Influence of GMAW Factors on the Tensile Strength of Commercial Steel

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الملخص

يعتبر اللحام إحدى الطرق المعروفة المستخدمة في الصناعة والطلب دائماً علي لحام فعال وذو جودة عالية. ودائماً يسعي المصنعين الي المنافسة في السوق من خلال الاعتماد على المهندسين والافراد المنتجين الي سرعة وكفاءة عمليات التصنيع للمنتجات الجديدة. يعتبر لحام الصهر بالغاز (GMAW) إحدى اكثر العمليات استخداما في الصناعة. تعتبر معطيات او متغيرات اللحام مثل التيار وفرق الجهد الكهربي للحام ومعدل تدفق الغاز ومعدل تغذية وحجم وسرعة سلك الإنصهار دورًا مهمًا في تحديد جودة اللحام. وتعتبر الطريقة الاحصائية تاجوشي (Taguchi) أداة فعالة لتحسين جودة وأداء عمليات التصنيع. وفي هذه الدراسة تمت عملية لحام الفولاذ منخفض الكربون (الفولاذ الصناعي) باستخدام لحام الصهر بالغاز تحت متغيرات محددة مسبقًا للحام وهي سمك طرفي اللحام وفرق الجهد اللحام وسرعة تغذية سلك اللحام. وتهدف الطريقة الاحصائية تاجوشي إلى تحديد عوامل المثلى لعملية اللحام وذلك لزيادة خواص قوة الشد والصلابة للحام. وأظهرت النتائج أن سمك طرفي اللحام كان له التأثير الأعلى على مقاومة الشد والصلابة للحام، يليها فرق الجهد الكهربي للحام اما سرعة تغذية سلك الانصهار كان لها أقل تأثير على قيم قوة الشد وصلابة للحام. وأظهرت النتائج ايضا ان اعلي قيم لقوة الشد والصلابة ظهرت في اللحام ذو سمك 10 مم، وفرق جهد اللحام المستخدم 20 عند فولت وسرعة تغذية سلك الإنصهار عند 5.9 م / دقيقة.

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. GMAW is one of the most widely used processes in the industry. The input factors such as welding current, welding voltage, Gas flow rate, wire feed rate, 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, GMAW has welded commercial steel under preset factors of base metal thickness, welding voltage and wire feed speed. Taguchi's design is to determine the optimal process factors for higher tensile strength and hardness. The analysis found that thickness had the highest effect on tensile strength and hardness of the welding, followed by wire feed speed voltage. The wire feed speed had the lowest influence on the tensile strength and hardness. It can conclude that the optimized combination is the base metal thickness of 10 mm, the voltage of 20 V and wire feed speed of 5.9 m/min.

Keywords: GMAW, Commercial steel, Taguchi method, Tensile strength, Hardness.

Introduction
Welding is a fabrication process in every large or small industry. It is a principal means of fabricating and repairing products by joining metals. The process is efficient, economical and dependable. The welding process finds its applications in air, underwater and space. Gas metal arc welding (GMAW) is 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 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 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.,* 2018).

The Taguchi method (TM) is a technique proposed by Dr Genichi Taguchi. It suggests a design method called an orthogonal array. In this, we can study more factors or factor space with a lesser number of experiments than the Factorial Design of Experiments (Jugulum and Taguchi, 2004). TM is considered simple, however, it is increasingly used in manufacturing industries (Tanco *et al.,* 2007).

Several researchers used the Taguchi method to determine the optimal GMAW process factors for higher tensile strength and hardness for mild steel (Raghu and Somasundaram, 2018) (Patil and Waghmare, 2013) (Mahesh and Appalaraju, 2017) (Jeet *et al.*, 2018). Some has found welding current had a major influence on the tensile strength of the welded mild steel (Raghu and Somasundaram, 2018). Others have found similar significant influence effect of welding current and speed (Patil and Waghmare, 2013) (Mahesh and Appalaraju, 2017). The hardness of the welding area has been investigated for fusion zone (FZ) (Ibrahim *et al.*, 2012) (Jeet *et al.*, 2018) (Tawfeek, 2017) (Yadav *et al.,* 2014) (Purwaningrum *et al.*, 2016) (Sankar *et al.,* 2021) and heat-affected zone (HAZ) (Yadav *et al.*, 2014) (Sankar *et al.*, 2021). The hardness of base metal has also been reported (Yadav et al., 2014) (Sultana *et al.*, 2014) (Sankar *et al.*, 2021).
Studies have reported that weldments that have higher tensile, have also higher hardness (Marimuthu, 2019) (Bodude & Momohjimoh, 2015) (Raghu and Somasundaram, 2018). In addition, 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 (Bodude & Momohjimoh, 2015) (Kamble & Rao, 2017) (Abd Razak & Ng, 2014) (Yadav *et al.*, 2014) (Tawfeek, 2017). The cause of low tensile strength and hardness is related to the grains structure that is coarse and dendrite in shape at FZ (Bodude & Momohjimoh, 2015) (Tawfeek, 2017). While the grains at HAZ are fine in structure, and due to that, it was reported to have higher hardness than at FZ (Yadav *et al.,* 2014) (Tawfeek, 2017). Consequently, HAZ was reported to have higher yield strength than FZ and base metal (Hooda *et al.*, 2012). In general, hardness at fusion zone (FZ) and heat-affected zone (HAZ) is higher than base metal area (Sankar *et al.*, 2021). Also, base metal without welding obtain lower tensile strength than welded ones (Purwaningrum *et al.*, 2016) (Sankar *et al.*, 2021), but show 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. Yadav et al. (2014) found that tensile strength and hardness increase with a thicker base metal. The solidification rate is faster at higher base metal thickness. The higher surrounding area around the fusion zone acts as a heat sink that absorbs heat from the weldment and distributes it along with the base metal. The study showed that 5 to 10 mm base metal thickness has contributed to the increase in tensile strength and hardness of the HAZ area.

Methodology

1. Materials and Experimentation

Mild steel was purchased from the local market and was 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, 2015). Figure 1 shows an illustration of the sample with dimensions for the tensile test with a V groove of 60°. Also, other samples were prepared for hardness testing and microstructure inspection in the same workshop. The welding of the samples has taken place in Saad Elkarimi Institute of Technology at Benghazi. The welding machine used is CEA MAXI 321 using NEXUS copper-coated mild steel welding wire as shown in Figure 2. The welding process is shown in figure 3. The shielding gas used is composed of 82% argon and 18% carbon dioxide with a flow of 18 liters per minute. Table 1 lists the composition of the base metal and welding wire. The base metal is non-alloy structural steel European standard EN 10025-2, grade S235JR (1.0038).

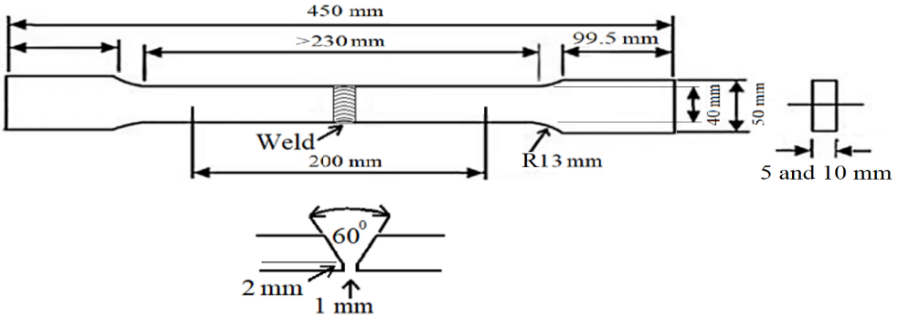

Figure 1. Samples dimensions for tensile test made according to ASTM E8/E8M (ASTM, 2021)

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

Component	Composition							
	C	Mn	S	Ni	Cr	P	Ni	Cu
EN 10025-2	0.17%	1.4%	0.025%	0.012%	-	0.025%	0.012 %	0.55%
AWS ER70 S-6 welding wire	0.12%	1.8%	0.035%	0.15%	0.15%	0.035%	-	0.35%

Figure 2: Welding machine CEA MAXI 321


Figure 3: Welding process

Three factors, that is, base metal thickness, welding voltage and welding wire feed speed used for the welding process each has two levels as listed in Table 2. The wire thickness is fixed for the experiment with 0.045 in (1.143 mm) thick. The current is estimated to be 106 A at 20 V and 287 A at 27.5 V.

Table 2. Factors used for the welding process

Code	factors	Unit	Level 1 (1)	Level 2 (-1)
A	Material thickness	cm	20	27.5
B	Voltage	v	20	30
C	Wire feed speed	m/min	5.8	10.5

2. Taguchi's Design

The experiment layout follows the 2-level's four factors resulting in a total of 8 runs. This method is known as Taguchi's L8 array. Table 3 below contains the experimental coded design values, while Table 4 contain the experimental actual values. The analysis was made with help of Minitab 18®.

Table 3. Coded design layout values (run table)

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

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 Figure 4. Hardness test was conducted in College of Mechanical and Engineering Technology at Benghazi using Ernst Rockwell principle bench hardness tester as seen in

Figure 5. 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.

Figure 4: Samples used for tensile strength

Figure 5: Ernst Rockwell hardness tester

The Taguchi design layout according with respect to welding factors are shown in Table 4. While Table 5 show the corresponding tensile strength and hardness of the weld samples.

The results show hardness decreases whenever the tensile decreases and vice versa. The tensile strength and hardness decline with the increase in voltage and wire feed speed, increasing with the thicker base metal.

Table 4. Actual Taguchi design layout with respect to welding factors

Std order	Material thickness (mm)	Voltage (v)	Wire feed speed (WFS) (m/min)
1	5	20	5.8
2	5	20	10.5
3	5	27.5	5.8
4	5	27.5	10.5
5	10	20	5.8
6	10	20	10.5
7	10	27.5	5.8
8	10	27.5	10.5

Table 5. Taguchi design layout with responses

Std order	Thickness (mm)	Voltage (v)	WFS (m/min)	Tensile strength (N/mm^2)	Heat input (J/mm)	Hardness (HRB)	EL%
1	5	20	5.9	176	363.43	26.3	3
2	5	20	10.6	145	363.43	25.8	4
3	5	27.5	5.9	173	1353.00	28.2	3
4	5	27.5	10.6	120	1353.00	25.2	6
5	10	20	5.9	305	363.43	35.7	7
6	10	20	10.6	238	363.43	30.4	7
7	10	27.5	5.9	233	1353.00	29.4	6
8	10	27.5	10.6	192	1353.00	27.1	7

The following plots (Figure 1 and Figure 2) is the main effects plots for signal-to-noise (S/N) ratios and means of the welding factors. The two plots are almost identical. The S/N ratios in Figure

1 interpret the influence of the welding factors by showing their mean S/N values. The S/N ratio measures how the tensile strength and hardness values vary relative to the higher under different noise conditions. The levels averages in the response tables show that the S/N ratios and the means are highest at the base metal thickness of 10 mm. It means it has the most effect by obtaining a maximum means value followed by wire feed speed at 5.9 m/min. The voltage shows the lowest influence at 20 V.

The following tables (Table 6 and Table 7) show the estimated model coefficients and analysis of variance (ANOVA) for S/N ratio for the welding factors. The tables obtain the smallest P value for thickness of 5 mm at 0.039, which is statistically significant because it is less that significance level of 0.05. The P values for voltage at 20 V and wire feed speed at 5.9 m/min have obtained non-significant with wire feed speed has higher p value than voltage. It means that their influence on the tensile strength and hardness is kept to a minimum. The model measures a fit of 86.85% on R^2 correlation.

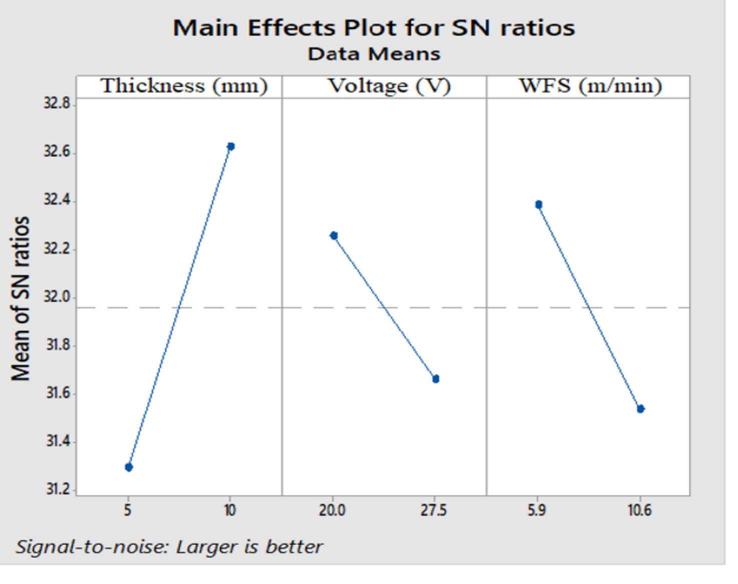

Figure 2. Main effect plot for S/N ratio for the welding factors

Table 6: Estimated Model Coefficients for S/N ratios

Term	Coefficient	SE Coefficient	T	P-value
Constant	31.9585	0.2198	145.388	0.000
Thickness (5 mm)	-0.6652	0.2198	-3.026	0.039
Voltage (20 V)	0.2972	0.2198	1.352	0.248
WFS (5.9 m/min)	0.4235	0.2198	1.927	0.126

Table 7: Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Thickness (mm)	1	3.5399	3.5399	3.5399	9.16	0.039
Voltage (V)	1	0.7068	0.7068	0.7068	1.83	0.248
WFS (m/min)	1	1.4351	1.4351	1.4351	3.71	0.126
Residual Error	4	1.5462	1.5462	0.3866		
Total	7	7.2281				

The responses tables (Table 8 and Table 9) 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 in Table 6. The order of the ranks in Table 8 confirm with Figure 1, as thickness obtained as the most influential welding factor followed by wire feed speed (WFS), while voltage has the lowest effect on the responses, the tensile strength of the welding and the hardness of the FZ. The optimum welding factors as demonstrated in Figure 2 and Table 9 have obtained higher responses values are 10 mm thickness, 20 V and WFS of 5.9 m/min.

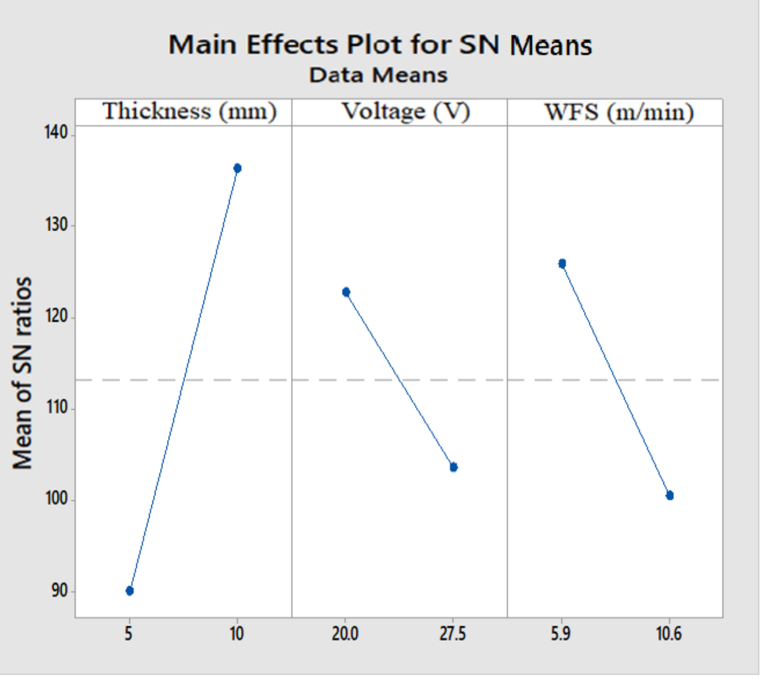

Figure 3. Main effect plot for means for the welding factors

Table 8: Response Table for S/N Ratios

Level	Thickness (mm)	Voltage (V)	WFS (m/min)
1	31.29	32.26	32.38
2	32.62	31.66	31.53
Delta	1.33	0.59	0.85
Rank	1	3	2

Table 9: Response Table for means

Level	Thickness (mm)	Voltage (V)	WFS (m/min)
1	89.94	122.77	125.83
2	136.32	103.49	100.44
Delta	46.39	19.29	25.39
Rank	1	3	2

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Conclusion

Mild steel plates were welded by GMAW using low carbon steel electrode wire. The welding factors used for thewelding 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 thickness affects the most followed by wire feed speed, while voltage had the lowest influence on the tensile strength and hardness. The welding factor's optimum combination is 10 mm base metal thickness, 20 V and WFS of 5.9 m/min.

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