# Taguchi Based Optimization of SMAW and TIG Welding Process Parameters on HSLA-DMR249A steel

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## Abstract

The HSLA- DMR249 A steel of dimension 300 x 150 x 10 mm is processed for Tungsten inert-gas (TIG) Welding and shielded metal arc welding (SMAW) and mechanical properties and parameters were optimised. Mechanical properties like micro hardness of the weldment were examined. The influenced varying process parameters like current, voltage and flow rate were taken into account for both welding processes to carry out the experiment runs. Taguchi strategy (L9) and ANOVA methods were used to find out various parameters. The most vital factor which influence the result of mechanical property of low alloy steels is current than by voltage and flow rate. Mechanical properties confirms that the welded portion by both SMAW and TIG methods was found to be harder of 323 VHN, 330 VHN. The optimum process parameters are found to be 200A current, 40V voltage, 13L/Min flow rate for the shielded metal arc welding (SMAW) and 180A current, 20V voltage, 13 L/Min flow rate for TIG welding.

**Keywords**. SMAW, TIG, HSLA- DMR 249A, Taguchi parameter, mechanical property

## 1. INTRODUCTION

Welding is an important economical process commonly employed in steel structures. The knowledge related to the properties of dissimilar and similar metals plays a major role in the advancement of light weight structures [1]. For construction and fabrication resolutions, the conventional arc welding process is generally employed [2]. The process is normally limited to the flat or horizontal-fillet welding positions [3]. A non-consumable tungsten electrode and an inert gas (argon) for arc shielding are used in Tungsten inert-gas (TIG) welding. Joints of aluminium and stainless steels are difficult-to-weld and fabricate and also the slag crevices and corrosion attack zones can be eradicated using TIG welding [4].

The DMR 249A steel is a High Strength Low Alloy (HSLA) steel are commonly used for strategic applications due to the basic factors like cost and availability. They are often replaced by carbon steels due to their improved characteristics related to strength and welding [5]. DMR 249A is one of low carbon micro-alloyed grade of steel with stern impact strength even at sub-zero temperature. current of 140 A, and voltage of 12 V are found to be the optimum welding parameters [6]. The current of 120A, Voltage of 25V and gas flow rate of 12 lit/min is the suggested level of the controllable parameters of TIG welding process as the minimization of the percentage of elongation and maximization of ultimate tensile strength [7]. Investigation of process parameter such as welding current, torch speed and arc gap on depth of penetration in A-TIG welding of SS 304L has been calculated [8].

Genichi Taguchi established Taguchi method as a process optimization technique [9]. The optimum working conditions determined from the laboratory work can be reproduced in the real production environment [10].

There is lack of in-depth study made by the researchers on the DMR 249A steel and also this examination assumes significance, as no systematic weldability study has been conveyed so far. The proposed work is to analyze the optimal process parameters of SMAW and TIG welding by using Taguchi technique to achieve desirable mechanical properties of DMR 249A steel joints.

## 2. EXPERIMENTAL DETAILS

### 2.1 Material and Properties of DMR 249A Steel

This high performance and low-cost steel (DMR 249A- base metal) used in this present work was developed by Indian Navy at Steel Plant (SMS II, BSL). The electrode/filler wire used in this work is E308L.

### 2.2 Welding Process Parameters and Levels

Among various SMAW and TIG welding process parameters, Pilot experiments were carried out on welded DMR 249A steel material on weld properties. In the present SMAW and TIG welding inspection, three major influenced process parameters, i.e., current, voltage and flow rate were considered and found to be most influencing process parameters. From the upshots, the range of the SMAW process parameters of 120-200A current, 28-40 V voltage and 10-13L/min flow rate and TIG welding process parameters of 120-180A current, 12-20 V voltage and 10-16L/min flow rate was recognized and offered in Table 1.

**Table 1: Levels of SMAW & TIG welding process**

| SN | Parameter/factors | Notation | Levels | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Coded | | | Original – SMAW | | | Original -TIG | | |
| | | | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| 1 | Current(A) | A | 1 | 2 | 3 | 120 | 160 | 200 | 120 | 150 | 180 |
| 2 | Voltage(V) | B | 1 | 2 | 3 | 28 | 34 | 40 | 12 | 16 | 20 |
| 3 | Flow rate(L/min) | C | 1 | 2 | 3 | 10 | 13 | 16 | 10 | 13 | 16 |

### 2.3 Experimentation on design matrix

In this present work, two DMR 249A steel plates of required dimension were castoff for welding by means of SMAW and TIG welding methods as per design matrix. The gas which was used for both SMAW well as for the TIG welding processes is the customary argon shielding gas and experiments were carried out as per standard procedure [11]. A welded specimen plate was formed and then endangered to mechanical testing after welding. The various mechanical properties presently involved are the hardness shown in table 2.

**Table 2: Taguchi- Design of experiments of SMAW & TIG welding process**

| Trail No | Coded | | | Original – SMAW | | | Original -TIG | | |
|---|---|---|---|---|---|---|---|---|---|
| | Current (Amps) | Voltage (Volts) | Flow rate (Lt/min) | Current (Amps) | Voltage (Volts) | Flow rate (Lt/min) | Current (Amps) | Voltage (Volts) | Flow rate (Lt/min) |
| 1 | 1 | 1 | 1 | 120 | 28 | 10 | 120 | 12 | 10 |
| 2 | 1 | 2 | 2 | 120 | 34 | 13 | 120 | 16 | 13 |
| 3 | 1 | 3 | 3 | 120 | 40 | 16 | 120 | 20 | 16 |
| 4 | 2 | 1 | 2 | 160 | 28 | 13 | 150 | 12 | 13 |
| 5 | 2 | 2 | 3 | 160 | 34 | 16 | 150 | 16 | 16 |
| 6 | 2 | 3 | 1 | 160 | 40 | 10 | 150 | 20 | 10 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 3 | 1 | 3 | 200 | 28 | 16 | 180 | 12 | 16 |
| 8 | 3 | 2 | 1 | 200 | 34 | 10 | 180 | 16 | 10 |
| 9 | 3 | 3 | 2 | 200 | 40 | 13 | 180 | 20 | 13 |

## 3. RESULTS AND DISCUSSION

### 3.1 SMAW WELDING

#### 3.1.1 Effect of Hardness on SMAW welding process parameters

ANOVA in Table 3 predicts, the F-value of experimental hardness model is 32.19, 3.51 and 0.64 for current, voltage and flow rate depict that, this model is crucial. Because of noise, 0.01% chance was there in this case to create "Model F-Value". The model terms P > F is less than 0.0500 which indicates, model terms are significant. All the input parameters in this experiment and their collaboration such as current (A), voltage (B) and flow rate (C) and interaction terms are eliminated from this model when the values are superior than 0.05000.

ANOVA points that of the various input parameters considered while welding, it is observed that the current, voltage and flow rate are found to be significant at 95% confidence. From the table 3 and 4, it is also found that the current contributes about 87.26% in change of hardness followed by voltage and flow rate with 11.39% and 0.337% respectively and ranked at top is current followed by voltage and flow rate with second and third position. In table 5, 97.4% (Predicted R-Squared) is highly coincide with 89.6% (Adjacent R-Squared) and this high precision shows the S/N ratio. From the figure 1, it is found that the hardness gradually increases from current 120–200 A when voltage is increased gradually between 28-40 W. It is concluded that from the above data, that current contributes to a greater extent than voltage. When considering flow rate, the hardness slightly increased between 10-13 L/min and decreases between13 to 16 L/min. Flow rate contributes only to a small percent.

Also, it is evident from the observation that signal to noise ratio if larger it is better in hardness values. The optimal process parametric combinations for maximum hardness of 323 VHN were found to be in 200A current, 40W voltage and 13 L/min flow rate respectively. These parameters are assured by the confirmation run and it's found to be in good agreement.

**Table 3: Analysis of Variance for S/N ratios on hardness in SMAW welding**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | % contribution |
|---|---|---|---|---|---|---|---|
| current | 2 | 0.79135 | 0.79135 | 0.395677 | 32.19 | 0.030 | 88.58 |
| voltage | 2 | 0.08618 | 0.08618 | 0.043091 | 3.51 | 0.222 | 0.61 |
| flow rate | 2 | 0.01577 | 0.01577 | 0.007883 | 0.64 | 0.609 | 1.67 |
| Residual Error | 2 | 0.02458 | 0.02458 | 0.012292 | | | |
| Total | 8 | 0.91789 | | | | | |

**Table 4: Response for S/N Ratios on hardness in SMAW welding**

| Level | current | voltage | flow rate |
|---|---|---|---|
| 1 | 49.38 | 49.57 | 49.73 |
| 2 | 49.57 | 49.65 | 49.63 |
| 3 | 50.08 | 49.81 | 49.68 |
| Delta | 0.70 | 0.23 | 0.10 |
| Rank | 1 | 2 | 3 |

**Table 5: Model Coefficients for S/N ratios on hardness in SMAW welding**

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 304.889 | 1.281 | 237.935 | 0.000 |
| current 120 | -10.556 | 1.812 | -5.825 | 0.028 |
| current 160 | -3.722 | 1.812 | -2.054 | 0.176 |
| voltage 28 | -3.556 | 1.812 | -1.962 | 0.189 |
| voltage 34 | -1.056 | 1.812 | -0.582 | 0.619 |
| flow rat 10 | 1.778 | 1.812 | 0.981 | 0.430 |
| flow rat 13 | -1.722 | 1.812 | -0.950 | 0.442 |

S = 3.844   R-Sq = 97.4%   R-Sq(adj) = 89.6%

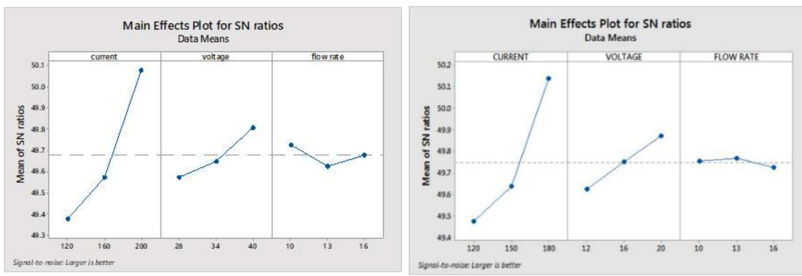


**Fig 1. Main effects plot for S/N ratios on Hardness in (a) SMAW & (b) TIG welding**

### 3.2 TIG WELDING

#### 3.2.1 Effect of Hardness on TIG welding process parameters

ANOVA in Table 6 predicts, the F-value of experimental hardness model is 274.63, 35.46 and 1.05 for current, voltage and flow rate depict that, this model is crucial. Because of noise, 0.01% chance was there in this case to create "Model F-Value". The model terms P > F is less than 0.0500 which indicates, model terms are significant. All the input parameters in this experiment and their collaboration such as current (A), voltage (B) and flow rate (C) and interaction terms are eliminated from this model when the values are superior than 0.05000.

ANOVA indicates that among the various input process parameters considered while welding, it is observed that the current, voltage and flow rate are found to be significant at 95% confidence. From the table 6 and 7, it is also noted that the current contributes about 88.26% in change of hardness followed by voltage and flow rate with 11.39% and 0.337% respectively and ranked first in current followed by voltage and flow rate with second and third position. In table 8, 99.7% (Predicted R-Squared) is highly coincide with 98.7% (Adjacent R-Squared) and this high precision shows the S/N ratio. From the figure 1a, it is found that the hardness gradually increases from current 120–150 A, and increases steadily from 150-180A and increased when voltage is increased gradually between 12-20 W. It is evident that from the above data, that current contributes to a higher extent than voltage. When considering flow rate, the hardness slightly increased between 10-13 L/min and decreases between13 to 16 L/min. Flow rate contributes only to a small extent.

Also, it is evident from the observation that signal to noise ratio of larger is better in hardness values. The optimal process parametric combinations for maximum hardness of 330 VHN were found to be in 180A current, 20W voltage and 13 L/min flow rate respectively. These parameters are confirmed by the confirmation run and its found to be in good agreement.

**Table 6 Analysis of Variance for S/N ratios on Hardness in TIG welding**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | %contribution |
|---|---|---|---|---|---|---|---|
| CURRENT | 2 | 0.716029 | 0.716029 | 0.358015 | 274.63 | 0.004 | 88.26 |
| VOLTAGE | 2 | 0.092461 | 0.092461 | 0.046231 | 35.46 | 0.027 | 11.39 |
| FLOW RATE | 2 | 0.002729 | 0.002729 | 0.001365 | 1.05 | 0.489 | 0.337 |
| Residual Error | 2 | 0.002607 | 0.002607 | 0.001304 | | | |
| Total | 8 | 0.813827 | | | | | |

**Table 7 Response for S/N ratios on Hardness in TIG welding**

| Level | CURRENT | VOLTAGE | FLOW RATE |
|---|---|---|---|
| 1 | 49.47 | 49.62 | 49.76 |
| 2 | 49.64 | 49.75 | 49.77 |
| 3 | 50.14 | 49.87 | 49.73 |
| Delta | 0.66 | 0.25 | 0.04 |
| Rank | 1 | 2 | 3 |

**Table 8 Model Coefficients for S/N ratios on Hardness in TIG welding**

| Term | Coef | SECoef | T | P |
|---|---|---|---|---|
| Constant | 49.7493 | 0.01204 | 4133.668 | 0.000 |
| CURRENT 120 | -0.2756 | 0.01702 | -16.192 | 0.004 |
| CURRENT 150 | -0.1120 | 0.01702 | -6.578 | 0.022 |
| VOLTAGE 12 | -0.1251 | 0.01702 | -7.348 | 0.018 |
| VOLTAGE 16 | 0.0019 | 0.01702 | 0.111 | 0.922 |
| FLOW RAT 10 | 0.0057 | 0.01702 | 0.337 | 0.768 |
| FLOW RAT 13 | 0.0179 | 0.01702 | 1.050 | 0.404 |

S = 0.03611   R-Sq = 99.7%   R-Sq(adj) = 98.7%

## 4. CONCLUSION

- From ANOVA table, the narrated results indicated that current is the most prominent factor than the voltage and flow rate for maximizing the mechanical properties of both the SMAW and TIG welding process and the percentage contribution of influenced factor of current on responses about 77.38 to 94.03 and 82.5 to 88.26 respectively.
- From the statistical tool revealed that optimal level of SMAW and TIG welding process variables for obtaining maximum mechanical properties were found to be hardness of 323 VHN, 330 VHN
- The obtained optimal influenced process parameters are found to be 200A current, 40V voltage,13L/Min flow rate for the SMAW process and 180A current, 20V voltage, 13 L/Min flow rate for TIG) welding.
- The hardness values were found to be higher in TIG welding than SMAW process due to presence of partial martensite and tempered martensite phase in the welded sample under optimal condition.

**REFERENCE**


1. Mers Paul Kah, Raimo Suoranta, Jukka Martikainen, Carl and t.fi, Techniques for joining dissimilar materials: metals and polymers, Rev. Adv. Mater. Sci, 36, 2014.
2. Stephen.R.Forrest, The path to ubiquitous and low-cost organic electronic appliances on plastic, International journal of science, Nature volume 428, 911–918, April 2004.
3. J. Haider, A theoretical model for gas metal arc welding and gas tungsten arc welding. I, Journal of Applied Physics 84, 3518, 1998.
4. Klas Weman, Welding processes hand book, A volume in Woodhead publishing series in welding and other joining technologies, Second edition, 2012.
5. Danijela A. Skobir, High-strength low-alloy (HSLA) steels, Materials and technology, 45, 295–301, 2011.
6. G.Magudeeswaran, Srihari. R. Nair, L. Sundar and N. Harikannan, Optimization of process parameters of the activated tungsten inert gas welding for aspect ratio of UNS S32205 duplex stainless steel welds, Defence Technology, Volume 10, Issue 3, 251-260, 2016.
7. Bolarinwa Johnson Kutelu, Saliu Ojo Seidu, Godwin Idenala Eghabor and Ayotunde Idris Ibitoye, Review of GTAW Welding Parameters, Journal of Minerals and Materials Characterization and Engineering, 6, 541-554, 2018.
8. Prashant S Lugade and Manish J Deshmukh, Optimization of Process Parameters of Activated Tungsten Inert Gas (A-TIG) Welding for Stainless Steel 304L using Taguchi Method, International Journal of Engineering Research and General Science Volume 3, Issue 3, 2015.
9. Samruddhi Rao, Pragati Samant, Athira Kadampatta and Reshma Shenoy, An Overview of Taguchi Method: Evolution, Concept and Interdisciplinary Applications, International Journal of Scientific & Engineering Research, Volume 4, Issue 10,2013.
10. Ozcan Tan, A. Sahin Zaimoglu, Sinan Hinislioglu and Selim Altun, Taguchi approach for optimization of the bleeding on cement-based grouts, Tunnelling and Underground Space Technology 20,167–173, 2005.
11. G. Dhanraj, V. Velmurugan and N. Balaji, Metallurgical Behaviour and Mechanical Properties on The Shielded Metal Arc Welding and Tungsten Inert Gas Welding Process of DMR 249A Steel, Journal of the Balkan Tribological Association, Vol. 24, No 4, 622–632, 2018.