“ANALYSIS OF WELD BEAD AND HARDNESS DURING MIG WELDING OF MILD STEEL”

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by

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CERTIFICATE

This is to certify that the thesis work entitled **"Analysis of Weld Bead and Hardness during MIG Welding of Mild Steel"** submitted by ASHUTOSH KUMAR, Enrollment No. 1800100695 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

In the present scenario of metal joining industries, the demand of the hour is to produce better strength and good quality welds. The MIG welding machine is specialized in joining complex shapes with better surface quality as compared to other conventional welding processes. The present investigation on MIG welding machine performed on bright Mild Steel is conducted to establish the influence of welding current, welding voltage and weld speed on hardness and surface quality. The experimental results concluded that hardness is mainly influenced by welding voltage followed by welding current and least by welding speed. In the case of surface quality assessed by SEM, it was found that each parameter has great influence on the quality of surface produced.

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Introduction

1.1 Fundamentals of MIG welding

The process of MIG welding works on the principle of developing a joint due to melting faying layers of the base or work metal by utilizing the heat produced by an arc of welding generated between workpiece specimen and a consumable electrode. To protect the welding arc and weld pool shielding inactive gas (inert gas) is used which comes out of the nozzle and forming a cover around the arc produced and weld pool. Metal Inert Gas welding is not considered as clean as Tungsten Inert Gas welding due to the variation in effectiveness of shielding gas to protect the weld pool. The arc produced in MIG welding is relatively longer in length and has less stability as compared to TIG welding arc. The stability is different for MIG and TIG arcs as in MIG, the arc is produced between base metal or work metal and the consumable electrode while in the case of TIG welding, arc is produced between work metal and non-consumable tungsten electrode. Stability of arc is decreased due to the consumption of the electrode during welding and hence we achieve less effective shielding of the weld pool for MIG wlding than TIG welding. MIG welding process and TIG welding are similar to each other except that MIG utilizes an automatically fed consumable electrode hence it offers high deposition rate and therefore it is suitable for good quality weld joints that are required in industrial fabrication. The electrode is fed automatically into the arc zone and torch is controlled either manual or automatically. Thus, this process is more suitable while welding of comparatively thicker sections of reactive metals.

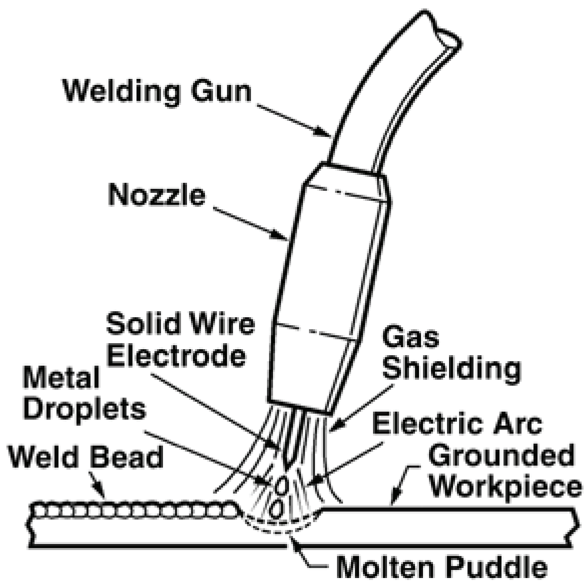

Figure 1.1 MIG Welding Process

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 1.2.

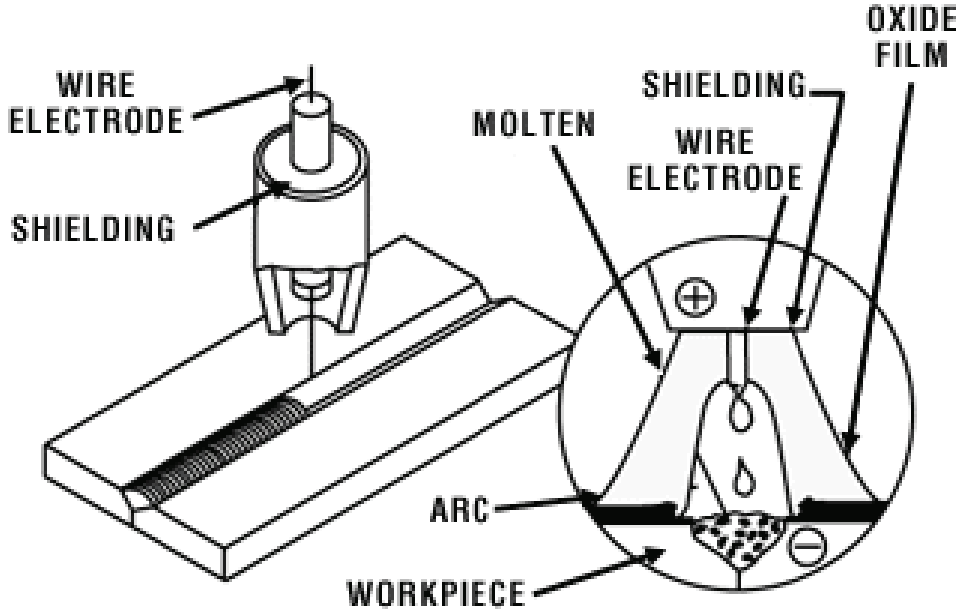

Figure 1.2 MIG welding area enlarged

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. Structure of Weld

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. The Heat Affected Zone

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 Arc generation during MIG welding process

1.4 The Power Source

Basically 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 Parameters

1.5.1 Welding Current

The welding current is amperage in the power supply as the weld is being produced. It is usually indicated on the power source meter, but usually a separate ammeter is normally used. For MIG welding, the welding current has direct relation with wire- feed speed. As the wire-feed speed is fluctuated the welding current also varies in the similar direction or we can say that an increase or decrease in the level of wire-feed speed will make an increase or decrease of the current as they are directly proportional to each other. But at higher welding currents and with small diameter wires, the burn-off curve will be non-linear. For this, the higher welding currents may cause large increase in the burn-off. This is because of the resistance heating of the wire extension beyond the guide tube.

1.5.2 Welding Voltage

The welding voltage setting will directly control the arc length. Moreover, a certain range is required so as to maintain a arc stability at any given welding current level.

1.5.3 Arc Travel Speed

The arc travel speed or welding speed is the linear rate which the arc travels along the workpiece. This parameter is usually expressed as inches or milimeters per minute. There are three general statements made regarding the arc travel speed:

1) For thicker materials, the travel speed must be small.
2) For a given condition of material thickness and joint design, when the welding current is increased, the arc travel speed will increase and vice versa.
3) Higher welding speeds are achieved using the forehand welding technique.

1.6 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.

1.7 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.

1.8 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.

1.9 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.

1.11 Weld Defects

Using correct welding conditions, techniques and the material quality standards, the MIG process will able to attain a very high quality weld deposit. But as it is with other welding process, weld defects may occur. Most defects encountered in welding are because of improper welding procedure. Once the causes of defect are known, the operator can easily diagnose the problem. Defects are usually encountered that majorly includes incomplete penetration, incomplete fusion, undercutting, porosity, and longitudinal cracking. This section deals with the corrective action that should be taken.

2

LITERATURE REVIEW

2.1 Literature Review

Many studies have been conducted by different researchers in the domain of welding technology. The investigations have been very well demented giving depth knowledge and insight on welding technology. The present research aims to investigate improvements to weld joint hardness and surface quality using Taguchi technique. Relevant literature on MIG welding have been studied, inspiration and emulation of the findings by the previous researchers are presented and discussed in this chapter.

K. Abbasi [1] 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. [2] 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. [3] 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. [4], 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. [5] 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. [6] 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 [7] in their investigation reveals that Weld Area Hardness is much higher than parent metal hardness and less than Heat affected zone Hardness.

Sindiri Mahesh and Velamala.Appalaraju [8] 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 [9] 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 [10] 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 [11] 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 [12] 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. [13] 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 there research. Vikas Chauhan et al. [14] 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.[15] 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. Vineeta 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.

Rakesh Kumar and Satish Kumar [22] through their research found that the highest tensile strength was achieved at 180 A current, 35 V voltage and 4 mm root gap while the maximum hardness was observed at a welding current of 180 amp, arc voltage of 40 volt and root gap of3 mm.

2.2 Problem Formulation

By the above literature study, the MIG welding parameters Welding speed, Welding current and Welding voltage are selected for this thesis for analyzing the hardness of the surface and the surface quality using Taguchi L9 orthogonal array

i. To investigate and analyze parameter in MIG welding for hardness of the surface

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

3

TAGUCHI APPROACH AND ANOVA

3.1 Taguchi Method

Taguchi has generated a methodology for the application of designing of experiments, which includes a practitioner's handbook. This methodology has taken the experiment design from the world of statistician and is applied fully into the world of manufacturing. This contribution have made the work much simpler by making the use of only fewer experimental designs, and providing a better understanding of the variations and the economic consequences of better quality engineering in the world of production. He introduced his approach using the experimental design for:

- Designing the products and processes which are robust to environmental conditions;
- Designing and developing products and processes which are robust to component variation;
- To minimizing variation about a target value, this philosophy of Taguchi is applicable. He proposed that optimizing engineering process or product should be carried out in three step procedure, they are the design of system, parameter design and tolerance design. In system design the engineer applies scientific engineering knowledge to produce a basic functional prototype design. During the stage of product design stage, the selection of the work materials, components, parameter values etc. are involved. Since system design is an initial step, functional design may be far from optimum in terms of quality and cost.

The objective of parameter design is to optimize the setting of process parameter value for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. Also it is expected that the optimum level of process parameters obtained by the parameter design are insensitive to the varying environmental conditions and other noise factors. Hence the parameter design plays a key role in Taguchi approach for achieving high quality without increasing cost. To solve the problem, Taguchi approach utilizes a special design of orthogonal arrays for studying the entire parameter space using small number of experiments. Loss function is afterwards defined so as to find the deviation between the desired values and experimental values. The value of this loss function is then transformed into a signal-to-noise ratio. Basically there are three category of performance characteristic during the analysis of the signal to noise ratio, they are the lower-the-better, the nominal-the-better, and the higher-the–better. The S/N ratio for each level of process parameter is computer based on the S/N analysis. Larger S/N ratio basically are corresponding to the better performance characteristic and hence the optimal level of the process parameter is the level having the highest S/N and ANOVA analysis, the optimum process parameters can be predicted. Finally, a confirmation test experiment is conducted to verify the experimental optimal set of process parameters obtained from the parameter design. The Taguchi method is adopted to obtain optimal machining performance in the die sinking.

1. **Larger is better (maximum) : $S/N_{LB} = -10 \log ((1/n)\ \Sigma\ (1/y_i^2))$**

2. **Smaller is better (minimum) : $S/N_{SB} = -10 \log ((1/n)\ \Sigma\ y_i^2)$**

Where, n is the number of observations or repetitions of a trial and y is the observed data.
The S/N ratios are basically expressed on a decibel scale. We would use S/NT for reducing the objective around a specific target, S/NL when the response is as large as possible, and S/NS when the response is as small as possible. Factor level that optimizes the appropriate S/N ratio is optimal.

The following steps are undertaken while using parameter design of the Taguchi method for optimizing a process with multiple performance characteristics:

- Identifying the performance characteristics and then selecting the process parameters to be evaluated.

- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Selecting appropriate taguchi orthogonal array and assigning the process parameters to the orthogonal array.
- Conducting the experiments on the basis of the orthogonal array.
- Analyzing the experimental results by using signal to noise ratio and ANOVA.
- Selecting the optimal level of process parameters by the S/N ratio and ANOVA.
- Verifying the optimum level process parameters by conducting confirmation experiment.

3.2 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

3.3 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.

3.4 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.

3.5 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.

3.6 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.

3.7 Tables for Taguchi Design of Experiment

The tables for Taguchi design of experiment for present work are shown below:

Table 3.1: MIG welding process parameters with their levels

S.No.	Parameters	Units	Level 1	Level 2	Level 3
1	Welding Current	A	180	230	280
2	Weld Speed	mm/sec	200	300	400
3	Welding Voltage	V	22	24	26

Table 3.2: Experimentation L9 Orthogonal Array

S.No.	Welding Current	Weld Speed	Welding Voltage
1	180	200	22
2	180	300	24
3	180	400	26
4	230	200	24
5	230	300	26
6	230	400	22
7	280	200	26
8	280	300	22
9	280	400	24

4

EXPERIMENTATION

4.1 Experimentation 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 25mm×25mm×4mm.

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: Workpiece of Mild Steel

Figure 4.5: Mild Steel welded work pieces

4.3 Hardness

Hardness is defined as the resistance offered by any material to the applied load in the form of indentation/scratch. Hardness of the weld specimen was found using Rockwell Hardness Testing Machine on C-Scale which uses a diamond cone indenter and a load of 150Kg was applied for 10 seconds before release. The Rockwell scale depends on indentation hardness of the material. In this test, the hardness is determined by measuring the depth of penetration of tester indenter under a high loading as compared to the penetration made by a preload. The hardness obtained is a dimensionless number noted as HRC, here C is the scale.

Figure 4.6 Rockwell Hardness Tester for measuring specimen hardness

4.4 Weld Surface Study

Weld surface quality was studied by CARL ZIESS EVO 50 SEM machine which is available at Department of Material Science and Engineering, IIT Kanpur. Surface of weld and base metal at SEM can be analyzed for its elemental composition in more detail using EDX system. This is a non-destructive analysis and the elements and their concentration in the sample can be determined reasonably accurately. .

Figure 4.7: CARL ZEISS EVO 50 SEM MACHINE

(COURTESY: DEPT. OF MATERIAL SCIENCE AND ENGINEERING IIT, KANPUR)

Resolution	2.0nm@ 30kV
Acceleration Voltage	0.2 to 30 kV
Magnification	5x to 1,000,000x
Field of View	8.5 mm at the Analytical Working Distance (AWD)
X-ray Analysis	8.5 mm AWD and 35° take-off angle
Detectors	SE in HV - Everhart-Thornley BSD in all modes - quadrant semiconductor diode

SPECIFICATION OF CARL ZIESS EVO 50 SEM MACHINE

5

RESULT AND DISCUSSION

RESULT AND DISCUSSION

5.1 Calculation for Hardness

Hardness of the weld specimen was found using Rockwell Hardness Testing Machine on C-Scale which uses a diamond cone indenter and a load of 150Kg was applied for 10 seconds before release. The Rockwell scale depends on indentation hardness of the material. In this test, the hardness is determined by measuring the depth of penetration of tester indenter under a high loading as compared to the penetration made by a preload. The hardness obtained is a dimensionless number noted as HRC, here C is the scale. The Hardness calculated for each specimen is shown in Table 5.1 above.

Table 5.1: Calculation for Hardness

Exp. No	Welding Current	Weld Speed	Welding Voltage	Rockwell Hardness HRC
1	180	200	22	60.5
2	180	300	24	62
3	180	400	26	61
4	230	200	24	62
5	230	300	26	59.7
6	230	400	22	62
7	280	200	26	58
8	280	300	22	61
9	280	400	24	60

5.1.1 Calculation of S/N ratio for Hardness

The S/N ratio condenses the multiple data points of hardness tested during MIG welding within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for hardness LARGER IS BETTER condition is opted. The equation for the calculation of S/N ratio for hardness is:

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

Table 5.2 Calculation of S/N ratio for Hardness

S.No	Rockwell Hardness HRC	Signal to noise ratio (db)
1	60.5	35.6351
2	62	35.8478
3	61	35.7066
4	62	35.8478
5	59.7	35.5195
6	62	35.8478
7	58	35.2686
8	61	35.7066
9	60	35.5630

5.1.2 Calculation of Mean S/N ratio for Hardness

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 Hardness

Level	Welding Current	Weld Speed	Welding Voltage
1	35.73	35.58	35.73
2	35.74	35.69	35.75
3	35.51	35.71	35.50
Delta	0.23	0.12	0.25
Rank	**2**	**3**	**1**

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

5.1.3 Analysis of Variance for Hardness

The following table shows ANOVA of Hardness conducted on MINITAB 16.0. The result shows that the contribution of welding voltage is most and is 40.57%.

Table 5.4 ANOVA of Hardness

Source	DOF	SS	Adj MS	F Value	Contribution
Welding Current	2	4.709	2.354	1.95	33.47%
Weld Speed	2	1.242	0.621	0.52	8.83%
Welding Voltage	2	5.709	2.854	2.37	40.57%
Error	2	2.409	1.204		17.13%
Total	8	14.069			100%

At least 95% confidence

Analysis of variance of hardness of MIG welded joint is shown in the above table 5.4. It is clear from the table that welding voltage is the most influencing parameter for hardness with a contribution of 40.57%. Similar effect is seen in the research of **Rajesh [22]**, where welding voltage was the most dominating parameter for hardness.

The second most dominating factor found for harness of the welded joint is welding current with a contribution of 33.47%. Weld speed is the least influencing parameter for hardness with a contribution of 8.83%.

CALCULATIONS OF ANOVA

Table 5.5 Values of Hardness corresponding to different levels of Welding Current

Welding Current Levels	Value 1	Value 2	Value 3
180	60.5	62	61
230	62	59.7	62
280	58	61	60

Means of each level of Welding Current are as follows:

$$\bar{A}\mathbf{1} = \frac{\mathbf{60.5 + 62 + 61}}{\mathbf{3}} = \mathbf{61.17}$$

$$\bar{A}\mathbf{2} = \frac{\mathbf{62 + 59.7 + 62}}{\mathbf{3}} = \mathbf{61.23}$$

$$\bar{A}\mathbf{3} = \frac{\mathbf{58 + 61 + 60}}{\mathbf{3}} = \mathbf{59.67}$$

Mean of Means of each level of Welding Current is given as follows:

$$\bar{\mathbf{A}} = (\bar{A}\mathbf{1} + \bar{A}\mathbf{2} + \bar{A}\mathbf{3})/\mathbf{3} = \mathbf{60.69}$$

Sum of Square for Welding Current is as follows:

$$\boxed{\boldsymbol{Sum\ of\ Square} = \mathbf{3}\ [\ (\bar{A}\mathbf{1} - \bar{A})^{\mathbf{2}} + (\bar{A}\mathbf{2} - \bar{A})^{\mathbf{2}} + (\bar{A}\mathbf{3} - \bar{A})^{\mathbf{2}}]}$$

SS of Welding Current = $3[(61.17 - 60.69)^2 + (61.23 - 60.69)^2 + (59.67 - 60.69)^2]$

SS of **Welding Current = 4.6872**

$$\boxed{\boldsymbol{Adj\ MS} = \frac{\boldsymbol{Sum\ of\ Square}}{\boldsymbol{Degree\ of\ Freedom}}}$$

$$\boldsymbol{Adj\ MS\ of}\ \textbf{Welding Current} = \frac{\mathbf{4.6872}}{\mathbf{2}} = \mathbf{2.3436}$$

$$\boxed{F\ Value = \frac{Adj\ MS}{Adj\ MS\ Error}}$$

$$F\ Value\ of\ \textbf{Welding Current} = \frac{2.3436}{1.204} = 1.946$$

$$\boxed{Percentage\ Contribution = \frac{Sum\ of\ Square}{Total\ Sum\ of\ Square}}$$

$$Percentage\ Contribution\ of\ \textbf{Welding Current} = \frac{4.6872}{14.069} = 33.31\%$$

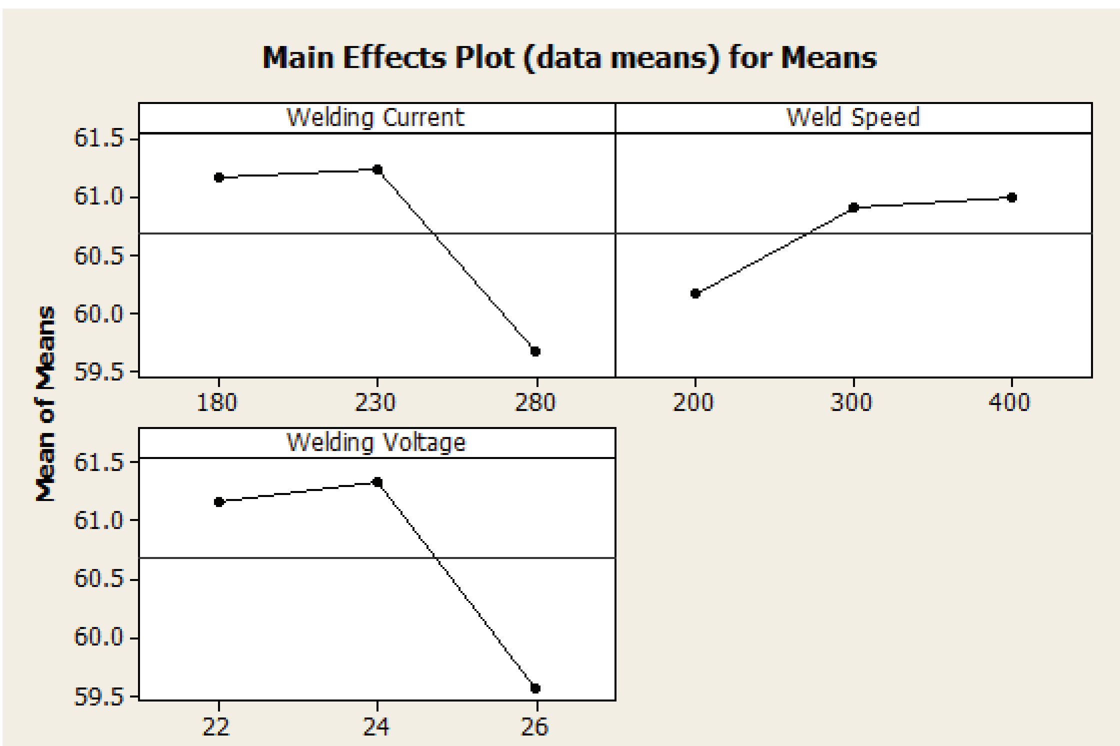

Figure 5.1: Main effect plot for Hardness

Figure 5.1 presents the mean effect plot for Hardness. It shows that the Hardness initially have negligible influence with both welding current and welding voltage but with further increase in their levels, hardness tends to decrease. Both these parameters have major influence on Hardness. Moreover, with increase in weld speed, initially hardness increase at a faster pace but with further increase in weld speed the hardness increases at a slower pace. Similar to the condition observed by Rajesh [22], here also the hardness follow the same trend and it first increase with increase in voltage and further it get decreased.

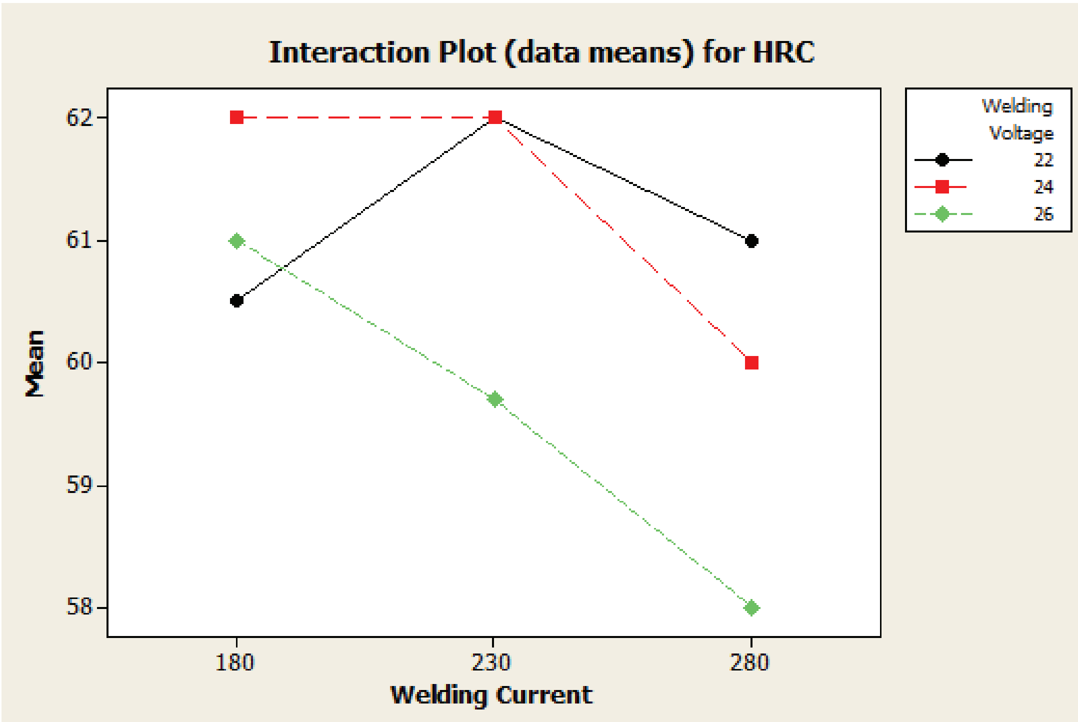

Figure 5.2: Interaction plot for parameters and Hardness

Figure 5.2 presents the interaction plot between Hardness of welded joint and welding current at different levels of welding voltage. The plot elucidates that the Hardness decreases with welding current at lower level of welding voltage. With increase in welding voltage level, the hardness obtained is higher but it decreases with increase in welding current. At higher level of welding voltage, initially the hardness obtained is low but with increase in welding current it first increases and then tends to decrease.

Optimal Levels of Parameters for Hardness

- **Welding Current : 230A**
- **Weld Speed : 400 mm/sec**
- **Welding Voltage : 24V**

5.2 Discussion on Surface Quality

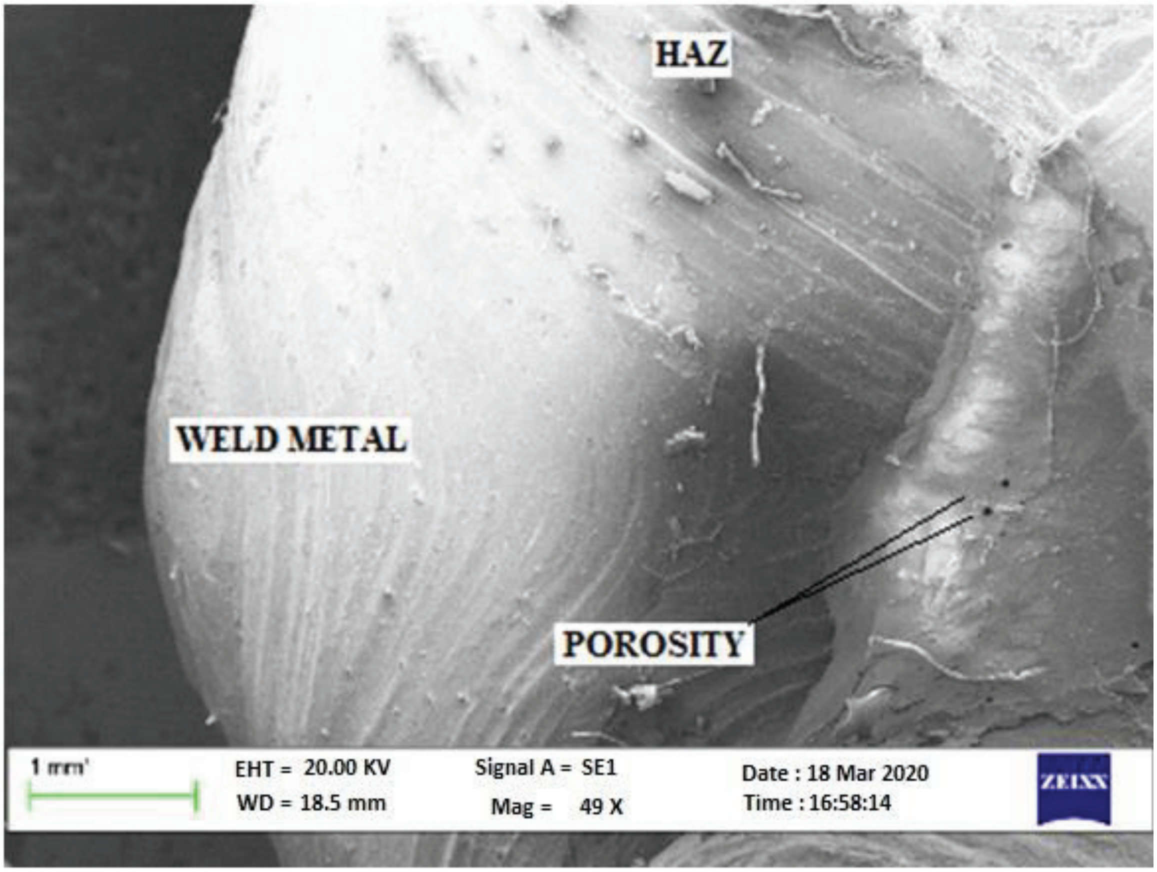

Figure 5.3 SEM image of sample 1

The above scanning electron microscopy image shows the quality of weld obtained at 180 Ampere welding current, 200 mm/sec weld speed and 22 V welding voltage. Image shows the uneven surface at the joint of weld. Few small porous spots are also visible beneath the weld bead near the area where beads of the double 'V' joint weld meet. The porosity is due to some air disturbed the delivery of shielding gas. The MIG welding gun is laid at such an angle that it spreads the gas flow out and actually sucks in the atmosphere from the back side, opposite the nozzle direction.

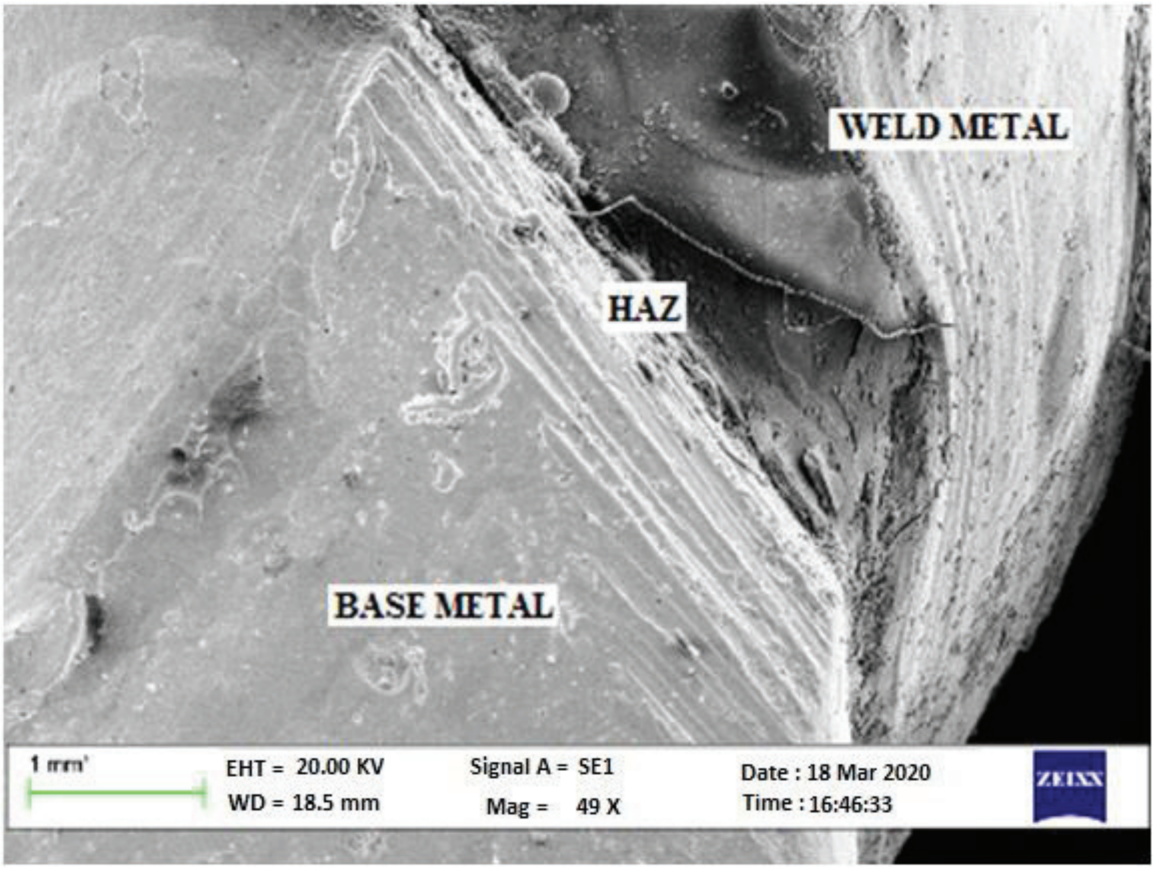

Figure 5.4 SEM image of sample 3

The above SEM image of specimen 3 shows the quality of weld obtained at 180 Ampere welding current, 400 mm/sec weld speed and 26 V welding voltage. Uneven surface of the weld is seen in the image. Appropriate weld joint is obtained at the present set of experiment. None of the flaws are visible on the surface of the weld and a good weld joint is obtained.

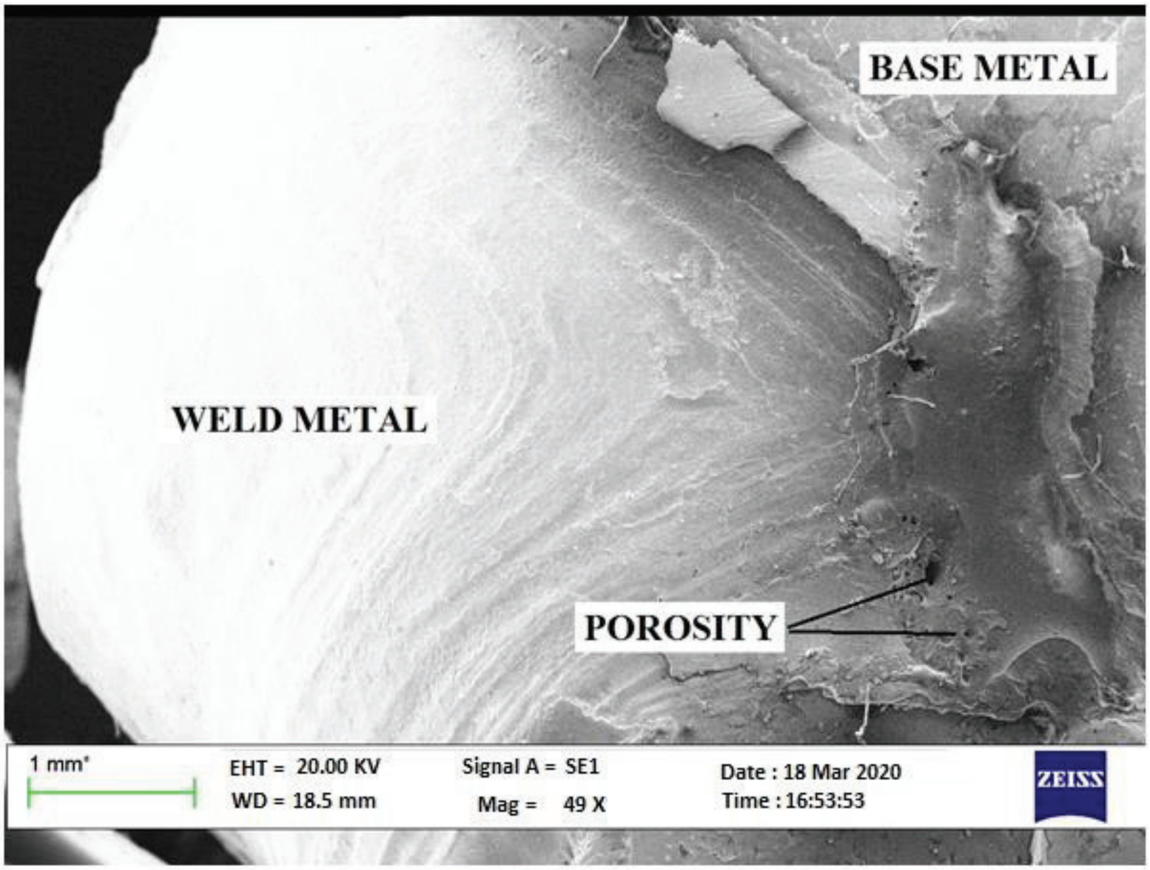

Figure 5.5 SEM image of sample 5

The above scanning electron microscopy image of sample 5 image shows the quality of weld obtained at 230 Ampere welding current, 300 mm/sec weld speed and 26 V welding voltage. Large porous spots are observed with this set of experiment porosity is due to some air disturbed the delivery of shielding gas. A 5° to 15° angle, perpendicular to the joint, is an acceptable angle for forehand or backhand methods with MIG welding.

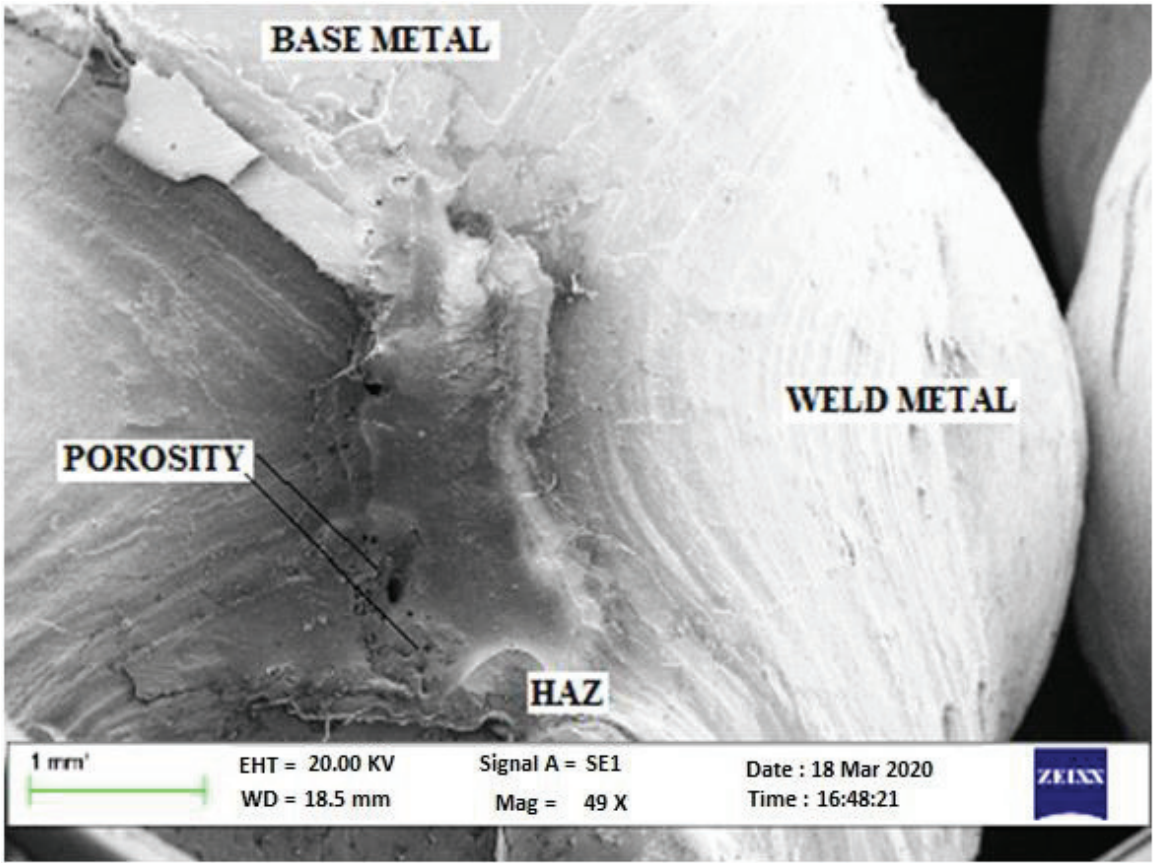

Figure 5.6 SEM image of sample 7

The above scanning electron microscopy image of sample 7 image shows the quality of weld obtained at 280 Ampere welding current, 200 mm/sec weld speed and 26 V welding voltage. More dispersed porous spots are observed with the present of experiment and porosity is due to combination of high level of current and voltage. The porous spots are smaller in size as compared to those observed in other set of experiments.

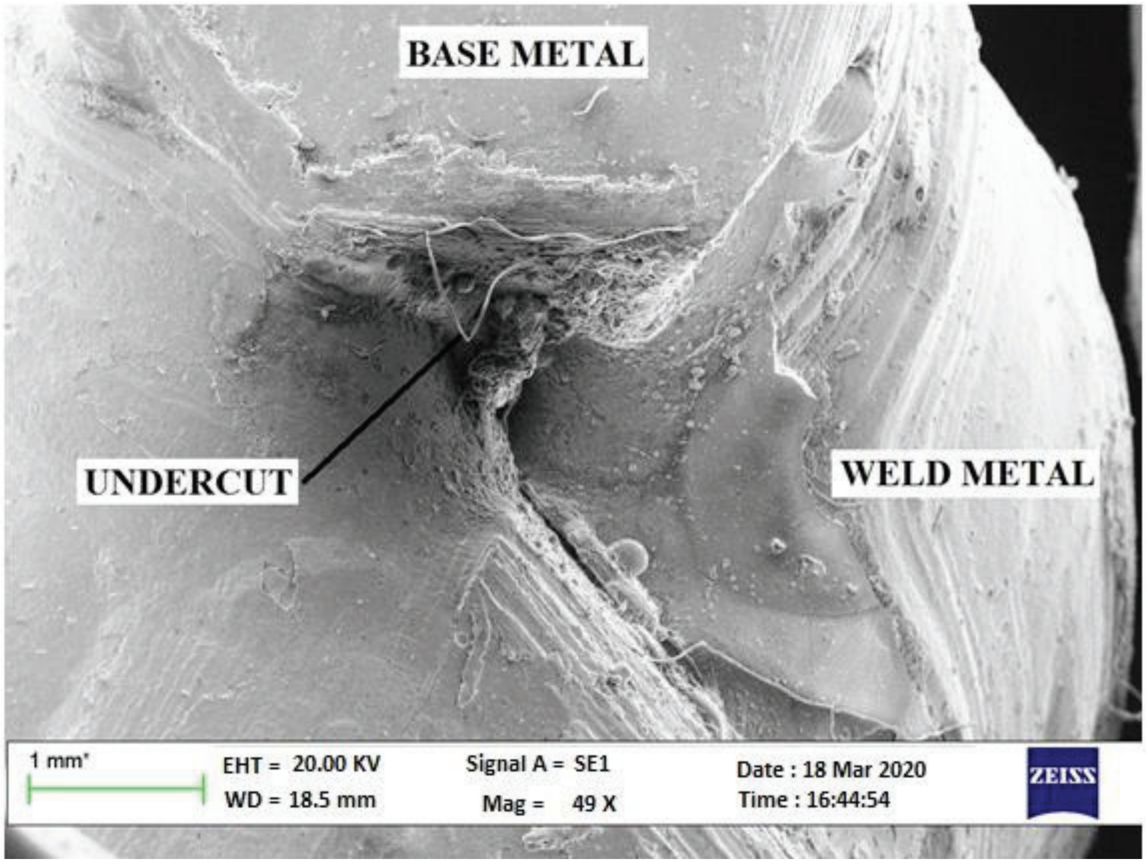

Figure 5.7 SEM image of sample 9

The above SEM image of sample 9 elucidates the structure of weld bead making joint between two MS plates. Its clear from the figure that the base metal is washed away due to the intense heat generated by the welding temperature and is visible in form of undercut. The cause for undercut is high speed of welding (400mm/sec) and excessive heat generation during welding.

5.3 Confirmation Test

Confirmation tests have been performed for Hardness with their optimum levels of process variables.

Table 5.6: Confirmation of expected and actual values of Hardness

Experiment No.	Optimum Machining Parameters			Hardness	
	Welding Current (A)	Welding Speed (mm/min)	Welding Voltage (V)	Actual	Expected
1	230	400	24	62	61.7
				Error (%)	0.48%

6

CONCLUSIONS

6.1 Conclusion

The present experimental investigation describes the optimization of MIG welding parameters on Mild Steel using L9 orthogonal array of Taguchi method. Factors like welding Current, welding voltage and weld speed were considered and their interactions were found for better hardness and better surface quality.

Following conclusions are made as per the investigation:

- Hardness initially has negligible influence with both welding current and welding voltage but with further increase in their levels, hardness tends to decrease.
- With increase in weld speed, initially hardness increase at a faster pace but with further increase in weld speed the hardness increases at a slower pace.
- Hardness first increases then get decrease with welding voltage [22]. Here also the same trend is observed.
- Welding voltage is the most influencing parameter for hardness with a contribution of 40.57%.
- Welding Voltage is the most dominating factor for hardness [22]. Here also we achieved the same outcome.

- The second most dominating factor found for harness of the welded joint is welding current with a contribution of 33.47%.
- Weld speed is the least influencing parameter for hardness with a contribution of 8.83%.
- The porosity at lower level is due to some air disturbed the delivery of shielding gas. The MIG welding gun is laid at such an angle that it spreads the gas flow out and actually sucks in the atmosphere from the back side, opposite the nozzle direction.
- At 180 Ampere welding current, 400 mm/sec weld speed and 26 V welding voltage. Uneven surface of the weld is seen but none of the flaws are visible on the surface of the weld and a good weld joint is obtained.
- At 230 Ampere welding current, 300 mm/sec weld speed and 26 V welding voltage, large porous spots are observed due to some air disturbed the delivery of shielding gas. A 5° to 15° angle, perpendicular to the joint, is an acceptable angle for forehand or backhand methods with MIG welding.
- At 280 Ampere welding current, 200 mm/sec weld speed and 26 V welding voltage, more dispersed porous spots are observed and porosity is due to combination of high level of current and voltage.
- At higher level of MIG welding parameters, the base metal is washed away due to the intense heat generated by the welding temperature and is visible in form of undercut. The cause for undercut is high speed of welding (400mm/sec) and excessive heat generation during welding.

7

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