Optimisation of process parameters of MIG Welding to Improve Quality of weld by using Taguchi Methodology.

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Abstract

For any manufacturing industry, welding is one of the most important and effectively used manufacturing process. In today's manufacturing scenario, optimization of welding process is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality which has to be achieved at minimal cost.

Quality of a weld is depends on welding input parameters. Weld penetration depth is one of the prime requirements of welded parts. The purpose of this research paper is focused on the analysis of optimum welding conditions to get highest penetration in weld by regression analysis. This paper presents an experimental study to investigate the effects of welding parameters like current, voltage and gas flow on penetration on cold rolled steel 3 mm thick steel strip. In this investigation, an effective approach is based on Taguchi method, analysis of variance (ANOVA and Regression analysis. It has been developed to determine the optimum conditions to get highest penetration in welding. Experiments were conducted by varying current, voltage and gas flow on penetration using L9 orthogonal array of Taguchi method. Experimental results from the orthogonal array were used as the reference data for the regression model to map the relationship between process parameters and penetration depth. The experiment was conducted on "Lever Complete Gear Shaft Assembly" of Bajaj auto two wheeler having material cold rolled steel. From the investigation it concludes that Current is most influencing parameter followed by Voltage and Gas flow on Penetration.

Keywords: ANOVA; CNC Turning; Surface Finish; MVLR analysis.

1. Introduction

Metal Inert Gas welding is one of the most fundamental and most applied processes in a real manufacturing environment amongst the various manufacturing processes.

Weld penetration has received important significance for many years. It has formulated an important design feature in many situations. Physical properties desired in any welded components are like tensile strength, Yield strength and, elongation. To achieve these physical properties, penetration is the key parameter to check. Weld penetration is the method of measuring the quality of a product and is an important parameter in welding process. It is one of the prime requirements of customers for welded parts [2].

1.1. MIG Welding Process :

A continuous consumable wire is fed through a suitable torch or gun which is used both as an electrode and filler, the gun or torch embodies a concentric gas nozzle which channels a protective gas which is usually fed from a separate cylinder out and around the newly formed weld preventing atmospheric contamination. The weld is formed due to the positive electrode (the continuous wire) coming into close contact with the negative electrode of the work piece allowing a large current to flow through the wire causing the tip to heat up beyond its melting point..

The type of gas or gas mixtures employed in welding varies with the metal being joined. To some extent the gas is chosen to reduce costs, the inert gases being very expensive, but more often the gas is chosen for its effect on the arc characteristics, e.g. burn off rate, type of metal transfer and penetration. These important parameters play a large part while selecting gas.

Gas mixture such as argon with carbon dioxide which combine the advantages of both gases. The main advantage of MIG welding process is high welding speed and greater deposition rates. In this process no slag is left behind, hence no need to clean the weld after finished welding operation; this saves lot of time of welder, enhancing the production rates. The important advantage is that low skill labour is required to operate the weld setup, provided all the welding process parameters are optimised. There is also one main advantage that, no stub end losses or wasted man hours for changing electrodes. A complete spool is employed as an electrode will last longer and is easily interchangeable.

MIG welding process can be easily automated with the help of welding fixtures and Robots.

MIG welding is the form of simple welding methods of metal welding as it does not require a high level of skill to achieve results. The process is semi-automatic because an electrode wire and gas are automatically fed through the gun at a user defined speed or pressure when the operator pulls down the trigger, the electronic arc can also be user defined and carried out automatically on operation. MIG is a quick and easy form of welding; it is used often by robotics in automated production lines.

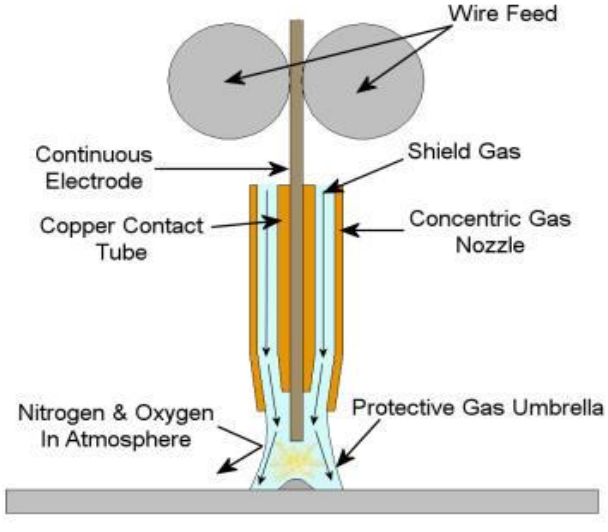


Figure 1 MIG Welding Process

The ability of a welding operation to produce a desired depth of penetration depends on various parameters. In welding process, the penetration depends on current, voltage, gas flow, welding speed, wire diameter. Even small changes in any of the mentioned factors may have a significant effect on depth of penetration. [3].

The aim of this study is to present and discuss the different optimization approaches and strategies in order to improve the depth of penetration based on the experimental research.

Before going to the main experimentation, some discussion with company peoples and with the help of research paper I have selected three input parameter like current, voltage and gas flow rate. By performing OVAT (One Variable at a Time) analysis it is clear that current, voltage and gas flow rate, are influencing parameters on Penetration and selected three levels for each parameter according to results. According to OVAT analysis following input parameters namely current, voltage and gas flow rate, are selected by keeping other process parameters constant which are less influencing on Penetration.

2. Experimental details

2.1 Design of experiments

Taguchi Technique is used to plan the experiments. The Taguchi method has become an influential tool for improving output during research and development, so that better quality products can be produced quickly and at minimum cost. Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has established a method [4] based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control variables. Thus the marriage of Design of Experiments with optimization of control parameters to find best results is attained in the Taguchi Method. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance, and computational cost [5]. "Orthogonal Arrays" (OA) gives a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions in optimization, help in data analysis and estimation of optimum results. In this study we have consider 3 factors which affect majorly on quality characteristic such as (A) Current, (B) Voltage(C) Gas flow rate. The design of experiment was carried out by Taguchi methodology using Minitab 14 software. In this

technique the main objective is to optimize the Penetration that is influenced by three input process selected for this investigation.

2.2 Selection of control factors

From the discussion with company peoples and with the help of research paper it strongly felt that the penetration is very important in lever complete gear shaft assembly as per customer requirement. So that Penetration in mm is selected as response parameter for experimentation.

2.3 Selection of orthogonal array

Since three controllable factors and three levels of each factor were considered L9 (3**3) Orthogonal Array was selected for this investigation.

2.4 Experimental set up

The essential equipments required for any MIG welding process, refer figure 2, are welding power source, Welding torch, Wire feed mechanism, shielding gas cylinder, Pressure Regulator, Flow meter, Gas preheater, Electrode wire, control panel, operator safety equipment and finally suitable welding fixture. A Series of experiment was conducted to evaluate the influence of MIG Welding process parameters on depth of penetration.

2.4.1 Power Source –

The test was carried out on JASIC MIG 350 SG Welding machine. The selection of welding machine is depends on material to be welded, overall dimensions, thickness of the material, It is thumb rule that minimum 25% of thickness should be the minimum penetration desired. It is obvious that larger is always better to achieve highest durability.

MIG welding is carried out on DC electrode (welding wire) positive polarity (DCEP). However DCEN is used (for higher burn off rate) with certain self shielding and gas shield cored wires.

DC output power sources are of a transformer-rectifier design, with a flat characteristic (constant voltage power source). The most common type of power source used for this process is the switched primary transformer rectifier with constant voltage characteristics from both 3-phase 415V and 1-phase 240V input supplies...

The overall components are considered and according to the minimum and maximum dimension of component, selection is carried out for a particular welding machine. Specification and description of machine is given in table 1 bellow.

Figure 2 MIG Welding setup

Table 1 Specification and Description of machine

Specification	Description
Input supply voltage	415 V +/- 10%
Maximum input current	32 Amps R.M.S.
Recommended switch fuse	32 Amps
Rated power	23 KVA
Welding current	400 Amps D.C.
Open ckt. voltage	55 v DC max
Output welding current	50A-400A DC
Cooling	Air
Dimensions	600*500*280 mm
Weight	40 Kgs.

2.4.2 Wire feed mechanism-

The main function of wire feed mechanism is to deliver electrode to the torch at a constant speed or at different speed as per required by the component.

The wire spool is mounted near the feeding mechanism and through feeder the electrode is allow to pass through welding torch as specific speed.

The wire-feed unit, or sub-assembly where this is mounted in the power source cabinet (known as a composite

MIG), provides the controlled supply of welding wire to the point to be welded. According to the welding wire size and

Arc voltage provided by the power source, a constant rate of wire speed is required, in MIG welding the power

source provides Arc voltage control and the wire feed unit provides welding wire speed control, (in MIG this equates

to welding current).d.

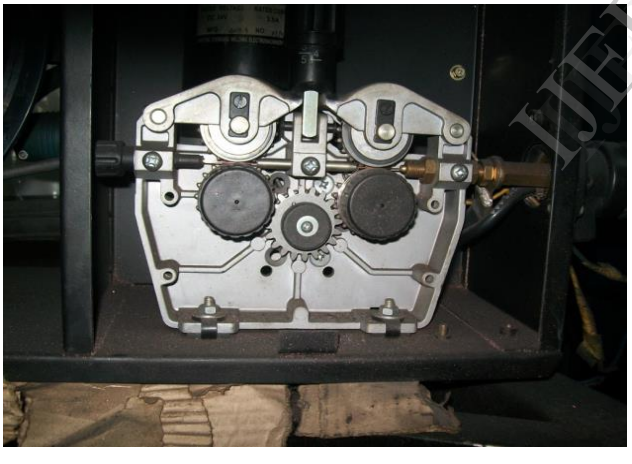


Figure 3 Wire Feed Mechanism

2.4.3 Gas preheater and Pressure Regulator-

The main objective is to regulate the pressure of the shielding gas and preheater is to maintain the temperature of gas optimum for the highest welding efficiency. The parameter setting is directly proportional to the consumption of the gas and hence has importance.

Figure 4 Gas Preheater and Pressure Regulator

2.5 Work material

A lever of Bajaj Discover-125 cc two wheeler selected for experimentation made of material cold rolled steel(Grade DD) and heat treated as carbonitriding. The minimum penetration requirement is normally one fourth of the thickness of the lever i.e.0.75 mm. Our aim of this project is to achieve maximum penetration by optimising the process parameter without affecting cost.

Figure 4 Lever Complete Gearshift

3. Experimental conditions

A series of experiment was carried out on JASIC MIG 350 SG Welding Machine .From OVAT analysis three input controlling parameters selected having three levels. Details of parameters and their levels used shown in the table 3.The experiment is done on lever complete gear assly.

All equipments are to be set with proper parameters like wire feed speed, Shielding gas cylinder pressure , Flow meter adjustment, Gas preheater temperature, Electrode wire spool positioning, , operator safety equipment setting and finally suitable welding fixture setting.

These are various initial setting for producing parts on MIG welding machines. Our project selected main contributing factors such as Current, Voltage and Gas flow. Besides these parameters there are other process parameters like Wire feed, Air Pressure, Fixture Rotational speed.

The above parameters are to be set for the optimum values so that the productivity, quality with the minimum cost is achieved. It is, hence, very essential to know the optimum process parameters.

Table 2 Process parameters and levels

Notation	Process parameters	Level 1	Level 2	Level 3
A	Current (Ampere)	120	140	160
B	Voltage (volts)	22	24	26
C	Gas Flow (lit/min)	15	20	25

The experimental design matrix is obtained by Taguchi methodology by using Minitab 14 software is shown in table 3 below. The parameters are set by studying the existing setup and quality requirements of components. The penetration depth is important quality parameter which affects the strength of the weld and thereby the durability of the product.

Table 3 Layout for Experimental Design according to L9 Array

Exp. No.	A Current (Ampere)	B Voltage (Volts)	C Gas Flow (Lit/min)
1	120	22	15
2	120	24	20
3	120	26	25
4	140	22	20
5	140	24	25
6	140	26	15
7	160	22	25
8	160	24	15
9	160	26	20

4. Results and Discussion

4.1 S/N Ratio Analysis

In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (LB). Higher is better S/N ratio used here because the quality characteristic is Penetration. Higher -the-better quality characteristic was implemented and introduced in this study.

Higher the better characteristic,

$$S/N = -10 \log10 (MSD)$$

Where MSD= Mean Squared Division

$$MSD = (1/Y_1^2 + 1/Y_2^2 + 1/Y_3^2 + \ldots\ldots\ldots\ldots)/n$$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and m is the target value of the result. Table 5 indicate avg. Penetration and

S/N ratios for different combinations of design matrix.

A combination of factors with highest S/N ratio is the optimum situation where the Penetration is maximum.

Table 4 summary Report for different trial conducted during Experimentation

Trial No.	Penetration (mm)			Avg. Penetration (mm)	S/N Ratio
	Trial 1	Trial 2	Trial 3		
1	0.92	0.83	0.95	0.9	-0.91515
2	1.13	1.10	0.95	1.06	0.50612
3	1.15	1.37	1.23	1.25	1.93820
4	1.31	1.22	1.10	1.21	1.65571
5	1.44	1.51	1.25	1.4	2.92256
6	1.48	1.59	1.28	1.45	3.22736
7	1.42	1.58	1.68	1.56	3.86249
8	1.81	1.51	1.48	1.60	4.08240
9	1.74	1.79	1.93	1.82	5.20143

Table 5 Estimated Model Coefficient for SN ratios

Term	Coef	SE Coef	T	P
Constant	2.49790	0.04810	51.928	0.000
Current 120	-1.9881	0.06803	-29.226	0.001
Current 140	0.10397	0.06803	1.528	0.266
Voltage 22	-0.9635	0.06803	-14.164	0.005
Voltage 24	0.00579	0.06803	0.085	0.940
Gas Flow 15	-0.3663	0.06803	-5.386	0.033
Gas Flow 20	-0.0434	0.06803	-0.639	0.588

Summary of Model S = 0.1443 R-Sq = 99.9%
R-Sq(adj) = 99.4%

Table 6 Response Table for Signal to Noise Ratios – Larger is better

Level	Current (Ampere)	Voltage (Volts)	Gas Flow (Lit/Min)
1	0.5097	1.5343	2.1315
2	2.6019	2.5037	2.4544
3	4.3821	3.4557	2.9078
Delta	3.8724	1.9213	0.7762
Rank	1	2	3

The level of a factor with the highest S/N ratio was the optimum level for responses measured. From the Table 6, it is clear that, the optimum value levels for higher Penetration are at a Current (160 Amp), Voltage (26 Volts), and Gas flow rate (20 ltr/min.) The response table includes ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank one to the highest Delta value, rank two to the Second highest, and so on. From both ANOVA and response tables it is clear that the most significant factor is Current (A), followed by Voltage (B) and Gas Flow (C). Figure 4 shows graphically the effect of the three control factors on Penetration depth.

Graph 1 Effect of process parameters on S/N Ratio

4.2 Analysis of Variance (ANOVA)

The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for design of experiment applications. In order to find out statistical Significance of various factors like Current (A), Voltage (B), and Gas Flow rate (C), and their interactions on Penetration, analysis of variance (ANOVA) is performed on experimental data. Table 7 shows the result of the ANOVA with the Penetration. The last column of the table indicates p-value for the individual control factors. It is known that smaller the p-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 8) indicate that, the Current (p=0.002), Voltage (p= 0.007) and Gas flow rate (p=0.044) in this order, are significant control factors effecting penetration. It means, the current is the most influencing factor and the Gas flow rate has less influence on the performance output compared to voltage.

Table 7 Analysis of Variance for S/N ratios (Penetration)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current (Ampere)	2	22.5417	22.5417	11.2708	541.22	0.002
Voltage (Volts)	2	5.5373	5.5373	2.7687	132.95	0.007
Gas Flow (ltr/min)	2	0.9123	0.9123	0.4561	21.90	0.044
Residual Error	2	0.0417	0.0417	0.0208		
Total	8	29.0329				

4.3 Percent contribution

Percent contribution to the total sum of square can be used to evaluate the importance of a change in the process parameter on these quality characteristics

Percent contribution (P) = (SS'A / SST) *100

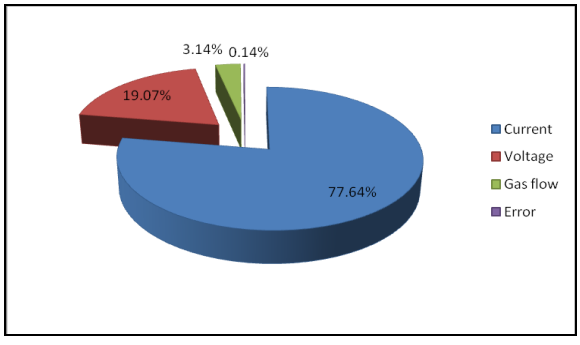
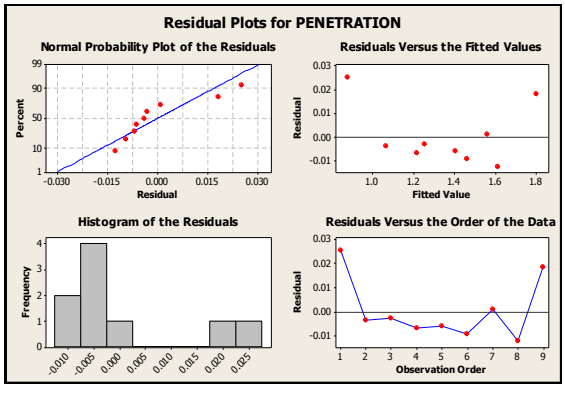


Table 8 Optimum Condition and Percent Contribution

SR. No.	Factors	Level Description	Level	Contribution (%)
1	A: Current	160	1	77.64
2	B: Voltage	26	2	19.07
3	C:Gas Flow	20	3	3.14

From the Table 8 it is clear that current is most influencing while gas flow rate is least influencing parameter on penetration depth.



Graph 2 Residual Plots for PENETRATION

4.4 Regression Analysis

Mathematical models for process parameters such as Current, voltage and Gas flow rate were obtained from regression analysis using

MINITAB 14 statistical software to predict penetration.

The regression equation is

Y = Penetration = -2.63+ 0.0148 CURRENT + 0.0720 VOLTAGE+0.00905 GASFLOW
…….. (1)

S = 0.0184685 R-Sq = 99.8%
R-Sq(adj) =99.7%

Where, Y = Response i.e. Penetration (mm), A = Current (Ampere), B = Voltage(volts), C = Gas Flow rate (ltr/min). If we put optimum parameters which are drawn by ANOVA in equation 1 it will give optimum value of quality characteristic which is maximum PENETRATION.

Yopt = -2.63+0.0148* A_3 + 0.0720 * B3+0.00905* C_2

Y opt = -2.96+0.0157*160 +0.0799*26+0.0102*20

Y opt = 1.814 (Predicted by Regression Equation)

In multiple linear regression analysis, R2 is value of the correlation coefficient and should be between 0.8 and 1. In this study, results obtained from Penetration in good agreement with regression models (R^2>0.80).

4.5 Conformation Experiments

In Order to test the predicted result, confirmation experiment has been conducted by running another four trials at the optimal settings of the process parameters determined from the Analysis i.e. $A_3B_3C_2$

Observation	Trial			Avg. Penetration	S/N
	1	2	3	(mm)	Ratio
1	1.89	1.65	1.86	1.80	5.1054

5. Conclusions

The Taguchi method was applied to find an optimal setting of the MIG WELDING process. The result from the Taguchi method chooses an optimal solution from combinations of factors if it gives maximized normalized combined S/N ratio of targeted outputs. The L-9 OA was used to accommodate three control factors and each with 3 levels for experimental plan selected process parameters are Current (120,140,160 Amperes), Voltage (22,24,26 volts, Gas flow rate are (15,20,25 ltr/min). The results are summarized as follows:

1) From the analysis, it is clear that the three process parameters, Current, Voltage and Gas flow rate have significant effect on Penetration.
2) The analysis of variance proves that the most influencing parameters on PENETRATION are current and voltage. While gas flow is least significant as compared to current and voltage.
3) The result of present investigation is valid within specified range of process parameters
4) Also the prediction made by Regression Analysis is in good agreement with Confirmation results.
5) The optimal levels of welding process parameters are found to be $A_3B_3C_2$:

Current (Ampere)	160
Voltage (Volts)	26
Gas Flow (ltr/min)	20

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