PRZEGLĄD SPAWALNICTWA
Welding
TECHNOLOGY REVIEW

DOI: https://doi.org/10.26628/simp.wtr.v95.1161.49-56

Original Article

Influence of Groove shape on the Mechanical Properties of Welded Commercial Steel

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Received: 19.08.2022; Accepted: 10.01.2023

Abstract: Manufacturers always seek for quality and effective welding to stay competitive in the market. There is a continuous demand for a quick and efficient manufacturing set ups for new products. GMAW is among the welding processes that is wieldy used in the industry. Welding factors such as welding voltage, welding current, gas flow rate, filler wire size and welding speed play a significant role in determining the welding quality. Taguchi design uses optimization technique for the process of experimentation as an effort to improve productivity and enhance product quality. This study discusses the welding of commercial steel welded using GMAW. The welding was controlled by welding current, welding speed and groove shape to test their influence on the welding strength, tensile strength and hardness. X groove shape welding has obtained lower tensile strength and hardness than V groove shape as did higher welding current and lower welding speed. The results concluded that welding current welding had the highest influence on tensile strength and hardness of the welding, followed by groove shape, while the welding speed had the minimum influence. The optimized combination of welding factors is 170 A, V groove shape and 150 mm/min.

Keywords: GTAW; Commercial steel; Tensile strength, Hardness, Taguchi design

Introduction

In industry, welding is a wieldy used manufacturing process for joining metals. It's efficient and applicable everywhere [1-3]. Gas tungsten arc welding (GTAW) or Tungsten inert gas (TIG) is considered one of the most widely used welding methods [4-6] to achieve strong [2] and multi-objectives welding [7]. GTAW is also advantageous in welding dissimilar welding, producing minimized heat-affected zone (HAZ), no slag and narrower bead geometry [8]. It used non-consumable tungsten as an electrode and shield gas to protect the weld pool from atmospheric contamination [5,9]. The quality of the welding depends on the welding factors, which consequently affect the microstructure of welding and thus its mechanical properties [7,10]. Greyjevo and Metodo [7] believed that the mechanical properties of welding can be controlled by the interaction of the welding factors which lead to different results in every process. To get desired welding quality it is important to optimize welding factors. Such optimization should fulfil all welding objectives [2]. Ramadan and Boghdadi [2] called this a multi-response optimization [2]. Factors such as welding current, welding voltage, gas flow rate, electrode diameter and welding speed have been studied and optimized for their influence on mechanical properties [2,11-13]. Taguchi design is a technique suggested by a design method called an orthogonal array. It proposed studying more factors with a fewer number of experiments than the Factorial Design of Experiments [14]. Taguchi design is simple however, it is increasingly used in manufacturing industries [15]. Abima et al. [12] have studied the effect of GTAW on the tensile strength and hardness of low carbon steel and found that increased current caused an increase in tensile strength, while hardness decreased. Multiple researchers have studied the influence of welding factors on the mechanical properties of dissimilar mild steel [13,16]. Others have used the Taguchi design to optimize welding factors [2,5,11]. Anand et al. [5] found that welding current had a higher effect on the tensile and hardness of the welding over the welding voltage and gas flow rate, while Singh et al. [11] concluded that gas flow rate obtained a higher effect on the tensile strength of welding followed by welding speed and welding current. This work will study the effect of welding current, welding speed and groove shape of welding joint on the tensile strength and hardness of welded mild steel using GTAW. The optimization of welding factors will be performed using the Taguchi design.

Materials and Methods

Mild steel from the local market was prepared using a CNC laser cutter in the Tasamim workshop at Benghazi. The tensile strength samples were prepared according to the American society of testing materials (ASTM) E8 / E8M [17]. Fig. 1 shows an illustration of the sample with dimensions for the tensile test with V and X groove shapes with each angle of 60°. Also, other samples were prepared for hardness testing. The welding of the samples has taken place in Altaibat Food Inc at Benghazi. The Welding was processed using welding power supply Daewoo Inverter Welder TIG/MMA and welding speed device YSG-12 Beetle Portable Gas Cutter (Fig. 2(a)). The shielding gas used is composed of 90% argon and 10% carbon dioxide with a flow of 10 millilitres per minute. The welding process is shown in Fig 2(b). Table I lists the composition of the base metal and filler wire. The base metal is non-alloy structural steel European standard EN 10025-2, grade S235JR (1.0038) and the welding filler used is E6013 (2.5 mm in diameter) mild steel. Table II shows the tensile strength and hardness properties of the base metal and filler wire.

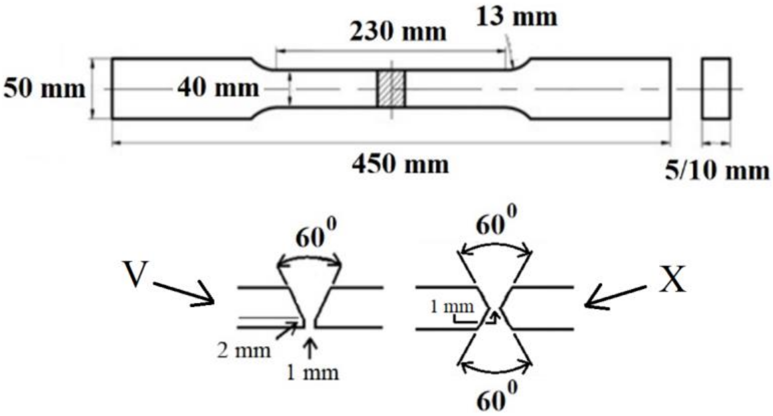

Fig 1. Samples dimensions for tensile test made according to ASTM E8/E8M [17]

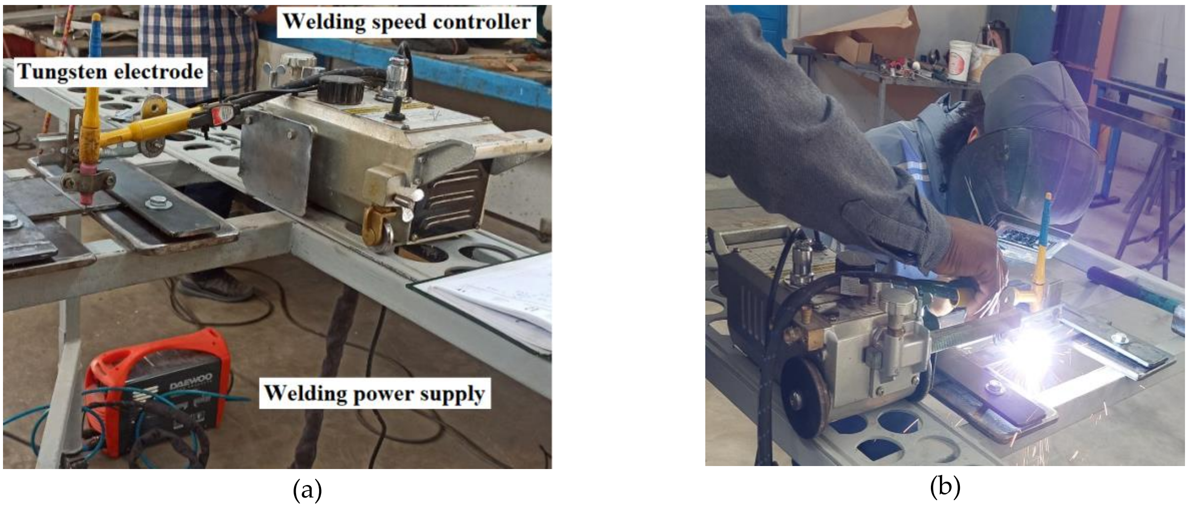

Fig. 2. (a) Illustration of the sample with dimensions for the tensile test; (b) Welding process.

The experiment layout follows the 2-level's four factors resulting in a total of 8 runs (Table III). This method is known as Taguchi's L8 array. Table IV below contains the experimental coded design values, while table V contains the experimental actual values. The analysis was made with help of Minitab 18®.

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 these samples have been repeated due to the failure of the first ones. The hardness test was conducted in the College of Mechanical and Engineering Technology at Benghazi using the Ernst Rockwell principal bench hardness tester (Fig. 4). The indenter used is a diamond cone (1200 in angle) with a load of 100 kg as pressure force. The hardness of the weld area was measured to demonstrate the change of the welding factors on them.

Table I. The chemical compositions of the base metal and welding wire used in the experiment [18]

Component	Composition									
	C	Mn	S	Ni	Cr	P	Si	Cu	Mo	V
Base metal (EN 10025-2)	0.17%	1.4%	0.025%	0.012%	-	0.025%	-	0.55%	-	-
Welding filler (E6013)	0.10%	0.6%	0.03%	0.3%	0.2%	0.035%	0.5%	0.35%	0.2%	0.05%

Table II. The tensile strength and hardness of base metal and filler wire [19,20]

Component	Tensile properties			Hardness properties
	Yield strength	Tensile strength	Elongation	Rockwell hardness B
Base metal (EN 10025-2)	235	360-510	26%	66.7 HRB
Filler wire (E6013)	482 MPa (70 ksi)	558 MPa (81 ksi)	27%	83 HRB

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 voltage is estimated to be between 20 V and 30 V. Table IV shows the Taguchi design layout according to welding factors and their corresponding tensile strength and hardness of the weld samples.

Table III. Factors used for the welding process

Code	Factors	Unit	Level 1	Level 2
A	Welding current	A	170	200
B	Welding speed	mm/min	100	150
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

Std order	Welding current (A)	Welding speed (mm/min)	Groove shape	Tensile strength (N/mm²)	Heat input (J/mm)	Hardness (HRB)	EL%
1	170	100	V	232	2700	24.0	4
2	170	100	X	202	2700	22.0	3
3	170	150	V	219	1800	25.7	4
4	170	150	X	191	1800	23.0	3
5	200	100	V	184	3600	22.7	3
6	200	100	X	158	3600	21.3	3
7	200	150	V	205	2400	22.2	4
8	200	150	X	169	2400	20.9	3

In general, there was a descending in the hardness with the decreased tensile strength, although the hardness often increased. For instance, if the groove shape factor was constant, the decreased tensile strength at the welded samples with the V base metal groove-shaped showed an increased hardness from sample 1 to sample 3 and from 8 to 6. At X groove-shaped base metal the results showed similarity. However, the tensile strength and hardness at V groove-shaped samples were higher than X when the welding current and welding speed were constant. The tensile strength has also descended with the increased welding current, while the welding speed showed an unclear pattern. Slower welding speed has obtained higher tensile strength at lower current. However, when the welding current reached 200 A, an increased tensile strength was shown at a higher welding speed. It is also noticeable that the higher current and slower welding resulted in higher heat input. The highest heat input corresponded with the lowest tensile strength. Interestingly, the lowest heat input showed higher but not the highest tensile strength value with the highest hardness values.

Fig 3. Samples used for tensile strength

Fig 4. Ernst Rockwell hardness tester

The extended heat in the welding leads to higher dilution of the fusion zone, which leads to increased internal stresses. Higher internal stresses can cause lower tensile strength and hardness of the welding. From a microstructural perspective, the higher heat input causes a prolonged cooling rate. This consequently reflects longer microstructural recrystallization time, and thus, results in coarser grains in the fusion zone and HAZ [21]. Jeet et al. [22] and Yadav et al. [23] have has explained that higher tensile strength and hardness of the welding area and HAZ are related to the faster cooling of the welding.

Plots (Fig. 8) and (Fig. 9) are the main effects of signal-to-noise (S/N) ratios and means of the welding factors respectively. Both the plots show a similar orientation of results. The S/N ratios in Fig 8 illustrate the effect of the welding factors by showing their S/N ratios concerning S/N mean. The S/N ratio measures how the response (tensile strength and hardness values) varies relative to the higher under different noise conditions. The higher S/N ratio is labelled in Fig 8 and Table VI as "Larger is Better", which corresponds to the experiment goal, that is, to maximize the response. The means plot in Fig 9 shows response means concerning the average of means. Table VII show the average of each response characteristic for each level of each welding factor. The Delta statistic is the highest minus the lowest average for each factor. The ranks are assigned based on delta values, which indicate the effectiveness of welding factors. Ranking indicates the strength of each factor as also indicated by the absolute values of the coefficient for S/N ratios in Table VIII. However, the coefficient values in Table VIII and Table IX are only for Level 1 factors as listed in Table III.

Fig 8 shows welding current of 170 A has a higher S/N ratio than at 200 A. It can also be seen in Table VI, where the values at Level 1 and Level 2 are listed. Also, the groove shape of V has shown a higher S/N ratio than groove shape X, while welding speed of 150 mm/min has shown a lower S/N ratio than 100 mm/min welding speed. Also, Fig 8 and Table VI show that welding current and groove shape both show close values of 30.42 and 30.41 respectively. Which considers welding current at 170 A has the highest S/N ratio. It means it has the most influence on the response followed by a closely similar influence of groove shape at V, while the welding speed at 150 mm/min shows the lower influence.

Also, it is clear from Fig 9 and Table VII that both welding current and groove shape show higher response means followed by much lower means obtained by welding speed It indicates that the highest tensile strength and hardness means were obtained at 170 A followed by groove shape V, while the welding speed of 150 mm/min shows lower response means.

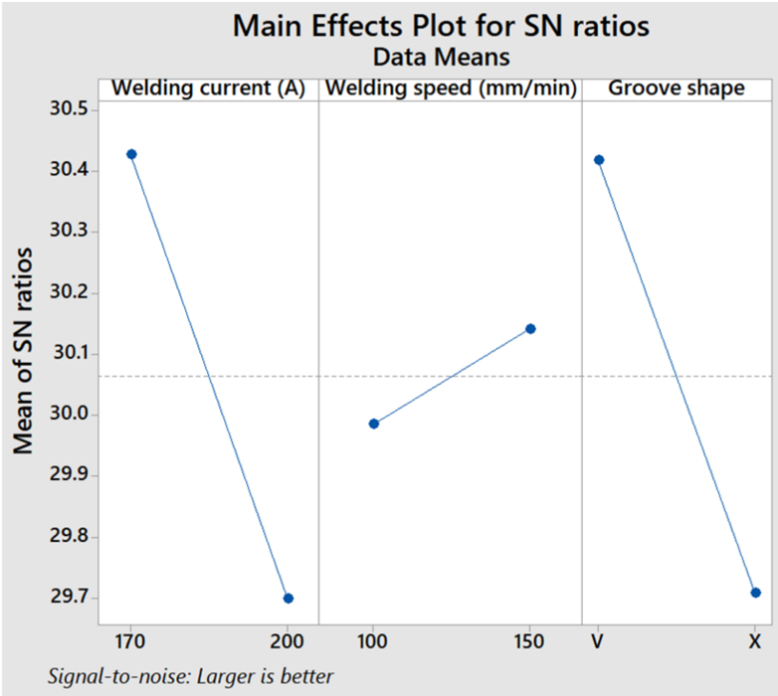

Fig 8. Main effect plot for S/N ratio for the welding factors

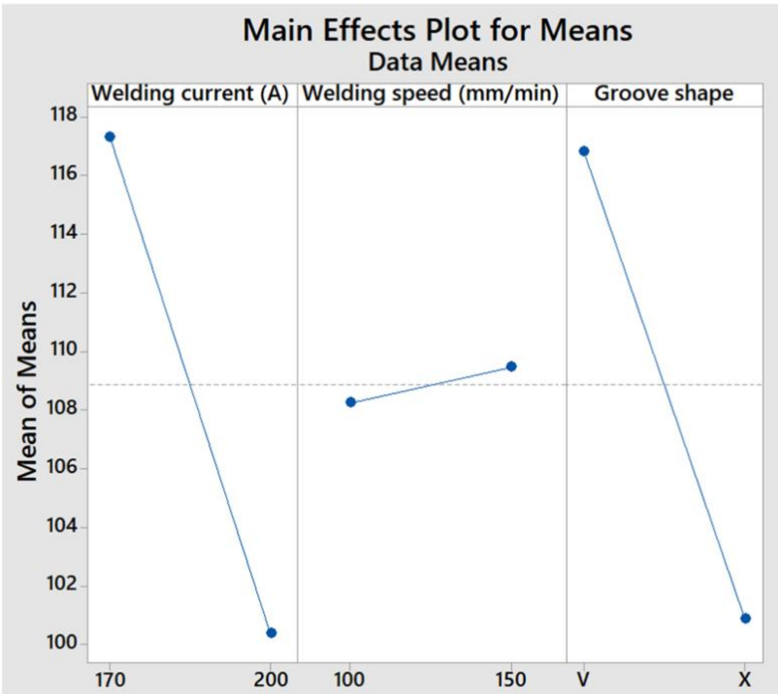

Fig 9. Main effect plot for means for the welding factors

Table VIII show the S/N ratios estimated model coefficients for welding factors, while Table IX show the means estimated model coefficients. Welding current at 170 A and groove shape V showed significant P values (population value) of 0.016 and 0.018 respectively while welding speed at 100 mm/min has shown to be non-significant (Table VIII). The significance value should be 0.05 or lower. It indicates that welding speed of 100 mm/min showed minimum influence on the tensile strength and hardness while welding current at 170 A and groove shape V showed higher influence. Also welding current at 170 A and groove shape V has shown to be significant on the tensile strength and hardness means as shown in Table IX. The results from Minitab didn't show P values for level 2 factors.

As a result, it is clear from the plots and tables that welding current and groove shape have shown higher influence and values on the tensile strength and hardness, while the welding speed has shown a much lower effect at 150 mm/min and minimum changes on the response mean is shown when the speed changed from 100 to 150 mm/min (Fig 9 and Table VII). The optimum welding factors for higher tensile strength and hardness are 170 A, 150 mm/min and groove shape V.

Table VI. Response ranking for S/N ratios

Level	Welding current (A)	Welding speed (mm/min)	Groove shape
1	30.43	29.99	30.42
2	29.70	30.14	29.71
Delta	0.73	0.16	0.71
Rank	1	3	2

*Larger is better

Table VII. Response ranking for means

Level	Welding current (A)	Welding speed (mm/min)	Groove shape
1	117.3	108.3	116.8
2	100.4	109.5	100.9
Delta	17.0	1.2	15.9
Rank	1	3	2

Table VIII. Estimated model coefficients for S/N ratios

Term	Coefficient	P-value
Constant	30.0633	0.000
Welding current (170 A)	0.3636	0.016
Welding speed (100 mm/min)	-0.0782	0.440
Groove shape (V)	0.3541	0.018

Table IX. Estimated model coefficients for means

Term	Coefficient	P-value
Constant	108.863	0.000
Welding current (170 A)	8.475	0.008
Welding speed (100 mm/min)	-0.612	0.736
Groove shape (V)	7.962	0.009

Conclusions

GTAW under a variation of welding factors was used to weld mild steel. A combination of welding current, welding speed and groove shape were studied to see their influence on the tensile strength and hardness of welding. The analysis is made using Taguchi's design. The results demonstrated that welding current affects the welding tensile strength and harness the most followed by a closely similar effect of groove shape, while welding speed had a minimum effect on the tensile strength and hardness. However, the variation in welding speed has shown close values of tensile strength and hardness. The welding factor's optimum combination is 170 A, groove shape V and welding speed of 150 mm/min.

Acknowledgement

The author would like to thank his family for their support and encouragement throughout this study. A sincere appreciation goes to Libyan Iron and Steel Company for their help, to the staff of the welding laboratory at Altaibat Food Inc. and Mr Thabit Elrabihi and the Head of laboratories Mr Salem Elmisrati at the College of Mechanical Engineering technology.

Funding: This research received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.

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