Experimental Evaluation of Mechanical Properties of Stainless Steel by TIG Welding at Weld Zone

D. Simhachalam[#1], N. Indraja[2], M. Raja Roy[3]

[#]Assistant Professor, Mechanical Engineering Department, Anil Neerukonda Institute of Technology and Sciences
Sangivalasa, Bheemili, Andhra Pradesh, India 531162

***Abstract*— *The present paper aims at studying the effect of welding process parameters on the mechanical properties of stainless steel 304(18Cr-8 Ni) welded joint obtained by TIG welding. The welding parameters like welding current,Gas flow rate and filler rod diameter have varying degree of influence on the properties of the welded joint. Impact strength and hardness are determined at Welded Zone. Specimens of size 40x15x5 mm are taken for experimentation it is observed that the welding current has a significant effect on the welding parameters as compared to the filler rod diameter. The filler rod diameter also has similar effect on the welding current, but the welding current has a higher effect compared to the filler rod diameter. The present paper also involves prediction of hardness, impact strength and depth of penetration using MINITAB software. The residuals obtained from the analysis using software were find to be within limits which proves the correctness of the experimental values.*

Keywords— TIG Welding, Wels Zone, Hardness, Response Surface Method.

I. INTRODUCTION

1.1 Introduction of Welding

Welding is an efficient and economical method for joining of metals. Welding has made significant impact on the large number of industries by raising their operational efficiency, productivity and service life of the plant and relevant equipment. Welding is one of the most common fabrication techniques which is extensively used to obtain good quality weld joints for various structural components. The present trend in the Submerged arc fabrication industries is to automate welding processes to obtain high production rate. Welding processes can be automated by establishing the relationship between the process parameters and weld bead geometry to predict and control the weld bead quality . These relationships can be developed by using of experimental design techniques.

1.2 Principle of TIG Welding

During TIG welding, an arc is maintained between a tungsten electrode and the work piece in an inert atmosphere (Ar, He, or Ar-He mixture). Depending on the weld preparation and the work-piece thickness, it is possible to work with or without filler. The filler can be introduced manually or half mechanically without current or only half mechanically under current

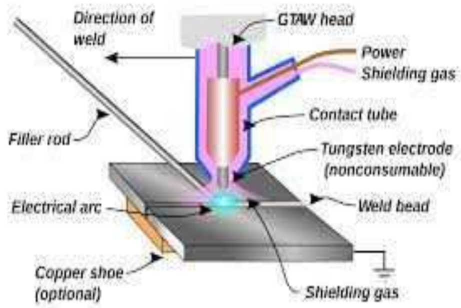


Fig1.2 Principle of TIG welding

The process itself can be manual, partly mechanized, fully mechanized or automatic. The Welding power source delivers direct or alternating current (partly with modulated or pulsed current). A major difference between the welding of steel and the TIG welding of aluminum is the adhering oxide film on the aluminum surface which influences the welding behavior and has to be concerned. This oxide film has to be removed in order to prevent oxides from being entrapped in the weld. The oxide film can be removed by varying the current type or polarity or also through the use of suitable inert gases

1.3 Equipment for TIG Welding

TIG welding equipment consists of the following components:

- Source of welding current (including welding controls, filtering condensers and pulse modulation)
- Torch unit with hose packet
- Gas cylinders with pressure-reducing valve and flow meter

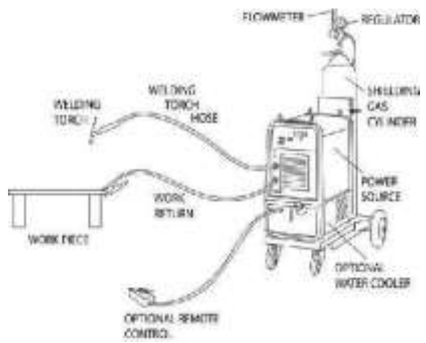


Fig 1.3 Equipment if Tig welding

Modern welding power sources can deliver both direct and alternating current. The power sources have falling characteristic curves. The current can be varied in steps or continuously. The voltage required depends on the distance between electrode and work-piece and determines the operating point on the characteristic line.

II LITERATURE REVIEW

- ARUN NARAYANAN, CIJO MATHEW, VINOD YELDO BABY, JOBY JOSEPH, "Influence of Gas Tungsten Arc Welding Parameters in aluminium 5083 alloy" International Journal of Engineering Science and Innovative Technology (IJESIT) ISSN: 2319-5967 Vol. 2 No. 5 September 2013. The present work deals with the identification of the best combination of welding parameters, in TIG welding of Aluminium alloy 5083. In this study two level full factorial experimental design is considered which consists of two factors and two levels. In order to avoid experimental errors two replications are performed for each experimental combination. The working ranges of welding parameters for conducting experiments are initially obtained by trial and from literature survey. After the experiment, various tests like Tensile test; Micro hardness, Macrostructure and Microstructure study are conducted to the welded specimens. The analysis of the test results is conducted and the combination of welding parameter ranges that gives best result is found. This combination can be considered as good working ranges for TIG welding of Aluminium alloy 5083.

- CHANDRESH.N.PATEL, PROF.SANDIP CHAUDHARY, "Parametric Optimization of Weld Strength of Metal Inert Gas Welding and Tungsten Inert Gas Welding By Using Analysis of Variance and Grey Relational Analysis" online international, reviewed and indexed monthly journal, RET academy for International Journals of Multidisciplinary Research (RAIJMR). Welding is a manufacturing process, which is carried out for joining of metals by Metal Inert Gas (MIG) welding and Tungsten Inert Gas (TIG) Welding. All welds will be prepared by MIG and TIG welding technique. In which input parameters for MIG welding are 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 is hardness.. For Experimental design we were used full factorial method ($L=m^n$) 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. We take a Grey Relational Analysis (GRA) optimization technique for optimization of different values. By analyzing the Grey relational grade we find the optimum parameters.

- LAKSHMAN SINGH, ROHIT KUMAR, NIDHI GUPTA AND MAYUR GOYAL, "To investigate the effect of TIG welding Parameters on 5083 Aluminum Alloy Weldability" ISSN: 2320-2491, Vol.2, No.4, June July 2013. In this study, TIG welding parameter's influence on Weldability of 5083 aluminium alloy specimens with dimension of 50 mm long x 50 mm wide x 5 mm thick is investigated. The welding parameters such as arc voltage, welding current, welding speed, gas flow rate and heat input are taken into account which influence the depth of penetration measured after welding. Investigate the effect of welding speed, gas flow rate and heat input on depth of penetration and found that depth of penetration increases first by increasing welding parameters till an optimum value and starts to decrease depth of penetration by further increment of welding parameters. Optimum Weldability can be achieved at arc voltage of 22volt, current of 215 ampere, welding speed of 146.48 mm/min., gas flow rate of 12.45 lt/min and heat inputs of 1937.47 joule/mm

- NIRMALENDHU CHOUDHURYA, RAMESH RUDRAPATIA AND ASISH BANDYAPADHYAYA."Design optimization of Process Parameters for TIG welding based on Taguchi Method". International Journal of Current Engineering and Technology. The present study pertains to the improvement of ultimate load of stainless steel – mild steel weld specimen made of tungsten inert gas (TIG) welding. L16 orthogonal array (OA) of Taguchi method has been used to conduct the experiments using several levels of current, gas flow rate and filler rod diameter. Statistical techniques analysis of variance (ANOVA), signal-to-noise (S/N) ratio and graphical main effect plots have been used to study the effects of welding parameters on ultimate load of weld specimen. Optimum parametric condition obtained by Taguchi method. Confirmatory test has been conducted to validate the predicted setting.

- SUSHEEL KUMAR SHARMA, SYED HASAN MEHDI "Influences of the Welding Process Parameters on the Weldability of Material" International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-5, June 2013. In this study, influence of the welding process parameters on the weldability of material, low carbon alloy steel(0.14% C) specification having the dimensions 75 mm X 50 mm X6mm welded by metal arc welding were investigated. The welding current, arc voltage, welding speed, heat input rate are chosen as welding parameters. The depth of penetrations were measured for each specimen after the welding operation on closed butt joint and the effects of welding speed and heat input rate parameters on depth of penetration were investigated.

III EXPERIMENTAL WORK

3.1 Base Metal

AISI 304 (SUS 304) Grade Stainless Steel. Stainless steel types 1.4301 and 1.4307 are also known as grades 304 and 304L respectively. Type 304 is the most versatile and widely used stainless steel. It is indicated by 18/8 which is derived from the nominal composition of type 304 being 18% chromium and 8% nickel. Type 304 Stainless Steel is an austenitic grade that can be severely deep drawn.

Applications

304 Stainless Steel is typically used in:

- Sinks and splash backs
- Saucepans
- Cutlery and flatware
- Architectural panelling
- Sanitary ware and troughs
- Tubing
- Brewery, dairy, food and pharmaceutical production equipment
- Springs, nuts, bolts and screws
- Medical implants

Fig 3.1 Filler Rods

Fig 3.2 Weld specimen

3.2 Weld joint preparation

Stainless steel of grade 304, with specification 300 x 284 x 5 mm are taken and cut into 36 specimens of 40x15 mm dimensions with hydraulic cutting machine. The specimens are joined in the form of butt joint as in fig.3.1.

3.3 Experimental conditions

Welding was carried out on Tig welding Machine at Navyasri Engineering Works, Autonagar, Visakhapatnam.

The welding procedure carried out here with inert gas argon and tungsten electrode of diameter 2.5 mm. The gas flow rate is kept constant 20 (lt/min). Here the varying input parameters are current and filler rod diameters. The current values are 50Amps, 65Amps, 80Amps. The filler rod diameters are 1.6mm, 2mm, 2.4 mm. For each current value we varied three filler rods to get welded joints of 18 pairs. The welding is carried out in the direction perpendicular to the grains.

Table 3.1: Welding conditions

Electrode	Tungsten
Electrode diameter	25.mm
Inert gas	Argon
Operation type	Manual

Table 3.2: Important weld parameters

S. No	Input Factor	Units	Value
1	Welding Current	Amperes	Variable
2	Filler rod diameter	Mm	Variable
3	Gas flow rate	lt/min	25

Fig 3.2 Performing of TIG Welding

3.4 Hardness Test

The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of Pascals, but should not be confused with pressure, which also has units of pascals.

$$HV = \frac{F}{A} \simeq \frac{1.8544F}{d^2}$$

Fig 3.4 Vickers Apparatus

3.5 Charpy impact test

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. A disadvantage is that some results are only comparative. It is utilized in many industries for testing materials, for example the construction of pressure vessels and bridges to determine how storms will affect the materials used. The apparatus consists of a pendulum of known mass and length that is dropped from a known height to impact a notched specimen of material. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after the fracture (energy absorbed by the fracture event).

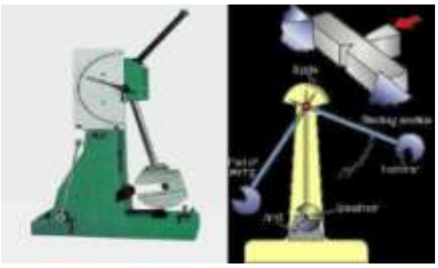


Fig. 3.6 Charpy Impact Test

The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain. The quantitative result of the impact tests the energy needed to fracture a material and can be used to measure the toughness of the material.

The welded specimen are reduced to 55*15*4 mm as per the equipment specifications and the specimen is kept as simply supported beam in the alignment place and the load is released to strike the specimen .this is done for rest of specimens.

3.6 Experimental values

S. No	Gas Flow Rate (Lt/ Min)	Welding Current (Amps)	Filler Rod Dia (mm)	Charpy Test (N/M m^2)	Hardness (VHN) BM	Hardness (VHN) WZ
1	20	50	1.6	119	442.02	301.56
2	20	50	2	109	425.15	338.98
3	20	50	2.4	102	412.68	373.12
4	20	65	1.6	112	453.83	350.27
5	20	65	2	105	438.18	309.32
6	20	65	2.4	100	421.12	307.41
7	20	80	1.6	110	458.69	319.15
8	20	80	2	104	421.53	290.45
9	20	80	2.4	98	410.1	308.75

IV RESUTS AND DISCUSSIONS

This study deals with the results and discussions of the experimental findings of welded joints prepared at constant gas flow rate, different welding currents and filler rod diameters. The specimens prepared under different welding currents and filler rod diameters and having different effects.

4.1 Response Surface Methodology

Response surface methodology uses statistical models and therefore practitioners need to aware that even the best statistical model is an approximation to reality. In practice, both models and parameter values are unknown and subject to uncertainty on top of ignorance. Ofcourse an estimated optimum. Need not be optimum in reality because of the address of the estimate end of the inadequacies of the model. None the less response surface methodology has been effective track record of helping researchers improve product and services for example box original response surface modeling unable engineer to improve a process that had been stuck at a saddle point for years. Box design reduce the cost of experimentation so that aquatic model could be fit which lead to different direction.

4.1 Mathematical model of Response Surface Methodology

The response surface is described by and second order polynomial equation of the form.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_{i^2} + \sum \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

Y is the corresponding response

(1.2…..S) are coded levels of S quantitative process variables. The terms are the second order regression coefficients. Second term is attributable to linear effect.
Third term corresponds to the higher order effects
Fourth term includes the interactive effects
The last term indicates the experimental error.

4.1.2 Different terms used in response surface methodology regression table

1. **P-values**: P- values are used to determine which of the effects in the model are statistically significant.

   If the P value is less than or equal to 0.5 conclude that the effect is significant. The P value is greater then 0.5 conclude that the effect is not significant.
2. **Co efficient**: Co-efficient are used to construct an equation representing the relationship between the response and the factors.

3. **R- squared:** R and adjusted R represent the proportion of variation in the response dirty explain by the model.

   R-sq describes the amount of variation in the observed responses that is explained by the model.

If we include unnecessary are can be artificial tree. Unlike or registered are make it smaller when we add terms to the model.

Analysis of variance table:
P-values are used in analysis of variance table to determine which of the effects in the model are statistically significant.

4.2 Graphs obtained

Normal plot of residuals: The graph plotted between the residuals vs their expected values when the distribution is normal. The residual from the analysis it should be normally distributed. In practice for balance daily balance designs are for data with a large number of observations moderate departure from normality do not seriously affect the results. The normal probability plot of the residual should roughly follow a straight line.

Residual Vs Fits: Graphic trees slotted between the residual vs deep fitted values the residuals should be scattered randomly about zero.

Residual Vs Order: This graph plot the residuals the order of the corresponding observations. The plot is useful when the order of the observations may influence the result, which can occur when data not collected in time sequence are some other weekend. This plot can be particularly helpful designed experiment in which did rams are not random.

4.3 Response Surface Regression: D.O.P versus WC, D

Coded co-efficients :

Term	Effect	Co efficient	SE-coefficient	T-value	P-value	VIF
Constant		2.531	0.162	15.60	0.001	
WC	-0.4267	-0.2133	0.088	-2.40	0.096	1.00
D	-0.7733	-0.3867	0.088	-4.35	0.022	1.00
WC*WC	0.387	0.193	0.154	1.26	0.298	1.00
D*D	0.287	0.143	0.154	0.93	0.421	1.00
WC*D	-0.405	-0.202	0.109	-1.86	0.160	1.00

4.4 Regression Equation in Uncoded Units

DOP = 8.22 - 0.0584 WC - 2.36 D + 0.000859 WC*WC + 0.896 D*D - 0.0337 WC

Histogram

A histogram is a graphical representation of the distribution of data. It is an estimate of the probability distribution of a continuous variable (quantitative variable) and was first introduced by Karl Pearson.

The Histogram is the most commonly used graph to show frequency distributions. Histograms give a rough sense of the density of the data, and often for density estimation: estimating the probability density function of the underlying variable. The total area of a histogram used for probability density is always normalized to 1. If the length of the intervals on the *X*-axis are all 1, then a histogram is identical to a relative frequency plot.

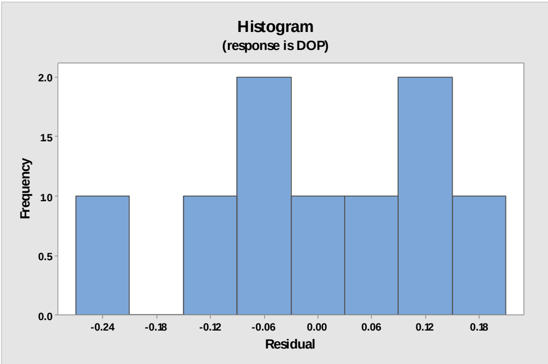


Fig-4.1 Histogram for Depth of penetration

Normal plot of residuals: Fig 4.2shows the graph plotted between the residuals versus their expected values when the distribution is normal. The residuals from the analysis should be normally distributed. In practice, for balanced or nearly balanced designs or for data with large number of observations, moderate departures from normality do not seriously affect the results. The normal probability plot of the residuals should roughly follow a straight line.

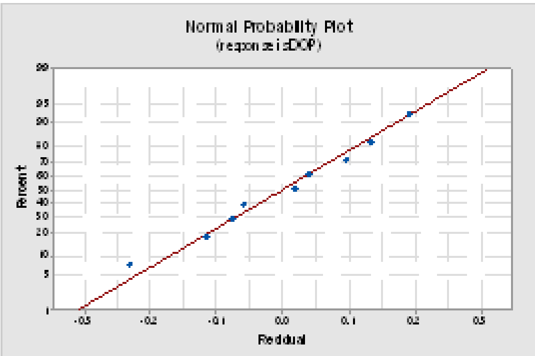


Fig-4.2 Normal Distribution plot for Depth of penetration

Main Effects

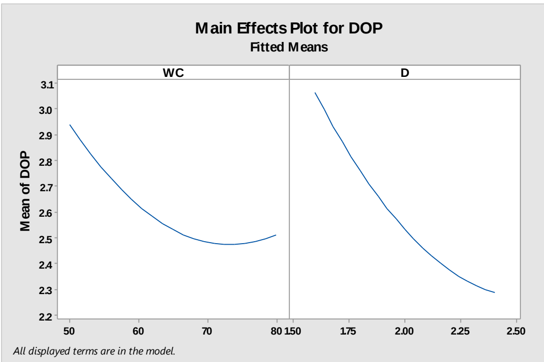


Fig-4.3 Main Effects for Depth of penetration

Interaction Effects

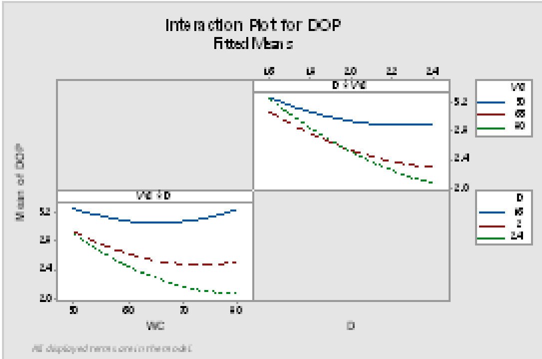


Fig-4.4 Interaction Effects for Depth of penetration

4.5 Response Surface Regression: IMP versus WC, D

Term	Effect	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant		4.889	0.881	119.01	0.000	
WC	-5.667	-2.833	0.483	-5.87	0.010	1.00
D	-13.667	-6.833	0.483	-14.16	0.001	1.00
WC*WC	2.333	1.167	0.836	1.40	0.257	1.00
D*D	2.333	1.167	0.836	1.40	0.257	1.00
WC*D	2.500	1.250	0.591	2.11	0.125	1.00

Regression Equation in Uncoded units

IMP = 229.5 - 1.280 WC - 59.8 D + 0.00519 WC*WC + 7.29 D*D + 0.2083 WC*D

Residual Histogram for IMP

A histogram is a graphical representation of the distribution of data. It is an estimate of the probability distribution of a continuous variable (quantitative variable) and was first introduced by Karl Pearson.

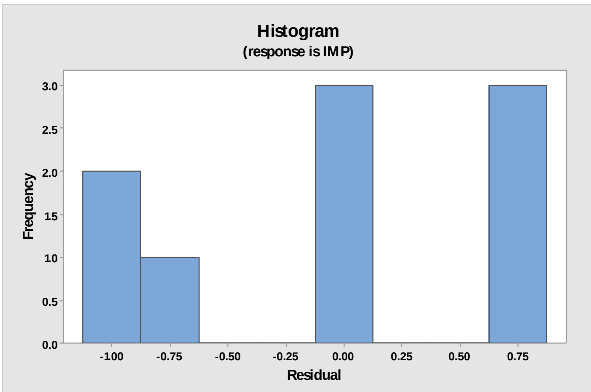


Fig-4.5 Histogram for IMP

Residuals vs Order for IMP

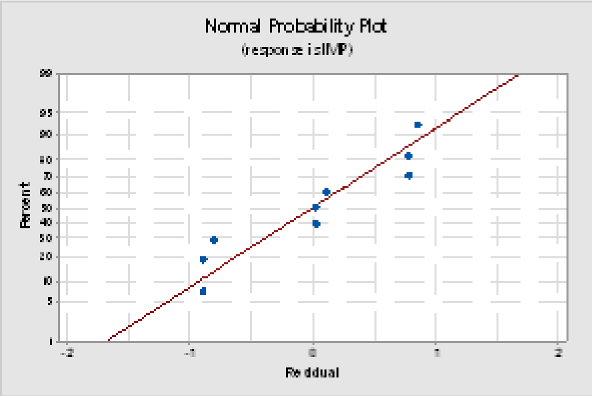


Fig-4.6 Normal Distribution plot for IMP

Main Effects

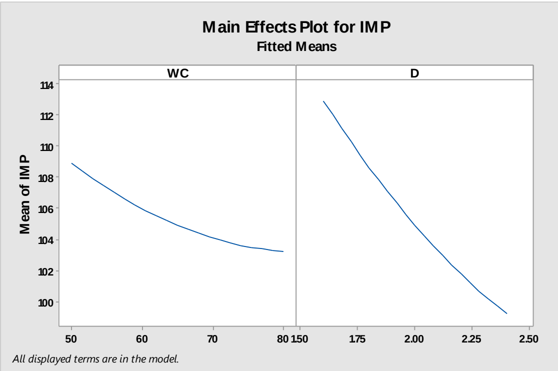


Fig-4.7 Main Effects for IMP

Interaction Effects

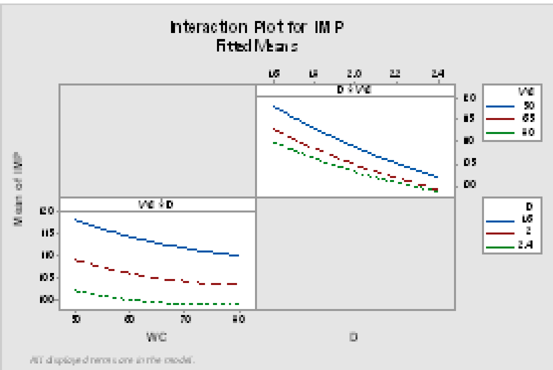


Fig-4.8 Interaction Effects for IMP

4.6 Response Surface Regression: Hardness at WZ versus WC, D

Coded co-efficients :

Term	Effect	Coefficient	SE coefficient	P-Value	T-Value	VIF
Constant		426.89	2.20	0.00	193.82	
WC	14.67	7.33	1.21	0.009	6.08	1.00
D	-36.67	-18.33	1.21	0.001	-15.20	1.00
WC*WC	3.33	1.67	2.09	0.483	0.80	1.00
D*D	9.33	14.67	2.09	0.112	2.23	1.00
WC*D	-2.50	-1.25	1.48	0.460	-0.85	1.00

Regression Equation in Uncoded units

WZ = 607.7 – 0.06 WC – 149.0 D + 0.00741 WC*WC + 29.2 D*D - 0.208 WC*D

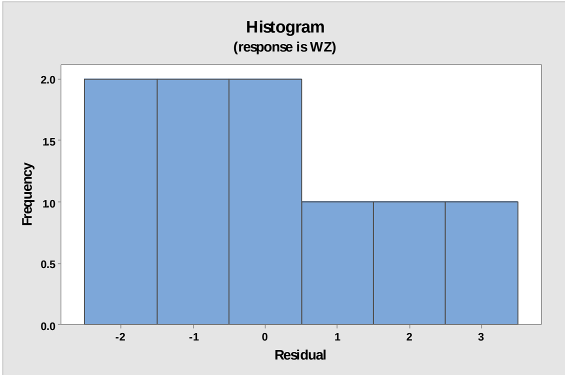


Fig-4.9 Histogram for hardness at WZ

Residuals vs Order for IMP

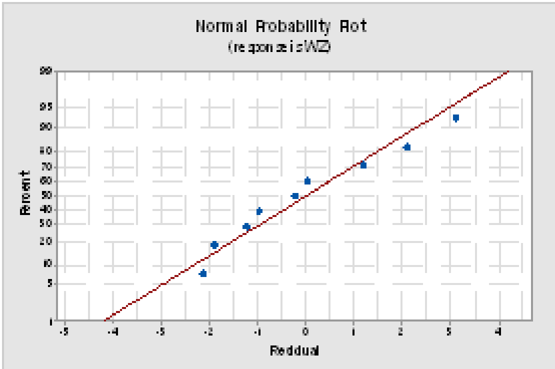


Fig-4.10 Normal Distribution plot for hardness at WZ

Main Effects

Fig-4.11 Main Effects for hardness at WZ

Interaction Effects

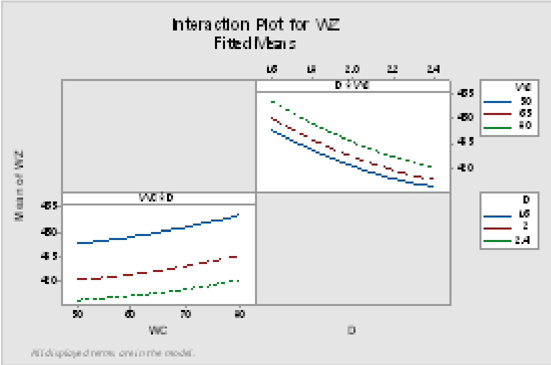
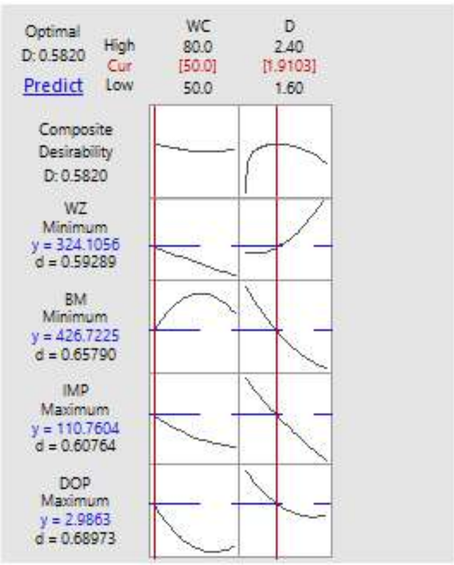


Fig-4.12 Interaction Effects for hardness at WZ

4.7 Response optimisation

A Minitab response optimizer tool shows how different experimental settings affect the predicted responses for factorial, response surface, and mixture designs. The optimal solution serves as the starting point for the plot. This optimization plot allows to interactively changing the input variable settings to perform sensitivity analyses and possibly improve the initial solution.

The optimization plot as shown in the fig signifies the affect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level settings (in red). The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates maximum values of DOP,Hardness and IMP at Weld Zone.



V. CONCLUSION

1. In this work, it is observed that by keeping constant gas flow rate and welding current and by varying the filler rod diameter in increasing order the depth of penetration and impact strength decreases.
2. From the experimental values, it is observed that by keeping constant gas flow rate and filler rod diameter and by varying the current in increasing order the depth of penetration decreases , impact strength decreases, and hardness increases at Weld Zone
3. Regression equation is successfully generated for predicting the hardness, impact strength, depth of penetration.
4. Using Minitab software response surface optimization has done for minimizing hardness and maximizing the impact strength and depth of penetration.
5. Experimental values and predicted values through response surface method are good in agreement with less than 10 percentage.

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