Study on the influence of groove shape on the tensile strength of commercial steel

DOI : 10.36909/jer.18695

Saleh Suliman Saleh Elfallah*

Mechanical Engineering Department, College of Mechanical Engineering Technology, Benghazi

* Corresponding Author: sselfallah87@gmail.com

ABSTRACT

In industry, welding is well known. There is a great demand for effective and quality welding. Manufacturers seek to remain competitive in the market. They rely on their manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products. Gas metal arc welding is one of the most widely used processes in the industry. Input factors such as welding current, welding voltage, Gas flow rate, wire feed speed, wire size and welding speed play a significant role in determining the welding quality. Taguchi's design has been a powerful and efficient optimization tool for better quality and performance output of manufacturing processes. In this study, Gas metal arc welding has welded commercial steel under preset factors of welding voltage, wire feed speed and groove shape. Base metal groove shape X welding obtained lower tensile strength and hardness than base metal groove shape V. Taguchi's design is to determine the optimal process factors for higher tensile strength and hardness. The analysis found that welding groove shape V had higher effect on the tensile strength and hardness of the welding, while the welding voltage has obtained higher tensile strength and hardness values. The optimum combination of welding factors was base metal groove shape V, 20 V and wire feed speed of 5.9 m/min.

Keywords: GMAW, Commercial steel, Groove shape, Taguchi method, Mechanical

properties.

INTRODUCTION

Welding is a fabrication process in every industry by means of fabricating and repairing products by joining metals. It finds its applications in air, underwater and in space. Gas metal arc welding (GMAW) is used widely for welding ferrous and non-ferrous metals. The gas used as shielding is inert like argon or helium or active like carbon dioxide and oxygen. GMAW can use on carbon steel, stainless steel, alloy steel and aluminium. Metal transfer across arc can be short circuit, globular, spray or pulsed transfer. The result of weld bead depends on welding current, arc voltage, composition and size of electrode, welding travel speed, and gradient and flow of shielding gas. GMAW can perform on the butt joint, corner joint, edge joint, lap joint and T-joint (Chavda *et al.*, 2013; Shah *et al.*, 2017). Taguchi ‘s design is a technique proposed by Dr Genichi Taguchi. It suggests a design method called an orthogonal array. In this, more factors or factor space is able to be studied with a lesser number of experiments than in the Factorial Design of Experiments (Hamzaçebi, 2020). Taguchi ‘s design is considered simple, however, it is increasingly used in manufacturing industries (Tanco *et al.,* 2007).

Several researchers used the Taguchi’s design to determine the optimal GMAW process factors for higher tensile strength and hardness for mild steel (Raghu *et al.*, 2018; Patil *et al.*, 2013; Mahesh *et al.*, 2017; Jeet *et al.,* 2018). Some have found welding current had a major influence on the tensile strength of the welded mild steel (Raghu *et al.,* 2018). Others have found a similar significant influence effect on welding current and speed (Patil *et al.*, 2013; Mahesh *et al.,* 2017). The hardness of the welding area has been investigated for fusion zone (FZ) (Jeet *et al.,* 2018; Tawfeek, 2017; Yadav *et al.,* 2014; Purwaningrum *et al.,* 2016; Sankar *et al.,* 2021), heat-affected zone (HAZ) (Yadav *et al.,* 2014; Purwaningrum *et al.,* 2016; Sankar *et al.,* 2021) and base metal (Yadav *et al.,* 2014; Sankar *et al.,* 2021; Sultana *et al.,* 2014).

Studies have reported that weldments that have higher tensile, have also higher hardness

(Raghu *et al.,* 2018; Marimuthu *et al.,* 2015; Bodude *et al.,* 2015). Also, tensile strength and hardness decrease with the increased welding current or voltage. Because an increase in current or voltage raises heat input into the weldment, which causes more internal stresses in the fusion zone (FZ) and heat-affected zone (HAZ), which in return deteriorates the mechanical properties in these areas (Tawfeek, 2017; Yadav *et al.,* 2014; Bodude *et al.*, 2015; Abd Razak *et al.,* 2014). The cause of low tensile strength and hardness is related to the grains structure that is coarse and dendrite in shape at FZ (Tawfeek, 2017; Bodude *et al.,* 2015. While the grains at HAZ are fine in structure, it was reported to have higher hardness than at FZ (Tawfeek, 2017; Yadav *et al.,* 2014). Consequently, HAZ was reported to have higher yield strength than FZ and base metal (Hooda *et al.*, 2012). In general, hardness in the fusion zone (FZ) and heat-affected zone (HAZ) is higher than in the base metal area (Sankar *et al.,* 2021). Also, the base metal without welding obtains lower tensile strength than welded ones (Purwaningrum *et al.,* 2016; Sankar *et al.,* 2021), but shows higher toughness (Sankar *et al.*, 2021). Bodude and Momohjimoh (2015) have concluded that an increase in filler material raises the input temperature and consequently the internal stresses. It can lead to a decrease in tensile strength and hardness of the weldments. This paper will investigate the effect of welding voltage, welding feed speed and base metal groove shape on the tensile strength and hardness of commercial steel to find optimum combination of factors for stronger and more effective welding. There are other factors that could be included such as welding current, welding speed, environment pressure and others. However, only three factors were in hand to deal with because not many studies have reported on the base metal groove shape.

METHODOLOGY

Materials and Experimentation

The commercial steel or also called mild steel used is a non-alloy structural steel European standard EN 10025-2, grade S235JR (1.0038) purchased from the local market and prepared in

Tasamim workshop at Benghazi using CNC laser cutter. The preparation of the samples was according to the American society of testing materials (ASTM) E8 / E8M for the tensile test (ASTM, 2021). Figure 1 shows sketch of the sample with dimensions for the tensile test with fixed base metal thickness of 10 mm with groove shapes V and X. Each has 60° on each angle. The welding on base metal groove shape X was performed on both sides, while it was at single side at base metal groove shape V. The groove of samples was prepared at College of mechanical Engineering Technology. Also, other samples prepared for hardness testing. The welding was performed at the welding lab at ambient temperature in Saad Elkarimi Institute of Technology at Benghazi. The welding filler used in welding process is NEXUS copper-coated mild steel welding wire (AWS ER70 S-6) for GMAW, while he welding machine used is CEA MAXI 321 as shown in Fig. 2(a) and the welding process is shown in Fig. 2(b). The shielding gas used is combined of 82% argon and 18% carbon dioxide. The gas flow rate is 18 ml/min. Table 1 lists the composition of the base metal and welding filler. Table 2 show the mechanical properties of base metal and welding filler. Table 3 show the experiment setup each has two levels and Taguchi's design will generate the required run for welding process and testing.

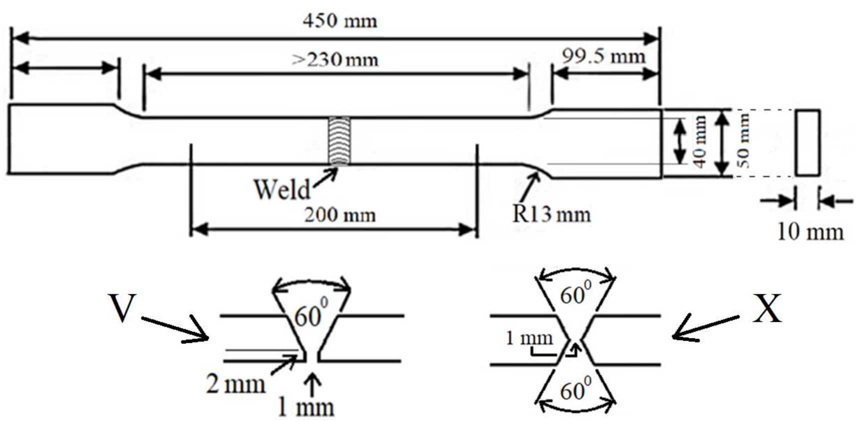

Figure 1. Samples dimensions for tensile test made according to ASTM E8/E8M (ASTM, 2021) with V and X groove shapes.

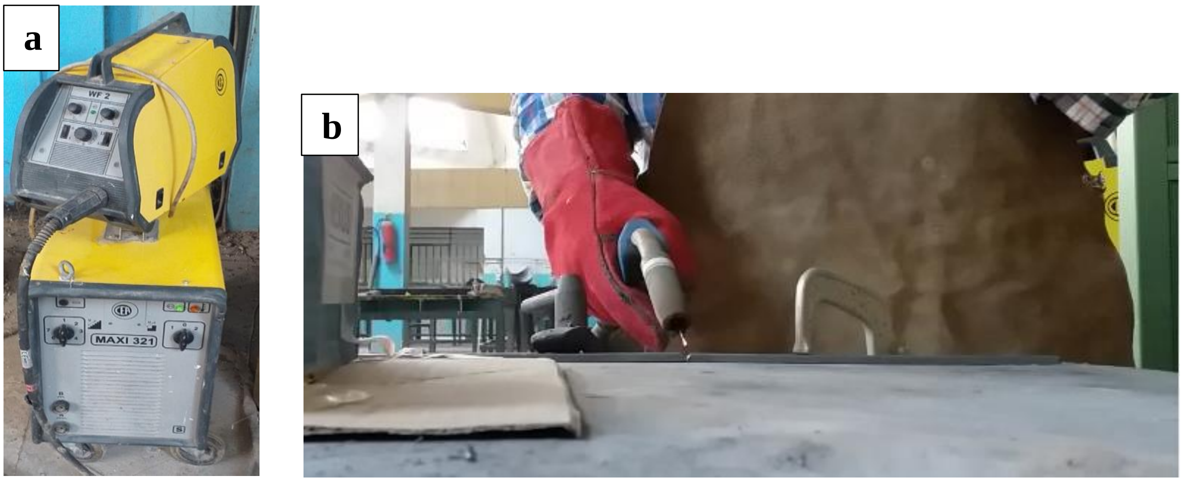

Figure 2. (a) Welding machine CEA MAXI 321, (b) Welding process.

Table 1. The chemical compositions of the metal joint and welding wire used in the experiment (World Material, 2022)

Component	Composition								
	C	Mn	S	Ni	Cr	P	Ni	Cu	Fe
Base metal	0.17%	1.4%	0.025%	0.012%	-	0.025%	0.012 %	0.55%	Balanced
Welding filler	0.12%	1.8%	0.035%	0.15%	0.15%	0.035%	-	0.35%	Balanced

Table 2. The tensile strength and hardness of base metal and welding filler (Ratiwi and Wibowo, 2019; World Material, 2022)

Component	Tensile properties			Hardness properties	
	Yield strength	**Tensile strength**	**Elongation**	**Brinell hardness**	**Rockwell hardness B**
Base metal	235	360-510	26%	≤120 HBW	66.7 HRB
Welding filler	483 MPa	583 MPa	26%	-	-

Table 3. Experiment setup for the welding process

Code	Factors	Unit	Level 1	Level 2
A	Voltage	V	20	30
B	Wire feed speed (WFS)	m/min	5.9	10.6
C	Base metal Groove shape	-	V	X

Taguchi's Design

The experiment setup follows the Taguchi's orthogonal array 2-level's three factors (2^3) resulting in a total of 4 runs (L4). However, Taguchi's design allows for the runs to be extended to 8 (L8). A previous study by Elfallah (2022) have used similar design. This method is known as Taguchi's L8 array to be able to obtain design of experiment's estimated coefficient. Table 4 show the Taguchi's design layout with respect to welding factors with the corresponding tensile strength and hardness of the weld samples. The analysis was made with help of Minitab 18®.

Tensile Strength and Hardness Testing

Tensile test carried out on Shimadzu (UEH-20) universal testing machine at Libyan Iron and Steel Company at Misrata. The tested sample is shown in Fig. 3(a). Hardness test was conducted in College of Mechanical and Engineering Technology at Benghazi using Ernst Rockwell principle bench hardness tester as seen in Fig. 3(b). The indenter used is a diamond cone with a load of 100 kg as pressure force. The hardness on the weld area was measured to demonstrate the change of the welding factors on them.

RESULTS AND DISCUSSION

The results show hardness decreases whenever the tensile decreases and vice versa. The tensile strength and hardness of weldments declined with voltage and wire feed speed increase. Also, the tensile strength and hardness decrease of weldments with the change of groove shape from V to X under the same voltage and WFS except at 20 V and 10.6 m/min, which shows the tensile strength and hardness of weldments increased when groove shape change from V to X. The decrease in tensile strength and hardness of X groove weldments compared to V groove weldments might be related to an increase in internal stresses resulting from double-sided weldments.

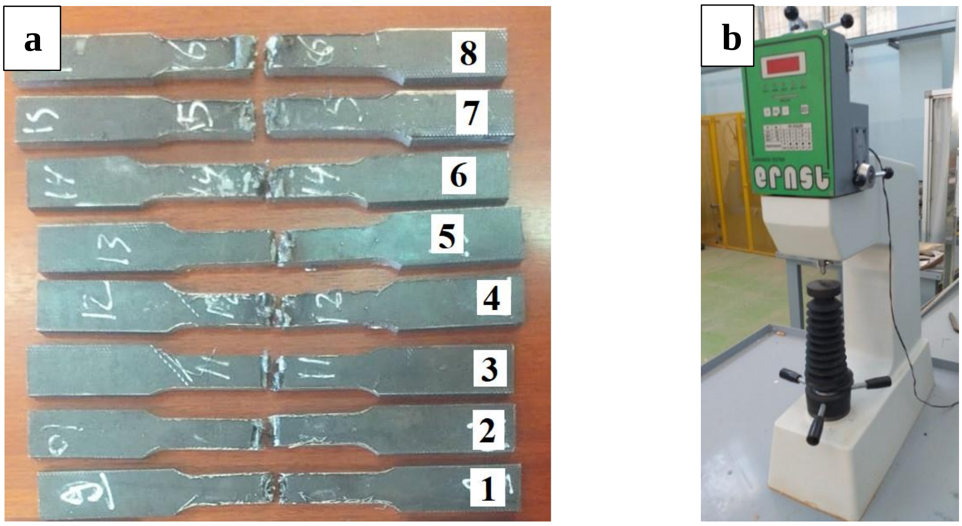

Figure 3. (a) Samples used for tensile strength, (b) Ernst Rockwell hardness tester

Table 4. Taguchi's design extended orthogonal array (2^3) layout with responses

Std order	Voltage (V)	WFS (m/min)	Groove shape	Tensile strength (N/mm^2)	Heat input (J/mm)	Hardness (HRB)	EL%
1	20	5.9	V	305	363.43	35.7	7
2	20	5.9	X	263	363.43	26.7	6
3	20	10.6	V	238	1353.00	30.4	7
4	20	10.6	X	253	1353.00	24.0	6
5	27.5	5.9	V	233	363.43	29.4	6
6	27.5	5.9	X	190	363.43	22.4	6
7	27.5	10.6	V	192	1353.00	27.1	7
8	27.5	10.6	X	164	1353.00	23.0	4

The plots at Figure 4 and Figure 5 are the main effects plots for signal-to-noise (S/N) ratios and Means of the welding factors respectively. The S/N ratios in Figure 4 are the values that interpret the influence of the welding factors. It measures the noise conditions of the welding factors on the higher tensile strength and hardness values. The S/N values corresponding to each level for each factor are also shown in the response table (Table 5). The Delta value in Table 5 is the highest minus the lowest S/N ratio for each factor. The ranking is assigned based on Delta values which indicate the effectiveness and strength of welding factors as also indicated by the absolute values of the coefficient in Table 7. The S/N value for groove shape V is the highest (32.62) versus the lowest (30.55) at groove shape X. The order of the ranks in Table 5 confirm with Figure 4, as base metal groove shape V has obtained highest effect on the tensile strength and hardness higher value followed by voltage at 20 V, while WFS at 5.9 m/min has showed the lowest effect.

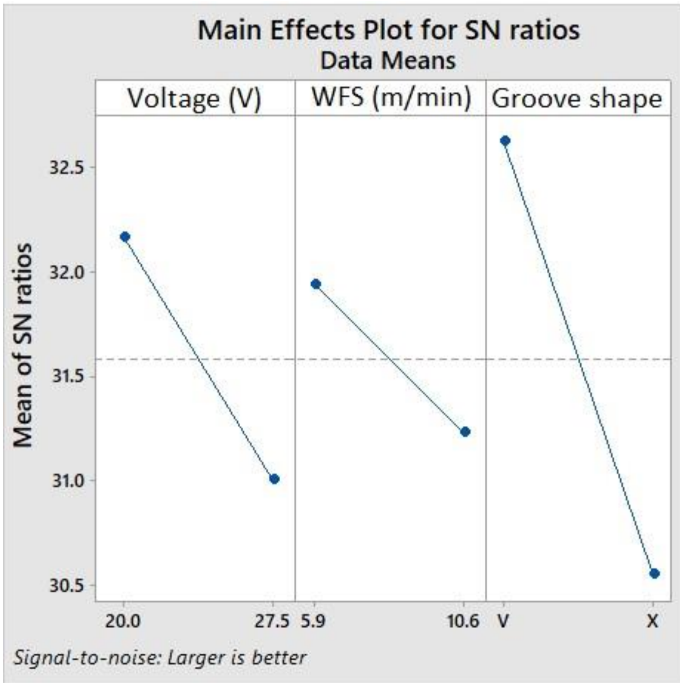

Figure 4. Main effect plot for S/N ratio for the welding factors

Table 5. Response Table for S/N Ratios

Level	Voltage (v)	WFS (m/min)	Groove shape
1	32.17	31.94	32.62
2	31.00	31.23	30.55
Delta	1.17	0.71	2.08
Rank	2	3	1

*Larger is better

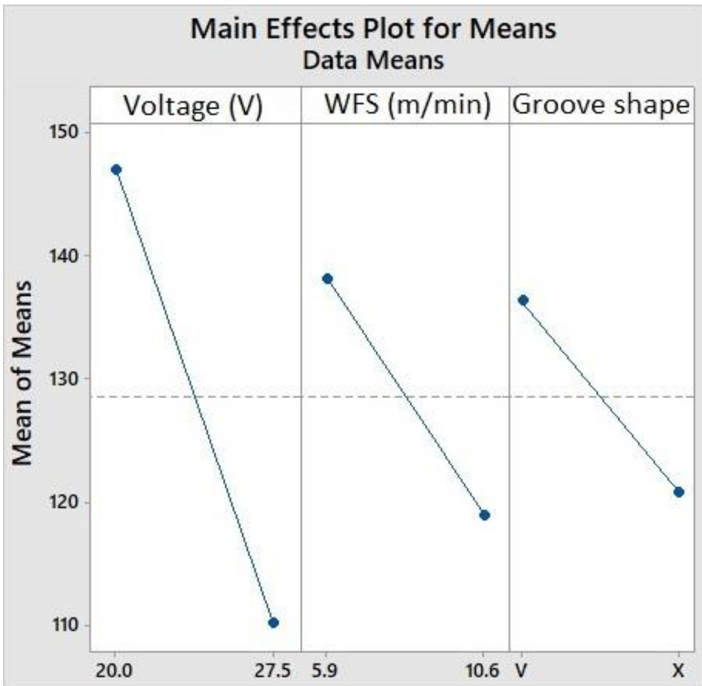

Figure 5. Main effect plot for means for the welding factors

Table 6. Response Table for means

Level	Voltage (v)	WFS (m/min)	Groove shape
1	147.0	138.2	136.3
2	110.1	118.9	120.8
Delta	36.9	19.2	15.6
Rank	1	2	3

Table 6 show the average of Means at Level 1 and Level 2 for every welding factor. From Figure 5 and Table 6 it is shown that voltage at 20 V has larger range of means values than the other welding factors, also indicated as (rank 1) in Table 6. It indicates that the average of higher tensile strength and hardness values are obtained at 20 V, while the values dropped drastically at 27.5 V. The WFS at 5.9 m/min and groove shape V both have shown close response means values that are lower than the ones at welding voltage.

The estimated model coefficients for S/N ratio for the welding factors and Means are shown in Table 7 and Table 8 respectively. Table 7 obtain the population value (P-value) for V groove shape at 0.002, which is considered statistically significant because it is less that significance level of 0.05. The P-value for 20 V has also showed significance with value of 0.019, while the WFS at 5.9 m/min did obtain to be non-significant with value of 0.081. It means that its influence on the tensile strength and hardness is kept to a minimum. While the base metal groove shape V has the highest effect on them followed by the voltage at 20. Table 8 show very low P-value at 20 V, which consider it has significance over the means value. Also WFS at 5.9 m/min showed to be significant, however, with higher P-value of 0.035. The base metal groove shape V has shown to be non-significant.

Table 7. Estimated Model Coefficients for S/N ratios

Term	Coefficient	SE Coefficient	T	P-value
Constant	31.5852	0.1536	205.670	0.000
Voltage (20 V)	0.5832	0.1536	3.797	0.019
WFS (5.9 m/min)	0.3559	0.1536	2.317	0.081
Groove shape (V)	1.0384	0.1536	6.762	0.002

Table 8. Estimated Model Coefficients for Means

Term	Coefficient	SE Coefficient	T	P-value
Constant	128.544	3.060	42.011	0.000
Voltage (20 V)	18.431	3.060	6.024	0.004
WFS (5.9 m/min)	9.606	3.060	3.140	0.035
Groove shape (V)	7.781	3.060	2.543	0.064

According the these results it is clear that the tensile strength and hardness higher values are affected the most by the base metal groove shape V followed by welding voltage at 20 V. While the WFS has showed no significant effect to obtained higher tensile strength and hardness values. However, the welding voltage at 20 V has higher tensile strength and hardness values followed by WFS at 5.9 m/min, while the base metal groove shape V has shown lower value and is considered to non-significant. The optimum welding factors according to Taguchi's design which obtained higher effect on higher tensile strength and hardness and higher mean values are base metal groove shape V, 20 V and 5.9 m/min WFS. It is recommended to take these measurements when welding commercial steel (EN 10025-2) with mild steel welding filler using GMAW for strong and sound, and effective welding.

CONCLUSION

Commercial steel plates were welded by GMAW using low carbon steel electrode wire. The welding factors used for the welding process are base metal thickness, welding voltage and wire feed speed (WFS). The analysis using Taguchi's design made on the effect of welding factors on the tensile strength and hardness of the welding. The results demonstrated that base metal groove shape V effects on the higher tensile strength and hardness the most according to the noise conditions analysis followed by lower welding voltage and lower wire feed speed. However, lower welding voltage has obtained higher tensile strength and hardness means at 20 V which is favorable for strong and effective welding. The welding optimum combination that has obtained higher effect and higher values of tensile strength and hardness are base metal groove shape V, 20 V and 5.9 m/min WFS.

ACKNOWLEDGMENT

The author would like to thank his family for the support and encouragement throughout our study. A sincere appreciation goes to Libyan Iron and Steel Company for their help, to the staff of welding laboratory at Saad Elkarimi Institute of Engineering Technology Benghazi and to the Head of laboratories Mr. Salem Elmisrati at the College of Mechanical Engineering technology Benghazi.

REFERENCES

Abd Razak, N.A. & Ng, S.S. 2014. Investigation of effects of MIG welding on corrosion behaviour of AISI 1010 carbon steel. Journal of Mechanical Engineering and Sciences 7(2): 1168-1178.
DOI:10.15282/jmes.7.2014.16.0114

ASTM, 2021. Standard test methods for tension testing of metallic materials, ASTM E8-04.
DOI: 10.1520/E0008-04

Bodude, M.A. & Momohjimoh, I. 2015. Studies on effects of welding parameters on the mechanical properties of welded low-carbon steel. Journal of Minerals and Materials Characterization and Engineering 3(3): 142-153.
DOI:10.4236/jmmce.2015.33017

Chavda, S. & Patel, T. 2013. A review on parametric optimization of MIG welding for medium carbon steel using FEA-DOE hybrid modeling. International Journal for Scientific Research & Development 1(9): 2321-0613.
http://ijsrd.com/Article.php?manuscript=IJSRDV1I9039

Elfallah, S.S.S. 2022. Influence of GMAW factors on the tensile strength of commercial steel. International Science and Technology Journal 29: 1-16.
https://www.stcrs.com.lyistjarticle-details.phpid=500

Hamzaçebi, C. 2020. Taguchi method as a robust design tool. In: Li, P., Pereira, P.A.R. & Navas, H. (Eds.). Quality Control - Intelligent Manufacturing, Robust Design and Charts. Pp. 1-19. IntechOpen, UK.
DOI: 10.5772/intechopen.94908

Hooda, A., Dhingra, A. & Sharma, S. 2012. Optimization of MIG welding process parameters to predict maximum yield strength in AISI 1040. International journal of Mechanical engineering and Robotics research 1(3): 203-213.
DOI:10.18178/ijmerr

Ibrahim, I.A., Mohamat, S.A., Amir, A. & Ghalib, A. 2012. The effect of gas metal arc welding (GMAW) processes on different welding parameters. Procedia Engineering 41: 1502-1506.
https://doi.org/10.1016/j.proeng.2012.07.342

Jeet, S., Barua, A., Parida, B., Sahoo, B.B. & Bagal, D.K. 2018. Multi-objective optimization of welding parameters in GMAW for stainless steel and low carbon steel using hybrid RSM-TOPSIS-GA-SA approach. International journal of technical innovation in modern science 4: 683-692.
https://www.semanticscholar.org/paper/Multi-Objective-Optimization-of-Welding-Parameters-Jeet-Barua/915a5a14f0bf7257aedca9e95ae3edc70bda0b0d

Mahesh, S. & Appalaraju, V. 2017. Optimization of MIG welding parameters for improving strength of welded joints. International Journal of Innovative Technology and Research 5(3): 6453-6458.
http://www.ijitr.com/index.php/ojs/article/view/1759

Marimuthu, P., Kannan, T.T.M. & Balaji, G. 2015. Evaluation of hardness and tensile strength of micro spot welded joints on different materials. International Journal of Applied Engineering Research 10(3): 2412-2414.
http://www.ripublication.com/Volume/ijaerv10n3spl.htm

Patil, S.R., & Waghmare, C.A. 2013. Optimization of MIG welding parameters for improving strength of welded joints. International Journal of Advanced Engineering. 14-16.
https://www.technicaljournalsonline.com/ijaers/VOL%20II/IJAERS%20VOL%20II%20ISSUE%20IV%20JULY%20SEPTEMBER%202013/325.pdf

Purwaningrum, Y., Wirawan Pu, M. & Alfarizi, F. 2016. Effect of shielding gas mixture on gas metal arc welding (GMAW) of low carbon steel (LR Grade A). Key Engineering Materials, Trans Tech Publications 705: 250-254.
https://doi.org/10.4028/www.scientific.net/kem.705.250

Raghu, R. & Somasundaram, S. 2018. An optimization of welding parameters for MIG welding. International Journal of Engineering Research and Technology 6(14): 1-5. https://www.ijert.org/an-optimization-of-welding-parameters-for-mig-welding

Ratiwi Y.R. & Wibowo, S.S. 2019. The effect of electrode and number of passes on hardness and micro structure of shielded metal arc welding. IOP Conference Series, Materials Science and Engineering, IOP Publishing 515(1): 012072. https://doi.org/10.1088/1757-899x/515/1/012072

Sankar, N., Malarvizhi, S. & Balasubramanian, V. 2021. Mechanical properties and microstructural characteristics of rotating arc-gas metal arc welded carbon steel joints. Journal of the Mechanical Behavior of Materials 30(1): 49-58. DOI:10.1515/jmbm-2021-0006

Shah, J., Patel, G., Makwana, J. & Chauhan, P. 2017. optimization and prediction of MIG welding process parameters using ANN. International Journal of Engineering Development and Research 5(2): 1487–1492. http://www.ijedr.org/papers/IJEDR1702233.pdf

Sultana, M.N., Hasan, M.F. & Islam, M. 2014. Analysis of mechanical properties of mild steel applying various heat treatment. Proceedings of the International Conference on Mechanical, Industrial and Energy Engineering. ICMIEE-PI-140160, Bangladesh.

Tanco, M., Viles, E., Ilzarbe, L. & Álvarez, M.J. 2007. Manufacturing industries need design of experiments (DOE). Proceedings of the World Congress on Engineering. World Congress on Engineering, UK.

Tawfeek, T. 2017. Study the influence of gas metal arc welding parameters on the weld metal and heat affected zone microstructures of low carbon steel. International Journal of Engineering and Technology 9(3): 2013-2019. DOI: 10.21817/ijet/2017/v9i3/1709030272

World Material, 2022. EN 1.0038 Steel S235JR Material Equivalent, Properties, Composition. https://www.theworldmaterial.com/1-0038-steel-s235jr-material/

Yadav, P.K., Abbas, M.D. & Patel, S. 2014. Analysis of heat affected zone of mild steel specimen developed due to MIG welding. International Journal of Mechanical Engineering and Robotics Research 3(3): 399. DOI: 10.18178/ijmerr