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Effect of the Groove Shaped Base Metal on the Mechanical Properties of Mild Steel Welding

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***Abstract*— the welding of commercial steel or mild steel is a common manufacturing process in industry and private sector. However, the constant demand for quality welding is continuous. It prompt for investigations and assessment on the welding properties. The mechanical properties such as tensile strength, hardness and toughness are crucial in determining the welding condition. A welding technique such as gas meal arc welding (GMAW) is an emerging manufacturing process that is known in industry, for effective and quality products. The welding factors such as welding current, welding voltage, Gas flow rate, wire feed rate, wire size and welding speed are crucial in determining the target welding. In order to find optimum welding conditions for better performance and quality welding, Taguchi's design or orthogonal array is an effective and reliable optimization tool that requires minimum runs. In this work, GMAW has welded mild steel under predetermined factors of groove-shape, welding voltage and wire feed speed (WFS). The analysis found that higher FZ hardness has higher welding transverse tensile strength welding. In addition, higher tensile strength shown at lower welding voltage, WFS and at V groove shaped base metal. The increased interpass heat input has shown higher FZ hardness and welding tensile strength. The welding voltage at 20 V followed by WFS at 5.9 m/min shown higher effect on the welding transverse tensile strength and higher means. While the groove shape V shown minimum effect on the responses and minimum means The optimum welding combination for higher welding transverse tensile strength are 20 V, 5.9 m/min and base metal groove shape V.**

Keywords—GMAW, Mild steel, Tensile strength, Hardness, Taguchi's design

I. INTRODUCTION

Mild steel or commercial steel also referred as low carbon steel is intensely used in industry for a variety of applications and in welded conditions. The metal properties such as tensile strength, hardness and toughness are important aspects to sustain the welding of the metal. Especially in load bearing conditions [1].

Gas metal arc welding (GMAW) is a well-known manufacturing process that is inevitable in the industrial sectors used widely for welding ferrous and non-ferrous metals. The gas used to shield the molten weld pool can be inert like argon or helium or active like carbon dioxide and oxygen. GMAW is practical for carbon steel, stainless steel, alloy steel and aluminum alloys. The metal transfer across arc experience short circuit, globular, spray or pulsed transfer. The result weld depends on welding current, arc voltage, base metal and filler composition, size the of filler, nozzle travel speed, and gradient and flow rate of shielding gas. GMAW can perform on the butt joint, corner joint, edge joint, lap joint and T-joint [2], [3].

The Taguchi's design is a technique suggests a design method called an orthogonal array that study more factors or factor space with a lesser number of experiments than Factorial Design of Experiments [4]. It measures the characteristics's performance that is called signal-to-noise (S/N) ratio. The S/N ratio is a logarithmic function, also called inverse of variance. The process optimization involves minimizing the variability, because in maximizing the S/N ratio, the variability of the process is reduced against the undesirable changes in noise parameters. Therefore, the chosen parameters should demonstrate maximum S/N ratios in order to get minimum variability. Its determination falls under one of three categories. Nominal the best, larger the best and smaller the best [5], [6]. Taguchi's design is considered simple; however, it is increasingly used in manufacturing industries [7].

Several researchers studied the optimization of GMAW process factors by Taguchi's design for higher tensile strength and hardness of mild steel. For instance, studies found that welding current had a major influence on the tensile strength of the welded mild steel [8], [9]. While others reported similar influence on tensile strength of welding by the arc voltage [10], [11], welding speed [9] and WFS [12], [13].

It was reported that weld bead or fusion zone (FZ) that has higher tensile, has also higher hardness [8], [14], [15]. It was shown by other studies that the tensile strength of FZ has decreased with the increased welding current [1], [16], voltage [1] and base metal thickness [17]. Others concluded that higher hardness of welding shown at higher welding current, voltage [1] and welding speed [1], [16]. However, Yada et al. [17] and Khamari et al. [18] reported that hardness increased at lower welding current and voltage [17], [18]. Bhatt et al. [16] showed that shielding gas with a mixture of 80 % argon and 20 % carbon dioxide show higher welding tensile strength. In general, studies concluded that welding that has higher tensile has also had higher hardness [8], [11], [12], [13], [14], [15]. However, it was also shown that welding that has higher toughness and tensile strength has lower hardness [1], [19]. Numerous studies concluded that an increased welding current, voltage and WFS have increased the heat input of the welding, which led to increase the internal stresses in welding FZ and the heat-affected zone (HAZ), that consequently deteriorated the mechanical properties of welding [15], [17], [20]. Multiple studies showed the base metal has lower hardness than FZ [17], [18], [21], [22], [23].

This study discusses the effect of groove shape, welding current, and speed on the transverse tensile strength and hardness of mild steel welding made by GMAW. The welding current and speed selected due to they were reported to effect on the welding properties. While the groove-shape to observe how the difference in groove shape of the base metal two-ends affect the transverse tensile strength and hardness of FZ. Taguchi's design is made to optimize the welding factor to obtain for more effective combination for higher transverse tensile strength of welding.

II. Materials and Experimentation

The mild steel or the base metal is non-alloy structural steel European standard EN 10025-2, grade S235JR (1.0038) brought from the local market was prepared by a CNC laser cutter router in the Tasamim workshop at Benghazi. The tensile strength samples prepared according to the American society of testing materials (ASTM) E8 / E8M [24]. Fig. 1 present a graphic illustration of the tensile strength sample showing the transverse welding and the groove shape configurations V and X each open has an angle of 60°. The hardness test conduct on other similar samples on the cross-sectioned weld bead. The welding of the samples was fabricated in Saad Elkarimi Institute of Technology in Benghazi. The welding was processed using welding power supply CEA MAXI 321 utilizing NEXUS copper-coated mild steel wire that has a thickness of 0.045 in (1.143 mm) as welding filler. The shielding gas used is composed of 82% argon and 18% carbon dioxide with a flow of 18 ml/min. The current is estimated to be 120 A at 20 V and 270 A at 27.5 V. The welding made manually with both hands with an approximate welding speed of 150 mm/min. The samples are fixed on a welding table with clamps. The number of passes made for each groove-shaped base metal is shown in Fig. 2 at higher WFS. Knowing that at lower WFS more passes were applied. Table I lists the composition of the base metal and filler wire. Table II shows the tensile strength and hardness properties of the base metal and filler wire.

The welding current, welding speed and groove shape are the factors used for the welding process each has two levels as listed in Table III. The welding current is estimated to be 120 A at 20 V and 270 A at 27.5 V accoding to the welder manual. The experiment layout follows the 2-level's three factors resulting in a total of 8 runs (Table III). This method is known as Taguchi's L8 array. Table IV shows the Taguchi design layout current and welding speed were constant. Table V contains the experimental actual values with the responses results, the tensile strength and hardness values. The analysis was made by Minitab 18®.

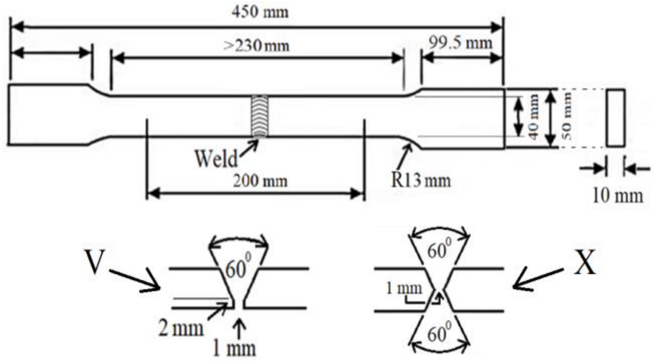

Fig. 1. Samples dimensions for tensile test made according to ASTM E8/E8M [17]

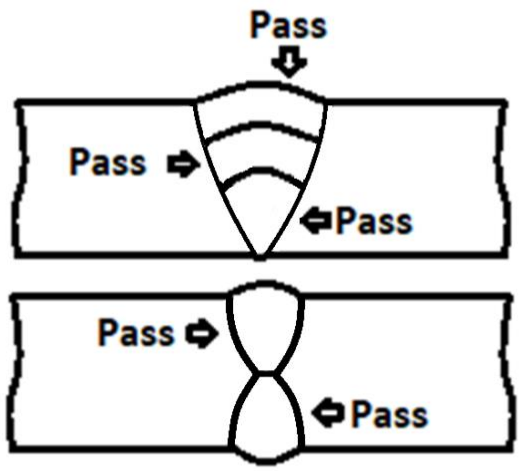

Fig. 2. Welding passes for V and X groove shapes base metal

Table I. The chemical compositions of the base metal and welding wire used in the experiment [25]

Component	Composition								
	C	Mn	S	Ni	Cr	P	Cu	Ni	Fe
Base metal (EN 10025-2)	0.17%	1.4%	0.025%	0.012%	-	0.025%	0.55%	0.012 %	Balance
Welding filler (AWS ER70 S-6)	0.12%	1.8%	0.035%	0.15%	0.15%	0.035%	0.35%	-	Balance

Table II. The tensile strength and hardness of base metal and filler wire [25], [26]

Component	Tensile properties			Hardness properties	
	Yield strength	Tensile strength	Elongation	Brinell hardness	Vickers micro-hardness
Base metal (EN 10025-2)	235	360-510	26%	≤120 HBW	≈2025 HV
Welding filler (AWS ER70 S-6)	483 MPa (70 ksi)	583 MPa (81 ksi)	26%	-	-

Table III. Factors used 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	Groove shape	-	V	X

Table IV. Coded design layout values

Standard order	A	B	C
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Table V. Taguchi design layout with responses (Tensile strength and hardness)

Std order	Voltage (V)	WFS (m/min)	Groove shape	Heat input (J/mm)	Tensile Strength (N/mm^2)	Vickers micro-hardness (HV)	Tensile Strength / hardness
1	20	5.9	V	768	305	2170	0.14
2	20	5.9	X	768	263	2158	0.12
3	20	10.6	V	768	238	2162	0.11
4	20	10.6	X	768	253	2170	0.12
5	27.5	5.9	V	2376	233	2155	0.11
6	27.5	5.9	X	2376	190	2143	0.09
7	27.5	10.6	V	2376	192	2157	0.09
8	27.5	10.6	X	2376	164	2151	0.08

Tensile test carried out on Shimadzu (UEH-20) universal testing machine at Libyan Iron and Steel Company at Misrata. The tested samples are shown in Fig 3. Some of the samples were repeated due to testing failure.

The hardness test conducted by BMS Bulut Makina Sanayi micro-hardness tester in the High Vocational Center of Casting at Tripoli. The indenter used is a diamond cone with a load of 1 kg pressure force. The indenter used is a diamond cone with 120°. The hardness of the weld bead or the FZ was measured to demonstrate the change in the welding parameters on them. The Vickers micro-hardness value is an average of three runs taken for each sample. The heat input was calculated from the equation (1):

$$\frac{\text{Voltage (V)} \times \text{Amperage (A)} \times 60}{\text{Travel speed (mm/min)}} \tag{1}$$

Multiplying by thermal efficiency of GMAW which is 0.8 to get heat input on the welding in J/mm. The WFS was neglected.

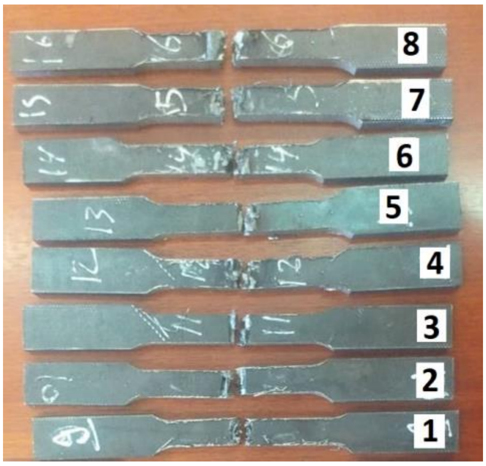

Fig. 3. Samples used for tensile strength

III. Results and discussion

Table V presents the transverse tensile strength of the welding and Vickers micro-hardness of FZ as responses for each combination of welding factors. Each combination corresponds to each sample is numbered at Std order. The tensile strength has increased with the increased hardness and vice versa. The tensile strength has decreased with the increased heat input, while the heat input has increased with the increased welding voltage and WFS. It is also noticed that tensile strength declined for welding that has X groove-shaped base metal, compared to V groove-shaped base metal samples. At similar voltage and WFS except for samples 3 and 4. The tensile strength to hardness ratio as shown in Table V was higher with the increased heat input and WFS.

The inclined heat input led to increased cooling rates [27], which, therefore, risen the internal stresses and consequently, the residual strains in the welding [27], [28]. The internal stresses were reported to causing declined hardness of welding [29] and deterioration of mechanical properties such as the tensile strength and toughness [11], [12], [13], [19]. A study by Unnikrishnan et al. [30] concluded that residual stresses are compressive at decreased heat input of welding and tensile at increased heat input. Therefore, similarly to previous studies the increased heat input as presented in Table V causing declined hardness of FZ and transverse tensile strength of welding. It is noticed that variation of hardness of FZ in Table V and the base metal as seen in Table II has led to tensile failure at FZ/HAZ or HAZ/base metal boundaries [12], [13], [18], [19]. As it shown in in Fig. 3 most of the samples shown failure in the welding area. The HAZ was reported to be a critical area of fracture in welding [31]. Unfortunately, the HAZ hardness was not recorded for this study. It's also noticed from Table V that the hardness of FZ and the transverse tensile strength are lower in X groove-shaped base metal welding compared to welding made at V groove shape. This is noticed at fixed welding voltage and WFS. It could be related to the X configuration feature, which has caused the welding to have irregularly shaped HAZ that causing higher chance of failure. Another hypothesis says that the higher welding interpasses in V groove shaped base metal welding causing internal heat treatment. It's due to more passes risen the interpass heat input [27], where each pass add additional heat input over the solidified welding. It's consequently results in relief internal strains due to the prolonged heat on the solidified welding caused recrystallization of the welding metal [32] and therefore the hardness of the FZ and the transverse tensile strength was increased. The tensile strength to hardness ratio has declined with the increased WFS and heat input of welding as seen in Table V. It indicates that the tensile strength has decreased concerning the hardness of FZ. E.g., the tensile strength has 14 % of the value of hardness at lower WFS, welding voltage at V groove shaped welding. In comparison to only 9 % at higher WFS and welding voltage. It indicates that transverse tensile strength decline faster than hardness of FZ. It could be due to the increased variation between the welding and the base metal. It is also noticed that X groove shaped base metal welding should lower ratio that V groove shaped welding. It is because the later was exposed to increased inter-pass heat input which was has a significant role in risen the hardness and most importantly the transverse tensile strength.

The plots in Fig. 3 and Fig. 4 show the signal-to-noise (S/N) ratios and means of data respectively for the welding factors on the welding transverse tensile strength. The hardness response was not included in the analysis since the objective of welding is to achieve higher transverse tensile strength. Regardless of the hardness of the FZ. The plots show similar orientation of results. The S/N ratio interpret the data by showing the effect of the welding factors on the higher tensile strength. The higher S/N ratio as labelled in Fig. 4 and Table VI, “Larger is Better” corresponds to the experiment goal, which to maximize the responses as shown in equation (2):

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n} y_i^{\ 2}] \qquad (2)$$

The welding voltage as seen in Fig. 4 and Table VI has the highest effect at 20 V on the higher values of welding transverse tensile strength with S/N value of 48.42. The Delta in Table VI is a result of minus the S/N ratio of each two levels of each welding factor. E.g., the minus of the S/N ratio for 20 V and 27.5 V showed higher delta value (wider gap), which indicate the effectiveness of the factor on the response and thus ranked the welding voltage first as it has higher effect on the tensile strength. The effect of WFS at 5.9 m/min came second (47.75), while the groove shaped base metal V had lower effect (47.56). The welding voltage had the lowest effect below the mean of S/N means by S/N of 45.72.

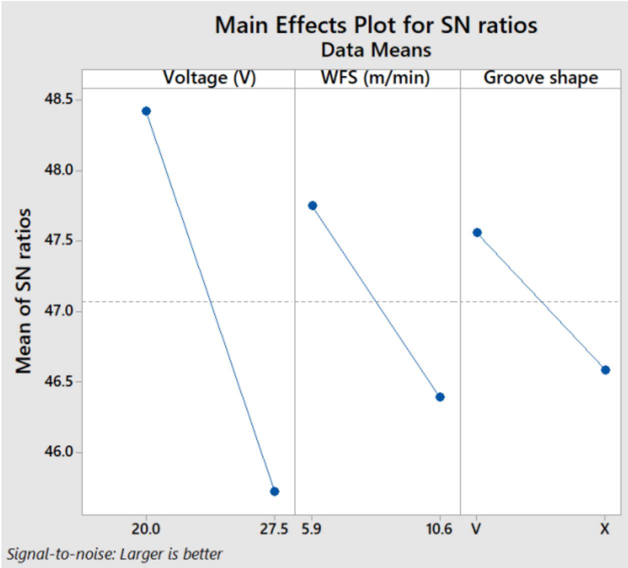

Fig. 4. Main effect plot for S/N ratio for the welding factors

Table VI. S/N ratios and ranking for welding factors

Level	Welding voltage (V)	WFS (m/min)	Groove shape
1	48.42	47.75	47.56
2	45.72	46.39	46.58
Delta	2.70	1.36	0.97
Rank	1	2	3

*Larger is better

The means of data as seen in Fig. 5 and table VII showed again the welding votage at 20 V had the highest tensile strength mean of 264.8 followed by 247.8 for the WFS at 5.9 m/min. While the groove shaped V showed lower mean by 242. The wider Delta of means for the welding voltage made it had the highest effect on the tensile strength means.

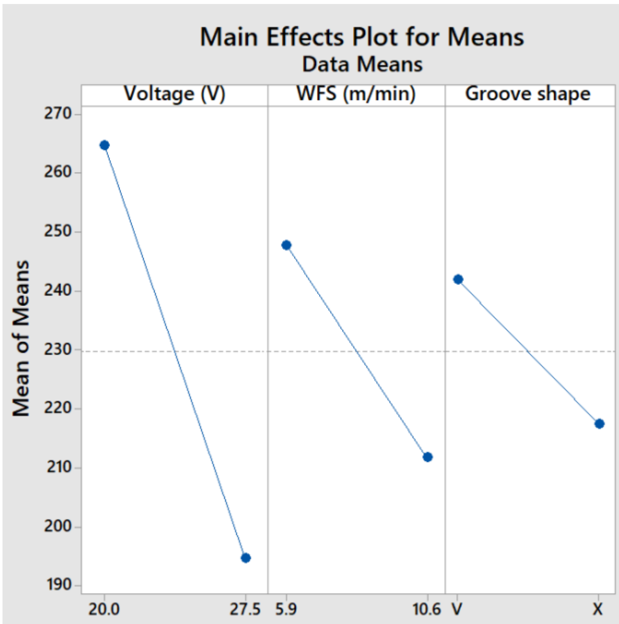

Fig. 5. Main effect plot for means for the welding factors

Table VII. Means and ranking for welding factors

Level	Welding voltage (V)	WFS (m/min)	Groove shape
1	264.8	247.8	242.0
2	194.8	211.8	217.5
Delta	70.0	36.0	24.5
Rank	1	2	3

The S/N ratios model of coefficients for welding factors is shown in Table VIII, while Table IX show the model coefficients of welding factors for tensile strength means. The welding voltage at 20 V and the WFS of 5.9 m/min has obtained significant P values (population value) of 0.004 and 0.038 respectively. While the base metal groove shaped V has shown non-significant P-value of 0.095. The significance level taken is 95 % (P of 0.05). It refers to welding voltage at 20 V has higher chance of occurrence 99.6 % compared to that of 96.6 % for The WFS at 5.9 m/min. According to the P-values in Table IX, the means presented similar occurrence of results repeatition for 20 V and 5.9 m/min WFS, 96.6 % and 96.6 % respectively. While the groove shaped V has 89.3 % chance of response repeating which is considered non-signficant. To predict the S/N ratio with the optimal conditions using equation (3):

$$\eta_{opt} = \eta_m + \sum_{i=1}^{f} (\bar{\eta}_i - \eta_m) \quad (3)$$

Where η_m = the mean of S/N ratio means, f = the number of factors, η_i = the mean of the signal-to-noise ratios at the optimal level of each factor i. The predicted value according to the Minitab 18® is 49.5882 for the S/N mean of means ratio, which is higher by 5 % than the value of the experiment (Table VIII). In addition, Taguchi's design predicted the mean of means to be 295, which is about 22 % higher that the actual mean of means value of 229.75. The analysis from the Minitab 18® unfortunately did not present P-values for level 2 factors.

Table VIII. Coefficients for S/N ratios

Term	Coefficient	P-value
Constant	47.0705	0.000
Welding voltage (20 V)	1.3492	0.004
WFS (5.9 m/min)	0.6813	0.038
Groove shape (V)	0.4872	0.095

Table IX. Coefficients for means

Term	Coefficient	P-value
Constant	229.75	0.000
Welding voltage (20 V)	35.00	0.004
WFS (5.9 m/min)	18.00	0.038
Groove shape (V)	12.25	0.107

The Taguchi's design concludes that welding voltage at 20 V followed by WFS at 5.9 m/min have shown higher influence on the welding transverse tensile strength and higher tensile strength means. The groove shape V has shown lower effect on the responses and lower means The optimum welding factors for higher welding transverse tensile strength are 20 V, 5.9 m/min and base metal groove shape V.

IV. CONCLUSIONS

The mild steel welded by GMAW at a variation of welding voltage, WFS, and base metal V groove shape combination of welding current, welding speed, and groove shape was studied to see their influence on the tensile strength and hardness of welding. The analysis was made by the orthogonal array's Taguchi's design. The results showed that higher FZ hardness has higher welding transverse tensile strength welding. Also, a higher tensile strength shown at lower welding voltage, WFS, and at V groove-shaped base metal. The increased inter-pass heat input has shown higher FZ hardness and welding tensile strength. The welding voltage at 20 V followed by WFS at 5.9 m/min showed a higher effect on the welding transverse tensile strength and higher means. While the groove shape V shows the minimum effect on the responses and minimum means the optimum welding combination for higher welding transverse tensile strength are 20 V, 5.9 m/min, and base metal groove shape V.

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REFERENCES

[1] S.I.A. Talabi, O.B.B. Owolabi, J.A.A. Adebisi, and T.A. Yahaya, "Effect of welding variables on mechanical properties of low carbon steel welded joint," Adv. Prod. Eng. Manag., vol. 9(4), pp. 181-186, 2014. http://dx.doi.org/ 10.14743 /apem2014.4.186

[2] S.P. Chavda, J.V. Desai, T.M. Patel, and L. Ksv, "A Review on parametric optimization of MIG welding for medium carbon steel using FEA-DOE hybrid modeling,". Int. J. Sci. Dev. Res., vol. 1(9), pp. 3-6, 2013. http://ijsrd.com/Article.php?manuscript=IJSRDV1I9039

[3] J. Shah, G. Patel, and J. Makwana, "Optimization and prediction of MIG welding process parameters using ANN," Int. J. Eng. Res Dev., vol. 5, pp. 1487–1492, 2017. http://www.ijedr.org/papers/IJEDR1702233.pdf

[4] C. Hamzaçebi, "Taguchi method as a robust design tool," in Quality control-intelligent manufacturing, robust design and charts, P. Li, P.A.R. Pereira, H. Navas, Eds. London: IntechOpen, 2020. https://doi.org/10.5772/intechopen.94908

[5] M.S. Phadke, Quality engineering using robust design, Prentice Hall: New Jersey, 1989.

[6] R. Unal, and E.B. Dean, "Design for cost and quality: The robust design approach", J. Param., vol. 11(1), 1991. https://doi.org/10.1080/10157891.1991.10462505

[7] S. Kumar, and R. Singh, "Optimization of process parameters of metal inert gas welding with preheating on AISI 1018 mild steel using grey based Taguchi method," Meas., vol. 148, pp. 106924, 2019. https://doi.org/10.1016/j.measurement.2019.106924

[8] R. Raghu, and S. Somasundaram, "An optimization of welding parameters for MIG welding," Int J. Eng, Res. Technol., vol. 6(14), pp. 1-5, 2018. https://www.ijert.org/an-optimization-of-welding-parameters-for-mig-welding

[9] S. Mahesh, and V. Appalaraju, "Optimization of MIG welding parameters for improving strength of welded joints," Int. J. Innov. Technol. Res., vol. 5(3), pp. 6453-6458, 2017. http://www.ijitr.com/index.php/ojs/article/view/1759
[10] D. Kalita, and P.B. Barua, "Taguchi optimization of MIG welding parameters affecting tensile strength of C20 welds," Int. J. Eng. Trends Technol., vol. 26, pp. 43-49, 2015. https://doi.org/10.14445/22315381/IJETT-V26P209
[11] S.S.S. Elfallah, "Study on the influence of groove shape on the tensile strength of commercial steel," J. Engg. Res., Online First Article, 2022. https://doi.org/10.36909/jer.18695
[12] S.S.S. Elfallah, "Influence of GMAW parameters on the tensile strength of commercial steel", Int. Sci. Techol. J., vol. 29, pp.1-16, 2022. https://www.stcrs.com.ly/istj/article-details.php?id=500
[13] S.S.S. Elfallah, "Effect of GMAW on the tensile strength and hardness of commercial steel," Int. J. Comput. Sci. Eng., vol. 10(9), pp.1-16, 2022. https://doi.org/10.26438/ijcse/v10i9.1420
[14] P. Marimuthu, T.T.M. Kannan, and G. Balaji, "Evaluation of hardness and tensile strength of Micro spot welded joints on different materials," Int. J. Appl. Eng. Res., vol. 10(3), pp. 2412-2414, 2015. http://www.ripublication.com/Volume/ijaerv10n3spl.htm
[15] M. A. Bodude, and I. Momohjimoh, "Studies on effects of welding parameters on the mechanical properties of welded low-carbon steel," J. Miner. Mater. Charact. Eng., vol. 3(3), pp. 142-153, 2015. https://doi.org/10.4236/jmmce.2015.33017
[16] B. Bhatt, and A.M. Sankhla, "Parametric optimization of GMAW process on mild steel Is-2062," Int. J. Technol. Res. Eng., vol. 3(9), pp. 2131-2134, 2016. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://nciet.srpec.org.in/paper/me/Vol1/NME17.pdf
[17] P.K. Yadav, M. Abbas, and S. Patel, "Analysis of heat affected zone of mild steel specimen developed due to MIG welding," Int. J. Mech. Eng. Robot. Res. vol. 3(3), pp. 399-404, 2014. http://www.ijmerr.com/show-124-447-1.html
[18] B.K. Khamari, S.S Dash, S.K. Karak, and B.B. Biswal, "Effect of welding parameters on mechanical and microstructural properties of GMAW and SMAW mild steel joints," Ironmak. Steelmak., 1-9, 2019. https://doi.org/10.1080/03019233.2019.1623592
[19] N. Sankar, S. Malarvizhi, and V. Balasubramanian, "Mechanical properties and microstructural characteristics of rotating arc-gas metal arc welded carbon steel joints," J. Mech. Behav. Biomed. Mater., vol. 30(1), 49-58, 2021. https://doi.org/10.1515/jmbm-2021-0006
[20] T. Tawfeek, "Study the influence of gas metal arc welding parameters on the weld metal and heat affected zone microstructures of low carbon steel," Int. J. Eng. Technol., vol. 9(3), 2013-2019, 2017. https://doi.org/10.21817/ijet/2017/v9i3/1709030272
[21] Y. Purwaningrum Y, M. Wirawan Pu, and F. Alfarizi, "Effect of shielding gas mixture on gas metal arc welding (GMAW) of low carbon steel (LR Grade A)," In *Key Eng.Mater. Trans Tech Pub.*, vol. 705, 250-254, 2016. https://doi.org/10.4028/www.scientific.net/kem.705.250
[22] L. Calderón, O. Bohórquez, M.A. Rojas, and A. Pertuz, "Experimental relationship of tensile strength and hardness of welded structural steel," J. Phys. Conf. Ser. vol. 2046(1), 012065, 2021. https://doi.org/10.1088/1742-6596/2046/1/012065
[23] A.T. Assefa, G.M.S. Ahmed, S. Alamri, A. Edacherian, M.G. Jiru, V. Pandey, and N. Hossain, "Experimental investigation and parametric optimization of the tungsten inert gas welding process parameters of dissimilar metals," Mater., vol. 15(13), 4426, 2022. https://doi.org/10.3390/ma15134426
[24] American Society for Testing and Materials. "*Standard test methods for tension testing of metallic materials"*, ASTM International, 2021. https://doi.org/10.1520/E0008-04
[25] World Material, "EN 1.0038 Steel S235JR material equivalent, properties, composition," Available Online: https://www.theworldmaterial.com/1-0038-steel-s235jr-material/ (Accessed on 19 February 2023).
[26] Y.R. Ratiwi, and S.S. Wibowo, "The effect of electrode and number of passes on hardness and micro structure of shielded metal arc welding," IOP Conf. Ser.: Mater. Sci. Eng., vol. 515(1), pp. 012072, 2019. https://doi.org/10.1088/1757-899x/515/1/012072

[27] R. Scharf-Wildenhain, A. Haelsig, J. Hensel, K. Wandtke, D. Schroepfer, A. Kromm, and T. Kannengiesser, "Influence of Heat Control on Properties and Residual Stresses of Additive-Welded High-Strength Steel Components", Metals. vol. 12(6), pp. 951, 2022. https://doi.org/10.3390/met12060951

[28] H. Vemanaboina, B. Sridhar Babu, E. Gundabattini, P. Ferro, and K. Kumar, "Effect of Heat Input on Distortions and Residual Stresses Induced by Gas Tungsten Arc Welding in SS 316L to INCONEL625 Multipass Dissimilar Welded Joints", Adv. Mater. Sci. Eng., 2021. https://doi.org/10.1155/2021/1028461

[29] N. Huber, and J. Heerens, "On the effect of a general residual stress state on indentation and hardness testing", Acta Materialia. vol. 56(20), pp. 6205-6213, 2008. https://doi.org/10.1016/j.actamat.2008.08.029

[30] R. Unnikrishnan, K. S. Idury, T. P. Ismail, A. Bhadauria, S. K. Shekhawat, R. K. Khatirkar, and S. G. Sapate, "Effect of heat input on the microstructure, residual stresses and corrosion resistance of 304L austenitic stainless steel weldments", Mater Character., vol. 93, pp. 10-23, 2014. http://dx.doi.org/10.1016/j.matchar.2014.03.013

[31] Z. Boumerzoug, C. Derfouf, and T. Baudin, "Effect of welding on microstructure and mechanical properties of an industrial low carbon steel", Eng., vol. 2(7), pp. 502, 2010. http://doi:10.4236/eng.2010.27066

[32] S.A. Swami, S. Jadhav, A. Deshpande, "Influence of MIG welding process parameters on tensile properties of mild steel", Eur. J. Eng. Sci. Tech., vol. 1(2), pp. 1-5, 2016. http://doi:10.24018/EJENG