“AN INVESTIGATION OF TENSILE STRENGTH AND SURFACE ROUGHNESS DURING GAS METAL ARC WELDING OF ALLOY STEEL”

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CERTIFICATE

This is to certify that the thesis work entitled **"An investigation of tensile strength and surface roughness during gas metal arc welding of alloy steel"** submitted by KHAN SARVAREALAM**, Enrollment No.** 1500100115 in partial fulfillment for the award of **Master of Technology** degree in **Mechanical Engineering Department** with specialization in Production and Industrial Engineering, to Integral University, Lucknow (U.P.). He has carried out his thesis work under my supervision and guidance and to the best of my knowledge; the matter embodied in this thesis has not been submitted to any other University/Institute for award of any degree to the candidate or to anybody else.

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ABSTRACT

Many research have been performed in the field of welding and the technology is advancing day by day. MIG welding is a technique of joining to metal pieces in an inert gas environment using a wire electrode constantly fed for producing arc and acts as filler metal for the weld pool. Almost all the metals can be easily welded by MIG welding process from copper to aluminium, low carbon steels and other alloy steels. The present investigation for optimization of MIG welding of Mild Steel is conducted to establish the influence of MIG welding process parameters on tensile strength and surface roughness. From the experimental results it is concluded that welding voltage is the main influencing parameter for tensile strength while welding speed is least influencing for it. In case of surface roughness, welding speed has major dominance while other parameters were less effective.

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Place: Lucknow Khan Sarvarealam

Date:

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INTRODUCTION

1.1 Introduction and Principle

Throughout the World, welding is a major fabrication technology that is used extensively for the construction of structures, buildings and bridges and in the civil, automotive, aircraft, aerospace, petroleum, shipbuilding, and electronic industries. Although welding is an addition technique, it is seen by many as a primitive science. During last several years, it has evolved as an interdisciplinary activity that requires synthesis of knowledge from different disciplines and incorporates the most advanced equipments of various basic engineering and applied sciences. Researchers from different disciplines such as arc and plasma physics, thermodynamics materials science, manufacturing, transport phenomena, modeling, robotics, economics, and from various engineering fields that includes mechanical, chemical, and electrical engineering are currently making new innovations. Considering some major industries, notably automobile, welding is performed primarily by the help of robots or automated assemblies. Moreover, in other industries like shipbuilding where heavy equipment production and small parts fabrication is done, welding is largely done by a manual process done by human operators. Skill training of fresh welders is an important activity both for industries and for the vocational institutions. Training is majorly important for welders who are working on critical items like pressure vessels, naval ships, etc where welding requires carefully inspection. Welding is joining process which has its own advantages and drawbacks. The most obvious advantage is that: Welding is usually the most economical way of joining components in terms of material usage and fabrication costs. Alternative mechanical methods of assembly require more complex shape description (for example drilling of holes and addition of fasteners for example rivets and bolts). The resulting mechanical assembly is usually heavier than the corresponding weldment.

Few draw backs of welding are that most of the welding operations are performed manually and are generally expensive due to labor cost; many welding operations are considered for skilled trades. Most welding processes, involving the use of high energy, are inherently dangerous and the welded joint can suffer from certain quality defects that reduce the strength of the joint.

Steel parts have are now replaced with aluminum alloys in many industries as their lightweight, easy fabrication and machinability, good corrosion resistance and other superior properties are achieved as compared to steel and other metals.

Considering the joining process for those industrial fields, welding is the best suited and easy application method. When the welding of steel alloys are considered, the costs are playing a vital role, hence, gas tungsten arc welding or TIG and gas metal arc welding or MIG techniques are majorly used. GMAW technique, which metal inert gas welding (MIG) is the subsystem, is the most cost efficient method used in industries. Hence for most of the applications, MIG welding is used for joining steel alloys. Although it incorporates several defects during MIG welding such as porosities, hot cracking and so, related with some properties of particularly heat treatable mild steels, these can be reduced by controlling welding parameters and choosing correct filler materials.

Although, due to the nature of welding, strength loss can be observed after welding. After welding, the main strength loss is observed in the heat affected zone and in vicinity. The strength at least in annealed condition of metal can be enough after welding, barely, the places of use are not always allow this situation.

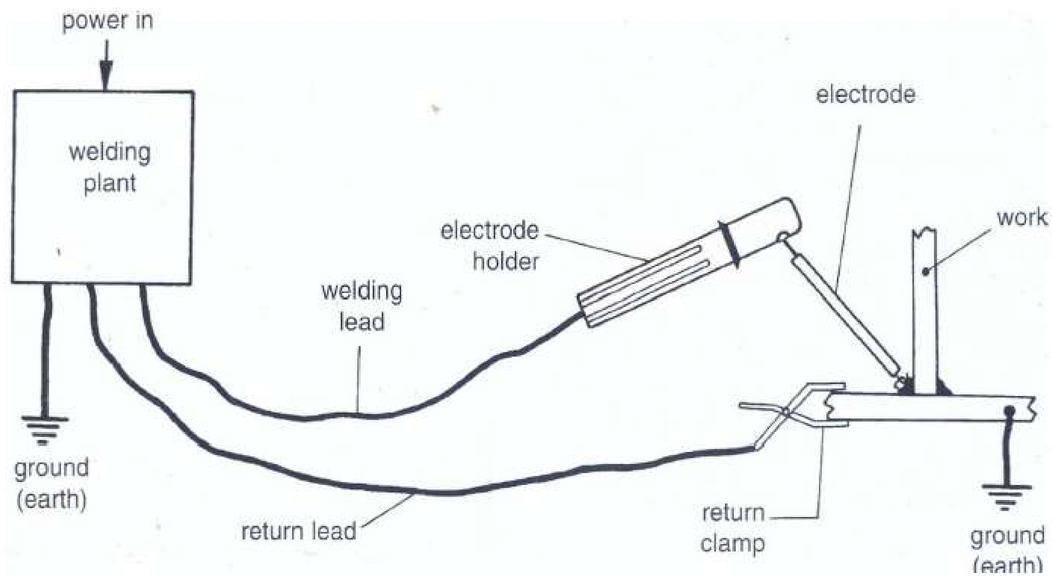

Figure 1.1 Circuit diagram of welding

During welding process, there are different parameters that are needed to be considered so as to obtain the objective characteristic of welding quality. To achieve a perfect arc all the parameters must be in conformity. In MIG welding technique, there are several important factors that are needed to be concern. These process parameters are generally arc voltage, welding current, weld speed, wire feed speed, free wire length, nozzle distance, weld direction, electrode extension, position of welding and the flow rate of gas. Basically, all these welding processes are employed with the objective of obtaining a welded joint and the weld quality with desired process parameters, to have excellent mechanical properties with great quality surface. So as to determine the welding input parameters which will lead to the desired weld quality, Design of Experiment is applied for study, through Taguchi technique which is widely used to develop a mathematical model for the welding process input parameters and the output variables of the weld joint.

1.2. Arc Welding

Arc welding process is a process of welding with a formation of an electric arc between an electrode rod and the metal workpiece by heating of the workpiece metal and causing to melt the filler metal and base metal together and the joint between them is created. This method was initially developed by aluminum and aluminum alloys but afterwards it is also used for steels.

In this study a subtype of arc welding method called Metal Inert Gas (MIG) welding will be used for welding of mild steel.

1.2.1. Metal Inert Gas Welding (MIG)

Metal-inert gas welding (MIG) is a process of joining metals by melting with the heat generated by arc established between a continuously fed filler wire electrode through the wire reel and the metal workpiece that can be seen in Figure 1.1

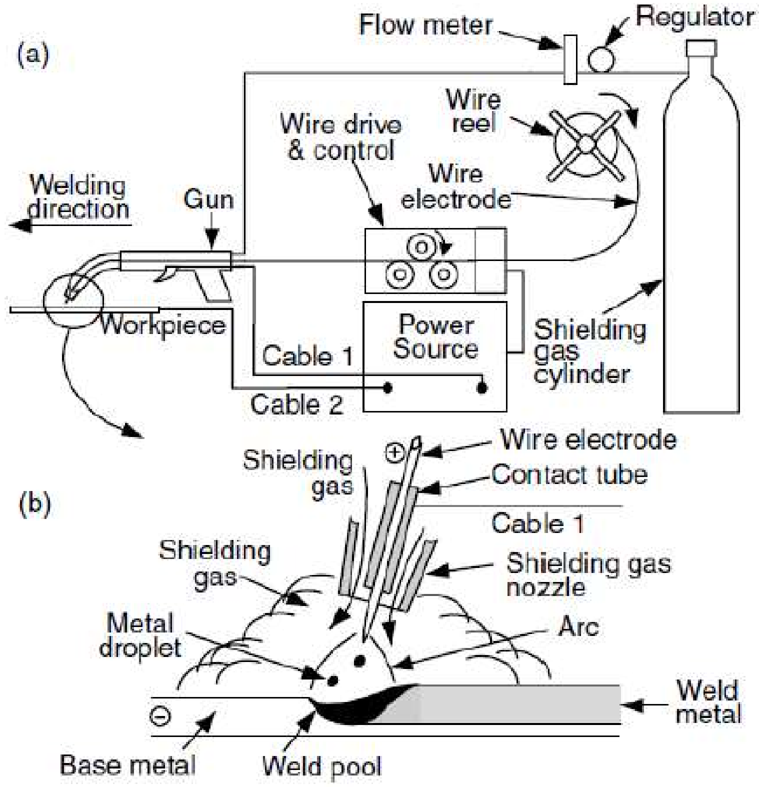

Figure 1.2 MIG welding: (a) overall process (b) welding area enlarged

The molten weld puddle and the arc zone are shielded by inert gases medium of argon or helium or carbon dioxide. Metal inert gas (MIG) is also known as Gas Metal Arc Welding (GMAW) and this method is the most common technique used for mild steels and a smooth metal transfer is observed with low spatter loss and good weld penetrations can be achieved by a stable arc.

Considering the shielding gases, argon, helium or carbon dioxide and their mixtures are used for ferrous and nonferrous metals as well as stainless and alloy steels. Although comparing the arc energies for argon arc, this energy is less uniformly dispersed as compared to helium arc as the lower heat conductivity of argon gas. Hence as a result of this phenomenon, argon arc plasma generally has a very high energy core and it is observed that an outer mantle of lesser thermal energy is seen and by this, a stable, axial transfer of metal droplets through argon arc plasma can be achieved.

1.3. Weld Structure

During the process of welding, when the arc is created, heat is generated in the weld pool and some regions of the base metal are directly affected by this heat generation and some other regions are not affected. With this respect, there are three major regions in the weldment area that can be easily distinguished either with naked eye or made visible with the help of chemical etching. The three weldment regions are called as the Weld Metal, Partially Melted Zone and the Heat Affected Zone (HAZ). Besides these three main regions, the remaining part of the metal can be called as parent metal or base metal which is least influenced by heat generated during welding.

Weld Metal is region which is completely melted and solidified by the electrode, therefore consists of base metal as well as the filler materials. When we increase the number of weld passes, the chemical composition of the weld metal reaches the chemical composition of the filler metal. The boundary that parts the weld metal and the base metal is known as the fusion line (FL) where the temperature of weld metal reaches the liquidus temperature. The region which is affected by the heat evolved by welding process and is between the weld metal and base metal is known as Heat Affected Zone (HAZ). This region starts from fusion line and ends at the point where solidus temperature is reached which is called the Partially Melted Zone (PMZ) where the heat is too low to completely melt tough it is high enough to alter the microstructure.

1.3.1. Heat Affected Zone (HAZ)

Heat Affected Zone (HAZ) is the region found between partially melted zone and the base metal. Hence, it is affected by the high temperatures generated during welding but no melting occurs across HAZ. However, as a result of the heat input, the base metal microstructure is changed and previously gained good mechanical properties are affected in a reverse direection. Therefore, so as to recover the mechanical properties in HAZ, post weld heat treatments are carried out.

Figure 1.3 Setup of MIG welding for the experiments

1.4 The Power Source

The direct current with constant potential power sources are used for most MIG welding processes. This contrasts with TIG and stick electrode welding which uses the constant current power source. A MIG power source provides a relatively constant amount of voltage during the process to the arc. This voltage also determines the length of the arc. When there is a sudden change in welding parameters, or a momentary change in arc length, the power source gradually increases or decreases the current depending on the change in arc length. The burn off rate of wire changes itself so as to restore the original length of the arc. As a result, permanent changes in length of arc are seen by adjusting the output voltage of the power source. The wire-feed speed selected by the operator prior to welding, determines the arc current. It can be easily changed over a considerable scale before the arc length changes much to cause stubbing to the workpiece or may cause the burning back to the guide tube.

1.4.1 Power Source Variables

The arc length must be self-correcting with the constant voltage welding system is desirable for producing stable welding conditions. Specific electrical parameters are required to control the heat of arc, spatter due to welding, etc. These electrical characteristics include voltage, slope, and inductance.

1.4.2 Voltage

It is the voltage across the end of the wire and the workpiece. As voltage drops are encountered in the welding processes, thus the arc voltage are difficult to be directly read on the power source voltmeter. Welding voltage has an important influence on the type of process variation or on the mode of metal transfer. Short arc welding desires relatively lower voltages while the spray arc needs higher voltages. It must be accounted that, too, with increase in welding current and wire burn off, the welding voltage must also be enhanced some as to maintain stability.

1.5 Welding Techniques

Initially, the general welding technique that influences the weld characteristics is position of torch. This generally refers to the technique with which the torch is held with respect to the weld joint. The position is basically narrated from two direction, they are the angle relative to the weld length and the angle relative to the plates. The back hand method generally shows that the torch is positioned such that the wire is feeding in opposite direction to that of arc travel. The filler metal is being fed directly into the weld pool previously deposited. In the forehand technique, the torch is a bit angled such that the electrode wire is fed in the direction same as that of arc travel. Furthermore the filler metal is deposited, for the most part, directly on the weld groove of workpiece. It should be considered that a change in direction of welding is not required to facilitate forehand or backhand welding, but only a reversal in the longitudinal torch positioning. Basically the operator finds that the backhand technique gives a more stable arc with lesser spatter on the workpiece.

1.6 Welding Conditions

The welding conditions should be considered only as a starting point with new applications. It does not represent the only direction in which a certain weld can be done. Modifying the welding conditions will lead to situations caused by differences in the welder’s skills and experience, the joint design and the equipment which are used. So as to achieve the optimal level of welding conditions that fulfills the particular requirements of a newer job, it is always desirable to perform qualifying experiments prior to the production. Although, this is the just a basic point for set a good, stable welding condition and it can be mostly be used for many applications. When there are changes in the welding conditions are required, they must be made carefully so as to achieve better results. All the modifications must be performed one at a time and the noted for future reference. The rules should be fixed to regardless of the welding technique finally chosen. Each table lists all the necessary situations to make a weld, based on the thickness of material, design of joints, and welding position. When referring these tables, there are few important points as below:

1. The voltage listed is the arc voltage and not the voltage read from voltmeter. The arc voltage is measured between the final point of electrical contact in the torch and the workpiece. It is not the voltage shown on the volt meter, that is generally 1.5 to 2.5 volts more depends on the size and length of power cable.
2. The weld size must be equal to the material thickness for fillet welds.
3. The joint designs shown are not the only designs which could be employed for a given material thickness.
4. These tables are on the basis of tip-to-work distance of 3/8 in. (9.4mm) for shorter arc welding and 3/4 in.(19.2mm) for spray arc welding.
5. The vertical welding techniques are basically designed for vertical up travel.
6. The welding conditions were made by use of specific shielding gases. If the shielding gases used are not similar, slight adjustments must be made for these conditions. Talking about welding conditions, a burn-off chart for each wire electrode is shown. With these charts, the wire-feed speed for any value current may be calculated.

1.7 Weld Quality Assurance

Independent of the material that is to be welded, there are some basic precautions which must be undertaken so as to avoid porosity in the weld and to eliminate lack-of-fusion defects.

1. The material to be welded must be as clean and all grease, oil, and other lubricants must be removed. For obtaining best quality welds, all scales, rust and other oxide coverings the work surface must be removed either mechanically or chemically. This is required while welding mild steel.
2. During the welding of carbon steel plate, only use the shielding gas and wire combinations are recommended for the specific variety of steel in use.

3. Basically avoid welding conditions that result in the very rapid weld bead solidification, like very high travel speeds. Porosity is caused when the gas which normally be evolved from the weld metal during slower cooling is trapped.

4. To maintain an adequate amount of shielding gas flow and to protect the welding area from wind and drafts.

5. Keeping the welding wire centered with the shielding gas pattern. Wire curvature is generally the main reason for the wire being off center. This can be avoided by using a wire straighter directly on the wire feeder.

6. During welding from both sides of a sheet and for those part where there has been no penetration of the first weld entirely through the material, confirm that the second pass must deeply penetrates the first pass. Inspect for the first pass that it has entirely penetrated, or where a root gap is used, grind the back side to good weld metal before the second weld pass is performed. This is compulsory when quality welds are required in mild steels, carbon and stainless steel.

7. Avoiding welding conditions that leads to the molten weld metal rolling out in front of the arc. This is the major reason for lack-of-fusion defects, and in particular, downhill welding.

8. During multi pass welding, grinding to a flat surface all weld beads must be done which appear to be peaked and exhibit poor welding.

9. Remove all the small patches of oxide slag found on the surface of weld bead with a file or screwdriver when another weld is to be made over it.

1.8 Joint Design

There are a few general practices that are considered while designing the weld joints. Plate 3/16 inch, (4.8mm) thick or less considers be butt welded with square edges employing the short arc process or rather a low current spray arc (mild steel) when a root gap of 0 to 1/32 inch is maintained. For all cases, a single pass can be employed when a permanent or temporary backup bar is applied. During the welding in the overhead position, the practice usually is to always butt weld with a backup bar. Although, if a backup bar of any kind is not utilized for 1/8 inch thick plate and above, it requires two passes usually one from each side. A bead should overlap greater than the original root gap so as to prevent porosity in centerline and poor fusion. To attain maximum overlap the back hand technique is used on the second side. Plates having 1/4 inch thickness and thicker are generally made single or double Vee grooves with 45° to 70° included angles based on base material and thickness so as to produce quality welds.

1.10 Specific Recommendations for Low Carbon Mild Steel

- Short arc welding should be used while welding thin materials in the flat position
- Either CO_2 or Ar-CO_2 mixtures must be used for arc stability, weld bead shape, minimal spatter thus resulting in better mechanical properties of the weld.
- While in case of spray arc welding, Ar-O_2 and Ar-CO_2 mixtures may be employed. Spray arc welding must be used in the flat position for single pass or multi-pass welding while used for thicker material.
- For low currents, vertical welds can be done using a downhill arc travel. They can use either backhand or forehand welding technique for welding in the flat position without any adjustments to the conditions. Basically, the forehand technique provides better visibility to the welder of the weld joint and a flatter weld puddle. While in case of backhand technique, it yields better penetration and is sometimes observed to be easier by the inexperienced welder.
- Moreover, the vertical up and the vertical down technique can also be used, but are not interchangeably. The travel speeds of vertical down welding are much more than that of vertical up. Vertical down is usually used for welding thin sections (up to 1/4 inch thick) where speed is important. Vertical up welding is preferred for welding thicker material sections where quality and strength are basic requirements.

2

LITERATURE REVIEW

2.1 Literature Review

Major studies have been under research by various researchers in the domain of welding technology. The researchers have performed investigations giving depth knowledge and insight knowledge of present welding technology. This investigation aims to optimize and improve weld joint tensile strength and surface finish using Taguchi technique. Relevant literature surveys on MIG welding have been performed and the inspiration of the findings by the various previous researches are presented and discussed in this chapter.

Sindiri Mahesh and Velamala.Appalaraju [1] through their experimentations concluded that with increase in the levels of the selected parameters for MIG welding of AISI 1050, the strength of welded joint is enhanced and all the selected parameters have impact on the strength of the joint.

Sanjay A. Swami et al [2] carried out the research and it was found that the gas flow rate has greater contribution in increasing the tensile strength of welded joint followed by welding current & gas combination. Gas flow rate has 93% contribution followed by welding current & gas combination An empirical relation is developed for correlating the tensile strength of welded joint with the process parameters. The correlation coefficients found close to 0.9 signifies that the developed model is significant. Therefore this model can be efficiently used for the prediction of the responses within the domain of the welding parameters.

Manoj Singla et al [3] by their study concluded that the Welding current was found to be most influencing variable to WDA. When a constant heat input is provided, and the welds are made using electrode negative polarity having a small diameter electrode and low voltage with low welding speed, it produce large bead area. Most effective design was found for two level fractional half area fractional designs to quantify to main and interaction influences of variable on the weld bead area.

Pushpendra Kumar Sharma et al [4] through their investigation found that the Tensile strength of weld increase in proportion to the weld bead width, because of the higher MIG parameters we observe wider weld head during the construction weld bead hardness. Hardness values are similar in both of them.

Biswajit Das, B. Debbarma et al [5] through their research concluded that the higher voltage (> 26.5 V) causes abrupt rise in penetration depth value, whereas very high current (> 150 A) also causes the same. Very high welding speed (> 0.16 m/min) cause a decrease in penetration depth.

H.J. Park et al. [6] through their investigation for optimizing the wire feed speed against the welding speed while performing MIG lap joint fillet weld of 1.6 mm on aluminum alloy. The experiments were carried with various wire feed speeds and the bead characteristics were evaluated. The wire feed speed was basically optimized for various welding speeds in their research.

Vikas Chauhan et al. [7] carried an investigation for studying the dissimilar metal plates joined by MIG welding. Current, voltage and travel speed were chosen for the analysis. Taguchi technique was used to plan the experiment design to acquire the data. The influence of each factor was examined by using the ANOVA. **S.Sivakumar et al.[8]** through their study investigated the influence of different factors on welding penetration, micro structural and measurement of hardness for mild steel of 6mm thickness by using MIG welding.

K. Abbasi [9] in their study found that when speed is taken as variable parameters, penetration depth increases with increase in speed upto an optimum value of 1450 mm/min, beyond that speed penetration starts decreasing. These researchers also found that when the heat input is considered, the depth of penetration will increase with heat input till 109 J/min. Beyond this value, the penetration depth will decrease.

Patil et al. [10] during the investigation while finding the effect of welding current, welding voltage, welding on the ultimate tensile strength (UTS) of AISI 1030 mild steel material during welding process used Taguchi method for designing the experiments and analysis of variance was employed for studying the welding characteristics of material and optimize the welding parameters.

Chandresh N. Patel et al. [11] in the study of design of experiment methods adopted the grey relational analysis (GRA) optimization technique, where the input parameters for MIG welding selected were welding current, wire diameter and wire feed rate and the performance measure was hardness.

Another investigation carried by **Ajit Hooda et al. [12]**, they developed a RSM model for predicting tensile strength of inert gas metal MIG welded AISI 1040 medium carbon steel. Welding voltage, current, and wire speed and gas flow rate were chosen as the parameters of the machine. RSM methodology was applied for optimizing the MIG welding process parameters so as to attain the maximum yield strength of the joint. **S.Utkarsh et al. [13]** in their investigation studied the influence of input parameter such as welding current, welding voltage, gas flow rate in l/min and welding speed in m/min so as to study the Ultimate Tensile Strength(UTS) of st-37 low alloy steel material in MIG Welding (GMAW). Experiments were carried out by using L9 orthogonal array. **Sudesh Verma et al. [14]** investigated the optimization of input parameters of metal inert gas welding by using Taguchi Method of experiment design for bead width and bead height. They found that each parameter has influence on the output parameters.

Srivani Valluru et al [15] in their investigation reveals that Weld Area Hardness is much higher than parent metal hardness and less than Heat affected zone Hardness.

Kanwal et al. [16] investigated for optimization of MIG welding parameters for Hardness using Taguchi method. Welding speed, current and voltage were taken as welding parameters. Aluminum alloys of grades 6061 and 5083 were the materials taken into consideration for their study.

Amit Pal et al. [17] in their investigation showed the effect of welding voltage, filler wire rate and v-butt angle for the strength of weld joint and the elongation obtained during the tensile test. All these parameters do not have similar effect on welding quality. Taguchi Orthogonal array has been used to optimize the weld quality of medium carbon steel. The ANOVA was performed to predict the percentage influence of each factor on results.

Jay Joshi et al. [18] carried the investigation of design of experiment method of the experimental data for optimization by the grey relational analysis method. For the study the input parameters for MIG welding selected were welding current, gas flow and wire feed rate while the output parameter selected was tensile strength. **B. Mishra et al.[19]** presented the influence of welding current, welding voltage, welding speed for the penetration depth of AISI 1020 steel while MIG welding. Taguchi method has been employed to plan the array of experiments. The data was acquired and optimized for various welding parameters and for the process. Finally they conducted the conformations tests for getting the difference between the actual and predicated values so as to examine the effectiveness during the analysis of penetration.

Nur Azhani Abd Razak et al. [20] through their research presented the corrosion behavior of low carbon steel while MIG welding at various welding voltages and filler materials. Butt joint were made on the specimens using the metal inert gas (MIG) process with welding voltage ranging between 19 to 21 V having 1 V interval, and the filler materials considered for the study were ER 308L and ER 70S-6 with 1.2 mm diameter. **Pranesh B. Bamankar et al [21]** studied the influence of MIG welding parameters on depth of penetration and bead width. They undertook experiments using welding current, arc voltage and welding speed for mild steel with 12 mm thick plate for studying the influence of these parameters on penetration depth. Taguchi method for design of experiments was used and L9 orthogonal array was selected considering three factors and three levels.

2.2 Problem Formulation

On the basis of above literature survey the parameters selected for this thesis work are welding voltage, welding current and welding speed so as to analyze the tensile strength and surface roughness using Taguchi L9 orthogonal array

i. To investigate and analyze parameter in MIG welding for tensile strength

ii. To investigate and analyze parameter in MIG welding for surface roughness

3

TAGUCHI APPROACH AND ANOVA

3.1 Taguchi Experimental Design

The Taguchi method incorporates the reducing of the variation in a process by robust design of experiments. The main objective of this method is to achieve high quality product at a lower cost to production. This Taguchi method was found a researcher called Genichi Taguchi. He developed this method for designing the experiments for investigating how different factors influence the mean and variance of a process performance measure that defines how good the process is functioning. This experimental design which was proposed by Taguchi involves the use of orthogonal arrays for organizing the parameters affecting the process and the optimum levels at which they should be varied. Instead of testing all possible combinations like that in the case of the factorial design, the Taguchi method only tests a pairs of combinations. This will allow the collection of the necessary data for determine what factors are mostly affecting the product quality with a least amount of experimentation, thus it will save time and resources. The Taguchi method is best used for intermediate number of variables (3 to 50), when few interactions are between the variables, and when only a few number of variables contribute significantly.

3.2 Design of Experiment

Conventional experimental design methods were too complex and were not so easy to use. Large numbers of experiments were carried out when the number of process parameters are more. Thus to solve this problem, Taguchi method uses a special design of orthogonal arrays so as to study the entire parameter space by using only a small number of experiments.

These orthogonal arrays are basically special standard experimental design which requires only a least number of experimental trials for finding the main factors influence on output. Before opting for an orthogonal array, the lowest number of experiment to be conducted are fixed which is based on the formula below

N Taguchi = 1+ NV (L – 1)

N Taguchi = Number of experiments to be conducted

NV = Number of parameters

L = Number of levels

In this work

NV = 3 and L = 3, Hence

N Taguchi = 1+ 4 (3-1) = 9

Therefore a minimum of 9 experiments are to be conducted. According on this, orthogonal array are to be selected that has at least 9 rows that is 9 experimental runs will be carried.

The following standard orthogonal arrays are commonly used to design experiments:

2-Level Arrays: L4, L8, L12, L16, L32

3-Level Arrays: L9, L18, L27

4-Level Arrays: L16, L32

For the present work L9 orthogonal design is sufficient. It will require a maximum of 27 experiments for optimizing the parameters. Taguchi experimental design of experiments suggested L9 orthogonal array, where only nine experiments are sufficient for optimizing the parameters. Based on these influencing factors, the variables are also assigned at columns in the orthogonal array. The last column is left as dummy, but none of the row should be left out. Once the orthogonal array is opted, the experiments are selected according to the level combinations. It is much important that all experiments are successfully conducted. The performance parameters are noted for each experimental run for analysis purpose.

Taguchi Orthogonal Array Design - L9 (3*3)

Table 3.1 depicts the Taguchi orthogonal array selector that shows the set of orthogonal array for the parameters and their respective levels. For three parameters and three levels L9 orthogonal array is selected from the array selector.

.Table 3.1 Array Selector

	PARAMETERS											
LEVELS		2	3	4	5	6	7	8	9	10	11	12
	2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16
	3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27
	4	L16	L16	L16	L16	L32	L32	L32	L32	L32		
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50

Table 3.2 Levels of process parameters used in Taguchi L9 Orthogonal Array

Experiment Number	Levels		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3.3 Signal to Noise Ratio

For Taguchi's design method, the design parameters (the factors that can be easily controlled by the designers) and noise factors (the factors that cannot be easily controlled by the designers, like environmental factors) are considered as influencing for the product quality. The Signal to Noise ratio is utilized in this analysis that takes both the mean and the variability of the experimental values into account. The S/N ratio basically depends upon the quality characteristics of the process to be optimized. Generally, there are three categories of performance characteristics for the analysis of the S/N ratio; they are, the lower-the-better, the nominal-the-better, and the higher-the-better. The S/N ratio for each response is usually computed differently according to the category of the performance characteristics and thus regardless of the category the larger S/N ratio will correspond to better process performance characteristic. For present study the material removal rate factor is the-higher-the-better performance characteristics. Once all of the S/N ratios have been tabulated for each run of an experiment, Taguchi depicts a graphical approach for analyze the data. For graphical approach, the signal to noise ratios and average responses are plotted for each parameter against each of its levels. The graphs, higher the better values were selected and finally the confirmation tests were conducted.

3.4 Proceedures of Taguchi Method

The breif structure of taguchi method is as follows

- Identifying the objective
- Selecting the factors
- Identifying uncontrollable factors and running test conditions
- Selecting of levels for controllable and uncontrollable factors
- Calculating the total DOF (degree of freedom)
- Selecting suitable orthogonal array
- Assigning factors to column
- Executing experiments as per the trial conditions in array
- Analyzing the obtained results
- Confirming the results

3.5 Application of S/N Ratio

The change in the product's quality characteristics which is under investigation, in response to a factor introduced in design of experiment is basically the signal of desired effect. Although, when experiments are conducted, there may be numerous external parameters which are not designed into the experiment and may influence the outcome of the experiments. Usually the noise factors are these external factors and their effect on the results of the quality characteristic under experiment is known as noise. The signal to noise ratio is the source of measuring the sensitivity of the quality characteristic which is investigated in a controlled environment, to those external dominating factors (known as noise factors) which are not under control. The concept of S/N ratio was originated in the electrical engineering field. Taguchi effectively applied this theory to achieve the optimum level of parameters from the experiments.

The aim of carrying experiments is always to find the highest possible S/N ratio for the result. A higher value of S/N ratio shows that the signal is much high than the random influence of the noise factors. Product design or process operation consistent with highest

S/N ratio, always yields the optimum quality with minimum variance. The S/N ratio is designed to measure the quality characteristics.

The Signal to Noise ratio basically expresses the scatter around a specific target value. Scatter is smaller for larger ratios. Having knowing the S/N ratio value of the samples before and after the experiment, Taguchi's loss function is used for estimating the potential cost saving from the improved product.

3.6 Advantage of S/N Ratio over Average

For analyzing the influence of experiments involving multiple runs, the use of signal to noise ratio over standard analysis is preferred. Analysis using the signal to noise ratio will offer the following advantages:

1. It will provide guidance for selecting optimum level parameter based on least scatter around the target and also on the average value close to the target.
2. It will offer objective comparison between two sets of experimental data having variation around target and the deviation of the average data from the target value.

3.7 Role of ANOVA

Taguchi replaces full factorial experiment method with a lean, low cost, quicker, partial factorial experiment. Taguchi's design for the partial factorial is based on specially developed OA's. Since the partial experiment is just a sample of the full set of experiment, the analysis of the partial experiment must be included by an analysis of the confidence that must be placed in the results. Analysis of Variance is routinely used that provides a measure of confidence. This technique does not directly analyze the data, but instead determine the variance of the data. The confidence is generally measured from the variance.

This analysis provides the variance for controllable and the noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. This is second benefit of this methodology.

3.8 Analysis of Variance (ANOVA)

Sir Ronald Fisher in the 1930's developed this methodology to interpret the results from agricultural experiments. It is not a complicated method but has a lot of mathematics associated with it. ANOVA is a statistically based methodology and an objective decision-making tool for determining and differentiating the average performance of groups of items tested.

3.9 Tables for Taguchi Design of Experiment

Tables for Taguchi design of experiment are shown below:

Table 3.3: Process Parameters and their levels

S.No.	Parameters	Units	Level 1	Level 2	Level 3
1	Welding Voltage	V	16	20	24
2	Welding Current	A	100	150	200
3	Welding Speed	mm/sec	5	10	15

Table 3.4: Experimentation L9 Orthogonal Array

S.No.	Welding Voltage	Welding Current	Welding Speed
1	16	100	5
2	16	150	10
3	16	200	15
4	20	100	10
5	20	150	15
6	20	200	5
7	24	100	15
8	24	150	5
9	24	200	10

4

EXPERIMENTATION

4.1 Experimental Setup

ESAB MIGMATIC MIG welding machine is used for the present thesis to weld the samples. The machine is as shown in the figure 4.1 on the next page while the specifications of the machine are shown below. MIG welding uses a electrode in form of wire through the wire reel that is constantly fed for producing arc and also serve the purpose of filler metal. Inert gas provides an medium for sound weld. The machine was available at Punjab Body Builder, Sarojini Nagar Industrial Area Lucknow.

Table 4.1 Technical Specifications of MIGMATIC 250

POWER SOURCE	MIGMATIC 250
Mains supply, Ph x V, Hz	3 x 415, 50
Open circuit voltage, V DC	16 – 34
Welding current range, A	40 – 250
Max. continuous welding current	
At 60% duty cycle, A	250
At 100% duty cycle, A	190
Voltage control steps (single knob)	10
Spot welding time, sec	0.2 – 2
Interval time, sec	0.2 – 2
Insulation class	H
Type of cooling	Forced Air
Dimensions, l x w x h, mm	620 x 390 x 580
Weight, Kg	78

WIRE FEEDER	MIGMATIC
Drive system	DC motor
Speed control	Stepless
Feed mechanism	Double roll quick changeover type
Wire feed speed, m/min	1.5 – 22
Wire diameter, mm	0.8 – 1.2
Wire type	MS
Weight, Kg	6

Figure 4.1: ESAB MIGMATIC 250 MIG welding machine

Figure 4.2: Welding of specimens on MIGMATIC 250 machine

Figure 4.3 MIGMATIC 250 machine panel showing parameters

4.2 Work Piece Material

The material used for the present work is Bright Mild Steel with specification of 8 mm thickness and 10 mm diameter.

Table 4.2 Properties of Mild Steel

Density g/cm³	Melting Point ºC	Yeild strength MPa	Elastic modulus Gpa	Possion's Ratio	Brinell Hardness
7.85	1427	510	200	0.26	217

Table 4.3 Chemical composition of the workpiece material (Mild Steel) by weight

Material	Fe	Mn	C	Cu	Si
% Composition	98.00	1.03	0.25	0.20	0.28

Figure 4.4: Mild Steel welded work pieces

Preparation of Work Samples

Figure 4.5 Mild Steel Flat Bars

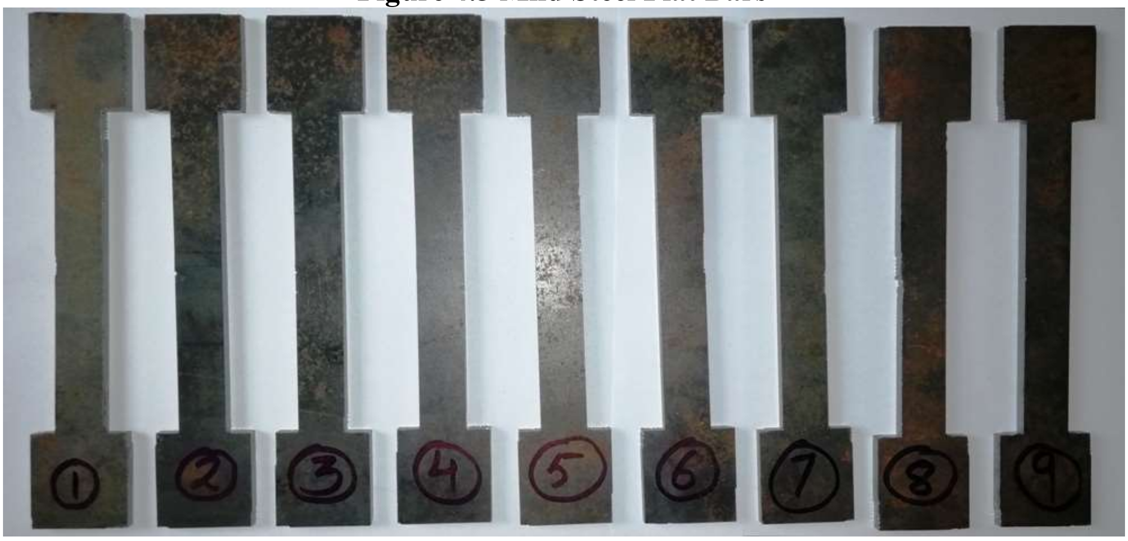

Figure 4.6 I-shaped specimens of MS bar prepared on laser cutting machine

4.3 Surface Roughness

The surface roughness of the welded bead surface had been measured using Roughness test JIS1994 gauss standard. Lower surface roughness of the welded bead surface was the preferable criteria that put into measured. Definitions and indications for surface roughness parameters (for industrial products) are specified. They are arithmetical mean roughness (Ra), maximum height (Ry), ten-point mean roughness (Rz), mean spacing of profile irregularities (Sm), mean spacing of local peaks of the profile(S) and profile bearing length ratio(tp). Surface roughness is given as the arithmetical mean value for a randomly sampled area. Mean center line roughness (Ra) is defined in the annexes of JIS B 0031 and JIS B 0061. A portion stretching over a reference length in the direction in which the average line extends is cut out from the roughness curve. In this lab testing, samples of single and overlap weld beads were inspected using Mitutoyo SJ-400 surface roughness machine. Data are measured at the top pitch of the weld bead. All data are measured 3 times for each sample at the 3 different pitches. The machine is set to follow JIS 1994 standard (Misumi Corporation, 2014). Figure 3.7 shows the machine for the roughness test.

Figure 4.7: Mitutoyo SJ-400 machine

4.4 Tensile Testing

Tensile testing was perfomed on UTM machine. The specimen was clamped on the UTM machine and tensile load was applied on it. On application of tensile load the specimen elongated and after a period of time when the load reaches a maximum value, the specimen breaks from the point where MIG welding was performed. This maximum tensile load is noted and in combination with the area of application of tensile load, the ultimate tensile strength is calculated for each specimen.

Figure 4.8 UTM Machine

Figure 4.9 Specimen before tensile loading on UTM

Figure 4.10 Specimen after breaking on UTM machine

5

RESULT AND DISCUSSION

5.1 Calculation for Tensile Strength

The tensile strength of the welded joint is calculated using universal testing machine (UTM). Tensile load is applied on the specimen and the ultimate tensile load is noted at which the welded joint breaks. By using the value of maximum tensile load and area subjected to tensile loading, the value of tensile strength is calculated. The calculation of tensile strength is as follows:

$$\textbf{Area subjected to tensile loading for specimen} = 3800\ mm^2$$

$$\textbf{Maximum tensile load for Specimen 1} = 1910.74\ kN = 1910.74 \times 10^3\ N$$

$$\textbf{Tensile Strength} = \frac{\textbf{Maximum tensile load}}{\textbf{Area subjected to tensile load}}$$

$$Tensile\ Strength\ of\ Specimen\ 1 = \frac{1910.74\ \times 10^3}{4150} = 460.42\ N/mm^2$$

Table 5.1: Calculation for Tensile Strength

Exp. No	Welding Voltage	Welding Current	Welding Speed	Tensile Strength N/mm^2
1	16	100	5	460.42
2	16	150	10	463.1
3	16	200	15	467.5
4	20	100	10	461.87
5	20	150	15	466.45
6	20	200	5	471.13
7	24	100	15	470.97
8	24	150	5	479.1
9	24	200	10	481.97

The above table 5.1 depicts the calculation for tensile strength for the MIG welded specimens as per L9 orthogonal array.

5.1.1 Calculation of S/N ratio for Tensile Strength

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for tensile strength

LARGER IS BETTER condition is opted. The equation for the calculation of S/N ratio for tensile strength is:

$$S/N_{LB} = -10 \log \left(\Sigma \left(1/y_i^2\right) \right)$$

Table 5.2 Calculation of S/N ratio for Tensile Strength

S.No	Tensile Strength	Signal to noise ratio (db)
1	460.42	53.2631
2	463.1	53.3135
3	467.5	53.3956
4	461.87	53.2904
5	466.45	53.3761
6	471.13	53.4628
7	470.97	53.4599
8	479.1	53.6085
9	481.97	53.6604

5.1.2 Calculation of Mean S/N ratio for Tensile Strength

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1+nf_2+nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor. nf_1, nf_2, nf_3 are S/N ratio for factor f at level u

The factors which affect the machining parameters show in the table as their respective ranks. Rank of the parameters depends on the value of delta. If the delta value of one parameter is higher than the other that shows first rank. Higher value of S/N ratio of each factor shows the optimal level of the factor. Welding voltage shows the main effect in the below response table followed by welding current. Weld speed is least effective as compared to other parameters.

Table 5.3 Calculation of mean S/N ratio for Tensile Strength

Level	Welding Voltage	Welding Current	Welding Speed
1	53.32	53.34	53.44
2	53.38	53.43	53.42
3	53.58	53.51	53.41
Delta	0.25	0.17	0.05
Rank	**1**	**2**	**3**

Delta = (Highest mean S/N Ratio – Lowest mean S/N Ratio)

5.1.3 Analysis of Variance for Tensile Strength

The following table 5.4 shows ANOVA of Tensile Strength conducted on MINITAB 16.0. The result shows that the contribution of welding voltage is most and is 70.09%. Welding current is the second most influencing parameter for tensile strength with a contribution of 28.05% while welding speed is the least dominating parameter and has negligible influence on tensile strength having a contribution of only 1.26%.

Table 5.4 ANOVA of Tensile Strength

Source	DOF	SS	Adj MS	F Value	Contribution
Welding Voltage	2	312.868	156.434	116.94	70.09%
Welding Current	2	125.237	62.618	46.81	28.05%
Welding Speed	2	5.631	2.815	2.10	1.26%
Error	2	2.675	1.338		0.60%
Total	8	446.411			100%

At least 95% confidence

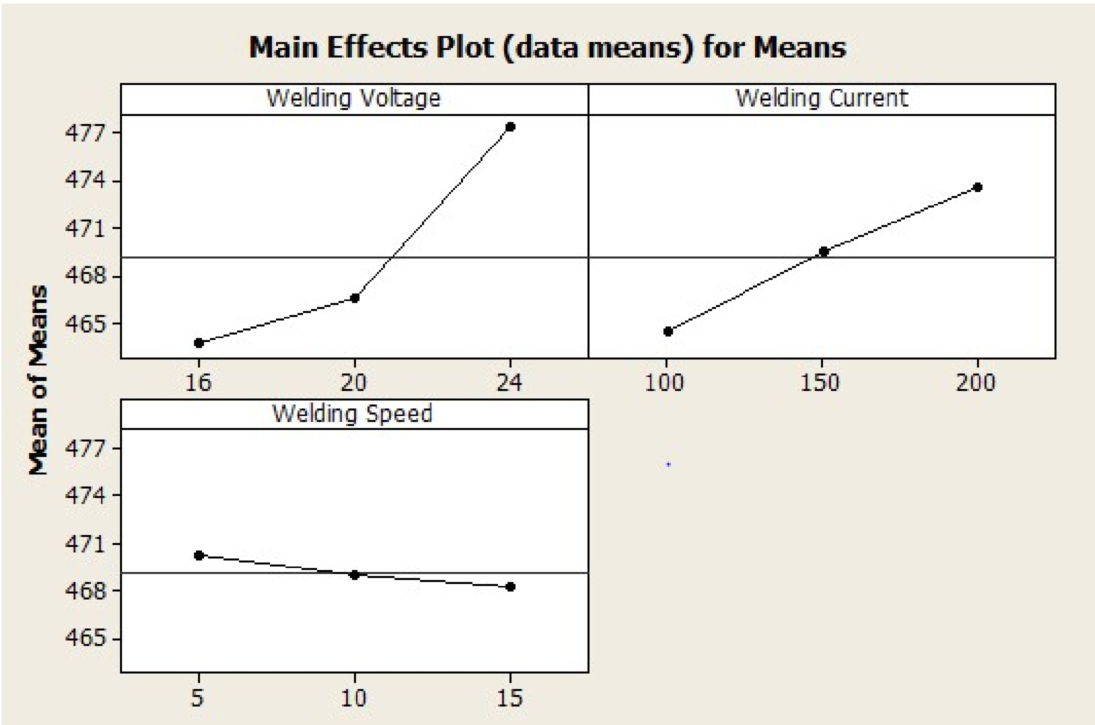

Figure 5.1: Main effect plot for Tensile Strength

Figure 5.1 presents the main effect plot for Tensile Strength. It shows that the Tensile Strength increases with both welding voltage and welding current. Welding voltage has major influence on tensile strength followed by welding current similar to that obtained by Sindiri Mahesh [1]. An increasing trend is observed for tensile strength with welding voltage [1]. Moreover, with increase in the level of welding current, the tensile strength is observed to follow an increasing trend but reverse is observed by Sindiri [1].

Welding speed is the least influencing factor for tensile strength [1] and has negligible contribution of only 1.26%.

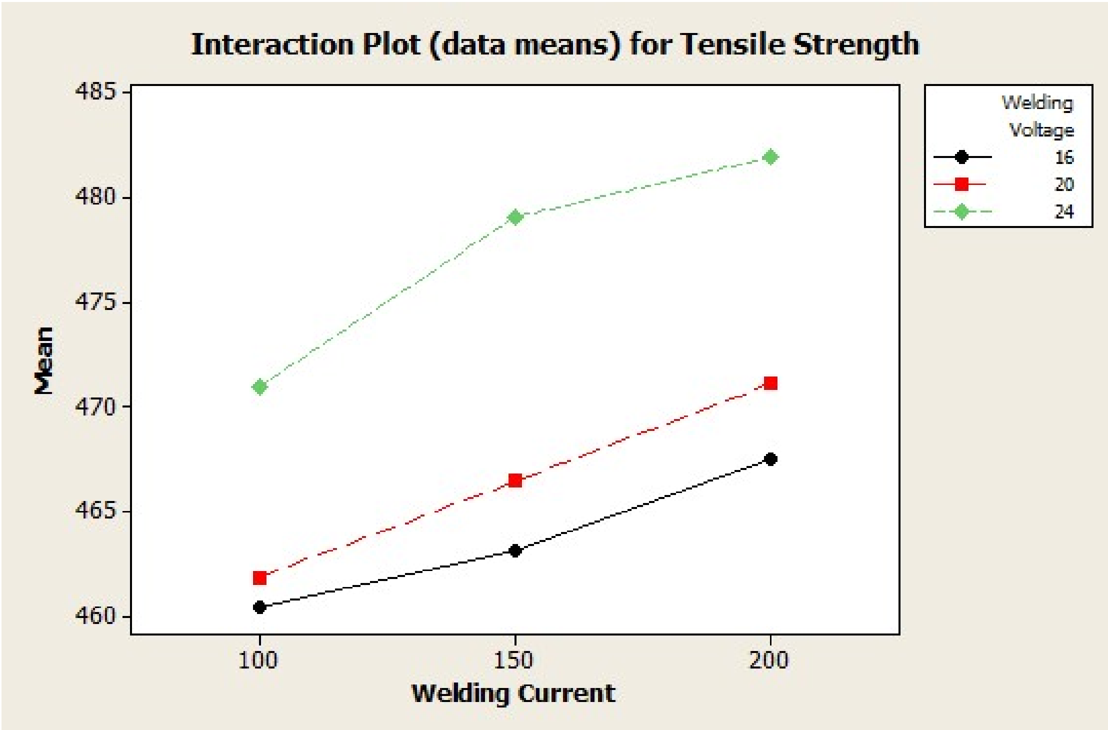

Figure 5.2: Interaction plot for parameters and Tensile Strength

Figure 5.2 depicts the interaction plot between tensile strength and welding current at different levels of welding voltage. The plot depicts that the tensile strength increases with MIG welding parameters at all levels. The tensile strength increases with welding current at every level of welding voltage.

Optimal Levels of Parameters for Tensile Strength

- **Welding Voltage : 24 V**
- **Welding Current : 200 A**
- **Welding Speed : 5 mm/sec**

5.2 Calculation for Surface Roughness

For calculation of Surface Roughness, the workpiece is placed below the surface roughness tester and the stylus of the tester is moved over the machined surface. By the motion of stylus on the machined surface, an average value of surface roughness is indicated by the tester on its digital meter. That value is jotted down for various specimens. Three surface roughness reading were taken for each specimen and their average was noted. These values are depicted in the following table 5.6.

Table 5.5: Calculation for Surface Roughness

Exp. No	Welding Voltage	Welding Current	Welding Speed	Surface Roughness (Ra)
1	16	100	5	3.71
2	16	150	10	1.52
3	16	200	15	1.78
4	20	100	10	1.23
5	20	150	15	2.59
6	20	200	5	3.68
7	24	100	15	2.41
8	24	150	5	2.79
9	24	200	10	3.93

5.2.1 Calculation of S/N ratio for Surface Roughness

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for surface roughness SMALLER IS BETTER condition is opted. This is considered as the defect and it should as low as possible.

The equation for the calculation of S/N ratio for Surface Roughness is:

$$S/N_{SB} = -10 \log \left((1/n) \Sigma y_i^2 \right)$$

Table 5.6 Calculation of S/N ratio for Surface Roughness

S.No	Surface Roughness	Signal to noise ratio (db)
1	3.71	-11.3875
2	1.52	-3.6369
3	1.78	-5.0084
4	1.23	-1.7981
5	2.59	-8.2660
6	3.68	-11.3170
7	2.41	-7.6403
8	2.79	-8.9121
9	3.93	-11.8879

5.2.2 Calculation of Mean S/N ratio for Surface Roughness

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1+nf_2+nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

Table 5.7 Calculation of mean S/N ratio for Surface Roughness

Level	Voltage	Current	Speed
1	-6.678	-6.942	-10.539
2	-7.127	-6.938	-5.774
3	-9.480	-9.404	-6.972
Delta	2.803	2.466	4.765
Rank	**2**	**3**	**1**

5.2.3 Analysis of Variance for Surface Roughness

The following table 5.9 shows ANOVA of Surface Roughness. The result shows that the contribution of welding speed is most and is 33.29%. Welding current is the second most influencing parameter for tensile strength with a contribution of 14.77% while welding voltage is the least dominating parameter and has a contribution of only 10.32%.

Table 5.8 ANOVA of Surface Roughness

Source	DOF	SS	Adj MS	F Value	Contribution
Welding Voltage	2	0.821	0.411	0.25	10.32%
Welding Current	2	1.174	0.587	0.35	14.77%
Welding Speed	2	2.647	1.323	0.80	33.29%
Error	2	3.307	1.654		41.62%
Total	8	7.949			100%

At least 95% confidence

Optimal Levels of Parameters for Surface Roughness

- **Welding Voltage: 16V**
- **Welding current : 150A**
- **Welding speed : 10 mm/sec**

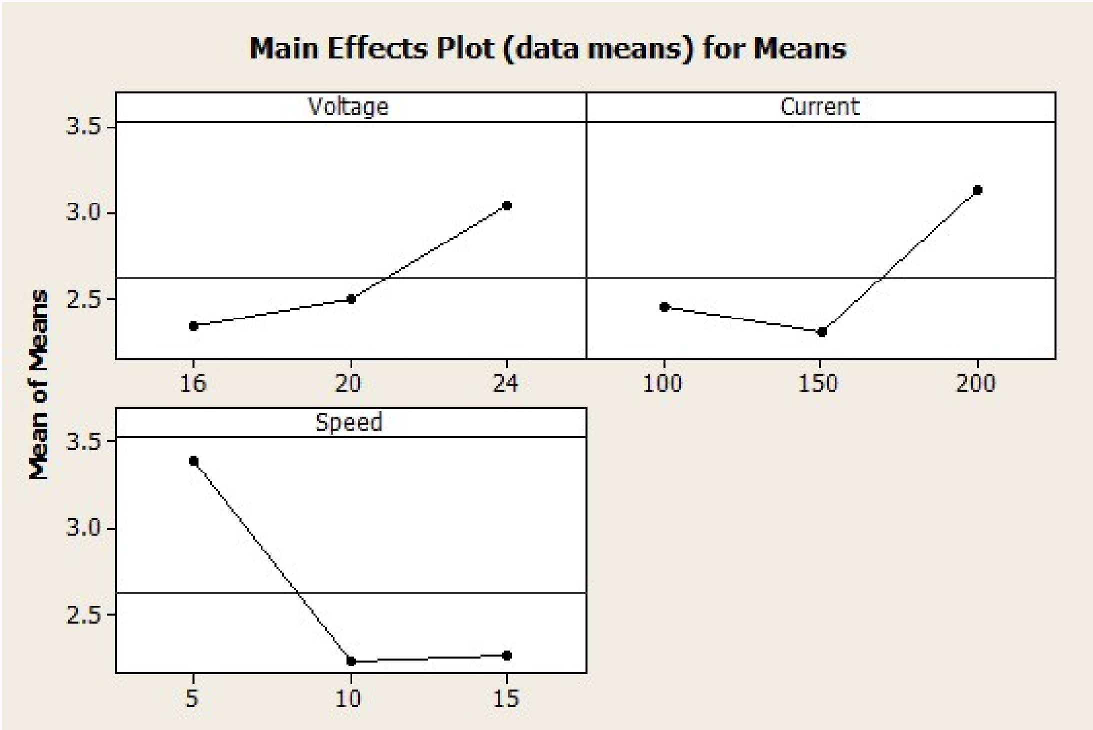

Figure 5.3: Main effect plot for Surface Roughness

The figure 5.3 illustrates that the surface starts to degrade with increase in levels of welding voltage. As we increase the level of welding voltage poor surface finish is obtained. For welding current, the surface roughness first improves but with further increase in the value of welding current the surface gets degraded. Welding speed is the most dominating parameter for surface roughness of MIG welded joint for the present set of parameters. The graph shows that the surface roughness first reduces with increase in the value of welding speed. But on further increase in level of welding speed above 10 mm/sec, the surface roughness slightly increases.

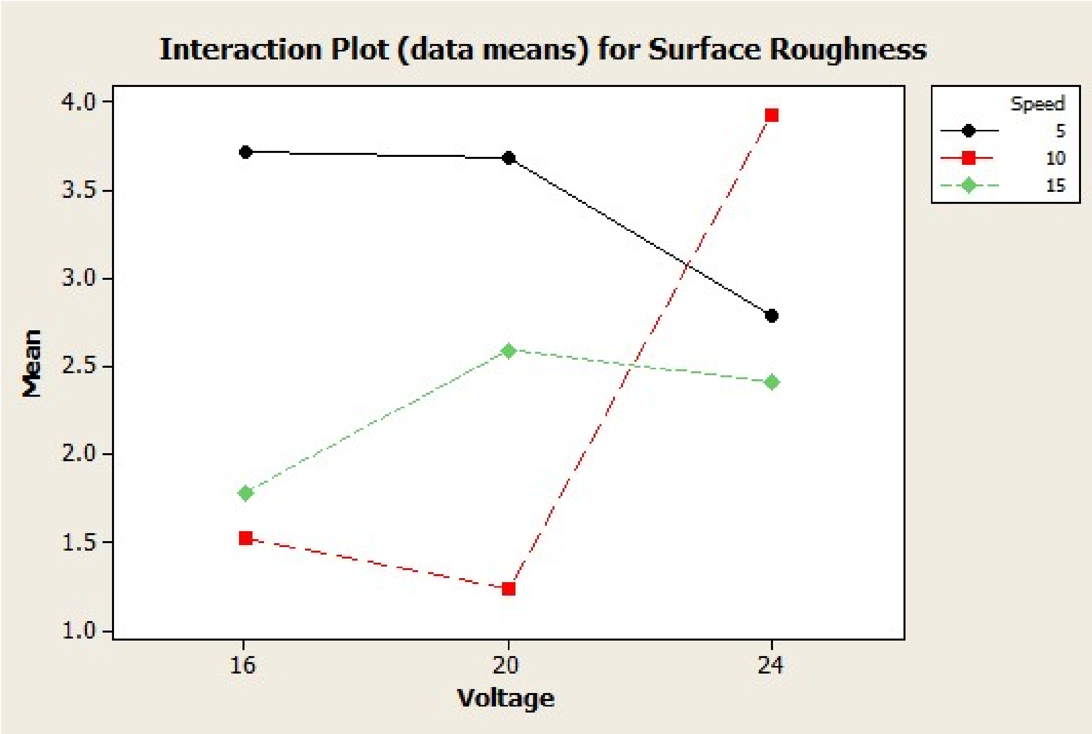

Figure 5.4: Interaction plot for parameters and Surface Roughness

Figure 5.4 shows the interaction plot between surface roughness and welding voltage at different levels of welding speed. It depicts that at lower level of welding speed, the surface roughness is higher. When the welding voltage value is increased at lower level of speed, the surface roughness get improved. At middle level of welding speed (10 mm/sec), the surface roughness obtained is lower. With increase in level of voltage at medium speed, the surface degrades. When it comes to higher welding speed, medium value surface roughness is achieved.

5.3 Confirmation Test

Confirmation tests have been performed for Tensile Strength and Surface Roughness with their optimum levels of process variables.

Table 5.9: Confirmation of expected and actual values of Tensile Strength

Experiment No.	Optimum Machining Parameters			Tensile Strength	
	Welding Voltage	Welding Current	Welding Speed	Actual	Expected
1	24	200	5	485.97	481.21
				Error (%)	0.98%

Table 5.10: Confirmation of expected and actual values of Surface Roughness

Experiment No.	Optimum Machining Parameters			Surface Roughness	
	Welding Voltage	Welding Current	Welding Speed	Actual	Expected
1	16	150	10	1.52	1.64
				Error (%)	7.89%

6

CONCLUSIONS

6.1 Conclusion

The current experimental investigation of MIG welding carried on mild steel studies the influence of MIG welding parameters for their optimization using L9 orthogonal array of Taguchi method. Factors like Welding Voltage, Welding Current and Welding Speed were chosen and their interactions were found. These results show the performance of parameters at different levels to optimize the Tensile Strength of welded joint and its surface roughness. From the study following conclusions were derived:

- Welding voltage is the most dominating parameter for tensile strength and has a contribution of 70.09%. Same was observed by Sindiri Mahesh [1].
- Tensile strength increases with increase in welding voltage [1]. Similar trend is observed to follow in present investigation. Welding voltage has major influence on tensile strength.
- Tensile Strength increases with welding current in this investigation which is opposite to that obtained by Sindiri [1]. With increase in the level of welding welding current, the tensile strength is observed to follow an increasing trend.

- Welding speed is the least influencing factor for tensile strength and has negligible contribution of only 1.26%. Same was observed by Sindiri Mahesh [1].
- Welding speed is the major influencing parameter for surface roughness with a contribution of 33.29%.
- As we increase the level of welding voltage poor surface finish is obtained. For welding current, the surface roughness first improves but with further increase in the value of welding current the surface gets degraded.
- The surface roughness first reduces with increase in the value of welding speed. But on further increase in level of welding speed above 10 mm/sec, the surface roughness slightly increases.

7

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