	6 9	7 10
		[3]	1 2	9 13	10 11	8 12	7 12	5 13	6 11	6 10	7 8	5 9
			[4]	10 12	8 13	9 11	6 13	7 11	5 12	7 9	5 10	6 8
				[5]	1 7	1 6	2 11	3 13	4 12	2 8	4 10	3 9
					[6]	1 5	4 13	2 12	3 11	3 10	2 9	4 8
						[7]	3 12	4 11	2 13	4 9	3 8	2 10
							[8]	1 10	1 9	2 5	3 7	4 6

[9]	1 8	4 7	2 6	3 5
	[10]	3 6	4 5	2 7
		[11]	1 13	1 12
			[12]	1 11

The number in the bracket at the bottom of each column of Table identities the column. Suppose to find, in which interaction of column 1 and 4 will appear, then move horizontally across the row [1] and vertically upward direction in the column [4]. The cell at the intersection of this row and column will give us the column numbers where the interactions will appear.

4.2 One-Factor-At-a-TimeExperiment:

In this approach, all the factor is set at a baseline (or starting point)of levels of each factor. One factor is varied accordingly over its range keeping the other factors at constant .After the completion of experiment a series of graphs are plotted to find the optimal setting of factors.For any experiment consisting of multiple factors, effect each factor is obtained by varying the level of each factor simultaneously. The clarification of this graphs are easy and straight forward due to which selection of optimal setting of levels of factors become convenient. The interaction effect between the factors cannot be studied by this method.

4.3Signal to Noise Ratio

Taguchi recommended the use of signal to noise(S/N) ratio to measure the deviation of the quality characteristic from the desired value. The signal represents the desired value (mean) and noise represents the undesired value (standard deviation)for the desired quality characteristics. Thus it is ratio of mean to standard deviation which is used to measure the deviation of quality characteristics from the desired value. There are three types of quality characteristics for the analysis of S/N ratio i.e. lower the better, nominal the better and higher the better. At each level of factors the S/N ratio is calculated through S/N analysis. S/N analysis is done by converting the raw data of an experiment to S/N ratio using formula given below. Taguchi recommends the use of S/N ratio to maximize the performance of the product or system by minimizing the effect of noise.

$$S/N = -\log_{10} (MSD)$$

Where the term Mean Squared Deviation (MSD) reflects deviation from the target value. The expression for MSD is different for different quality characteristics.

a) For smaller the better quality characteristics:
   $MSD = (Y_1^2+Y_2^2+........+Y_n^2)/r;$
b) For nominal the best quality characteristics:
   $MSD = \{(Y_1-Y_0)^2+(Y_2-Y_0)^2+......+(Y_r-Y_0)^2\}/r$
c) For higher the better quality characteristics:
   $MSD = (1/Y_1^2+1/Y_2^2+........+1/Y_n^2)/r$
   Where $Y_1, Y_2, Y_3......$ result of experiment, r is the number of repetitions and Y_0 target value of result

The aim of this experiment is to produce highest possible S/N ratio for the result. A high value of S/N ratio implies that the signal is much higher than the random effects of the noise factors. It converts all types of quality characteristics to Higher the better type i.e. Greater the value of S/N ratio, more desirable is the condition.

4.4Data Analysis:

Many methods have been suggested by Taguchi for analysing the data; observation method, ranking method, column effects method, ANOVA (Raw data ANOVA and S/N ANOVA), plot of average response curves (main effect plot) etc.

4.4.1 Main effect:

For a factor having L number of levels, average value of the output variable ($\bar{Y}_L$) for each level of that factor is determined and called main effect of that factor. To find out the main or average effect of a factor at a certain level, all the values of the output variable, of those trials that contain that factor at that level; are added and divided by total number of output values (data) considered for the addition.

Main effect plot: The graphical representation of effect of each level of a factor is called Main Effect Plot of the factor. To draw a Main Effect Plot, Main effect of each level of factor is found out and plotted in a graph where the output variable lies in the vertical axis and level lies in the horizontal axis.

4.4.2 Analysis of variance (ANOVA):

The reduction in the number of experiments in Taguchi's OA from the traditional design of experiment increases the risk of significance of the factors. This can be compensated by performing ANOVA at a certain level of confidence. ANOVA ascertains that the variation in output response of an experiment is due to the change in the level of the factors or due to the chance factors. It is used to analyse the influence of the factors towards the output response. ANOVA provides a statistical test to determine the equality of means of all the factor. The statistical significance of the experiment is determined by ratio of two variance known as F-ratio.

ANOVA is of two types depending on the type of data used:

a) Raw data ANOVA
b) S/N data ANOVA

However in the present investigation, Raw data ANOVA methodis exclusively used.

4.4.2 Raw data ANOVA:

In Raw data ANOVA average values of the output of each of the trial condition is used for the analysis. The important terms of Raw data ANOVA is given below:

1) Degree of Freedom, f:

It is the number of independent pieces of information which is used during the estimate of any parameter

Degree of Freedom (DOF) of a factor (f_A):

For a factor A having L number of levels, DOF is given by:

$f_A = L-1$

Degree of Freedom (DOF) of interaction of factor A and B (f_{AxB}):
If f_A and f_B is the DOF of factor A and B, then DOF of interaction AB is given as:
$F_{AxB} = f_A x f_B$

Total Degree of Freedom of the experiment (f_T):
For an experiment having n number of trials with r repetitions, DOF is given by:
$f_T = n*r-1$

Error Degree of Freedom, f_e**:**
For an experiment having m number of factors, DOF of the error is given by:
$f_e = f_T - \sum_{k=1}^{m} f - DOF\ of\ interaction$

2) Correction Factors (CF)

It is the operation to isolate the variance carried by a factor from the variance caused by the error. It is deducted from the sum of square of a factor and added to the sum of square of the error. It can be calculated as

$$CF= T^2/N$$

Where, $T=\sum^{n}_{i=1}\sum^{r}_{j=1}Y_{ij}$, Y= value of the output variable of the i^{th} trial condition and j^{th}repetition

N=n+r, total number of data.

In performing S/N data ANOVA the correction factor becomes

$$CF=T^2/n$$

Where $T=\sum^{n}_{i=1}Y_i$, Y=value of S/N ratio of the i^{th} condition n=number of trials

3) Sum of Squares, S

It is the measure of deviation of the experimental data from the mean value of the data. The various type sum of squares can be calculated as

- Sum of square of a factor(say A), S_A
  The sum of square of a factor A can be calculated as
  $$S_A= [(A^2_1+A^2_2+\ldots+A^2_n) /N]-CF$$

Where, A_i= summation of values of these trials which contains factor A at level 1,
A_2=summation of values of those trials which contains factor A at level 2, A_L=summation of values of those trials which contains factor A at L^{th} level, N= total number of data, CF= correction factor.

- Sum of square of interaction between factors (say A and B),S_{AxB}
  The sum of square of the interaction between two factors say A and B is calculated as

$$S_{AxB}=S_{AB}-S_A-S_B$$

Where S_{AB}= $[(Y^2_1+Y^2_2+\ldots+Y^2_n)/r]$ –CF, Y_1, $Y_2\ldots Y_n$=average outputvalues of the trial condition 1, 2…n, r=number of repetitions.

- Total sum of square ,S_r
  The total sum of square is given by

$S_r=\sum^n_{i=1}\sum^r_{j=1}Y_{ij}^2$-CF

- Sum of square of error ,S_r
  The error sum of square for an experiment having m factors is calculated by

$$S_e=S_r- \sum^m_{i=1}S_i - \sum\text{sum of square of interactions}$$

4) Variance, V

It measures the distribution of the data about the mean of the data. It is known that higher degree of freedom also increases the variation. Since the DOF is not considered in the calculation of sum of squares. Therefore to compensate this sum of square is divided with DOF to obtain the actual variation. So the variance of a factor is calculated as

$$V=s/f$$

5) Variance ratio or F ratio, F

It is the ratio of variance due to the effect of a factor to the variance due to the error term. It is used to measure the significance of the factor under investigation w.r.to the variation of all the factors included in the error. It can be calculated as

$$F=v/v_e$$

where, V= variance of the factor under investigation, V_e= error variance

When the calculated F value is less than the tabulated F value for a selected confidence level then the factor is insignificant i.e. it does not contribute to the sum of squares at that confidence level.

6) Tabulated F value or critical F value

It is the F value obtained from a standard F table at a given confidence level. The values can be obtained by entering the DOF of the factor and the error term.

7) Pure sum of squares, S

It is obtained by subtracting the product of the DOF of a factor and error variance from the sum of square of that factor. For example, consider an experiment having two factors A and B of DOF $f_A$and f_B and then the pure sum of squares can be calculated as

$$S_A^{/}=S_A - f_A + V_e$$

$$S_B^{/}=S_B - f_B + V_e$$

Now the pure sum of squares of the error term is calculated as-

$$S_e^{/} = Se+(f_A+f_B) + V_e$$

Where, S_A, S_B = sum of square of factor A and B, V_e= error variance

8) Percent contribution, P

The percent contribution of any factor (say A) is calculated as-

$$P_A= (S_A^{/} /S_T) \text{ x}100$$

where, $S_A^{/}$=pure sum of squares of factor A, S_T=total sum of square

CHAPTER 5
METHODOLOGY

METHODOLOGY
Chapter 5

5.1 Factor and Level Selection:

The performance of MIG arc welding depends on various factors. From literature survey (Satyaduttsinh P. et al.,2014), the factors listed in Table 5.1 are found to be affecting welding performance.

Table 5.1: Factors affecting welding performance

Serial No	Factors	Range	Type
1	Current	150 – 250 A	Operational
2	Voltage	20 – 30 V	Operational
3	Welding speed	40 – 80 dm/min	Operational
4	Gas flow rate	8 – 16 lit/min	Design
5	Electrode angle	30^0 – 150^0	Design
6	Arc length	0.5 – 2.5 mm	Operational
7	Wire diameter	0.8 – 1.6 mm	Design

In already published literature it is found that welding is primarily affected by current and voltage. The main factor associated with welding are found to be: current , voltage and welding speed, called primary factors (Satyaduttsinh P. et al.,2014) whereas gas flow rate, electrode angle, arc length and wire diameter are the secondary factors Out of these factors, three factors viz. current, voltage and gas flow rate are chosen for the current study (considering constant wire diameter). The chosen factors are independent of each other and can be controlled separately.

But the above levels of the three factors are for specimen of 3 mm thickness. But as the specimen thickness is 2 mm so for to get the exact levels OFAT (One factor at a time method) has been used by taking hardness as the response variable.

5.2 Experimental Setup

All the experiments have been conducted (TORNADO MIG 400, manufactured by ADOR FRONTECH LIMITED as shown in Fig5.1 on the same machineto cancel out the effect of machine variables. The basic objective of these experiments was to find out the optimal combination of different levels of the parameters among all possible combinations.

.

Fig 5.1: TORNADO MIG 400

5.3 Electrode Specification

ER70S-4 is a kind of mild steel copper coated welding wire, suitable for CO2 gas protective welding with stable feasibility, good welding seams, less spatter and excellent welding process properties. It is applicable to weld high tensile steel at 490N/mm2 grade, low current, usually used for steel C 15, C 20. Welding wireER70S-4 of diameter 1.0 mm has been used in the experiment, chemical composition and current range of welding wire are shown in Table 5.4a andTable 5.4b.

Table 5.4(a) Chemical composition of ER70S-4 welding wire

Chemical composition	C	Mn	Si	P	S	Cu
	0.07~0.15	1.00~1.50	0.65~0.85	≤0.025	≤0.035	≤0.50

(Courtesy: Changzhou City Yunhe Welding Material Co., Ltd)

Table 5.4(b)Welding current Specification

Wire Size(mm)	φ 0.8	φ 1.0	φ 1.2	φ 1.6
Welding current(A)	40~140	50~220	80~350	120~450

(Courtesy: Changzhou CityYunhe Welding Material Co., Ltd)

5.4 Test Piece Preparation and Testing:

The twenty-seven test pieces MS rods were first turned to make a 90-degree V-groove on which the welded metalhave been filled up. The samples were welded and specimen surface were prepared for Rockwell hardness number. The tests have been performed on Rockwell Hardness Testing Machine. The test specimens for experiment (Hardness) are shown in Fig5.2 below.

Fig 5.2: Test specimens for experiments

5.5 Analysis of Experimental Data

Experimental data obtained from each of the experiment is analysed separately to obtain optimum level of the factors. For data analysis the following methods are used:

a) Main effect plot
b) Raw data ANOVA

From the data analysis, optimum level of the factors will be determined for each of the experiment. Estimated average values of the response will be calculated and hence range of each response has also to be found out. For a particular factor, the range will be selected by choosing three levels; one at the upper and lower limits of the optimum level at an equal interval, and the third one with the optimum level itself.

5.2 Experiment Design

To carry out the investigation a Design of Experiment (DOE) approach has been chosen. The combinations of the levels are selected with the help of an orthogonal array.

Selection of a proper array for an experiment is very important as it decides number of trial in the experiment. For the present investigation, the selection procedure is given below:

Variable factors:

a) Current (Let the three three levels be: I_1, I_2, I_3)

b) Voltage (Let the three levels be: V_1 V_2, V_3)

c) Gas flow rate (Let the three levels be: G_1, G_2, G_3)

These three factors each at three levels have been considered.

DOF of factor A (current), f_A = level – 1 = 3 – 1 = 2

DOF of factor B (voltage), f_B = level – 1 = 3 – 1 = 2

DOF of factor D (gas flow rate), f_c = level – 1 = 3 – 1 = 2

DOF of the experiment, $f_{exp}= f_A + f_B + f_C = 2 + 2 + 2 = 6$

The smallest three level Taguchi OA is L9, which has four columns.

DOF of L9 OA, f_{L9} = Number of columns x (Level – 1) = 3 x (3 – 1) = 6

As DOF of the experiment is equal to DOF of L9 OA, hence L9 OA is selected.

5.4 Column Assignment of the Factors

From the triangular table (refer to Table 4.1, Chapter 4), the three factors are assigned to the three columns. The details of the experiment are given below:

a)Array used:

Taguchi Orthogonal Array L9 with 9 trials. Column assignment is shown in Table 5.2. The objective of this experiment is to find out the optimal factor combination.

Table 5.2: Column Assignment of the Factors

No of Trials	Factors (Columns)			
	Current (A)	Voltage (V)	Gas flow rate (lit/min)	Unused
1	I_1	V_1	G_1	1
2	I_1	V_2	G_2	2
3	I_1	V_3	G_3	3
4	I_2	V_1	G_2	3
5	I_2	V_2	G_3	1
6	I_2	V_3	G_1	2
7	I_3	V_1	G_3	2
8	I_3	V_2	G_1	3
9	I_3	V_3	G_2	1

5.5 Response Variable

The response variable chosen here is Rockwell hardness of MIG welding on the test piece material. Here it has been assumed that lower the hardness of the welded parts, better is the performance. All the experiments have been performed using the same machine to cancel out the effect of machine variables.

5.10 Confirmation Experiment

Confirmation experimentis the final step in verifying the conclusions from the previous round of experimentation. The optimum values for each of the significant process parameters (the in significant process parameters are set at economic level) and selected number of tests will be performed to ascertain that the results under constant specific conditions. The average of the confirmation experiment results are compared with the anticipated average based on the parameters and levels tested. Confirmation experiment is crucial step and highly recommended to verify the experimental conclusions (Roy, R.K.(1990)). In the experimentation two final optimal settings for each optimal responses were made and hence tested for experimental conclusions.

CHAPTER 6
RESULTS & DISCUSSIONS

6.1 ANALYSIS OF ONE-FACTOR-AT-A-TIME EXPERIMENT DATA

The experimental data obtained from the One-factor-At-A-Time experiments have been analysed as discussed in chapter 6. Results of experimental analysis are given below:

6.1.1Results of Experiment 1:

Constant factors: Voltage = 22 V, Gas flow rate = 16 L/min

Variable factor: Current (150, 160, 170, 180, 190 A)

Array used: OFAT with 3 repetitions

Hardness data obtained for 3 repetitions are given in Table 6.1

Table 6.1: Experimental data for experiment 1

Voltage (V)	Gas Flow Rate (L/min)	Current (A)	Hardness			Average Hardness
			R1	R2	R3	
22	16	150	50	53	49	50.67
22	16	160	52	54.5	53	53.17
22	16	170	68	64	66	66
22	16	180	70	75	72	72.33
22	16	190	49	50	47	48.67

- **Main Effect Plot:**

Main effect plot is drawn by taking the average values of hardness at each level. It is shown in Fig. 6.1

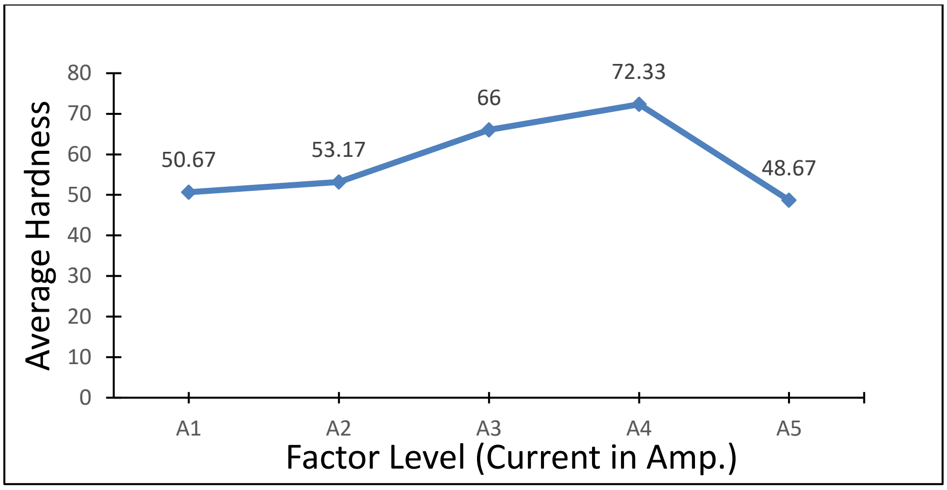


Fig. 6.1 Main Effect Plot 1

- **Raw data ANOVA:**

The values of hardness of experiment 1 with 3 repetitions are used to analyze the variance and it is found that the factor current is significant with percentage contribution of 96.4%. The ANOVA analysis is shown in Table 6.2

Table 6.2: Raw data ANOVA for experiment 1

Source	f	S	V	F	F(0.05)critical	P	Comment
Current	4	1289.67	322.41	66.94	3.48	96.4	Significant
Error	10	48.16	4.816	1		3.59	
Total	14	1337.83	327.23			100	

From the main effect plot 1, considering the minimum hardness, the optimum level of factor is found to be trial 5 (current 190A, voltage 22V, Gas flow rate 16LPM).

6.2 Results of Experiment 2:

Constant factors: Current = 190A, Gas flow rate = 16 L/min

Variable factor: Voltage (18, 20,22,24,26 V)

Array used: OFAT with 3 repetitions

Hardness data obtained for 3 repetitions are given in Table 6.3

Table 6.3: Experimental data for experiment 2

Voltage (V)	Gas Flow Rate (L/min)	Current (A)	Hardness			Average Hardness
			R1	R2	R3	
18	16	190	60	59	58.5	59.17
20	16	190	62	63	62	62.33
22	16	190	69	70	72	70.33
24	16	190	53	54	52	53
26	16	190	65	65.5	64	64.83

- **Main Effect Plot:**

  Main effect plot is drawn by taking the average values of hardness at each level. It is shown in Fig. 6.2

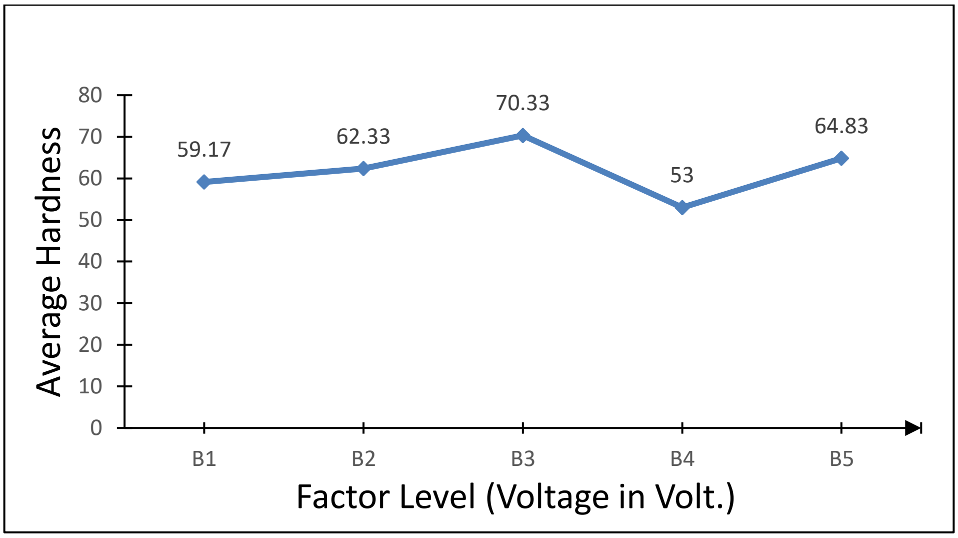


Fig. 6.2 Main Effect Plot 2

- **Raw data ANOVA:**

The values of hardness of experiment 2 with 3 repetitions are used to analyze the variance and it is found that the factor voltage is significant with percentage contribution of 97.56%. The ANOVA analysis is shown in Table 6.4

Table 6.4: Raw data ANOVA for experiment 2

Source	f	S	V	F	F(0.05)critical	P	Comment
Voltage	4	499.47	124.87	100.37	3.48	97.56	Significant
Error	10	12.44	1.244	1		2.44	
Total	14	511.91	126.114			100	

From the main effect plot 2, considering the minimum hardness, the optimum level of factor is found to be trial 4 (current 190A, voltage 24V, Gas flow rate 16LPM).

6.3 Results of Experiment3:

Constant factors: Voltage = 24 V, Current = 190A
Variable factor: Gas flow rate (10, 12, 14, 16, 18 L/min)
Array used: OFAT with 3 repetitions

Hardness data obtained for 3 repetitions are given in Table 6.5

Table 6.5: Experimental data for experiment 3

Voltage (V)	Gas Flow Rate (L/min)	Current (A)	Hardness			Average Hardness
			R1	R2	R3	
24	10	190	60	62	61	61
24	12	190	57	58	55	56.7
24	14	190	52	54	50	52
24	16	190	50	48	49.5	49.17
24	18	190	53	54.5	54	53.83

- **Main Effect Plot:**

Main effect plot is drawn by taking the average values of hardness at each level. It is shown in Fig. 6.3

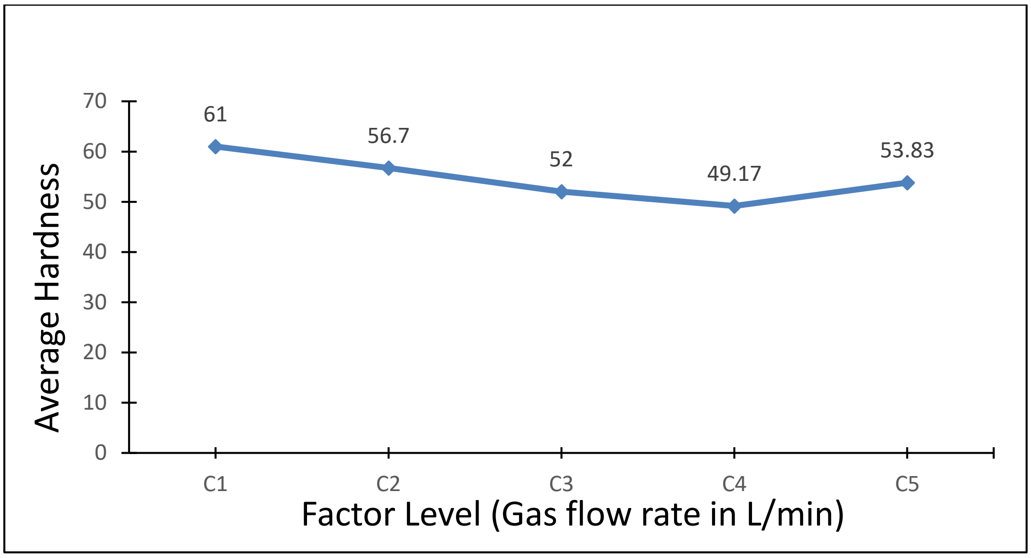


Fig 6.3: Main Effect Plot 3

- **Raw data ANOVA:**

The values of hardness of experiment 3 with 3 repetitions are used to analyze the variance and it is found that the factor feed is significant with percentage contribution of 97.3%. The ANOVA analysis is shown in Table 6.6

Table 6.6: Raw data ANOVA for experiment 3

Source	f	S	V	F	F(0.05)critical	P	Comment
Gas Flow Rate	4	246.57	61.64	92	3.48	97.3	Significant
Error	10	6.7	0.67	1		2.64	
Total	14	253.33	62.31			100	

From the main effect plot 3, considering the minimum hardness, the optimum level of factor is found to be trial 4 (current 190A, voltage 24V, Gas flow rate 16LPM).

6.2 Process Parameters

From the One-Factor-At-A-Time experiment, the following ranges of the input parameters have been considered for investigation as summarised in Table 6.1:

Table 6.1: Process Parameters

Sl.no.	Parameters	Level 1	Level 2	Level 3
1	Welding Current (amp)	170	190	210
2	Welding voltage (volt)	22	24	26
3	Gas flow rate(lit/min)	14	16	18

Taguchi Orthogonal Array L9 with 9 trials is formed as shown below from the determined levels of the factors to find out the optimal factor combination:

Table 5.2: Column Assignment of the Factors

No of Trials	Factors (Columns)		
	Current (A)	Voltage (V)	Gas flow rate (Lpm)
1	170	22	14
2	170	24	16
3	170	26	18
4	190	22	16
5	190	24	18
6	190	26	14
7	210	22	18
8	210	24	14
9	210	26	16

6.2 Experimental Results

The data (Rockwell Hardness) has been analysedfor mean response. The mean response and main effect are recorded in Table 6.2

No of Trials	Curren (A)	Voltag (V)	Gas flow rate (lit/min)	Hardness			Average	S/N
				R1	R2	R3		
1	170	22	14	57	70	45	57.33	21.00371
2	170	24	16	60	55	53	56.00	16.49984
3	170	26	18	54	57	55	55.33	16.62758
4	190	22	16	55	59	60	58.00	13.1527
5	190	24	18	77	71	70	72.67	20.9108
6	190	26	14	67	60	62	63.00	9.852767
7	210	22	18	60	64	62	62.00	4.259687

8	210	24	14	63	64	67	64.67	10
9	210	26	16	59	60	57	58.67	11.02662

6.2.1: Main effect plot

The graphical representation of effect of each level of the process parameters (current, voltage ,gas flow) affecting on surface hardness are discuss below:

a) Main effect plot of welding current:

Fig 6.1 indicates the main effect plot of welding current along abscissa with three levels of current 170A, 190A, 210A; Average responses are shown in the Y-axis.

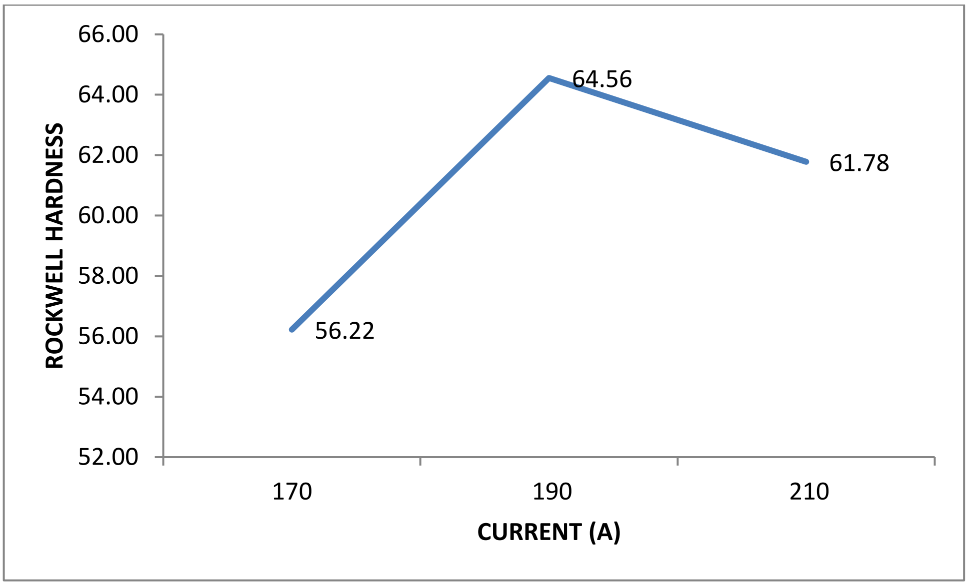


Fig 6.3: Main Effect Plot 4

From the above main effect plot it is observed that the Rockwell hardness increases when the current is increased from 170A to 190A but any more increase in the current causes the Rockwell hardness to decrease.

(b) Main effect plot of welding voltage:

Fig 6.2 indicates the main effect plot of welding voltage with three equal levels of factor (22V, 24V, 26V); Average responses are shown in the Y-axis)

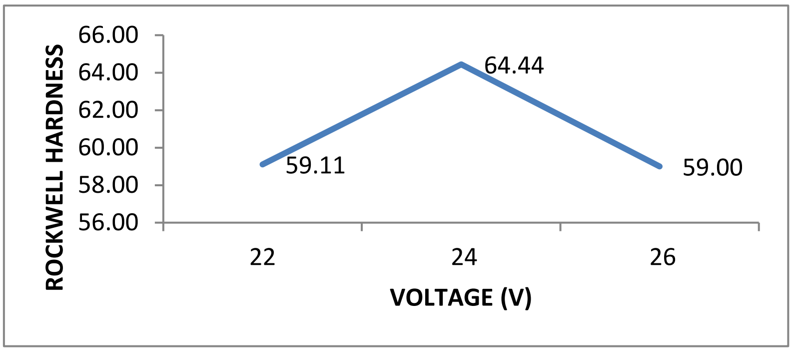


Fig 6.3: Main Effect Plot 5

From the above main effect plot it is observed that the Rockwell hardness increases when the voltage is increased from 22V to 24V but any more increase in the voltage causes the Rockwell hardness to decrease

a) Main effect plot of gas flow (CO_2) rate:

Fig 6.3 indicates the main effect plot of shielding gas flow with three levels (14 lit/min, 16 lit/min 18lit/min); Average responses are shown in the Y-axis)

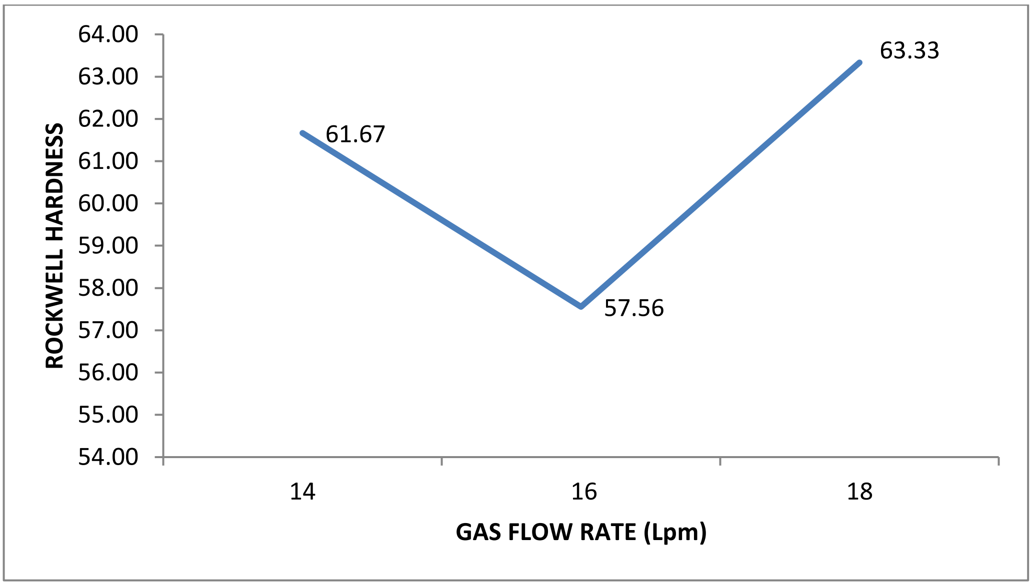


Fig 6.3: Main Effect Plot 6

From the above main effect plot it is observed that the Rockwell Hardness decreases when the gas flow rate is increased from 14lit/min to 16lit/min and increases with increase in gas flow. Gas flow rate is not a significant factor for change in surface Hardness. It is because air cooling cannot able to change the solidification phase drastically.

6.2.2 Raw data ANOVA

Table 5.7 shows raw data ANOVA of experiment (Hardness). From raw data ANOVA analysis it can be seen that calculated F value for current and voltage is higher than tabulated F value at 95% confidence level. Thus it is clear that, current and voltage has a strong influence on the surface hardness. Gas flow rate has no significant effect on mean.

ANOVA Table								
Source	f	S	V	F	S'	P	F(0.05) Critical	Comment
A	2	324.074	162.037	6.562	274.689	23.857	3.493	Significant
B	2	174.296	87.148	3.529	124.911	10.849	3.493	Significant
C	2	159.185	79.593	3.223	109.800	9.536	3.493	Insignificant
e	20	493.852	24.693	1	642.007	55.758		
Total	26	1151.407	353.470			100		

6.2.3 S/N data ANOVA

Table 5.8 shows S/N data ANOVA of experiment (Hardness). From S/N data ANOVA analysis it has been observed that calculated F value for current and voltage are higher than tabulated F value at 95% confidence level. Thus it is clear that both welding current and voltage have significant effect on variation. Gas flow rate has no significant effect on variation. It is observed in the analysis, current has the greatest percentage contribution of 40.71% and voltage has 8.97% on variation . It can be concluded that current has greatest effect followed by voltage and gas flow.

Table 5.8: S/N Data ANOVA of experiment (Hardness)

Source	f	S	V	F	S'	P	F(0.05) Critical	Comment
Current	2	142.605	71.302	3.386	100.493	40.717	6.944	Significant

Voltage	2	19.979	9.990	0.474	-22.133	8.968	6.944	Significant
Gas flow	[2]	[0.108]	Pooled	--	--	--		
e	4	84.223	21.056	1.000	168.446	68.250		
Total	8	246.807	102.348			100.000		

6.2.4 Factor classification

From the above raw data ANOVA (Table 5.7) and S/N data ANOVA (Table 5.8), factors; Current, Voltage and Gas flow can be classified as follows:

Welding Current : Class I (Parameters which affect both average and variation).

Welding Voltage : Class I (Parameters which affect both average and variation).

Gas flow rate (CO_2) : Class IV (Parameters which affect nothing).

6.2.5 Optimum factor combination

From the Main Effect Graph (Fig 6.1, 6.2, 6.3) of factors: Current ,Voltage and Gas flow, the optimum factor combination is

Current =170A,

Voltage =26V,

Gas flow =16Lpm

As L9 OA, has been used hence factor interactions cannot be studied.

6.2.7 Confirmation experiment

Confirmation experiment for all the three optimum factor combinations for Current, Voltage and Gas flow was conducted with two repetitions. In this experiment optimum factor combination, i) Current =170A, ii) Voltage =26V, iii) Gas flow =16lit/minwere tested. All the experiments were conducted on the same machine to cancel out the effect of machine variation during experiment. The results has been summarized below in Table5.9

Table 5.9: Conformation experiment

Trial No	Parameters			Response(Rockwell Hardness)		Average (Rockwell Hardness)
	Current	Voltage	Gas flow	R1	R2	
1	190	24	18	57	58	57.5

6.3 Microstructure Study

The grain structure of both the parent metal and the metal after welding at optimized setting with magnification 500x for both are shown below:

Fig. 6.7 Microstructure of Parent Material (Magnification at 500x)

Fig. 6.8 Microstructure of Material After Welding at Optimised Setting (Magnification at 500x)

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

The effects of various process parameters on the quality of MIG welding have already been discussed in previous chapters. From the OFAT experiment, the initial optimal levels of the factors are found to be 190A current, 24V voltage and 16Lpm gas flow rate. Optimal sets of process parameters that yield optimal quality of welding (Hardness) has also been obtained.

The conclusions summarised below have been drawn for the welding process parameters:

a) Welding current : 180A-210A
b) Welding voltage : 22V-24V
(c) Gas flow rate (CO_2) :14lit/min-18lit/mim.

The experiments has been conducted for obtaining the mechanical property of MIG welding (Hardness) where current, voltage and gas flow have been taken as variable factor (with three levels) for the experiment. The optimum predicted surface hardness is found to be 57.5 (Rockwell) at 170A current, 26V voltage and16Lpm gas flow. The average value of mechanical property (surface hardness) of Confirmation experiment falls within the calculated range.

A minor study on the microstructural change has been done in the experiment. It has been observed that grain size at weld portion seems to be almost similar to that of the parent metal. Hence, hardness seems to be at par with the parent metal.

In the present investigation, interaction effect has not been studied. For economic evaluation other process parameters and responses can be carried out.

REFERENCES

- Boob, A.andGattani, G.K. (2013) 'Study on Effect of Manual Metal Arc Welding Process Parameters on Width of Heat Affected Zone (Haz) For MS 1005 Steel', International Journal of Modern Engineering Research (IJMER) Vol. 3, Issue-3, Pp-1493-1500.
- Kadani, M. and Purohit, G.K. (2013-14) 'Developing A Bead Geometry Based Criterion for Selection of Process Parameters of Metal Inert Gas Welding Using Taguchi Techniques', Journal of Information, Knowledge and Research in Mechanical Engineering, Vol.3, Issue-1, Pp. 589-597.
- Kumar, D.and Jindal S.(2014) 'Optimization of Process Parameters of Gas Metal ARC Welding by Taguchi's Experimental Design Method', International Journal of Surface Engineering & Materials Technology, Vol. 4, No. 1, Pp.24-27.
- Patel, C.andChaudhary, S. (2013) 'Parametric Optimization of Weld Strength of Metal InertGas Welding and Tungsten Inert Gas Welding by Using Analysis of Variance and Grey Relational Analysis', International Journal of Research in Modern Engineering and Emerging Technology, Vol.1, issue-3, Pp. 48-56.
- Roy, R.K. (1990). *A primer On the Taguchi Method, 1st Edition*, Van Nostrand Reinhold, USA.
- Satish,R., Naveen,B. and Rao, V.S.(2012) 'Process Parameter Optimization of Dissimilar Pipe Joints Using GTAW', International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue-3, Pp.2525-2530.
- Satyaduttsinh P.,Desai,V.and Petal, T.M.(2014) 'A Review on Optimization of MIG Welding Parameters using Taguchi's DOE Method', International Journal of Engineering and Management Research Vol.4, Issue-1, Pp.16-21.
- Singh,V.(2013) 'An Investigation for Gas Metal Arc Welding optimum Parameters of Mild Steel AISI 1016 using Taguchi Method', International Journal of Engineering and Advanced Technology (IJEAT),Vol. 2, Issue-6, Pp.407-409.
- Verma,S. and Singh, R.(2014) 'Optimization of Process Parameters of Metal Inert Gas Welding by Taguchi Method on CRC Steel IS 513 GR 'D'', International Journal of Advance Research in Science and Engineering IJARSE, Vol.3, Issue -9, Pp.187-197.
- Vishwakarma,B. , Verma,M. and Mishra,T.K.(2013) 'Investigation of Welding Parameters On Mechanical Properties of Different Welding Joints of Mild Steel', International Journal on Mechanical Engineering and Robotics (IJMER),Vol.1, Issue-1 ,Pp.23-27.

APPENDIX