

# Analysis of Process Parameters of MIG/MAG Welding using Design of Experiments

<sup>[1]</sup>Prof Shashank Divgi <sup>[2]</sup>Prof Poojesh Anvekar, <sup>[3]</sup> Prof Suraj Damsadekar  
<sup>[1][2][3]</sup> Girijabai Sail Institute of Technology, Karwar

**Abstract:-** Welding parameters are the most important factors which affect the quality productivity as well as the cost of production. This paper presents the influence of welding parameters such as welding voltage, gas flow rate, wire feed rate etc, on weld strength, weld pool geometry of the most used metal in the fabrication industry which is Medium Carbon Steel material by the welding process of MIG/MAG WELDING. Hence the different variable parameters are analyzed by using Design of experiment method along with MAT9 SOFTWARE and Analysis of variance techniques are used to investigate the Optimized set of parameter and then the confirmation tests have been carried out to compare the predicted values to the experimental values to confirm its effectiveness in the analysis of weld strength and depth of penetration.

**Keywords:--** CO<sub>2</sub>, DOE, MIG/MAG, MDR, DOF, S/N Ratio, DF, SS, MS, OPT,

## I. INTRODUCTION

MIG/MAG Welding is the form of Gas Metal Arc Welding where Carbon dioxide gas is used during welding and is called as Metal Active Gas welding which is also called as the semi-automatic process where an arc is established between a continuous filler metal (consumable) and the work. The CO<sub>2</sub> gas is used as an active gas which helps in raising the metal temperature to melting point and also shields the weld pool. Figure below shows the process sometimes referred as MIG/MAG Welding.

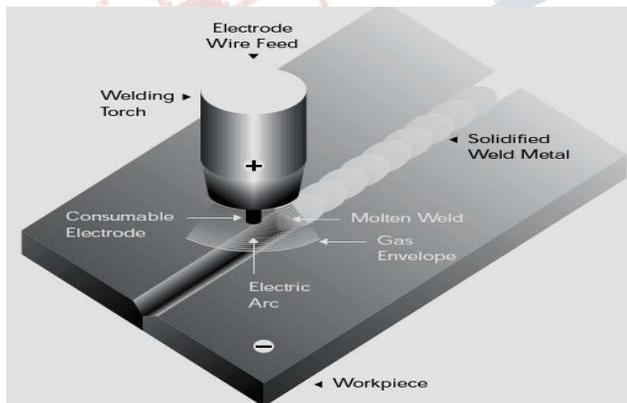


Fig 1.1 MIG/MAG Welding

This project was developed to study the MIG/MAG welding parameters in smooth welding using a D.C power source and the main purpose are listed below

- ◆ To study about the MIG/MAG welding parameters of Mild Steel of 10 mm thick
- ◆ To design a series of experiment using the help of Design of experiment (DOE) layout
- ◆ To study about the best combination of solution for maximizing the material deposit rate (MDR) with Taguchi Method
- ◆ All the experimental data taken are analyzed using MATLAB 9 software

## II. LITERATURE REVIEW

Metal inert gas /Metal Active gas welding as the name suggests is a process in which the source of heat is an arc generated between a consumable metal electrode that flows automatically with the help of a wire feeder and the work piece. The arc and the molten puddle are protected from the atmospheric air with an externally supplied shielding gas such as Argon, Nitrogen, Helium, mixture of Argon-Helium or Carbon Dioxide. It is often abbreviated form as MIG/MAG which is an arc welding process where in coalesce is obtained by heating the job with an electric arc produced between the work piece and the metal electrode fed continuously. This is a process of welding which consists of Heating Melting and Solidification of parent metal and the filler material in localized fusion zone by a transient

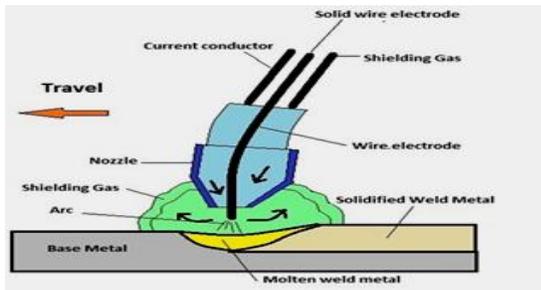


Fig. 2.1 The Principle of the MIG/MAG Welding

### III. DESIGN OF EXPERIMENT

Design of Experiment (DOE) is a powerful statistical technique introduced by R. A. Fisher in England in 1920's to study the effect of multiple variables simultaneously which can be highly effective when used to optimize the product and process design and to study the multiple factors on process.

Study the influence of individual factors on the performance and determine the factor which has more influence and which has less. It can also find which factor should have more tolerance and the tolerances should be relaxed. In industry, designed experiments can be used to systematically investigate the process or product variables that influence the product quality. And therefore Designed experiments are often carried out in four phases.

- ◆ Planning
- ◆ Screening (also called process characterization)
- ◆ Optimization
- ◆ Verification

#### A) Taguchi Method

A Taguchi design, or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor. In robust parameter design, we first choose control factors and their levels and choose an orthogonal array appropriate for these control factors. The control factors comprise the inner array. At the same time, we determine a set of noise factors, along with an experimental design for this set of factors. The noise factors comprise the outer array.

The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factor settings for that run of the control factor in the inner array. Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run: the cell values indicate the factor settings for the run. By default, MATLAB's orthogonal array designs use the integers 1, 2, 3... to represent factor levels. If we enter factor levels, the integers 1, 2, 3, ..., will be the coded level for the design.

#### B) Review of Experiment

**G. Haragopal, P V R Ravindra Reddy and J V Subrahmanyam** presented a method to design process parameters that optimize the mechanical properties of weld specimens for aluminium alloy (Al-65032), used for construction of aerospace wings. The process parameters considered for the study were Gas Flow Rate, current, groove angle and pre-heat temperature. Process parameters were assigned for each experiment. The experiments were conducted using the L9 orthogonal array. Optimal process parameter combination was obtained. Along with this, identification of the parameters which were influencing the most was also done. This was accomplished using the S/N analysis, mean response analysis and ANOVA. Mechanical properties obtained for three samples of each run were obtained. Signal to noise ratio for each quality (S/N) ratio for each quality characteristic was calculated, significant parameters were identified and optimum input parameter for each quality characteristic were predicted from S/N values and mean response. Analysis of variance (ANOVA) ascertained significant parameters identified through S/N analysis. A confirmation test was conducted at optimum conditions to ensure correctness of analysis.

**Omar Bataineh, Omar Barqawi** was identified and optimized the main factors that have significant effect on weld joint strength through factorial design experiments. Welding experiments were carried out using MIG Welding process and an ER1100 filler wire with 1.2 mm in diameter was used as a consumable electrode. The shielding gas used was 100% pure Argon. Test specimens were composed of two pieces each, and each piece was 100 mm × 50 mm × 8 mm in size and made of 1070 aluminium alloy.

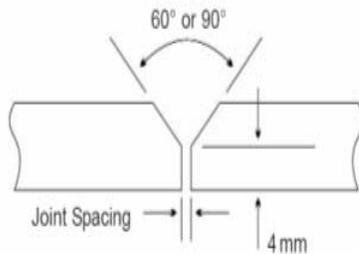


Fig 3.1 Joint geometry for the welding specimens

The factors that were studied are arc voltage, filler feed rate, gas flow rate, specimen edge angle and preheat temperature. Results of factorial design experiments and the analysis of variance (ANOVA) showed that arc voltage and filler feed rate are the only significant factors of the five. Optimal settings of arc voltage and filler feed rate were reached using regression analysis at 24 V and 7 in/s, respectively, at which the mean weld strength is maximum.

The changes in gas metal arc welding parameters are influenced the effect of the microstructure of weld metal. The increased welding current, welding speed and arc voltage the grain size of microstructure also different from one point to another point.

**Pawan kumar, Dr.B.K.Roy** was worked carried out on plate welds AISI 304 & Low Carbon Steel plates using gas metal arc welding (GMAW) process. Taguchi method is used to formulate the experimental design. Design of experiments using orthogonal array is employed to develop the weldments. The input process variables considered here include welding current, welding voltage & gas flow rate. A total no of 9 experimental runs were conducted using an L9 orthogonal array and the ideal combination of controllable factor levels was determined for the hardness to calculate the signal-to-noise ratio. After collecting the data signal-to-noise (S/N) ratios were calculated and used in order to obtain optimum levels for every input parameter. The Nominal-the-better quality characteristic is considered in the hardness prediction. The Taguchi method is adopted to solve this problem. Subsequently, using analysis of variance the significant coefficients for each input parameter on tensile strength & Hardness (WZ & HAZ) were determined and validated.

**Chandresh N. Patel** used Full factorial method for Design of Experiment for optimization work. By use of the experimental data optimal process parameter combination was achieved by grey relational analysis (GRA) optimization technique. In this work, input parameters for MIG welding were welding current, wire diameter and wire

feed rate and the output parameter is hardness. Also the input parameters for TIG welding are welding current, wire diameter and the output parameter was hardness. AISI 1020 or C20 material was used for welding. Experiments were performed on plates of thickness 5 mm and double V-groove joint is used. And input parameters for MIG welding were welding current, wire diameter and wire feed rate and the output parameter is hardness. Also the input parameters for TIG welding are welding current, wire diameter and the output parameter was hardness. For Experimental design full factorial method ( $L=m^n$ ) was used to find out number of readings. To find out percentage contribution of each input parameter for obtaining optimal conditions, we were used analysis of variance (ANOVA) method. Grey relational analysis (GRA) optimization technique was used for optimization of different values. A grey relational grade obtained from the grey relational analysis is used to optimize the process parameters. By use of ANOVA analysis the percentage contribution of MIG welding for welding current is obtained 94.01 %, wire diameter of 0.402 % and wire feed rate of 0.016 % and the error is of 5.56 %. This error is due to human ineffectiveness and machine vibration. By use of ANOVA analysis the percentage contribution of TIG welding for welding current is 73.36 % and wire diameter of 23.90 % and the error is of 2.74 %. This error is due to human ineffectiveness and machine vibration. From the ANOVA it is conclude that the welding current is most significant parameter for MIG and TIG welding.

#### IV. MIG/MAG WELDING EFFECTING PARAMETERS:

Weld quality and weld deposition rate both are influenced very much by the various welding parameters and joint geometry. Essentially a welded joint can be produced by various combinations of welding parameters as well as joint geometries. These parameters are the process variables which control the weld deposition rate and weld quality. The weld bead geometry, depth of penetration and overall weld quality depends on the following operating variables.

- ◆ Electrode size, Welding current, Arc voltage
- ◆ Arc travel speed, welding position
- ◆ Gas Flow rate, Shielding Gas composition
- ◆ Electrode extension (length of stick out)

##### 4.1) Electrode Size:

The electrode diameter influences the weld bead configuration (such as the size), the depth of penetration,

bead width and has a consequent effect on the travel speed of welding. As a general rule, for the same welding current (wire feed speed setting) the arc becomes more penetrating as the electrode diameter decreases. To get the maximum deposition rate at a given current, one should have the smallest wire possible that provides the necessary penetration of the weld. The larger electrode diameters create weld with less penetration but wider in width. The choice of the wire electrode diameter depends on the thickness of the work piece to be welded, the required weld penetration, the desired weld profile and deposition rate, the position of welding and the cost of electrode wire. Commonly used electrode sizes are (mm): 0.8, 1.0, 1.2, 1.6 and 2.4. Each size has a usable current range depending on wire composition and spray- type arc or short- circuiting arc is used.

#### 4.2) Welding Current:

The value of welding current used in MIG/MAG has the greatest effect on the deposition rate, the weld bead size, shape and penetration. In MIG/MAG welding, metals are generally welded with direct current polarity electrode positive (DCEP, opposite to TIG welding), because it provides the maximum heat input to the work and therefore a relatively deep penetration can be obtained. When all the other welding parameters are held constant, increasing the current will increase the depth and the width of the weld penetration and the size of the weld bead.

#### 4.3) Welding Voltage:

The arc length (arc voltage) is one of the most important variables in MIG/MAG that must be held under control. When all the variables such as the electrode composition and sizes, the type of shielding gas and the welding technique are held constant, the arc length is directly related to the arc voltage. High and low voltages cause an unstable arc. Excessive voltage causes the formation of excessive spatter and porosity, in fillet welds it increases undercut and produces narrower beads with greater convexity, but an excessive low voltage may cause porosity and overlapping at the edges of the weld bead. And with constant voltage power source, the welding current increase when the electrode feeding rate is increased and decreased as the electrode speed is decreased, other factors remaining constant. This is a very important variable in MIG/MAG welding, mainly because it determines the type of metal transfer by influencing the rate of droplet transfer across the arc. The arc voltage to be used depends on base metal thickness, type of joint, electrode composition and size, shielding gas composition, welding position, type of weld and other factors.

#### 4.4) Shielding Gas:

The primary function of shielding gas is to protect the arc and molten weld, pool from atmosphere oxygen and nitrogen. If not properly protected it forms oxides and nitrides and result in weld deficiencies such as porosity, slag inclusion and weld embrittlement. Thus the shielding gas and its flow rate have a substantial effect on the following: Arc characteristics, Mode of metal transfer, penetration and weld bead profile, speed of welding, cleaning of action, weld metal mechanical properties. Argon, helium and argon-helium mixtures are used in many applications for welding non-ferrous metals and alloys. Argon and Carbon dioxide are used in Carbon steel.

**Table 4.1 Shielding gases and gas mixture for MIG/MAG Welding**

Shielding gas	Chemical Behaviour
Argon	Inert
Helium	Inert
Ar+He (20-80to 50-50%)	Inert
Nitrogen	
Ar+25-30% N <sub>2</sub>	
Ar+1-2% O <sub>2</sub>	Slightly Oxidizing
Ar+3-5% O <sub>2</sub>	Oxidizing
CO <sub>2</sub>	Oxidizing
Ar+20-50% CO <sub>2</sub>	Oxidizing
Ar+10% CO <sub>2</sub> +5% O <sub>2</sub>	Oxidizing
CO <sub>2</sub> +20% O <sub>2</sub>	Oxidizing
90% He+7.5% Ar+2.5% CO <sub>2</sub>	Slightly Oxidizing
60 to 70% He+25 to 35% Ar+4 to 5% CO <sub>2</sub>	Oxidizing

#### V. ARC TRAVEL SPEED:

The travel speed is the rate at which the arc travels along the work- piece. It is controlled by the welder in semiautomatic welding and by the machine in automatic welding. The effects of the travel speed are just about similar to the effects of the arc voltage. The penetration is maximum at a certain value and decreases as the arc speed is varied. For a constant given current, slower travel speeds proportionally provide larger bead and higher heat input to the base metal because of the longer heating time. The high input increases the weld penetration and the weld metal deposit per unit length and consequently results in a wider bead contour. If the travel speed is too slow, unusual weld build-up occurs, which causes poor fusion, lower penetration, porosity, slag inclusions and a rough uneven bead. The travel speed, which is an important variable in MIG/MAG, just like the wire speed (current) and the arc

voltage, is chosen by the operator according to the thickness of the metal being welded, the joint fit-up and welding position

## VI. PROJECT METHODOLOGY

### 6.1 Specimen Preparation

16 test specimens having dimension 100mm x 50mm x 10 mm were prepared for the experimental work. The material for test specimen was MILD Steel.



Fig. 3.1 Test Specimen

### 6.2 Material

Mild Steel, also known as Plain Carbon steel is the most common form of steel because of its relatively low price while it provides material properties which can be used for various applications. It contains approximately 0.05-0.25% Carbon making it malleable and ductile. It has relatively low tensile strength, but it is cheap and easy to form. The Density of Mild Steel is approximately 7.85 g/cm<sup>3</sup> and Young's modulus is 210 GPa. Mild steel has ferromagnetic properties, which makes it ideal for manufacturing of electrical devices and motors. It yields itself easily to magnetisation

Table 6.1 Chemical Composition and Mechanical Properties of Mild steel

CHEMICAL COMPOSITION	
Carbon	0.16-0.18%
Silicon	0.40% Max
Manganese	0.70-0.90%
Sulphur	0.040% Max
Phosphorus	0.040% Max

MECHANICAL PROPERTIES IN COLD DRAWN CONDITIONS		
Max Stress	400-560 N/mm <sup>2</sup>	Dependent on ruling section
Yield Stress	300-440 N/mm <sup>2</sup>	Dependent on ruling section
0.2% Proof Stress	280-420 N/mm <sup>2</sup> Min	Dependent on ruling section
Elongation	10-14% Min	Dependent on ruling section

### 6.3 Equipments

Equipments for the experiment use is

1. MIG/MAG Welding System
2. Digital Weight Balancer equipment
3. Gun travel equipment

#### 6.3.1 MIG/MAG Welding System

MIG/MAG Welding used in this is Sparkline Welder Make MIG/MAG Welding Machine No.11464569.

Table 6.2 Technical Features of MIG/MAG Machine

Welding Voltage range	18-43 V
Current range	40-320 A
Duty Cycle	60%
Welding Current @ 60%	400 amps
Welding Current @ 100%	310 amps
INSULATION	H
PROTECTION CLASS	IP 23
COOLING	FORCED AIR
Weight	50 Kg
Wire Feeder	2 ROLL SERVO
Include	CO <sub>2</sub> Pre heater MIG/MAG TORCH CO <sub>2</sub> Flow meter And Regulator ARGON Flow meter And Regulator

### 6.3.2 Digital Weight Balancer equipment

The weight of the work pieces (specimens) before and after the Welding process needs to be measured in order to obtain the amount of Material Deposit Rate (MDR).

### 6.3.3 Power Supply

The power supply required depends on the material thickness and welding speeds desired. Increasing the power increases the welding speed. Power ratings are commonly between 20 and 200 kW.



Fig 3.2 Dc Power Supply

### 6.4 Design Factors

Design of Experiments technique has been utilized to obtain the best combination of design factors to achieve optimum performance measures. MIG/MAG Welding involves several input parameters to be considered during machining process. In this thesis, the combination factors such as Gas Flow Rate [Lit/Min], Current [A], Welding Speed [mm/min] and Arc Gap [mm] are considered. These factors are the most important to have the best value for Material Deposit Rate (MDR) when welding material like Mild Steel or Nickel Base Alloy etc.

#### 6.4.1 Gas Flow Rate

The primary function of an active gas is to ensure that the welding of the Mild steel is in proper temperature or required temperature and the weld molten pool form atmospheric oxygen and Nitrogen. The Oxygen will ensure that the temperature will rise to a sufficient level so that the molten pool is formed on the weld position on the metal to be welded

#### 6.4.2 Current

Current is the value of current given during welding process. The cause of the burn-through was the increase in the welding current or the decrease in the welding speed. When the welding current increases or the welding speed decreases, the stable State of the key hole changes accordingly. If the welding current and the flow

rate of the CO<sub>2</sub> gas are increased and/or the welding speed is decreased, the process will withstand larger variations in the welding parameters.

#### 6.4.3 Travel Speed

Travel speed is the linear rate at which the arc is moved along the weld joint. With all other conditions held constant, weld penetration is a maximum at some travel speed. The penetration will decrease when the travel speed is changed, and the weld bead will either become narrower or wider. When the travel speed is decreased, the filler metal deposition per unit length increase; and a large, shallow weld pool is produced. The welding arc impinges on this pool rather than the base metal as the arc advances. This limits penetration but produces a wide weld bead.

#### 6.4.4 Arc Gap

Arc gap is the gap between the electrode or electrode wire and the work piece to be welded.

### 6.5 Mig/Mag Welding Response

There is one parameter of MIG/MAG Welding response measured in this study, known as:

#### i. Material Deposit Rate (MDR)

##### 6.5.1 Material Deposit Rate

The material deposit rate, MDR, can be defined as the volume of material deposited by the machining time. Material deposit Rate (MDR) is given by:

$$MDR = WDW/T \text{ [g/min]}$$

Where,

WDW: Work piece Deposit weight (g)

T: welding time(s)

WDW is the weight different between before and after work piece welding. The Volume different can be calculated when information regarding material density Available. The relation between WDW and WDV is given as follow:

$$WDV = WDW/\rho$$

Where,

$\rho$  : Work piece density (g/ mm<sup>3</sup>)

The density of the Mild Steel is 7.85 g/cm<sup>3</sup> or 0.00785g/mm<sup>3</sup>.

## VII. DESIGN OF STUDY

### 7.1 Outline of Thesis Work

It is found already many work has been done in MDR but very little work has been done on optimization of MIG/MAG welding. Here in our thesis work we will try to find out optimal value of MDR. For this we have consulted to Industrial Technological Institute, Pernem-Goa. They suggested that Mild steel materials are cheaply available and widely used in MIG/MAG welding. Taguchi method using design of experiments approach can be used to optimize a process. Here we will to apply D.O.E approach for modelling of MDR in MIG/MAG welding process and the various input parameters will be taken under experimental investigation and then model will be prepared then again experimentation work will be performed. The results obtain will be analyzed and the models will be produced by using MATLAB software. This will help in improving the effective and efficient working of the MIG/MAG welding process.

#### Various Input parameters

- Voltage
- Current
- Arc Gap
- Welding Width (width of cut)
- Welding Speed
- Material Type and Thickness
- Gas Flow Rate

After extensive brain storming with the experts of Industrial Technological Institute, Pernem-Goa, it has been found that above are important input parameters for studying material deposit rate. As we are going to perform our work on Sparkline Welder make MIG/MAG welding No.11464569 and after literature review four main input parameters selected are **Gas Flow Rate, Current, Welding Speed, and Arc Gap**. The other two parameters **Welding Width (3-4mm) and Material Thickness (10mm)** is kept fixed for the whole experiment. The material used is **Mild Steel** in the overall experiment.

### 7.2 Design Of Experiment

The objective of this research work is to study MDR, the design variables can be summarized as follows:

- a) Two levels of the Gas Flow Rate (10 Lit/min and 15 Lit/min).
- b) Two levels of Current (240A and 280A).
- c) Two levels of Welding Speed (150mm/min and 300mm/min).
- d) Two levels of Arc Gap (2mm and 4mm)

For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for four design variables (namely Gas Flow Rate, Current, Welding Speed and Arc gap) which would constitute the L16 orthogonal array.

The one most important output is Material Deposit Rate the same has been selected as response parameter for this research work also. The effect of the variation in input process parameter will be studied on these two response parameters and the experimental data will be analyzed as per Taguchi method to find out the optimum machining condition and percentage contribution of each factor. The following machining parameters were kept fixed.

**Table 7.1 Fixed Machining Parameters**

Sl. No.	Machining Parameters	Fixed Value
1	Material Type	Mild Steel
2	Material Thickness	10 mm
3	Welding Width	3-4 mm
4	Operating Voltage	440 V

### 7.3 Selection Of Orthogonal Array And Parameter Assignment

In this experiment, there are four parameters at two levels each. The degree of freedom (DOF) of a two level parameter is 2 (Number of Levels minus 1), hence total DOF for the experiment is 4. The DOF of the orthogonal array selected should have higher than that of total DOF of the experiment.

**Table 7.2 Parametric Level Assignment**

Parameter	Unit	Level 1	Level 2	DOF
Gas Flow Rate	Lit/min	10	15	1
Current	Ampere	240	280	1
Welding Speed	mm/min	150	300	1
Arc Gap	mm	2	4	1

7.3.1 Standard L16 Array with (2\*4) :- Column number 1 2 4 and 8 of L16(2\*\*15) Array is used for this experiment:-

Table 7.3 Experimental Layout in Coded Factor Levels

Runs	Gas Flow Rate	Current	Welding Speed	Arc Gap
1	1	1	1	1
2	1	1	1	2
3	1	1	2	1
4	1	1	2	2
5	1	2	1	1
6	1	2	1	2
7	1	2	2	1
8	1	2	2	2
9	2	1	1	1
10	2	1	1	2
11	2	1	2	1
12	2	1	2	2
13	2	2	1	1
14	2	2	1	2
15	2	2	2	1
16	2	2	2	2

The above table displays the L16 (2\*4) Taguchi design (orthogonal array). L16 means 16 runs. 2\*4 means 4 factors with 2 levels each. This array is orthogonal; factor levels are weighted equally across the entire design. The table columns represent the control factors, the table rows represent the runs (combination of factor levels), and each table cell represents the factor level for that run.

7.4 Signal To Noise (S/N) Ratio

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modelled by a quadratic function as shown in equation (1)

$$L(Y) = K (Y - T^2) \dots \dots \dots (1)$$

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be  $\mu$  and standard deviation to be  $\sigma$ . Let desired performance be  $\mu_1$ . Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor  $(\mu_0/\mu)$  Since on target is goal the loss after adjustment is due to variability remaining from the new standard deviation.

Loss after adjustment shown in equation (2):

$$K(\mu_0/\mu)^2 \sigma^2 \dots \dots \dots (2)$$

The factor  $\frac{\mu^2}{\sigma^2}$  reflects the ratio of average performance  $\mu^2$  (which is the signal) and  $\sigma^2$  (the variance of performance) the noise. Maximizing  $\frac{\mu^2}{\sigma^2}$  or S/N ratio therefore becomes equivalent to minimizing the loss after adjustment. Finding a correct objective function to maximize in an engineering design problem is very important. Depending upon the type of response, the following three types of S/N ratios are employed in practice:

Larger is Better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the larger-is-better S/N ratio using base 10 log is:

$$S/N = -10 * \log(\text{Sum of } (1/Y^2)/n)$$

Where

Y = responses for the given factor level combination and, n = number of responses in the factor level combination.

Smaller is Better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller-is-better S/N ratio using base 10 log is:

$$S/N = -10 * \log(\text{Sum of } (Y^2)/n)$$

Where Y = responses for the given factor level combination and

n = number of responses in the factor level combination.

- In my thesis work MDR is considered larger is better. Value of MDR is measured by difference between initial and final weight after machining.

### 7.5 ANOVA (Analysis of Variance)

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material Deposit rate. Based on the ANOVA, the relative importance of the machining parameters with respect to material removal rate and surface roughness is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data:

1. within treatment variability
2. Observation to observation variability

So ANOVA helps us to compare variabilities within experimental data. In my thesis ANOVA table is made with help of **MATLAB** software. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the *mean squared error* of Y about its target T.

The initial techniques of the analysis of variance were developed by the statistician and geneticist R. A. Fisher in the 1920s and 1930s, and are sometimes known as Fisher's ANOVA or Fisher's analysis of variance, due to the use of Fisher's *F distribution* as part of the test of statistical significance.

#### 7.5.1 Various formulas for ANOVA:

##### Degrees of freedom (DF)

It indicates the number of independent elements in the sum of squares. The degrees of freedom for each component of the model are:

$$\begin{aligned} \text{DF (Factor)} &= r - 1 \\ \text{DF (Error)} &= n_T - r \\ \text{Total} &= n_T - 1 \end{aligned}$$

Where  $n_T$  = the total number of observations and  $r$  = the number of factor levels.

##### Sum of squares (SS)

The sum of squared distances, SS Total is the total variation in the data. SS (Factor) is the deviation of the estimated factor level mean around the overall mean. It is also known as the sum of squares between treatments. SS Error is the deviation of an observation from its corresponding factor level mean. It is also known as error within treatments. The calculations are:

$$\text{SS (Factor)} = \sum n_i (y_{i.} - y_{..})^2$$

$$\begin{aligned} \text{SS Error} &= \sum_i \sum_j (y_{ij} - y_{i.})^2 \\ \text{SS Total} &= \sum_i \sum_j (y_{ij} - y_{..})^2 \end{aligned}$$

Where  $y_{i.}$  = mean of the observations at the  $i_{th}$  factor level,  
 $y_{..}$  = mean of all observations and  
 $y_{ij}$  = value of the  $j_{th}$  observation at the  $i_{th}$  factor level.

##### Pure sum of square

$$\text{SS' (Factor)} = \text{SS (Factor)} - \text{DF (Factor)} * \text{MS (Error)}$$

##### Mean square (MS)

The calculations for the mean square for the factor and error are:

$$\begin{aligned} \text{MS (Factor)} &= \text{SS (Factor)} / \text{DF (Factor)} \\ \text{MS (Error)} &= \text{SS (Error)} / \text{DF (Error)} \end{aligned}$$

##### F Value

It is a test to determine whether the factor means are equal or not. The formula is:

$$F = \text{MS (Factor)} / \text{MS (Error)}$$

The degrees of freedom for the numerator are  $r - 1$  and for the denominator are  $n_T - r$ . Larger values of  $F$  support rejecting the null hypothesis that the means are equal.

## VIII EXPERIMENTAL ANALYSIS

### 8.1 Experimental Layout

Since in my thesis work there are four factors and two levels for each which are shown below:

Table 8.1 Values of variables at different level

Control Factor	Unit	Level 1	Level 2	DOF
Gas Flow Rate	Lit/min	10	15	1
Current	Ampere	240	280	1
Welding Speed	mm/min	150	300	1
Arc Gap	mm	2	4	1

After deciding parameters and levels as shown above orthogonal array L16 decided as per degree of freedom of each factor and DOF of interaction among the parameters. Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per literature review. Now perform experiment as per orthogonal array (L16) on Sparkline Welder make MIG/MAG welding No.11464569, output like MDR is being given in tabulated form. After the experimental results

have been obtained, analysis of the results was carried out analytically as well as graphically. Graphical analysis is done by MATLAB, shows interactions of all parameters. Then ANOVA of the experimental data has been done to calculate the contribution of each factor in each response. Then we calculated S/N ratio for MDR of the specimens.

Then we obtain optimal conditions has been calculated for MDR of the specimen. The following table shows readings of MDR at each experiment, it also shows S/N ratio for MDR at each experiments.

Table 8.2 Calculation Sheet for MDR

Exp. No	Mass 1 (before Welding)	Mass 2 (after welding)	Mass gain(g)	Time Taken	MDR (g/sec)
1	710	760	50	36	1.3889
2	710	760	50	35	1.4286
3	710	750	40	30	1.3333
4	710	750	40	28	1.4286
5	710	755	45	32	1.4063
6	710	745	35	28	1.2500
7	710	745	35	26	1.3462
8	710	745	35	25	1.4000
9	710	745	35	32	1.0938
10	710	745	35	31	1.1290
11	710	740	30	28	1.0714
12	710	755	45	28	1.6071
13	710	745	35	26	1.3462
14	710	745	35	25	1.4000
15	710	745	35	23	1.5217
16	710	740	30	22	1.3636

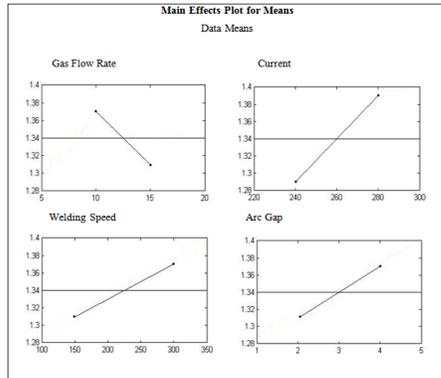
Table 8.3 Experimental Layout and S/N ratios for MRR (Actual Factor Levels)

Exp. No	Gas Flow Rate (Lit/Min)	Current (A)	Speed (mm/Min)	Arc Gap (mm)	MDR (g/sec)	S/N Ratio for MDR
1	10	240	150	2	1.3889	-2.8534
2	10	240	150	4	1.4286	-3.0982
3	10	240	300	2	1.3333	-

					33	2.4986
4	10	240	300	4	1.4286	-3.0982
5	10	280	150	2	1.4063	-2.9616
6	10	280	150	4	1.2500	-1.9382
7	10	280	300	2	1.3462	-2.5823
8	10	280	300	4	1.4000	-2.9226
9	15	240	150	2	1.0938	-0.7788
10	15	240	150	4	1.1290	-1.0538
11	15	240	300	2	1.0714	-0.5990
12	15	240	300	4	1.6071	-4.1209
13	15	280	150	2	1.3462	-2.5823
14	15	280	150	4	1.4000	-2.9226
15	15	280	300	2	1.5217	-3.6465
16	15	280	300	4	1.3636	-2.6937

### 8.2 Experimental Results For MDR

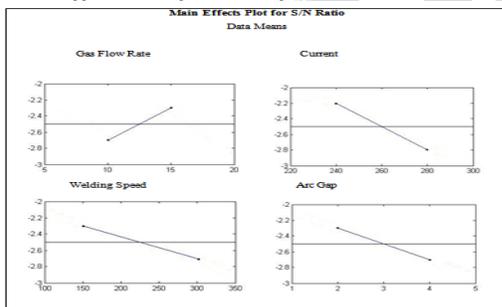
8.2.1 Main Effect Plot for Mean of MDR



Graph 8.1 Effects of various factors on Mean of MDR

By using MATLAB software we obtain some interactions if we look at the graph we will observe that with increase in Gas Flow Rate MDR ratio is decreasing. Material Deposit rate increase with increase in current, welding speed and Arc Gap

8.2.2 Main Effect Plot for S/N of MDR



Graph 8.2 Effects of various factors on S/N Ratio of MDR

By using MATLAB software we obtain some interactions if we look at the graph we will observe that with increase in Gas Flow Rate S/N ratio is increasing. S/N ratio decrease with increase with increase in Current, Welding Speed and Arc gap.

8.3 Analysis Of Variance (ANOVA)

Since as already stated ANOVA help us to identify which parameter is important for us after literature review following ANOVA table is obtained for MDR. MATLAB software is used for statistical calculation purpose.

Table 8.4 ANOVA Table for MDR

Parameters	DOF	SS	MS	F	P	Contribution (%)
Gas Flow Rate	1	1.261	1.261	0.5747	0.933	9.06
Current	1	2.477	2.477	1.1258	0.276	17.74
Welding Speed	1	1.766	1.766	0.8022	0.484	12.64
Arc Gap	1	1.544	1.544	0.7019	0.654	11.06
Residual Error	11	6.887	0.626			49.48
Total	15	13.918				100

Table 5.4 Shows the Analysis of Variance (ANOVA) for MDR response. The important information can be obtained here is the percentage influence of all factors over responses. P value less than 0.400 indicate model terms are significant. In this case Welding Speed is significant model term. Values greater than 0.4000 indicate the model terms are not significant. The percentage contribution by each of the process parameter in the total sum of squared deviation SS<sub>t</sub> can be used to evaluate the importance of the process parameter change on the quality characteristic.

8.4 CONFIRMATION TEST

From S/N ratio and mean of each level of every factor we will construct response table for MDR which are given below

Table 8.5 Response table for S/N ratio of MDR

Level	Gas Flow Rate	Current	Welding Speed	Arc Gap
1	-2.7441	-2.2626	-2.2736	-2.3128
2	-2.2997	-2.7812	-2.7702	-2.7310
Effect	0.4444	0.5186	0.4966	0.4182
Rank	3	1	2	4

From above response table and min effect plot of MDR we can conclude that the optimum condition for MDR is, A2B1C2D2 i.e.,

- Gas Flow Rate: 15 Lit/Min
- Current: 240 A
- Welding Speed: 300mm/min
- Arc Gap: 4 mm

After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated Optimum S/N ratio using the optimal level of the design parameters can be calculated:

$$\hat{\eta} = \eta_m + \sum_{i=1}^q (\bar{\eta}_i - \eta_m)$$

Where,  
 $\eta_m$  is the total mean of the multi response signal-to-noise ratio,  
 $\bar{\eta}_i$  is the mean of the multi response signal-to-noise ratio at the optimal level, and  
 $Q$  is the number of the process parameters that significantly affect the multiple quality characteristics.

Based on the above equation the estimated multi response signal to noise ratio can be obtained.

#### 8.4.1 Prediction of Optimum Value of MDR:

$$\hat{\eta} = \eta_m + \sum_{i=1}^q (\bar{\eta}_i - \eta_m)$$

Here= -2.5220

Optimum S/N ratio for MDR=  $-2.5220 + (-2.2997 + 2.5220) + (-2.2626 + 2.5220) + (-2.7702 + 2.5220) + (-2.7310 + 2.5220) = -2.4975$

And the corresponding value for

$$\text{MDR} = Y_{\text{opt}}^2 = 10^{-\frac{\hat{\eta}_{\text{opt}}}{10}} = 1.777256$$

Predicted Optimum Value of MDR,  $Y_{\text{opt}} = 1.3331$  g/sec

**Table 8.6** Confirmation Test Result for MDR

Number	Gas Flow Rate (Lit/min)	Current (A)	Welding Speed (mm/min)	Arc Gap (mm)	MDR (g/sec)
1	10	240	150	2	1.3889
2	10	240	300	2	1.3333
3	10	280	300	2	1.3462
4	15	280	150	2	1.3462
5	15	280	300	4	1.3636

Average= 1.3556

After performing experiment as per given optimum level for MDR following results obtained

**Table 8.7** Summary Table for Result

MDR (g/sec)	Optimum value of A2B1C2D2=1.3331	Experiment value of A2B1C2D2=1.3556	Percentage = 1.69 %

So we can say that there is 1.69% improvement in MDR. This finding indicated that the experiments in this study possess excellent repetitiveness and great potential for future reference.

## IX. MATHEMATICAL MODELLING

### 9.1 Introduction To Regression Analysis

The term multiple regression literally means stepping back towards the average. It was used by British mathematician Sir Francis Galton. Regression analysis is a mathematical measure of the average relationship between two or more variables in terms of the original units of the data. In regression analysis there are two types of variables. The value whose value is influenced or is to be predicted is called *dependent variable* and the variable which influences the values or is to be used for prediction is called *independent variable*. Regression analysis can be done in two ways;

- Bivariate regression
- Multiple regression

#### 9.1.1 Bivariate Regression:

Two variables X and Y may be related to each other or inexactly. In physical sciences, variables frequently have an exact relationship to each other. The simplest relationship can be expressed by

$$Y = a + bX$$

Where the values of the coefficient, **a** and **b**, determine respectively the precise height and steepness of the line. Thus coefficient *a* represent to as the *intercept* or constant, and coefficient *b* referred to as the *slope*.

In contrast, relationship between variables in social sciences is almost always inexact. The equation for a linear relationship between two social science variables would be written as:

$$Y = a + bX + e$$

Where  $e$  represents the presence of error

### 9.1.2 The least Squares Principle

In postulating relationship among social science variables, we commonly assume linearity. Of course this assumption is not always correct. Least square principle tells us or identified best line which can fit the model for example. The question arises out of all possible line we should choose. From the scatter plot we will calculate prediction error is calculated as:

**Prediction error = observed error - predicted**

Summing the prediction error for all observation would yield a total prediction error (TPE).

$$b = \frac{\sum(X_t - \bar{X})(Y_t - \bar{Y})}{\sum(X_t - \bar{X})^2}$$

$$a = \bar{Y} - b\bar{X}$$

These values of  $a$  and  $b$  are our least square estimates. As we know **Multiple Regression Analysis** is used when more than two parameters are used. In my thesis there are 4 parameters so I will consider multiple regression analysis. In multiple regression analysis linear equation is given by:

$$y = a + bx_1 + cx_2 + \dots + NX_3$$

Where  $b$ ,  $c$  etc are called partial slope. Some terms which are considered in multiple regressions are discussed below:

### 9.1.3 Residual

The difference between an observed value ( $y$ ) and its corresponding fitted value ( $\hat{y}$ ) is called residual. Residual values are especially useful in regression and ANOVA procedures because they indicate the extent to which a model accounts for the variation in the observed data.

### 9.1.4 Sampling Error

When estimating a population parameter from a sample it is important not only to derive a specific value but also estimate the effect of the sampling error on the estimate. To accomplish this it is necessary to consider the concept of a sampling distribution for a regression coefficient. This could be easily understood as the distribution of estimates of the regression coefficient that would be result if sample of given size were drawn repeatedly from the population and coefficient calculated from each sample. Because coefficient estimated from random samples will deviate from population values by varying amounts, the estimates, the estimates of the coefficient from a series of random samples of population will not be identical but instead will distribute themselves around a mean. The estimated standard deviation of the sampling distribution of a regression coefficients is known as a *standard error* and is denoted by 's'.

### 9.1.5 Coefficient of Determination R<sup>2</sup>

This is called *coefficient of determination* indicates explanatory power of any regression model. Its value lies between +1 and 0. It can also be shown that  $R - sq$  is the correlation between actual and predicted value. It will reach maximum value when dependent variable is perfectly predicted by regression equation.

### 9.1.6 Multicollinearity

Multicollinearity means that none of that independent variable or linear variable is perfectly correlated with another independent variable or linear combination of other independent variable. In multiple regression if there is colinearity among variables, then regression surface not even define (because in multiple plain) as there are infinite number of surface that fit the observation equally well and therefore it is impossible to drive unique estimates of the intercepts and partial slope coefficient for the regression.

### 9.2 First Order Linear Model For MDR

With the help of MATLAB Software, we developed first order linear model and ANOVA Table.

The regression equation for MDR is

$$\text{MDR (g/sec)} = 0.452 - 0.0205 \text{ Gas Flow Rate (Lit/min)} + (0.000167 \text{ Current (A)} + 0.000621 \text{ Welding Speed (mm/min)} + 0.0194 \text{ arc gap (mm)})$$

$$S = 0.061058$$

$$R - Sq = 80.7\%$$

$$R - Sq(\text{adj}) = 70.5\%$$

Analysis of Variance

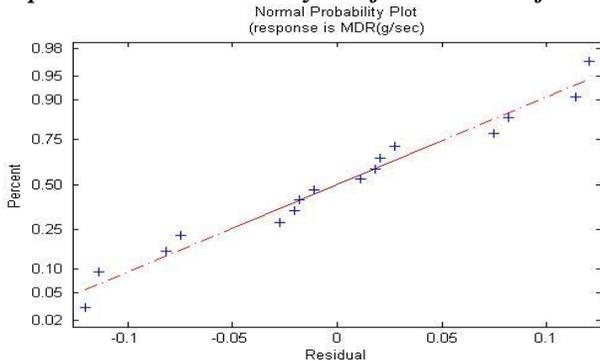
**Table 9.1 ANOVA Table for Regression**

Source	DF	SS	MS	F	P
Regression	4	0.075593	0.018898	7.52	0.06
Residual error	11	0.014535	0.001321		
Total	15	0.090128			

**Model Adequacy Check:** The P- value of Regression equation (0.060) indicates that the regression model is significant. The coefficient of determination ( $R^2$ ) which indicates the goodness of fit for the model so the value of

R2 =80.7% which indicate the high significance of the model.

**Graph 9.1 Normal Probability Plot for Residuals of MDR**



This graph indicates that the residual follows a straight line and there are no unusual patterns or outliers. As a result, the assumptions regarding the residual were not violated and the residuals are normally distributed.

## X. RESULTS

The optimum levels of parameters for maximizing MDR are A2B1C2D2 i.e.,  
 Gas Flow Rate: 15 Lit/min  
 Current: 240 A  
 Welding speed: 300mm/min  
 Arc Gap: 4mm

After performing experiment as per given optimum level for MDR following results obtained

**Table 10.1 Results before and after optimisation**

MD R (g/sec)	Optimum value of A2B1C2D2=1.3331	Experiment value of A2B1C2D2=1.3556	Percentage = 1.69 %
c)			

So we can say that there is 1.69% improvement in MDR. This finding indicated that the experiments in this study possess excellent repetitiveness and great potential for future reference.

## XI CONCLUSION

This thesis has presented an application of the Taguchi method to the optimization of the machining parameters of MIG/MAG Welding Machine. As shown in this study, the Taguchi method provides a systematic and

efficient methodology for determining optimal parameters with far less work than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal parameters. It has been shown that Material Deposit Rate (MDR) can be significantly improved in the MIG/MAG welding process using the optimum level of parameters.

## Bibliography

### Journals:

1. Howell, D.C.(2007).Statistical Methods for Psychology (6<sup>th</sup> ed.).Pacific Grove, CA: Duxbury
2. A Review on Optimization of MIG Welding Parameters using Taguchi's DOE Method
3. G. Haragopal, P V R Ravindra Reddy, G Chandra Mohan Reddy and J V Subrahmanyam, "Parametric design for MIG welding of Al-65032 alloy using Taguchi Technique", *Journal of Scientific and Industrial Research*, Vol. 70, October 2011, pp.844-858.
4. Omar Bataineh, Anas Al-Shoubaki; Omar Barqawi "Optimising Process Conditions in MIG Welding of Aluminum Alloys Through Factorial Design Experiments" *Latest Trends in Environmental and Manufacturing Engineering*, ISBN: 978-1-61804-135-7
5. Izzatul Aini Ibrahim, "The Effect of Gas Metal Arc Welding (GMAW) processes on different welding parameters", *International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012)*, 2012.07.342
6. Pawan Kumar, "Parametric Optimization of Gas Metal Arc Welding of Austenitic Stainless Steel (AISI 304) & Low Carbon Steel using Taguchi's technique", *International Journal of Engineering Research and Management research*, Vol. 3, Issue 4, Aug 2013, pp.18-22
7. Chandresh N. Patel, "Parametric Optimization of Weld Strength of Metal Inert Gas Welding and Tungsten Inert Gas Welding By Using Analysis of Variance and Grey Relational Analysis" *Modern Engineering and Emerging Technology*, Vol. 1, Issue: 3, April-2013.
8. K.Srinivasulu Reddy, "Optimization & Prediction of Welding Parameters and Weld bead Geometry In Submerged Arc Welding" *International Journal of Applied Engineering Research And Development (IJAERD)*, Vol.3 Issue3, Aug2013, PP,1-6

**Books:**

1. Ador Welding Limited, "Modern Arc Welding Technology", Oxford & IBH Publishing Co. Pvt. Ltd.
2. S.K.Hajra Choudhury, A.K.Hajra Choudhury, Nirjhar Roy," ELEMENTS OF WORKSHOP TECHNOLOGY", Vol: 1 Manufacturing Process, Media Promoters and Publishers Pvt. Ltd.
3. Salawadagi Sushant S.& Kumbhar S. B "The Effect Of Microstructure on Hardness and Toughness of Low Carbon Welded Steel using Inert Gas". 2321-5747, Vol:1, Issue-2, 2013 Paper ID 02014405.
4. S.R. Meshram and N.S Pohokar "Optimization of Process Parameters of Gas Arc Welding to improve quality of Weld Bead Geometry" 2321-0613, Vol:1, Issue-9, 2013.
5. R. Satish, B. Naveen, "Weldability and Process Parameter Optimization of dissimilar pipe joint using GTAW". 2525-2530, Vol-2 2012.
6. The Welding Manual- TIG, MIG, And arc welding, the ultimate guide to welding create by Richard Runk
7. Learn to Weld: Beginning MIG welding and metal fabrication basics (Book by Stephen Blake Christena) Originally Published 2013
8. Basic TIG And MIG welding(Book By Charles W. Briggs, Edward M. Roden And Ivan H Griffni) Originally Published 1971.
9. Welding Engineering and Technology by Dr. R.S.Parmar, By khanna Publisher. Originally Published 1<sup>st</sup> Jan 2004
10. Welding Metallurgy and Weldability of stainless steels, John C Lippold and Damian J. Kotecki Published by Wiley India Pvt.Ltd.
11. Manufacturing Technology: Foundary, Forming and Welding,4e (Volume 1) by Dr. P N Rao Publisher Tata McGraw Hill Education Pvt.Ltd.
12. Welder's Handbook ,A guide to Plasma Welding Oxy Acetylene ARC MIG and TIG Welding By Richard Finch, S.A.E,A.W.S.
7. [www.mig-welding.co.uk](http://www.mig-welding.co.uk)>MIG
8. [www.weldingengineer.com](http://www.weldingengineer.com)>1mig
9. [www.mdr-meccanica.it.eng](http://www.mdr-meccanica.it.eng)
10. [www.bernardwelds.com/mig-welding-shielding-gas-basics](http://www.bernardwelds.com/mig-welding-shielding-gas-basics)

**Website:**

1. Gas Welding, [www.en.wikipedia.org/wiki/gas\\_welding](http://www.en.wikipedia.org/wiki/gas_welding)
  2. [www.weldability.com](http://www.weldability.com)
  3. [www.ijemr.net](http://www.ijemr.net)
  4. [www.lincolnelectic.com](http://www.lincolnelectic.com)
  5. Mild Steel Properties-  
[www.kvsteel.co.uk>steel>mild-steel](http://www.kvsteel.co.uk>steel>mild-steel)
  6. [www.gowelding.org>mig-gmaw](http://www.gowelding.org>mig-gmaw)
-