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The effect tig welding parameters on mechanical properties of stainless 321 by Taguchi method

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Abstract

Welding is an area in which technological developments out match the developments in its science base which is primarily driven by the phenomenal industrial demand for welded structure. Taguchi s Design of experiment approach is used to study the effect of welding parameters on the mechanical properties of stainless steel 321. This research investigates the effects of welding current, gas flow rate and welding speeds at different ranges on the welding joints, hardness, and tensile behavior of austenitic stainless steel type 321. The factor used in this study consisted of welding current, gas flow rate and welding speed each of which had three levels. L9 orthogonal array were selected according to the aforementioned factor and levels and experimental tests were performed. Signal-to-noise (SN) ratio was used to evaluate the experimental result. , the as-received 321 austenitic stainless steel sheet was cut with shear cutting machine into sample of dimensions 350 mm length, 260 mm width and 2 mm thickness, Eighteen samples were produced, nine samples were defended in to group A, B and C respectively. The grouped samples were further cut into two equal halves with milling machine and welded using Tungsten Inert Gas Welding (TIGW) process. The obtained welded samples and as-received sample were machined to standard tensile test specimens, and tensile test was made using standard approaches.. The analysis of the variance (ANOVA), the best optimal levels and the effect of the process parameters on welding joints were obtained. In addition the optimum welding sample was number two which has maximum tensile strength of 462.87 N/mm2 and maximum hardness of 123 HB. this was obtained from welding current of 50A, welding speed of 6mm/sec and gas flow rate 30 l/.

1.0 Introduction

Welding is a joining process of similar materials but nowadays it is also joining dissimilar metals by the application of heat. Welding can be done with or without the application of pressure. It is can be done addition of filler materials or without addition of filler materials. While welding the edges of metal pieces either melted or brought to plastic condition and it is used for permanent joints. The joint gets stronger when it cools down. Its heats when the weld pool is used with the work piece and produces weld in that time. In all fabrication companies welding is very essential.[1]. welding is used extensively for fabrication of different components in 2 automobile bodies, bridges, aircraft frames, chemical plants, nuclear reactors, structural and earth moving equipment, railway wagons, pipe and tube fabrication, ship building, general repair works, Welding often an industrial process it may be used for different environments, including open air under water and in outer space. Many different energy sources can be used for welding, including gas flame, electric arc, laser, electron beam, friction, ultra sound SMAW and TIG. [2]. For this research Tungsten inert gas (TIG) process has been chosen. Tungsten inert gas (TIG) welding is an arc-welding process that produces coalescence of metals by heating them with an arc between a nonconsumable tungsten electrode and the base metal. This process was originally developed for hard-to weld lightweight metals such as aluminum, magnesium and titanium. Many delicate components in aircraft and nuclear reactors are TIG welded and therefore TIG weld quality is of extreme importance. Basically, TIG weld quality is strongly characterized by the weld pool geometry; this is because the weld pool geometry plays an important role in determining the mechanical properties of the weld. TIG weld quality is strongly characterized by the weld pool geometry. This is because the weld pool geometry plays an important role in determining the mechanical properties of the weld [3]. The Taguchi method is one of the techniques that could be applied to optimize the input welding parameters. Optimization of process parameters is the key step in the Taguchi method in achieving high quality, without increasing the cost. Generally, the quality of a weld joint is directly influenced by the welding input parameter settings. Selection of proper process parameters is important to obtain the desired weld bead profile and quality [4].

2.0 Experimental Methodology:

The material used in this investigation was stainless steel 321 and dimensions of 350mm, 260mm, 2mm each were used as work–piece materials.. The joints were produced using TIG welding process with welding parameters and levels. Specimens for the mechanical testing were prepared as per ASTM (B557) standards. The hardness test for weld region was tested by using Brinell hardness testing machine. The applied force was 1000 N and 10 mm diameter ball indentor was used in Brinell hardness testing machine. The indentation after testing was measured using optical microscope. The standard formula was used to calculate the Brinell hardness number.

2.1 Plan of Experiments:

Taguchi method was used for designing the experiments, L9 orthogonal array was applied which composed of three columns and three rows, which mean that 9 experiments were carried out. DOE were selected based on a three welding parameters with 3 levels each. The selected welding parameters for this study are: welding current, welding speed and gas flow rate. Table. 1 shows the input variables and experiment design levels. Taguchi method was applied to the experimental data using statistical software MINITAB 19. The SN ratio for each level of process parameters is computed based on the SN analysis. Regardless of the category of the quality characteristic; a higher SN ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameter is the level with the highest SN ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed for each response individually to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted.

2.2 Variable factor levels of stainless steel 321:

the selection of the parameter were decided by considering the objective of present study and before selecting a particular orthogonal array (OA) to be used as a matrix for conducting the experiments: 1). The number of parameters and interactions of interest. 2). The numbers of levels of the parameter of interest. The non-linear behavior, if exists, among the process parameters can only be studied if more than two levels of the parameters are used.[5]. Therefore, each parameter was analyzed at three levels. The selected numbers of the process parameters and their levels are given in Table 1 For the sake of simplification; the second order interaction among the parameters is not considered.

Table 1: Variable factor levels

Factor	Level 1	Level 2	Level 3
Welding Current (Amp)	50	65	75
Welding speed (mm/sec)	3	6	11
Gas flow rate l/min	20	30	40

2. 3 Selection of orthogonal Array:

Each of the three level parameter has two degree of freedom (DOF) (Number of level – 1), the total DOF required for three parameters each at three levels is 8[=4x (3-1)]. As per Taguchi’s method the total DOF of the OA must be greater than or equal to the total DOF required for the experimentation.[6]. So an L9 OA (a standard 3- level OA) having 8(=9-1) degree of freedom was selected for the present research. The standardized Taguchi-based experimental design used in this research was an L9 orthogonal array, as described shown in Table 2.

Table 2: L9 (3^3) Taguchi orthogonal array

Experiment number	Welding Current (A)	Welding speed (B)	Gas flow (C)
3	1	1	1
2	1	2	2
1	1	3	3
1	2	1	2
5	2	2	3
6	2	3	1
1	3	1	3
6	3	2	1
9	3	3	2

2. 4 Hardness:

In this study the hardness values of the stainless steel 321 was determine to be welded using Tungsten inert gas. The better hardness value of the welding piece was compared to the one with Base metal hardness. It was also deemed necessary to characterize the weld metals in terms of hardness. Hardness which is a good indicator of metal strength and it is also well known that local metal having high hardness are prone to environmental corrosion and cracking. In addition, phases with different hardness levels dominant in an alloy may influence the path of proliferating cracks.[7]. Hardness of steel measurements was carried out using a Brinell hardnesss is normally indicative of metal strength, Three readings were taken in the center of the base metal on the flat surface. A conical indenter with a 120-degree angle and (150g) load were used. However, this system was too rough for accurate measurement of discrete weldment regions such as heat affected zone (HAZ). Therefore all the data and result obtained in the experiment were subjected to some human errors and machines efficiency handling and using.

2. 5 Tensile Testing:

Tensile testing is also employed in this study to calculate the stress and strain of the metal steels. The mechanical properties of materials are determined by performing designed laboratory experiments that replicate as nearly as possible the service conditions. In the real world, there are many factors involved in the nature in which loads are applied on a material. The following are some common examples of how these loads could be applied tensile, compressive and shear, just to name a few. These properties are important in materials selections for mechanical engineering and design. Other factors that often complicate the design process include temperature and time factors. The topic of this study is confined to the tensile property of steel. This test is a destructive method, in which a specimen of a standard shape and dimensions (prepared according to ASTM B557: standard test method for tensile properties of steel is subjected to an axial load. The tensile test is commonly done to provide basic design information, to identify the strength of materials and as a means for specification of materials.[8]. The tensile test was carried out by using Zwick/Roell. SP1000 testing machine. The sheet type specimen was used for tensile test. Three specimens of each regime were tested as showing respectively in (Figure 1 and Figure 2) to ensure the repeatability from which the average is calculated. .

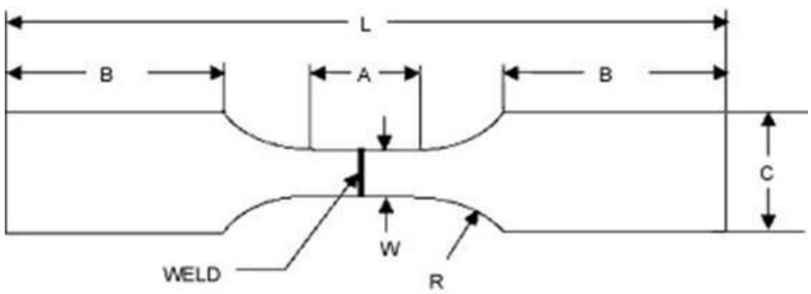

Figure .1 ASTM B557 Testing specimen

Table 3 : Dimension of the Tensile Test Specimen

Name	Dimensions (mm)
L	**350**
A	**50**
W	**20**
R	**25**
B	**90**
C	**35**
T	**2**

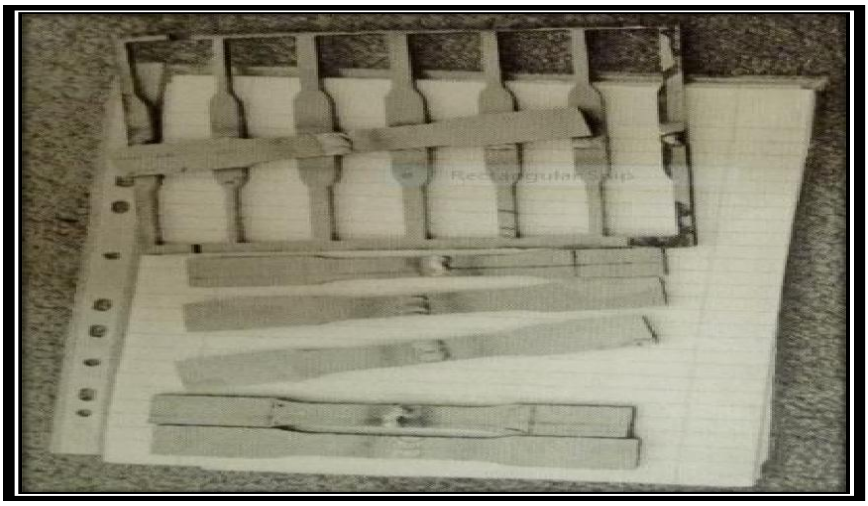

Figure 2: specimen of welded stainless steel 321

3.0 Results and Discussion:

Introduction: In this research an L9 orthogonal array with 3 columns and 9 rows was used. Nine experiments were required to study the welding parameters using L9 orthogonal array. The experimental layout for the welding process parameters using the L9 orthogonal array is shown in Table 1 The responses for signal– to–noise ratio are presented in Table 2 Design expert 17 software was used for analyzing the measured responses. After performing all the experiments with predetermined values of process parameters, the tensile strength is measured and the micro hardness is measured. The results are given in the table.3 and 4 respectively. The welding current, welding speed and gas flow rate were then given three levels as shown in the table 1. These ranges would be expected to produce good welding joints on the stainless steel 321sheets.

3.1 Conducting the Experiments :

The experiments, sorted in table.3, is randomly run by the TIG welding machine and Three measured the welding area, HAZ area and base metal area data values were collected of each experimental run were calculated in table 4.

Table-.3: Response of Tensile strength and Hardness

Experimental no	Current AMP	speed mm/sec	Gas flow L/min	Tensile N/mm^2	Hardness HB
1	50	3	20	380.39	101
2	50	6	30	462.87	123
3	50	11	40	370.45	108
4	65	3	30	442.82	116
5	65	6	40	365.37	103
6	65	11	20	416.47	104
7	75	3	40	390.75	110
8	75	6	20	435.32	106
9	75	11	30	430.75	104

3.2 The effect of hardness on the TIG welding of stainless steel 321:

The hardness distribution profile on the transverse cross -section of the joint, welded L9 specimen . The hardness values of base metals 108 HB. The hardness of welding area was higher than that of base metal due to fast cooling rate.. The higher values of the hardness at the weld zone were reached to123 HB and lower hardness value was 101 HB. Main effect plots for micro hardness are as shown in figure 3. In order to see the effect of process parameter on micro hardness using L9 orthogonal array and experiments are performed and the experimental data are given in table.4. It is clear that as groove angle increasing the hardness also increasing. It was observed that as root face goes up to 1.5 mm the hardness will be decreasing. If the roots face goes up to 2 mm the hardness will be increasing. It was observed that as root gap increasing the hardness also will increase.

Table: 4 Hardness of TIG welding for stainless steel 321

Exp no	Current	Speed	Gas flow	HB1	HB2	HB3	Avg (HB)
1	1	1	1	102	106	95	101
2	1	2	2	121	124	127	123
3	1	3	3	104	106	114	108
4	2	1	2	118	116	114	116
5	2	2	3	97	108	104	103

6	2	3	1	113	106	93	104
7	3	1	3	101	100	129	110
8	3	2	1	103	101	114	106
9	3	3	2	95	111	106	104

Figure 3 show that the maximum value of hardness was obtained at welding current of 50A, where the lowest value was obtained at welding current of 75A.. This maximum value of hardness was achieved due to the fast rate cooling of the top of welding pool,which is also alead.

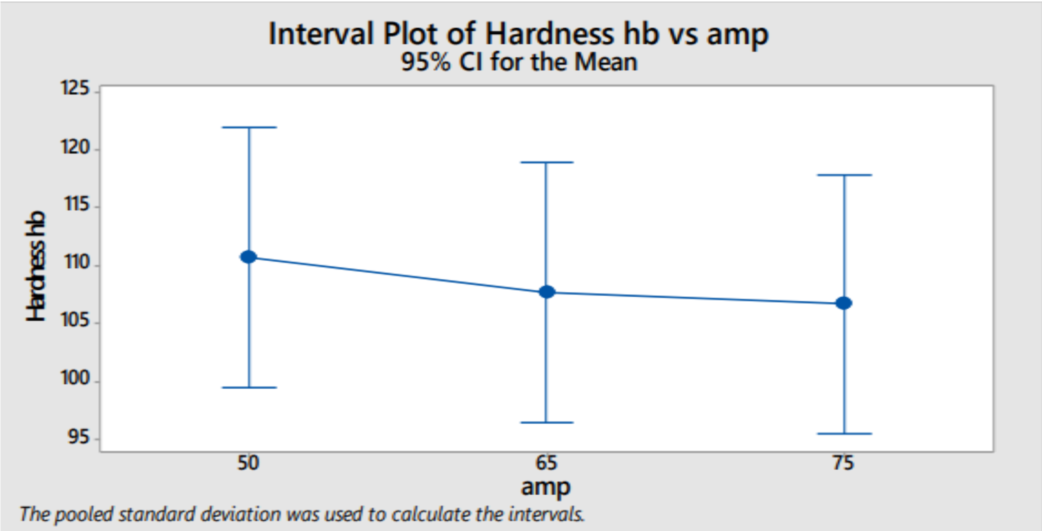

Figure.3 welding current vs hardness

Figure 4. indicated that the maximum hardness value obtained at the welding speed of 6mm / s. This indicated that when the welding speed was low (3mm/s) the value of the hardness was low and that also for the high value of welding speed (11mm/s).

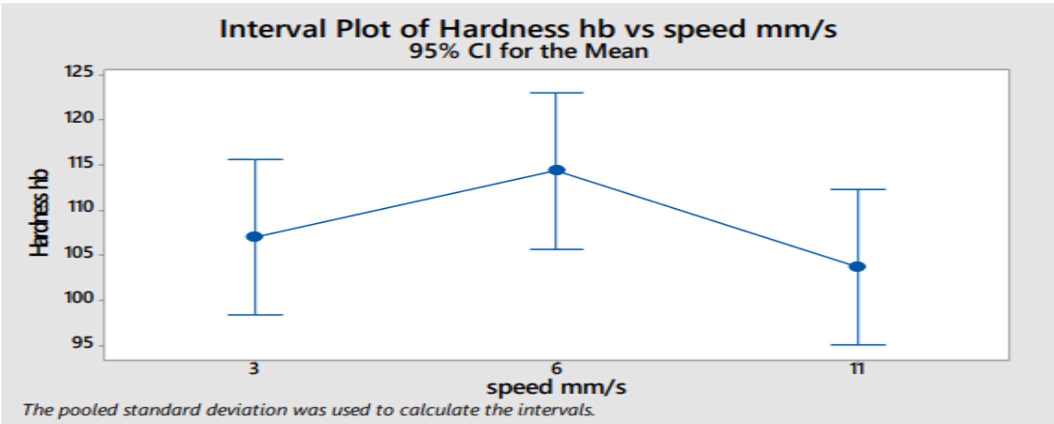

Figure.4 welding speed vs hardness

Figure 5 show that the maximum hardness value obtained at the gas flow rate of(30 l/min) .This indicated that when the gas flow rate was low (20 l/min) the value of the hardness was low and that also for the high value of gas flow rate (40l/min).

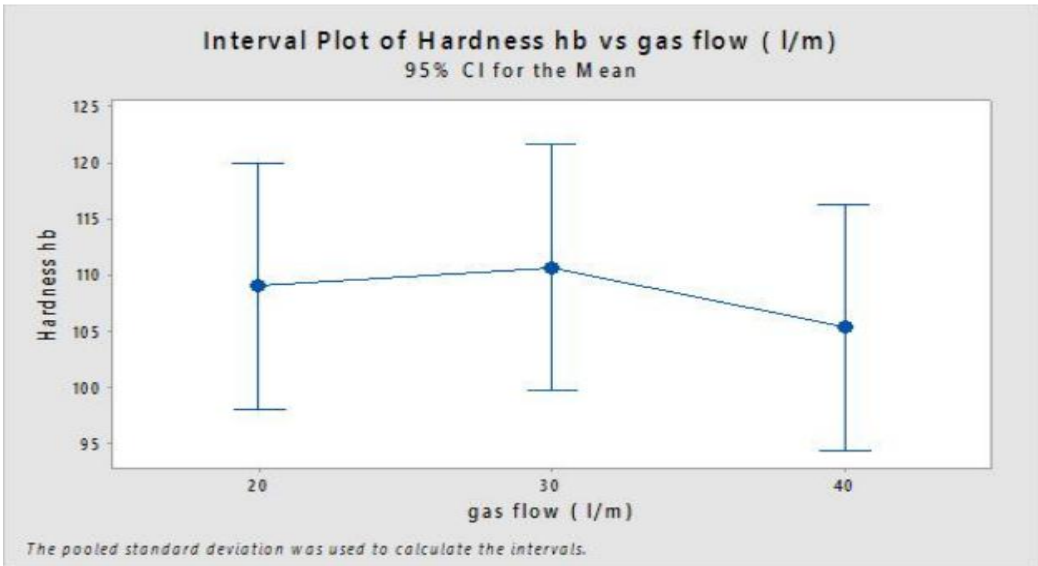

Figure.5 gas flow rate vs hardness

From the table(.3) and figure (6) it is observed that the experiment number two has the maximum tensile value which was (462.87 N/mm$^{2)}$ under welding current of(50A), welding speed of (6mm/sec) and gas flow rate of (30 l/min), where the lowest tensile value which was (365.37 N/mm^2) obtained from experiment number five under welding current of (65A), welding speed of (6mm/sec) and gas flow rate of (40 l/min). Than the optimum parameters areas fallowing ; welding current of(50A), welding speed of (6mm/sec) and gas flow rate of (30 l/min).

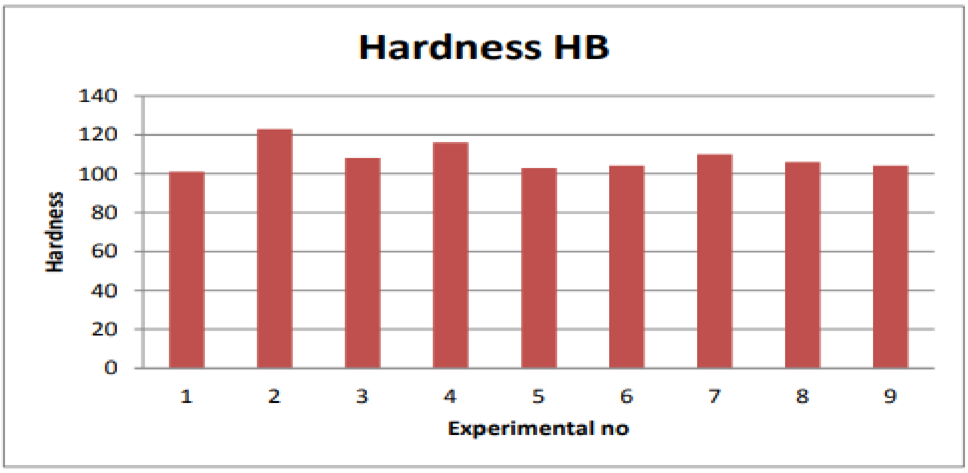

Figure.6 number of experiments vs hardness

4.0 The effect of tensile strength on the TIG welding:

From the interaction plot shown in figure 7 it is observed that the interaction of the tensile strength value increases with respect to welding current. This increase in tensile strength with the increase of welding current is due to the slow rate of cooling which are .

Table: 5 Tensile strength of TIG welding for stainless steel 321

Exp no	Current	speed	Gas flow	Tensile
1	1	1	1	380.39
2	1	2	2	462.87
3	1	3	3	370.45
4	2	1	2	442.82
5	2	2	3	365.37
6	2	3	1	416.47
7	3	1	3	390.75
8	3	2	1	435.32
9	3	3	2	430.75

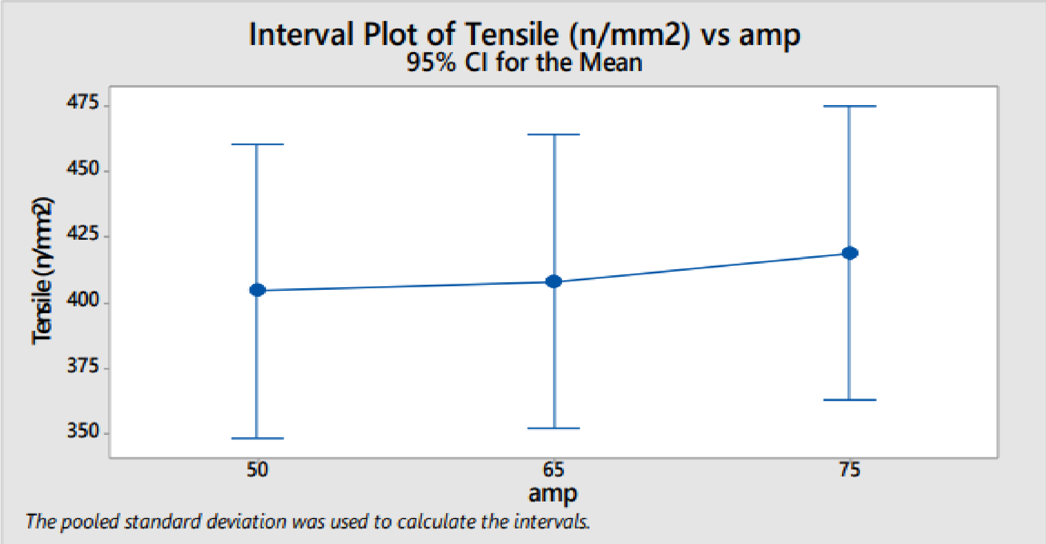

Figure.7 welding current vs tensile strength

Figure 8 shows that the maximum tensile strength value obtained at the welding speed of 6mm/sec. This indicated that when the welding speed was low (3mm/sec) the value of the tensile strength was low and that also for the high value of welding speed (11mm/sec).

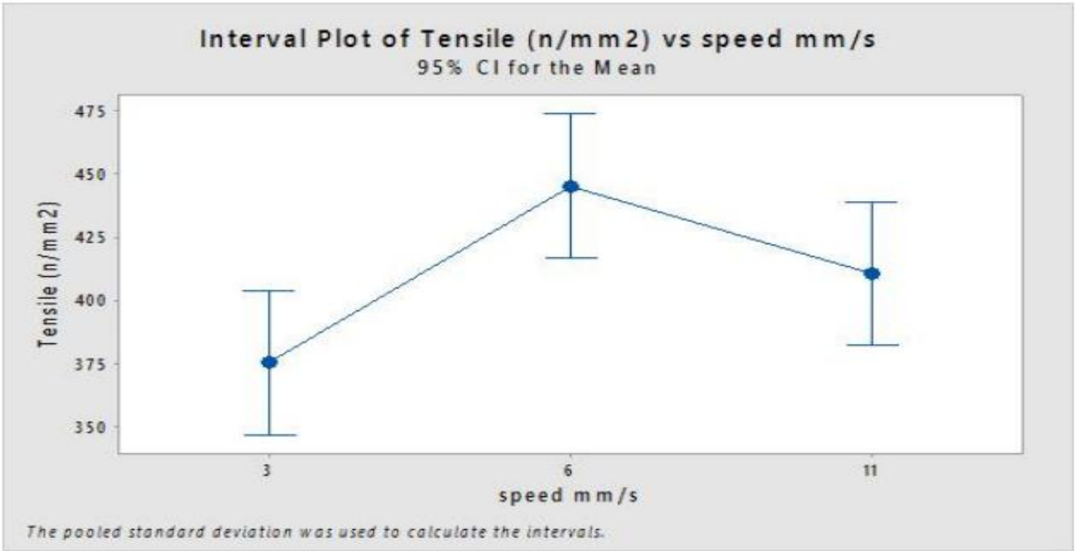

Figure.8 welding speed vs tensile strength

Figure 9 illustrate that the maximum tensile strength value obtained at the gas flow rate of (30 l/ that when the gas flow rate was low (20 l/min) the value of the tensile strength was low and that also for the high value of gas flow rate (40 l/min) l/min).

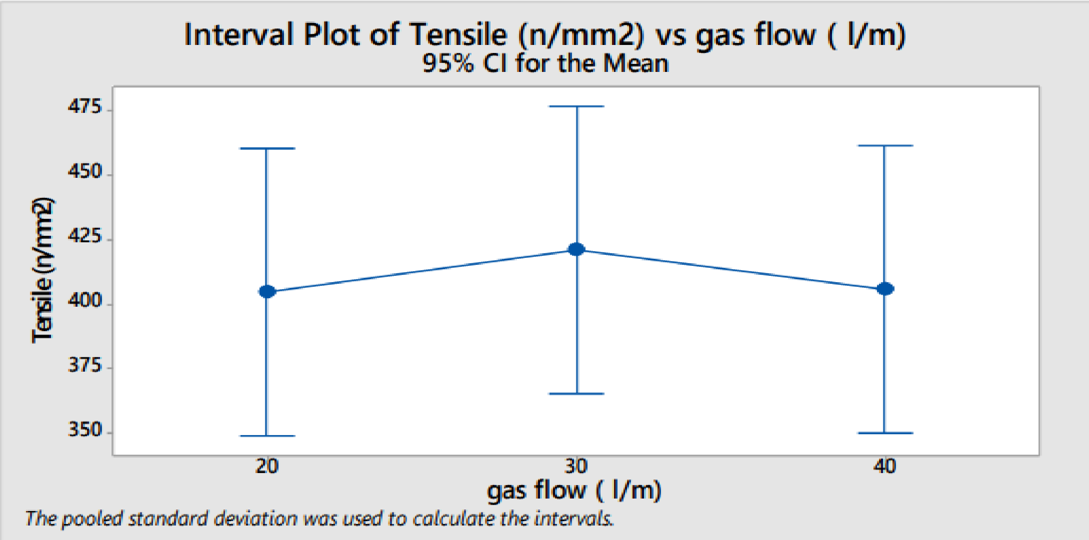

Figure.9 gas flow rate vs tensile strength

From the table.3 and figure 10 it is observed that the experiment number two has the maximum tensile value which was (462.87 N/mm^2) under welding current of (50A), welding speed of (6 mm/sec) and gas flow rate of (30 l/min), where the lowest tensile value which was (365.37 N/mm^2) obtained from experiment number five under welding current of (65A), welding speed of (6mm/sec) and gas flow rate of (40 l/min).

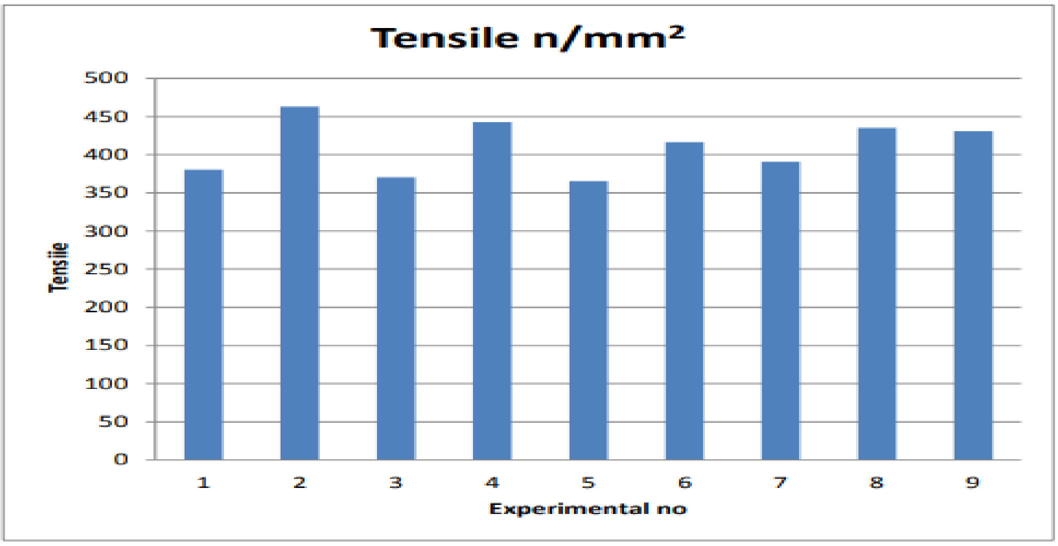

Figure.10 number of experiments vs tensile strength

4.1. Analysis of ANOVA:

Table.6 shows the result of the analysis of variance (ANOVA) for Tensile strength. The analysis of variance was carried out for a (95%) confidence level. The ANOVA Tables 6 shows that, the F value corresponding to all parameters are greater than the tabulate value of F(0.05). The main purpose of the analysis of variance is to investigate the influence of design parameters on optimal surface finish by indicating the parameters that significantly affect the quality characteristics of the machined surfaces.

Table.6: ANOVA Table for S/N ratio

Source	DOF	Sum of Square	Mean Square	(F)	Probability (P)
Welding current	2	38.86	39.44	54.18	0.043
Welding speed	2	48	29.43	64.75	0.017
Gas flow	2	0.7919	0.384	0.91	0.523
Error	2	0.8433	0.429		
Total	8	88.495			

In this case welding current and welding speed are significant parameter and gas flow is non significant parameter. The value of $P \leq .05$ indicates those models are significant. In ANOVA table value of F is very significant, The analysis of variance was carried out for a (95%) confidence level in this it make an assumption that value of $P < .05$ are found to be significant parameter. Gas flow is nonsignificant parameter also graph shows that gas and current have a least effect on the welding specimen. The average effect responses table for mean under the array in table.7 indicates the mean of the response variable means for each level of each control factor. This specifies the mean surface roughness value that each level of each control factor produced during this experiment. The S/N effect table under the array in Table.7 indicates the mean of the S/N values for each level of each control factor Table.6 and Table.7 shows average effect response for the raw data and effect response table for S/N ratio.

Table.7: Response Table for the Mean

Source	DOF	Sum of Square	Mean Square	(F)	Probability (P)
Welding current	2	27804.7	13897.5	64.08	0.43
Welding speed	2	38195.4	1947.1	0.7434	0.019
Gas flow	2	951.7	450.9	1.53	0.395
Error	2	686.4	294.1		
Total	8	67638.2			

5. Conclusion :

The following conclusions were drawn from the results of this research: .

1. The L9 orthogonal array has been used with three control parameters allowed this study to be conducted with a sample of 9 work pieces.
2. In this research it found that the control factors had varying effects on the Tensile strength, welding speed having the highest effects.

3. Optimum parameter setting for weld strength is obtained at welding current of (50 amps), welding speed of (6mm/s), and (30 l/min) of gas flow rate.
4. Optimum Ultimate Tensile Strength was obtained for the welding area,

HAZ area and base metal area sample at moderate welding speed (6 mm/s), welding current (50 Amp), and of gas flow rate (30 l/min).

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