

# Parametric Optimization of Tungsten Inert Gas (TIG) Welding by using Taguchi Approach

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**ABSTRACT:** The present work deals with the optimization of welding process variables by using Tungsten inert gas welding. In this process input variables are voltage (V), current (I) and welding speed (S) with tensile strength and hardness as responses of low carbon steel (ASTM A29). The investigation is based on Taguchi approach [L<sub>9</sub>], using Analysis of variance (ANOVA) to determine the influence of parameters with the optimal condition. Finally, the confirmation test has been carried out to compare the predicted value of tensile strength and hardness with the experimental value.

**KEYWORDS:** TIG Welding, Mild Steel, Taguchi Approach, Hardness, Tensile strength.

## I. INTRODUCTION

In the present world, welding is mostly used in manufacturing industries, aerospace industries, automobile industries etc. We know that there is various welding process are present, among the various welding process, Tungsten inert gas (TIG) welding plays a major role in the welding of mild steel or thin sections of non-ferrous metals such as copper alloys, aluminum alloys, magnesium and stainless steel. Tungsten inert gas (TIG) welding is also known as Gas tungsten arc welding (GTAW). It is a one of the most widely used methods in many manufacture industries. Tungsten inert gas (TIG) welding is an inert-gas shielding arc-welding process using non-consumable electrode. The electrodes may also contain 1 to 2% thoria (thorium oxide) mixed along with the core tungsten or tungsten with 0.15 to 0.40% zirconia (zirconium oxide). As pure tungsten electrode are less expensive but it will carry less current. The thoriated tungsten electrodes carry high currents and are more desirable because they can strike and maintain a stable arc with relative ease. The zirconia added tungsten electrode is better than pure tungsten but inferior to thoriated tungsten electrodes. We know that TIG welding has several advantage like joining of dissimilar metals, the absence of slag, low heat affected zone and etc. Since input parameters play a major role in determining the quality of a welded sample. So, welding parameters those are affecting the arc should be calculated and their variable conditions during the process must be known before, in order to get good or optimum results, in order to get a perfect arc, we have achieved stable parameters. We also know that the properties of the welded sample are affected by a greater number of welding parameters. Properties are Hardness, Impact force, Tensile strength etc.

Now, in order to overcome from this problem, there are various optimization methods are there to get desired output. Now in this experiment, we are using mild steel, so mild steel means which contain only a small percentage of carbon (C) and also it is strongest and most important it is not easily tempered or hardened. As we know that using high carbon

# International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 3, March 2016

steel it is very difficult to weld, as mild steel is easy to weld and most important fact that most of the people are not aware of this fact that certain types of high carbon steel, for example, stainless steel and special technique are used for welding due to that reason that, it is less brittle than high carbon steels. The mild steel is more flexible than other steel. The present experiment mainly focused on the weldability of low carbon steel ASTM A29 with the process of TIG welding. The work details of process parameters (welding voltage, welding current and wire speed) influence on the response (Tensile strength and Hardness) by using analysis of variance (ANOVA) with the help of Taguchi array [L<sub>9</sub>].

Rajendra Singh et al. [1] conducted an experiment, in this experiment they are aimed at minimizing the defects in stainless steel pipes without determining the value of strength and durability. Nirmalendhu et al. [2] carried an experiment, in this experiment; they are using stainless steel- mild steel and using Taguchi approach (L16) to conduct the experiments using process parameters like currents, gas flow rate and filler rod diameter. Finally, they conduct the experiment and get that from the ANOVA, and found that none of the welding parameters affects the ultimate load. S.Amal Bosco Jude et al. [3] develop an experiment; in this they are studying the effect of grain refining element (Mg<sub>2</sub>Si) present in TIG welded sample. Finally, they found that optimal condition at voltage 13 volts, welding speed 140 mm/min, shielding gas flow rate 10 liters/min and welding current 140 amps. Ajit Khatter et al. [4] conducted an experiment on stainless steel 304 using Taguchi method and optimization of Process Parameter. They are using an L<sub>9</sub> orthogonal array for their experiments. Finally, they get an optimum parameter of welded sample at current 150 amps, voltage 28 volts, and gas flow rate 14 liters/min. Prashant S Lugade et al. [5] conducted an experiment on stainless steel 304L using Taguchi approach and optimized the process parameters. Finally, they found the result that the optimum values of process parameters for weld sample are, electrode gap 1 mm, travel speed 100 mm/min, welding current 200 A and gas flow rate 10 lit/min and the percentage of contribution of process parameters for tensile strength are welding speed (44.87%), gas flow rate (6.12%), arc gap (20.85%) and welding current (28.14%). G. Magudeeswaran et al. [6] developed an experiment on duplex stainless steel. In this experiment, they are mainly focused on increasing the depth of penetration. Finally, conduct the experiment and found that the optimum welding parameters if the electrode gap of 1 mm, a travel speed 130 mm/min, current 140 A, and voltage 12 V. Ugur Esme et al. [7] conducted an experiment using grey relation analysis and Taguchi method. Finally, after the experiment, they get a conclusion that the bead height, width, penetration, heat affected zone of the welded sample are much improved by using Grey relation analysis in combination with Taguchi approach. Lalit S. Patel et al. [8] conducted an experiment, in this experiment their main aim to how to maximizing tensile strength and minimizing distortion. They are using Taguchi approach and analyzed with the help of ANOVA. Finally, they conclude that the root gap is a great significant parameter for tensile strength and current is great signification for distortion. Shekhar Rajendra Gulwade et al. [9] conducted an experiment on austenitic stainless steel using Taguchi approach. In this experiment, they had taken the welding parameter like welding voltage, current and gas flow rate. Finally, conducted a test to compare predicted value with the experimental value in the help of ANOVA analysis for hardness and finally get the optimal parameter for hardness is 188.70 BHN and S/N ratio is 45.51. Dinesh Kumar.R et al. [10] developed an experiment on 304L austenitic stainless steel sheets using Taguchi approach. In this paper, they are taken process parameters like the pulse on time, welding current, voltage, pulse off time and standoff distance. They are using Taguchi approach to get the optimal result using an L<sub>27</sub> orthogonal array. Finally, they conduct a test, a get an optimum value for the selected parameter for welded sample are current 125A, Stand-off 2mm, Frequency 3 Hz, Gas flow 10 liters/min and speed and current are most affecting parameter. Sreejith S Nair et al. [11] carried out an experiment on experimental investigation of multipass tig welding using response surface. In this experiment, they put more emphasis on penetration, tensile strength and hardness. Finally, they get optimum process parameters for TIG welding for SS 304 steel are wire diameter 3mm and welding current 140 amps. J. Pasupathy et al. [12] carried out an experiment on galvanized steel with AA1050 using Taguchi method and results are carried with the help of ANOVA. Finally, they conduct a test in which they are comparing the predicted values with the experiments values for the analysis of strength and lastly they get optimal welding parameters i.e. strength is 99.01 Mpa and S/N ratio is 39.91. Ravinder et al. [13] investigated an experiment on mild steel and stainless steel (202) using Taguchi approach. In this experiment, they have taken process parameters like welding current, voltage and gas flow rate to optimize the TIG welding process and they are using Taguchi approach using (L<sub>9</sub>) orthogonal array. J.Pasupathy et al. [14] carried out an experiment on low carbon steel AA1050 using Taguchi orthogonal array. Finally, conduct a test and find out the optimal welding parameter are the strength of welded sample

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

is 61.37 Mpa and S/N ratio is 16.45. Kuang-Hung Tseng et al. [15] conducted an experiment to optimize the delta ferrite content, angular distortion, weld morphology and hardness of stainless steel 316L using TIG welding process. Finally, conduct a test to get an optimal result. They use MoO<sub>3</sub> and SiO<sub>2</sub> fluxes weld depth is increase and bead width decrease. M. P. Chakravarthy et al. [16] conducted an experiment on 70/30 Cu-Ni Alloy using Taguchi approach. Finally, they conduct the test to predict the optimal values of tensile strength welded sample are 368.8 MPa. Dara Eshwar et al. [17] conducted an experiment on aluminum alloy Al-65032 using Taguchi approach. Finally, they conduct the test on the basis of L9 orthogonal array. A.Sivasankaran et al. [18] investigated an experiment on aluminum alloy (8011) using Taguchi approach (L16 orthogonal array). Finally, they conduct the test to compared the predicted value of ultimate tensile strength with the experimental value and finally conclude that the optimal parameters for ultimate tensile strength are 155.682 and the improvement in S/N ratio is 0.894. Mallikarjun Kallimath et al. [19] conducted an experiment on aluminum alloy Al6061 Taguchi and Regression analysis methods. Finally, they conduct the test and found that Gas flow rate is the major contributing factor and also gas flow rate and current are the most influencing factor with to bead length. Er. Parvinder Singh et al. [20] conducted an experiment on Stainless Steel (SS316) using Taguchi approach. Finally, they conduct the test and find out the optimal parameter are current is 120 Amp, gas flow rate is 5 liters/min and a number of passes are 2.

## II. TAGUCHI METHOD

A Japanese scientist i.e. Genichi Taguchi, develop a technique on an orthogonal array. This method is widely used in manufacturing industries. The main objective of this method is to provide a high-quality product at very low cost to the producer (manufacturer). Taguchi developed an array for predict how different parameters affect the mean and variance of the process parameters. He made the method in such a way that each factor have equally weighted because each factor is evaluated independently of other factors, so that's why the effect of one factor does not affect the value of other factors [18] or we can it is statistically technique that allows us to improve the consistency of production. Taguchi method recognizes that not all factors that cause variability can be controlled. These uncontrollable factors are called noise. Taguchi designs try to identify controllable factors to evaluate variability that occurs and then determines optimal factor setting that minimize the process variability. A process designed with this goal will produce more consistent output and performance regardless of the environment in which it is used. The experimental steps are explained by using flow diagram as shown in Fig.1. In this flow chart, we can see that various step of Taguchi's method and show how Taguchi method is applied in the problem.

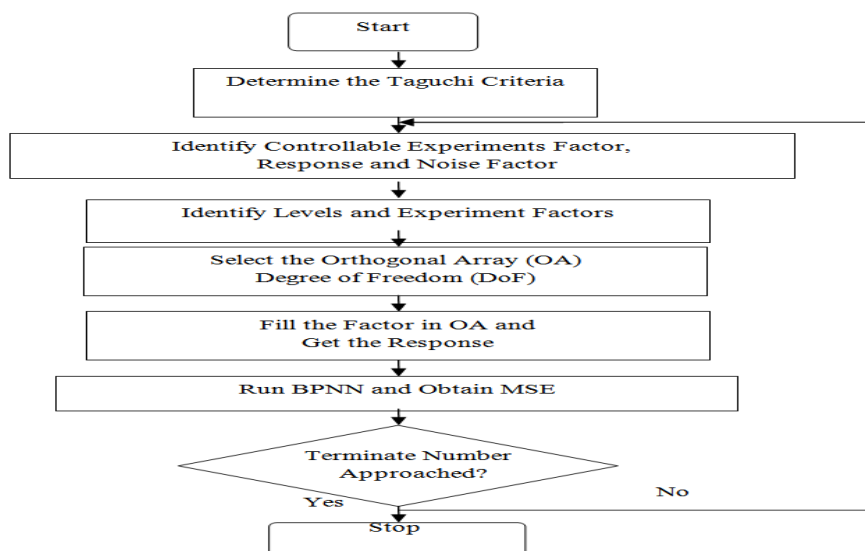


Fig.1 Flow chart of Taguchi method

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

### III. EXPERIMENTAL PROCEDURE

In this experimental work, the sample is welded at three different levels of welding parameter i.e. voltage, current and speed as shown in table 1.

Table-1: Welding parameter and their levels

Parameter	Current(I)	Voltage(V)	Speed(S)
Unit	Amp	Volt	Mm
Symbol	I	V	S
Level 1	200	18	2.2
Level 2	215	22	2.7
Level 3	230	26	3.2

Table-2: Chemical Composition of Low Carbon Steel ASTM 29

Element	%
Carbon	0.70-0.80
Iron, Fe	98
Manganese, Mn	0.40-0.70
Sulphur, S	0.05
Phosphorous, P	0.04

The dimension of work sample is length 200 mm, width 100 mm, thickness 80 mm. Now the setup has been ready and was prepared for doing TIG welding on given sample. The chemical composition of low carbon steel ASTM 29 is shown in table 2, in which it show the percentage of elements like carbon, iron, manganese, sulphur and phosphorous present in low carbon steel ASTM 29. Fig 2 shows the welded sample of low carbon steel ASTM 29 by using TIG welding.

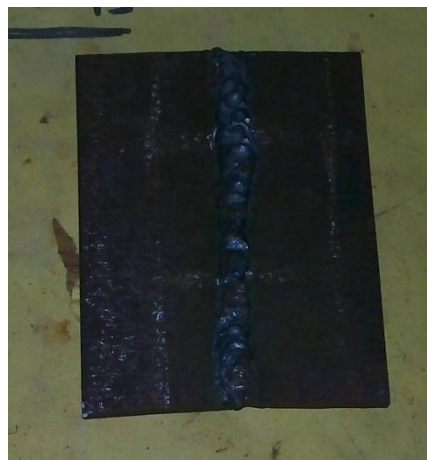


Fig 2: Welded Sample of Low Carbon Steel ASTM A29

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

Table-3: L9 Orthogonal Array Design matrix

Voltage	Current	Speed
18	200	2.2
18	215	2.7
18	230	3.2
22	200	2.2
22	215	2.7
22	230	3.2
26	200	2.2
26	215	2.7
26	230	3.2

Total nine experiments were performed based on L9 orthogonal array shown in Table 3. The effect of different parameters such as welding voltage, current and wire speed of low carbon steel ASTM A29 was analysed and observed the tensile strength and hardness of all nine welded sample and observed the value of tensile strength and hardness with its S/N ratios are shown in Table 4. For measuring micro-hardness they are first rubbed with emery paper size no. 1/0, 2/0 & 4/0 and then clean with the help of acetone solution.

Table- 4: Response of Tensile and Hardness with S/N ratio

Run	Tensile Strength (Mpa)	S/N Ratio	Hardness (HAZ)	S/N Ratio
1	380	51.59567	167.4	44.47511
2	350.5	50.89376	146.3	43.30489
3	330.7	50.38868	155.3	43.82343
4	490.8	53.81809	246	47.8187
5	400.5	52.05205	188	45.48316
6	350.6	50.89624	165.6	44.38121
7	450.8	53.07968	218	46.76913
8	380.1	51.59796	152.6	43.67109
9	370.2	51.36873	178.4	45.0279

## IV. RESULTS AND DISCUSSION

We know that Analysis of variance (ANOVA) is a statistical tool used to analyse the S/N ratio. Here the term “signal” represents the desirable mean value and the “noise”- undesirable value. Hence, we can say that S/N ratio show the amount of variation, which is represented in the performance characteristics.

### ANOVA OF TENSILE STRENGTH

In this paper, calculated the Tensile strength and applying Taguchi approach for the analysis with the help of ANOVA (L<sub>9</sub>). According to data are found, we get a graph of the signal-to-noise (S/N) ratio is shown in Fig 3. Calculated S/N ratio is shown in Table 4 using minitab-16.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

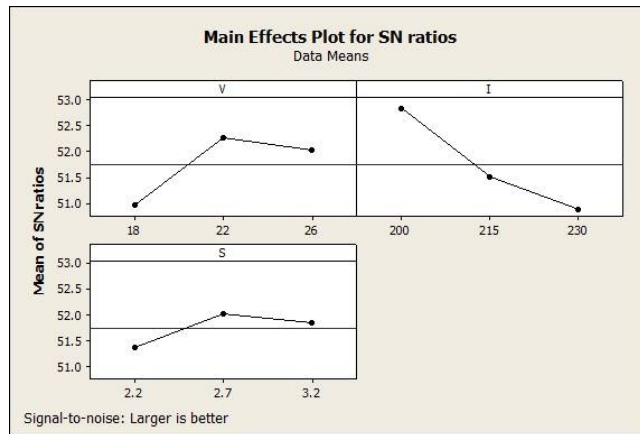


Fig-3: Main Effects plot of process parameters on tensile strength for S/N ratio

The ANOVA is one of the widely used methods for portioning variability into an identifiable source of variation and the associated DOF in an experiment. F-test used for analysing the significant effects of the process parameters, which form quality characteristics. In Table-5 show, the result of ANOVA analysis of S/N ratio of low carbon steel ASTM A29. The ANOVA obtained  $R^2$  and  $R_{adj}^2$  as 98.35% and 93.01%. The ANOVA revealed the influence of process parameters on a response. From Fig. 3 it was observed that the welding voltage (18 volts), welding current (230 amp), and wire speed (2.2) gives an optimal tensile strength.

Table-5: Analysis of Variance for Signal to Noise Ratio of tensile strength

Source	DF	Seq Ss	Adj SS	Adj MS	F	P	PC
V	2	2.8528	2.8528	1.4264	16.92	0.056	29.58%
I	2	5.9195	5.9195	2.9598	35.11	0.028	61.38%
S	2	0.7026	0.7026	0.3513	4.17	0.194	7.29%
Residual	2	0.1686	0.1686	0.0843			1.75%
Total	8	9.6434					100.00%

The response table for S/N ratio for tensile strength is shown in Table-6 which shows their ranking and factors level values of each factor. From the response tables, the optimal condition for Tensile strength as the welding current (I3) is a dominant parameter on the tested specimens, followed by welding voltage (V1) and wire speed (S1). The ranking of the parameters is shown in Table 6. This refers the optimal condition of Tensile strength as V1A3S1. It is observed from Table-5, that current (I) is the most important factor which effects tensile strength maximum with percent contribution of 61.38% followed by welding voltage with percent contribution 29.58% then wire speed with percent contribution 7.29%.

Table-6: Response Table for S/N Ratio for Tensile Strength

Level	V	I	S
1	50.93	52.83	51.36
2	52.26	51.51	52.03
3	52.02	50.88	51.84
Delta	1.3	1.95	0.66
Rank	2	1	3

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

## ANOVA OF HARDNESS

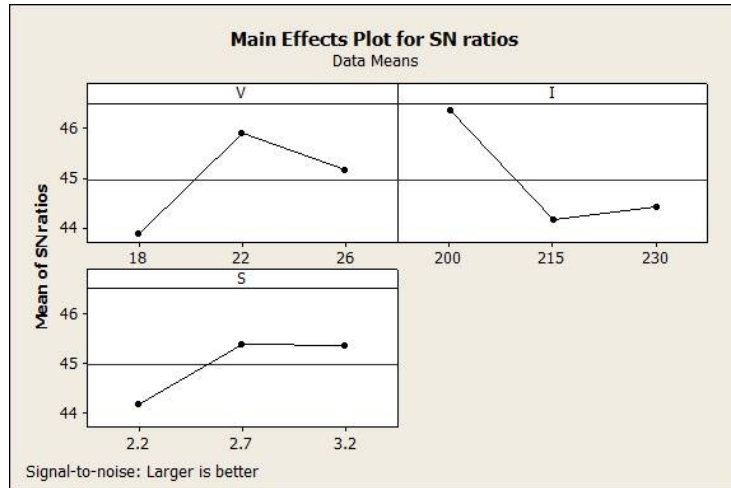


Fig-4: Effects of process parameter on hardness S/N ratio

From Fig. 4 it was observed that the welding voltage (18 volts), welding current (215 amp), and wire speed (2.2) gives an optimal Hardness. We know that the S/N ratio for each parameter was determined by averaging the S/N ratios at the corresponding level. The effect of parameters such as welding voltage, current, and wire speed was analysed on Table-4. It is observed that the process parameters with the greatest S/N ratio have optimum quality with less variance. The ANOVA obtained  $R^2$  and  $R_{adj}^2$  as 99.33 and 97.22%. The ANOVA revealed the influence of process parameters on a response.

Table-7: Analysis of Variance for Signal to Noise Ratio of Hardness

Source	DF	Seq Ss	Adj SS	Adj MS	F	P	PC (%)
V	2	6.3115	6.3115	3.15577	50.49	0.019	35.09%
I	2	8.6891	8.6891	4.34456	69.51	0.014	48.31%
S	2	2.8589	2.8589	1.42946	22.87	0.042	15.90%
Residual	2	0.125	0.125	0.0625			0.70%
Total	8	17.9846					100.00%

From response table for S/N ratio for hardness is shown in Table-8, we can predict that the wire speed is a dominant parameter on the tested specimens, followed by welding voltage and welding current. The ranking of the parameters is shown in Table 8. From the response tables, the optimal condition for Tensile strength as the welding current (I2) is a dominant parameter on the tested specimens, followed by welding voltage (V1) and wire speed (S1). This refers the optimal condition of the Hardness as V1A2S1. It is observed from Table-7, that current (I) is the most important factor which effects hardness maximum with percent contribution of 48.31% followed by welding voltage with percent contribution 35.09% then wire speed with percent contribution 15.90%.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

Table-8: Response Table for S/N Ratio for Hardness

Level	V	I	S
1	43.87	46.35	44.18
2	45.89	44.15	45.38
3	45.16	44.41	45.36
Delta	2.03	2.2	1.21
Rank	2	1	3

### MULTIPLE LINEAR REGRESSION MODELS:

Multiple linear regression equations are developing a relation between the process variables and response. The value of regression coefficient  $R^2$  (0.9825) is in good agreement with the adjusted  $R^2$  (0.9301) for the Tensile strength of the welded sample of ASTM A29.  $R^2$  (0.9930) is in good agreement with the adjusted  $R^2$  (0.9722) for the Hardness of the welded sample of ASTM A29. Considering that both values are very close to unity, this model gives a good result between the independent parameters and responses.

The regression equation developed for the surface roughness of the Tensile strength is as follows:

$$\text{Tensile Strength} = 842 + 5.83 V - 3.00 I + 23.8 S \quad \text{----- (1)}$$

The regression equation developed for the Hardness of ASTM A29 is as follows:

$$\text{Hardness} = 354 + 3.33 V - 1.47 I + 25.2 S \quad \text{----- (2)}$$

We can predict from Equations. (1) & (2) that the Welding Current (I) plays a greater role on Tensile and Hardness, followed by welding voltage (V) and wire speed (S). The coefficient associated with welding current (I) is negative, thus indicating that the Tensile and hardness as decreases with increasing welding current. Conversely, the Tensile and hardness increase with increasing welding voltage and wire speed because the coefficients of these factors are positive. Wire speed has a greater effect on Tensile and hardness as compared with other parameters according to its coefficient value in the TIG welding.

### CONFIRMATION TEST

The confirmation test is the last step in the experimental process. The confirmation test results are listed in Table 9. From the table listed the actual and predicted values with error. The % of error determined by the ratio of the difference between actual and predicted to actual once. The % of error has been less than ( $\pm 5\%$ ) which is significant.

Table-9: Conformation Test

Exp Run	Tensile Strength			Hardness		
	Cal.	Exp.	Error	Cal.	Exp.	Error
1	399.3	380	-5.078	175.38	167.4	4.55
3	333.1	330.7	-0.725	156.48	155.3	0.754
5	389.52	400.5	2.741	179.25	188	-4.881
6	356.42	350.6	-1.66	169.8	165.6	2.473
9	379.74	370.2	-2.57	183.12	178.4	2.577



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

## V. CONCLUSION

The investigation results show that

1. The present study on ASTM A29 using Tungsten inert gas welding process.
2. The Welding Current has the greatest influence on Tensile and Hardness in the welded sample of ASTM A29 followed by welding voltage and wire speed.
3. The optimal conditional for Tensile strength as the welding current (230) is a dominant parameter on the tested specimens, followed by welding voltage (18) and wire speed (2.2).
4. The optimal condition of Hardness, such as the welding voltage (18 volts), welding current (215 amp), and wire speed (2.2) can be used to achieve better hardness in ASTM A29.

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