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Investigation on The effect of Different Welding Parameters on Welding Quality of 304L Stainless Steel

*Taha Abdulla , Mousa May
Department of Materials Engineering, Faculty of Energy and Mining Engineering, Sebha University, Libya
*Corresponding Author: Tah.abdullah@sebhau.edu.ly

Abstract This study focuses mainly on studying the effect of a range of welding parameters on the weld quality of 304L stainless steel welded bars, using ER-308L filler wire. All welding experiments carried out in this work were conducted at the Welding Lab, The University of Tripoli, Libya. The welding process is performed with the use of Gas Tungsten Arc semi-automatic welding manner. The effects of different welding parameter (welding current, welding speed, and the flow rate of shielding gas) on the quality of welding joint (welding bead width, weld penetration and heat affected zone(HAZ))wereinvestigated. The optimum welding conditions based on the analysis of the data from the different experiments for tensile and hardness tests of the welded sampleswere established.A modeling approach; named Taguchi method, which examines the effect of the measured weld bead width, welding penetration and the size of heat affected zone(HAZ) region on the weld quality was used. The modeling results compared with the data from the mechanical properties of the welded samples and investigate whether there is a link between the modeling approach and the experimental work.The results showthata good quality welding joints of 304L stainless steel, with a welding current of 185 A, welding speed of 135 mm/min and gas flow rate of 10 L/min should be used. These combination of welding conditions provided the best tensile and hardness mechanical properties for the welded samples, and find a reasonable agreements with the Taguchi modeling approach.

Keywords: Welding Parameters, Stainless Steel 304L, Taguchi Method, Mechanical Properties.

التحقيق في تأثير متغيرات لحام مختلفة على لحام عينات الفولاذ المقاوم للصدأ نوعية L304

*طه عبدالله و موسى مي
قسم هندسة المواد– كلية الطاقة وهندسة التعدين– جامعة سبها، ليبيا
*للمراسلة: Tah.abdullah@sebhau.edu.ly

ملخص تركز هذه الدراسة بشكل أساسي على دراسة تأثيرمجموعة من متغيرات تقنية اللحام على جودة اللحام لعينات القضبان الملحومة من الفولاذ المقاوم للصدأ L304، وذلك باستخدام سلك حشوER-308L. أجريت جميع التجارب اللحام التي نفذت في هذا العمل في مختبر لحام جامعة طرابلس، ليبيا. تمت عملية اللحام باستخدام غازالتنغستن وقوس اللحام بطريقة شبه آلية.وقد تم التحقيق في ثاتيرمتغيرات اللحام المختلفة (تياراللحام، سرعة لحام، ومعدل تدفق غازالتدريع) على جودة وصلة اللحام (عرض حبة اللحام، واختراق اللحام، والمنطقة المتأثرة بحرارة اللحام (هاز)). أنشئت أفضل ظروف اللحام استنادا إلىتحليل بيانات من تجارب مختلفة من اختبارات الشد والصلابة على عينات ملحومة. تم استخدام طريقة النمذجة، اسمها طريقة تاجوشى، التي تبحث في تأثيرقياس عرض حبة اللحام، اختراق اللحام والمنطقة المتأثرة بحرارة اللحام (هاز) على جودة اللحام. تمت مقارنة نتائج النمذجة مع البيانات من الخواص الميكانيكية للعينات الملحومة والتحقيق في ما إذا كانت هناك صلة بين نهج النمذجة ونتائج الاختبارات المعملية. وتبين أنه للحصول على نتائج ممتازة لوصلة لحام من L304 الفولاذ المقاوم للصدأ، ينبغي استخدام تيارلحام من 185 أمبير(A) واستخدام سرعة لحام 135 مم / دقيقة ومعدل التدفق الغاز 10 لتر / دقيقة. هذه المجموعة من متغيرات اللحام قدمت أفضلا لخواص الميكانيكية لاختبارالشد والصلابة للعينات الملحومة، والتي وجدت اتفاقات معقولة مع نهج النمذجة تاجوشى.

الكلمات المفتاحية: متغيرات اللحام، الفولاذ المقاوم للصدأ L304، طريقة تاجوشى، الخواص الميكانيكية.

1. Introduction

Although steel is the basic metal of the industrial economy, scientific advances must be made not only in the search for new metals, but in the processes needed to join these metals. The earliest method of joining two pieces of metal into a unit was by heating them and allowing them to melt together, and this union is known as fusion [1,2]. It has changed a little from ancient times, but today, heat for fusing the joint during welding comes from a burning gas or an electric current. Electric current is now the most commonly heat source for welding. The heat melts metals to be joined and the filler metal (if it is used) together in the welding pool. Shielding the welding pool from the atmosphere during welding is a very important to produce good joints. This is achieved byusing covered electrodes (with flux) as a filler metals. It can also be done by shielding the welding pool with an inert gas (helium, argon, etc.), which does not interact chemically with other elements and will not burn [3,4]. One of the processes which have grown up out of this shielding principle is Gas Tungsten Arc Welding process (GTAW). This process has become a popular choice of welding processes when high quality required. Because welding involves melting, solidification, and ensure quality and adequate properties of a weldment, especially in critical applications such as pressure vessel building, arctic gas and oil pipe lines. The close attention and controlfor the process can be obtained by using the automated welding technique instead ofthe manual welding. For instance, gas tungsten arc welding can be accomplished by semi-automated or full-automated manner [5]. It canalsobe done with or without filler metal. The automated process is characterized with many advantages (such as, improved weld integrity and repeatability, increased output, decreased scrap, and a much higher current can be used) since the process parameters is kept constant during welding until the process is finished[1,3].Stainless steel is an iron-containing alloy made up of two or more chemical elements used in a wide range of applications.It has excellent resistance to stain or rust due to its chromium content.They achieve their characteristics through the formation of invisible and adherent chromium rich oxide surface film.This oxide forms and heals itself in the presence of oxygen [6]. Most of stainless steel grades have a three-digit designation; the 200 series and 300 series are generally austenitic stainless steels, whereas the 400 series are either ferritic or martensitic. Some of stainless steel grades have a one or two letter suffix that indicates a particular modification of the composition such as 304L (L letter for low carbon content grade). Stainless steels also can be divided into four families based on the characteristic of the crystallographic of the alloys: namelymartensitic, temperature transformation reactions, close attention and control needed to be exercised to ferritic, austenitic, and duplex (austenitic plus ferritic)[6,7]. In this work , stainless steel 304L is used as the substrate material to investigate the effects of welding parameters on its welding quality. This alloy can be welded even in severe corrosive conditions. In many cases, it eliminates the necessity of annealing weldments except for applications specifying stress relief.It has slightly lower mechanical properties than type 304, and the carbon is kept to 0.03% as maximum. The type 304L is more expensive, and it is considered as weldable stainless steel.Since it does not require post weld annealing.Therefore, it is extensively used in heavy gauge components.Carbon included in this grade of stainless steel, imparts great physical strength at high temperatures[8].

2. Experimental Procedures

2.1. Material's Specifications

All welding experiments carried out in this work were conducted at the Welding Lab, at The University of Tripoli, Libya. The welding machine used was Gas Tungsten Arc Welding. This machine was used to weld different samples of 304L stainless steel, using ER-308L filler wire. Base metal chemistry is an important consideration for situations where joints are welded, since the type of filler metal will be determined according to the chemical composition of the base metal to be welded. Filler materials are used to introduce more metal to the weld zone to fill the joint or increase the size of the weld. Tables 2.1& 2.2show the chemical composition and other mechanical properties of 304L stainless steel, respectively[9].

Table 2.1 - Chemical composition of 304L stainless steel [5].

Type	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**N**	**Fe**
304L	0.030	2.0	0.75	0.045	0.03	19	10	0.10	rest

Table 2.2 - Mechanical properties of 304L stainless steel [5].

Type	**Tensile Strength (MN/m²)**	**Yield Strength (MN/m²)**	**Hardness**	
			Rockwell (HRB) max	**Brinell (HB) max**
304L	564	210	82	156

Table 2.3 provides some information on the chemical composition of ER-308L filler wire used [10,11].

Table 2.3- The chemical composition of ER-308L filler wire used [5].

AWS Class	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**
ER308L	0.03	2.5	0.30	0.03	0.03	19.5	11.0	0.75

2.2. Sample Preparation

The samples used in this study were cut to a size of 250mm length, 2 mm thickness, and 20 mm width. The welding process was carried out at different welding conditions, according to the table 2.4. From this table, we build up an L9 (3^3) orthogonal array and this will allow us to perform 9 experiments. The L9 table is shown in Table 2.5.

Wide range of welding parameters was used in this study. These welding parameters were selected based on previous works, [12]that have been carried out by the lab technicians in Tripoli University. This means that these welding parameters are commonly used in gas tungsten arc welding (GTAW).

Table 2.4 -Process Parameters for each condition and response factors

Symbol	Process Parameters	Level 1	Level 2	Level 3
A	Welding current (A)	**165**	**175**	**185**
B	Welding speed (mm/min)	**135**	**174**	**235**
C	Flow rate of gas (L/min)	**5**	**10**	**15**

2.3. Layout of the Experiments

The interaction effect between the welding parameters is neglected. In this study, an L9 (3^3) orthogonal array which has 8 degrees of freedom was used. Nine experiments are required to study the entire welding parameter space when the L9 orthogonal array is used[12]. The experimental layout for the welding process parameters using the L9 orthogonal array is shown in table 2.5.

Table 2.5- Experimental layout (L9) showing different welding parameters

Experimental number	Factor A Welding current (A)	Factor B Welding Speed (mm/min)	Factor C Gas flow rate (L/min)
1	165	135	5
2	165	174	10
3	165	235	15
4	175	135	10
5	175	174	15
6	175	235	5
7	185	135	15
8	185	174	5
9	185	235	10

2.4.Tensile Strength Tests

All the experiments were carried out on the tensile test machine shown in figure 2.1. During the test, the sample is pulled from each end with increasing the load.When a certain load is reached (load at which the sample yield), the sample begins to fail and then break. From the stress-strain curves produced, the values of, ultimate tensile strength σ_{UTS} and failure stress $\sigma_F$are extracted. The failure region in which each sample failed was recorded and all of this information is shown in table 3.1.

Figure 2.1 A tensile test machine used in this work

2.5. Hardness Tests

Hardness test machine (Rockwell) was used to test the samples in this work (see figure 2.2).All hardness tests were measured on samples which were broken from the weld region, and other samples were cut from the weld region to allow the hardness tests to be made. The samples were prepared by grinding and polishing and then the hardness was performed on these cross-sections.

Figure 2.2 Hardness test machine (Rockwell) used in this work

2.6. Taguchi Modeling Approach

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. The optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. The results obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits,and thus improving the product quality [13]. In the present work, Taguchi's approach is used to study the effect of process variables on the weld quality of 304L stainless steel. This is achieved by quantifying the variations in the experimentally measured weld bead width, penetration and the HAZ size data. Taguchi method uses S/N ratio, which the Signal to the Noise ratio of the data. The term 'Signal' here is related to the true data within a certain limit, and the term 'Noise' is related to amount of deviation in the data, which are outside the range of the true data. The key parameters that have a major effect to reduce variation (improved quality) can be identified by looking at the amount of variation present as a response. The S/N ratio can be obtained using the following equations [14].

$$\eta = -10\log_{10}(MSD) \qquad (1)$$

where ' η ' is the S/N ratio and MSD is the Measured Standared Deviation and can be obtained from :

$$MSD = \frac{1}{n}\sum\frac{1}{P^2} \qquad (2)$$

Where 'n' is the number of experiments and 'P' is the actual measurement. The largest signal to noise ratio (average) is considered to be the optimum level. This means that a high value of signal to noise ratio indicates that the signal is much higher than the random effects of the noise factors.

Taguchi method has been used in other studies for optimization of SAW welding. For instance, Pillia, K. R., Ghosh [15,16] have presented some investigations on the interactions of the process parameters of submerged arc welding (SAW) using the same technique.

3. Results and Discussions

3.1. TensileTest Results

The fracture behavior of welded joint showed in figure 3.1. Welded samples tested in this work showing (a, b) samples failed in the base metal after a tensile test. However, sample(c) failed in the weld metal. These results may be attributed to the differences in welding speed and the flow rate of gas used.

Figure 3.1 failed welded joint tested in this work

The mechanical properties such as ultimate tensile stress σ_{UTS}, failure stress σ_F and fracture point of the tested samples were determined. The results are recorded and shown in table 3.1.

Table 3.1-Tensile Test Results

Sample number	σ_{UTS} (N/mm²)	σ_F (N/mm²)	Fracture point
1	589	577	HAZ
2	588	575	HAZ
3	544	272	Weld metal
4	608	582	HAZ
5	605	583	HAZ
6	462	229	Weld metal
7	613	597	Base metal
8	612	525	Base metal
9	608	561	Base metal

It can be seen from table 3.1 that although samples 1, 2 and 3 were welded under similar current (165 A), their tensile properties are not the same. This can be directly linked to the differences in both welding speed and the flow rate of the welding gas. It should be noted that the same conditions apply for samples 4, 5, 6, and 7, 8 and 9. So this change in mechanical properties must be explained and linked to a specific welding parameter (e.g. welding speed and gas flow rate). The ultimate tensile stress σ_{UTS} and the failure stress $\sigma_F$are lowest when the fracture occurs in the weld metal of the welded samples (with a value averaging at 503 ±58 N/mm² for $\sigma_{UTS}$and a value of 251 ±30N/mm²for the failure stress σ_F). The ultimate tensile stress σ_{UTS}increased for samples that have fractured at the HAZ (averaging at 597 ±10 N/mm²), while these properties are the highest for samples that were fractured at the base metal (with a value of 611 ±2 N/mm²). This can be related to the fact that hardness is proportional to the tensile strength of the metal, see equation(3) [17]. This leads to the fact that any increase in hardness will certainly results in increase in the tensile strength. Note that the hardness in equation (3) is by Brinell and the hardness measured in this work is by Rockwell, however, all of these values can be converted to Brinell hardness HB, using specific tables that can be found in some books [16, p.134].

$$\sigma_{UTS} = 3.45 \times HB \quad (3)$$

3.2. Hardness Test Results

Hardness tests were conducted across the weld metal, HAZ and the weld metal. The results for each type of microstructure are shown in table 3.2.

Table 3.2 - Hardness Test Results (HRC)

Specimen. No	Base Metal			HAZ			Weld Metal		
1	18	16	17	13	12.5	12	8	7.5	9
2	16	14	17.5	14.5	13	11.5	8	7	7.5
3	16	15	15.5	13	14	14.5	7	8.5	6.5
4	16	16	14	14	12.5	12	7	6.5	8
5	14.5	17	16	13	11.5	12.5	7.5	7.5	9
6	16.5	17.5	15.5	13	13.5	12.5	6.6	8	8.5
7	14	16.5	17	14	12.5	14.5	7	6.5	6.6
8	17	18	17.5	15	13.5	12.5	8	7	8.5
9	15	14	16	12.5	11.5	13	7.5	6.5	7.5

The average hardness (HRC) value for each sample and in each region was calculated and these are shown in figure 3.2. Generally, it can be seen that there is a reduction in hardness in the welding region (weld materials and HAZ) as compared with the base metal. The lowest average hardness for all samples is found to be at the weld metal, with a value averaging at 7.5±0.5 HRC.

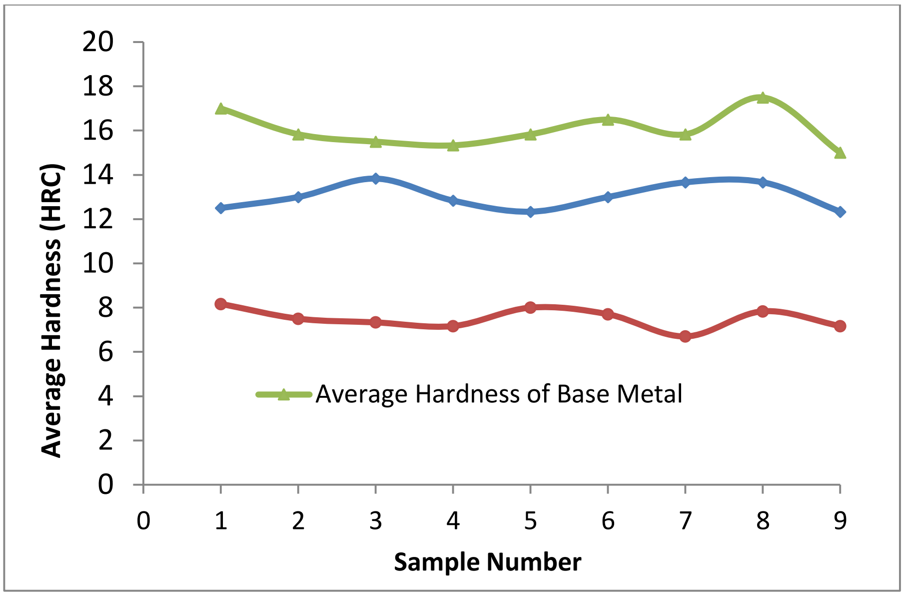

Figure 3.2 Average of hardness (HRC) for the base metal, HAZ and weld metal.

However, there is an increase in the hardness profile in the HAZ (an average value of 13±0.6 HRC was found), which suggests that cooling rate is the dominant parameter controlling weld mechanical properties. The HAZ region experiences higher cooling rate than the weld metal giving it higher hardness. Moreover, a grain refinement (re-crystallization process) may occurin the HAZ, which could lead to material softening in this region and this may be the reason for having lower hardness than the base metal [17]. During welding the material experiences intense melting, sharp thermal gradients and fast cooling rates may happened. This associated with the transformation to austenite at high temperatures and non-equilibrium microstructures on faster cooling in steels, which makes analysis of microstructure very complicated [18].The average hardness found for the base metal in this experiment was 16±0.8HRC.

3.3.Taguchi ApproachResults

In this work, the S/N ratio was calculated using equation (1) and (2), see section 2.6. This was carried out separately for weld bead width, weld penetration and the size of HAZ region of the welds. The effect of current (A), welding speed (mm/min) and gas flow rate (L/min) are also considered in this modeling approach.

3.3.1. S/N Ratio for Bead Width

The data for S/N ratio for the bead width of all welding experiments is shown in table 3.3 below. The highest value of S/N ratio is considered to be the best welding conditions. This is because higher value of S/N ratio means that the amount of the true data is much larger than the variations. However, an average S/N ratio (for weld bead width) must be calculated separately for samples that were welded under similar welding current (A), welding speed (mm/min), and gas flow rate (L/min). This is shown in figure 3.3, which illustrates the effect of different welding currents, speeds, and gas flow rates on the weld qualitydepending upon measured weld bead width.It can be seen from figure 8 that the value of S/N ratio increases with increasing the welding current. This means that the highest welding current (185 A) used provides the highest S/N ratio (better weld bead quality). The effect of welding speed and gas flow rate both have different trends, as compared with the effect of welding current, in relation to the S/N ratio.

Table (3.3) Mean and S/N ratio of the weld bead width tests from different conditions

Experimental number	Measured Weld Bead width (mm)					Average Weld Beadwidth (mm)	S/N Ratio
1	6.3	5.5	5.2	5.4	5.6	5.6	21.953
2	3.2	4	3.9	3.1	-	3.6	17.994
3	3.3	3	3.3	3.5	-	3.3	17.280
4	5.5	5.6	5.8	5.2	-	5.5	21.844
5	5	4.9	5.7	5.6	-	5.3	21.475
6	4.8	4.5	5	5.1	4.6	4.8	20.614
7	7.3	7.5	7	6	7.3	7.0	23.916
8	6.4	6.3	5.9	6.5	6.4	6.3	22.976
9	5.1	5	4.9	5	4.6	4.9	20.793

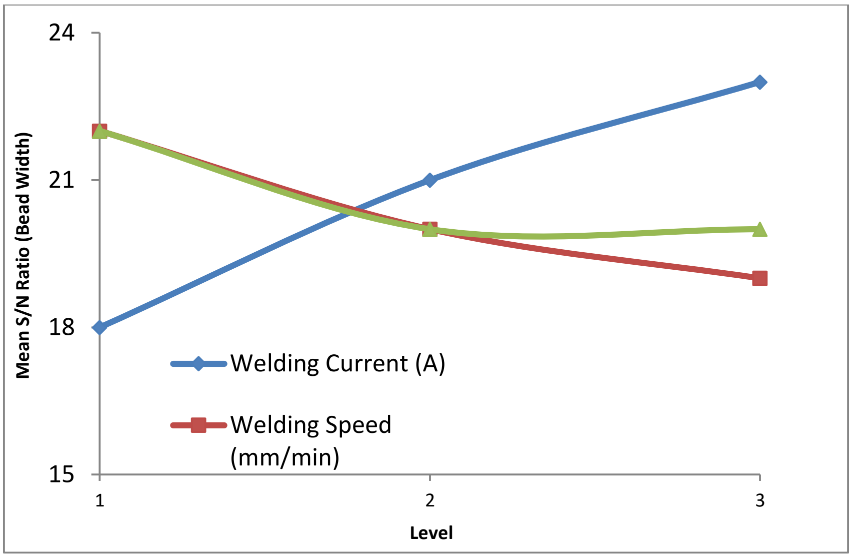

Figure 3.3 S/N ratiovs the weld bead width

It can be seen from the same figure that the lowest welding speed (i.e. 135 mm/min, from level 1 welding parameters) gives the highest value of S/N ratio. This means that lower welding speed gives better quality welding bead width.The effect of gas flow rate on the S/N ratio follows almost the same trend. The highest value of S/N ratio can be obtained from the lowest gas flow rate in level 1 condition (i.e. 5 L/min).

3.3.2. S/N Ratio for Bead Penetrations

Similar procedures were used to calculate the S/N ratio for the measured weld penetration. Again, this was done for all samples, and the resulting values are shown in table 3.4 below.Theaverage S/N value for samples which are welded under similar current (A), welding speed (mm/min) and gas flow rate (L/min) must be calculated separately, see figure 3.4.

Table (3.4) - Mean and S/N ratio of the penetration test

Experimental number	Measured Weld Penetration (mm)					Mean Penetration (mm)	S/N Ratio
1	1	0.5	0.7	1.1	0.7	0.80	5.0515
2	0.9	0.6	0.8	0.66	–	0.74	4.374
3	0.6	0.8	0.5	0.58	–	0.62	2.837
4	1.4	1.3	1.2	1.62	–	1.38	9.787
5	1.1	1.2	1	1.06	–	1.09	7.738
6	1	0.9	0.7	0.9	0.75	0.85	5.578
7	1.9	2.1	2	1.8	1.75	1.91	12.610
8	1.7	1.8	1.7	1.6	1.8	1.72	11.700
9	1.4	1.5	1.7	1.64	–	1.56	10.852

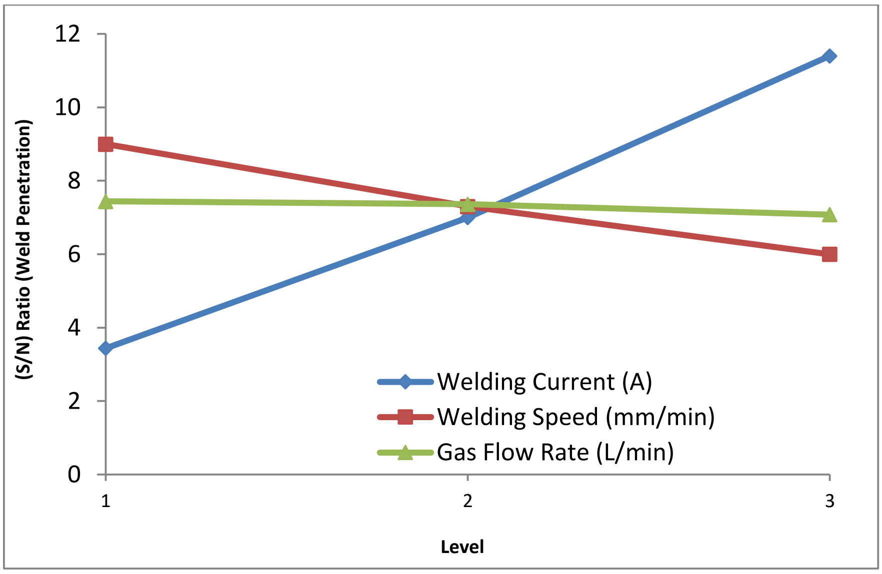

Figure (3.4) S/N ratio vs the weld bead penetration

From the above figure, the largest value of S/N ratio is achieved with the highest current (i.e. 185 A). Differenteffectscan be distinguished for the welding speed on the S/N ratio. The highest value of S/N ratio is accomplished with the lowest welding speed of 135 mm/min. This means that there is less variations in the data obtained (weld penetration measurements) at this speed. The best quality data are those with fewer variations, whereas the low quality data are those with increased variations.The change in gas flow rate does not produce clear effect on the S/N ratio. There is a very small decrease in the S/N ratio with increasing the gas flow rate, but this can fall within the experimental error. During welding, shielding gas protects the weld from air contamination and perhaps its effect may be small or limited.

3.3.3. S/N Ratio for HAZ Size

The average values of the S/N ratio were calculated based on the measurements of the HAZ size, see table (3.5).The data for the averaged S/N ratio of different welding conditions is presented in figure 3.5.

Table (3.5) Mean and S/N ratio of the HAZ test

Experimental Number	Measured HAZ (mm)					Mean HAZ (mm)	S/N Ratio
1	3.6	2.7	3.8	3	2.5	3.12	16.872
2	3	2.7	2.4	3	–	2.775	15.854
3	2.1	2.4	3	2.5	–	2.5	14.948
4	3.2	3.5	3	–	–	3.23	17.173
5	2.9	2.8	3	2.74	-	2.86	16.117
6	2.8	3	2.7	3.1	2.4	2.8	15.932
7	2.8	3.4	3.8	3.5	3.5	3.4	17.619
8	3.2	3.4	3.1	3	–	3.175	17.024
9	3	2.9	2.9	2.8	2.8	2.88	16.177

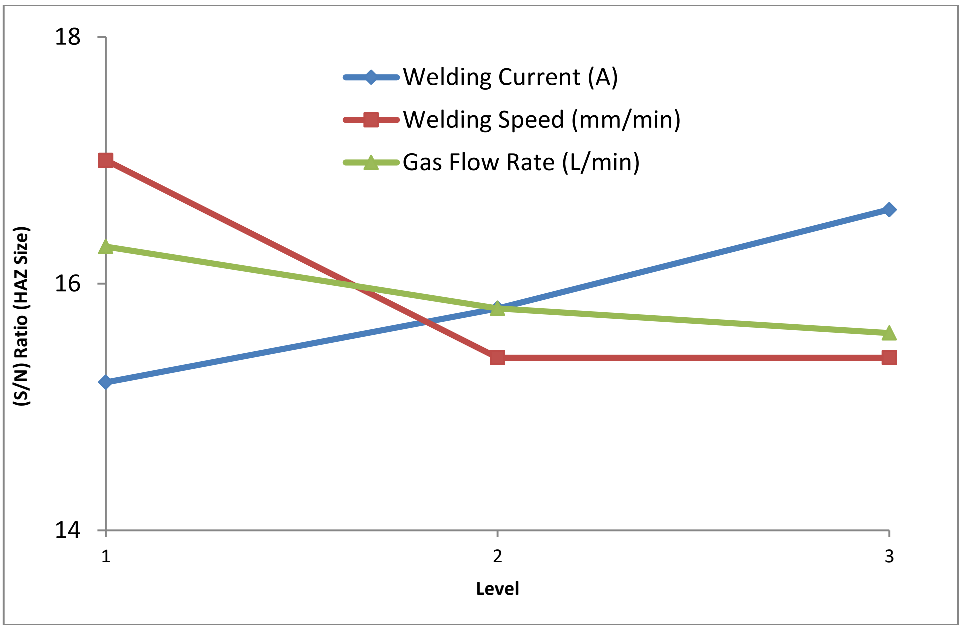

Figure 3.5 S/N ratio vs the HAZ size

For the HAZ size, the S/N ratio increases with increasing the current, meaning that the better quality weldments can be made with the higher current of (185 A).The effect of welding speed can be also seen. The highest S/N ratio is achieved with the lowest welding speed (135 mm/min). The S/N ratio for both welding speeds (174 and 235 mm/min) remained almost the same, meaning that there might not be any effect for any further increase of the welding speed on the quality of the HAZ size of the weldments. Furthermore, it can be seen that there is some effect of gas flow rate on the S/N ratio for investigating the quality of the HAZ size. The highest value of S/N ratio is accomplished with the lowest gas flow rate (5 L/min). The value of S/N decreases with increasing the gas flow rate, although the decrease is not substantial.

3.3.4.Taguchi Method Vs the Ultimate Tensile and Failure Stresses

The effects of welding parameters on ultimate tensile stress σ_{UTS} and the failure stress $\sigma_F$using a Taguchi model was demonstrated similar trends, seefigure3.6 and 3.7, respectively.

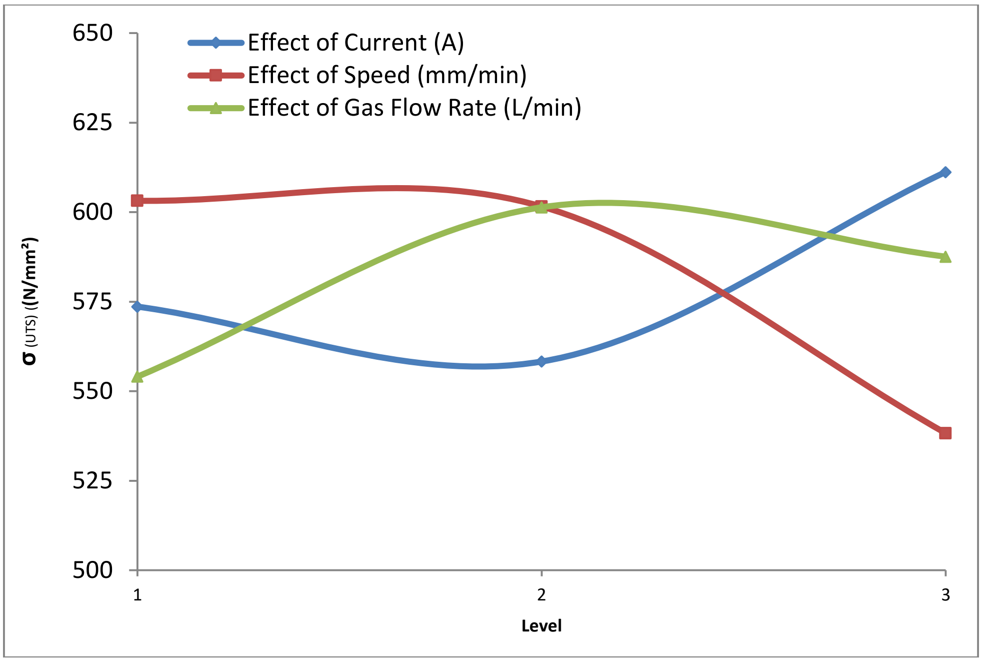

Figure 3.6 The effect of welding parameters on the ultimate tensile stress

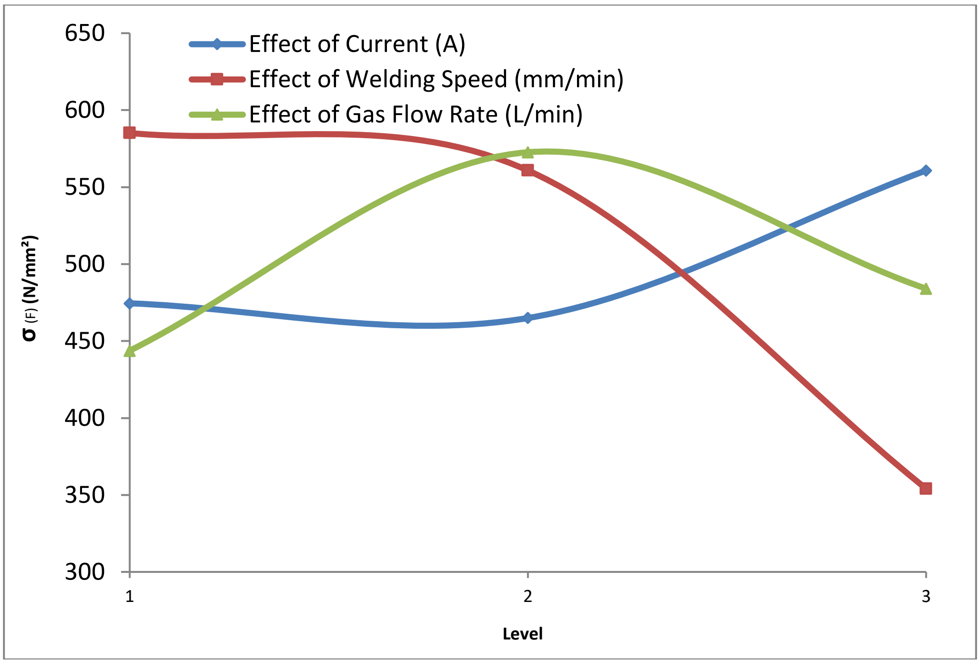

Figure 3.7 The effect welding parameters on the failure stress (σ_F) of the tested samples.

3.4.Effects of Welding Current on Tensile Stress

There is a large increase in the ultimate tensile stress σ_{UTS}(from 573.6±25N/mm² to 611.2±2N/mm²) with the highest current used (185 A), see figure 11. Although there is a very small decrease in σ_{UTS} and σ_F when increasing the current from 165 A to the current 175 A (as shown in table penetration and welding speed which can result in good mechanical properties of the weld. This is in agreement with the results shown by Taguchi method, in which it was proved that the current in 185 A gives the highest S/N ratio, as seen in figures 8, 9 and 10. This means that the quality of the weld bead width, penetration and the HAZ are the best when higher current was used. Based on the above discussion and the fact that in arc welding, the voltage is directly related to the length of the arc, 3.1 and 3.2), this decrease is still within the experimental error. This is because in the arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input.If the current is sufficient enough, it will melt more quickly, increasing weld

and the current is related to the amount of heat input. To increase the hardness in the HAZ and welding metal, the welding temperature should reach critical value, and this will lead to a certain cooling rate that will allow martensite to be formed leading to a significant increase in the hardness [19]. In this study, welding current was proved to be very important and must be high enough to achieve good quality weldments. This finding is based on the experimental results and finds a good agreement with Taguchi modeling approach. So, if the current is low, the overall heat input will decrease thereby decreasing the size of the weld pool and heat-affected zone. This may result in low quality weldment.

3.5. Effects of Welding Speed on Tensile Stress

The tensile strength tends to decrease with increase the welding speed. The reduction in tensile strength is more evident with highest speed,(i.e. 235 mm/min). For welding speed (i.e. 135 and 174 mm/min), the mechanical properties remained the same at the highest value of 603N/mm². So, it can be concluded that a very high welding speed may result in low quality weldments and this can affect the mechanical properties of the welded samples. Taguchi modelling approach showed that the highest S/N ratio was found for the lowest welding speed of 135 mm/min (see figures3.3, 3.4 and 3.5). It is known that higher S/N ratio mean better welding quality in terms of welding bead width, penetration and the HAZ. Thus, this is another correlation between Taguchi method and the experimental results for the effect of welding speed on the tensile strength of the welded samples in this work. Welding speed can be very effective in providing improved welding joints. The results in the present study shows that low welding speed can give quality weldments, whereas, faster welding speed may result in reduced total heat input into the body, leading to poor mechanical properties.

3.6. Effects of Gas Flow Rate on Tensile Stress

There is no clear indication on the effect of the gas flow rate on the tensile strength of the welded samples. This can be extrapolated from the figure (3.6), where the tensile strength increased from 554.1 N/mm² to 601.4 N/mm² with increasing the gas flow rate (5 to 10 L/min). The increase in σ_{UTS} was followed by a decrease to 587.6 N/mm² when increasing the gas flow rate to 15 L/min. The same trend is observed with the failure stress in figure (12). This uncertainty can be explained by the fact that a shielding gas feeds through the welding gun protects the process from contaminants in the air.However, any oxygen in contact with the weld pool, whether from the atmosphere or the shielding gas, causes dross as well. As a result, sufficient flow of inert shielding gases is necessary, and welding in unstable air should be avoided.As stated in Ref. [20], the desirable rate of shielding-gas flow depends primarily on weld geometry, speed, current, the type of gas, and the metal transfer mode. Welding flat surfaces requires higher flow than welding grooved materials, since gas disperses more quickly. Faster welding speeds, in general, mean that more gas must be supplied to provide adequate coverage. Additionally, higher current requires greater flow, and generally, more helium is required to provide adequate coverage than if argon is used [20].

From the above discussion, higher gas flow rate should be used with higher welding speed and higher current, especially for flat surfaces such as the samples in this work. However, this effect was not observed in this study. It might be that the effect of this parameter is limited and not as effective as the welding current and speed.The effect of gas flow rate could have less effect on the quality of the weld joints, since it is mainly concerned with protecting the weld pool from air contamination. Furthermore, weld quality is concerned with dross and porosity. If not controlled, they can lead to weaker, less ductile welds.

4. Conclusions

In this work, the effects of using different welding parameters on the weld quality and the tensile mechanical properties of the welded 304L stainless steel samples were investigated.

The main findings in this work are:

1. It has been noted that within the range of welding parameters used, the highest current of (185 A) gives the optimum condition for good quality welding joints. This finding is based on the present experimental results and finds a good agreement with Taguchi modeling approach.
2. Welding speed can be very effective in providing improved welding joints. The results shows that low welding speed (135 mm/min) can give quality weldments, whereas faster welding speed may result in reduced total heat input into the body leading to poor mechanical properties.
3. The effect of gas flow rate could have less effect on the quality of the weld joints, since it is mainly concerned with protecting the weld pool from air contamination. The best gas flow rate used was 10 L/min, which have made a good quality and good mechanical property weldments.
4. Taguchi analytical models examined to explain the effect of the measured welding bead width, penetration and the size of the HAZ region on the weld quality.This model finds some agreements with the experimental results for the effect of welding current and welding speed, but does not provide correct correlation for the effect of gas flow rate.
5. To sum up, the best combination of welding parameters within the range of the values provided in the present work; to obtain good quality welding joints of 304L stainless steel, a welding current of 185 A, welding speed of 135 mm/min and gas flow rate of 10 L/min should be used. These combinations of welding conditions provided the best tensile and hardness mechanical properties for the welded samples.

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5. References

[1]- R.dixon and A.L.Liby, "Welding Theory and Practice" Vol.8D.L.Olson 1990 /22-4-2013.

[2]- Schey, John A. (2000) [1977], "Introduction to Manufacturing Processes", McGraw-Hill series in mechanical engineering and materials

science (3rd ed.), McGraw-Hill Higher Education.

[3]- Raymond J. Sacks, "Essentials of Welding" 1984/22-4-2013.

[4]- Hichen G K, Gas-tungsten arc welding, ASM Handbook, Vol 6, "Welding, Brazing and Soldering", pp 190-194.

[5]- Aoki A,.Takeichi M,.Seto M,.Yamaguchi S, (2004), "Development of GTAW robot system for aluminum frame", IIW Doc XII-1814-04.

[6]- A. lsmail, 2014 "Corrosion Behavior Of Austenitic Stainless Steel In High Sulphate Content" Advanced Materials Research Vol. 893 (2014) pp 397-401

[7]- Metals Handbook, Desk edition, second edition, ASM 1998.

[8]- William F.Smith, 1993,'Structure and Properties of Engineering Alloys', second Edition.

[9]- http://www.matweb.com/search/DataSheet.aspx?MatGUID=e2147b8f727343b0b0d51efe02a6127e. Mat. Web. Materials Property Data. Data sheets for over 115,000 metals, plastics, ceramics, and composites. Access date 22-4-2013

[10]- Gower A Kennedy 1982,' Welding Technology', second edition.

[11]- William H. Minick 1996, 'Gas tungsten Arc Welding handbook'.

[12]- Sharma Umangkumar, Chavda Mehul, Patel Jigar, Prof. K. D. Bhatt. 'Optimization of Welding Parameters Using Taguchi Method for Submerged Arc Welding of Conveyor Pulley'. 5th National Conference on "Recent Advances in Manufacturing (RAM-2015)", 15-17 May, 2015.

[13]- Y. S. Tarng & W. H. Yang (1998) 'Application of the Taguchi Method to the Optimization of the Submerged Arc Welding Proces's, Materials and Manufacturing Processes, 13:3, 455-467.

[14]- S. Fraley, M. Oom, B. Terrien, and J. Z. Date, "Design of Experiments via Taguchi Methods: Orthogonal Arrays, the Michigan Chemical Process Dynamic and Controls Open Text Book, USA, 2006

[15]- Pillia, K. R., Ghosh, A., Chattopadhyaya, S., Sarkar, P. K., Mukherjee, K.," Some investigations on the Interactions of the Process Parameters of Submerged Arc Welding", Manufacturing Technology & Research (an International Journal), 3, 1(2007), pp. 57-67.

[16]- Ghosh, A., Chattopadhyaya, S., Sarkar, P. K.,"Output Response Prediction of SAW Process", Manufacturing Technology & Research (an International Journal), 4, 3(2008), pp. 97-104.

[17]- A. Vairis and M. Petousis. 'Designing experiments to study welding processes: using the Taguchi method'. Journal of Engineering Science and Technology Review 2 (1) (2009) 99-103.

[18]- William D. Callister, Jr, 'Materials Science and Engineering, an introduction', 1997, fourth edition, John Wiley & sons, Inc., USA

[19]- H. Haji, B.P. Wynne, E.J. Palmiere, 'a Microstructure Analysis of Friction Stir Welded HSLA-65'. International symposiums of friction stir welding, proceedings, Germany 2010.

[20]- Yogesh Vashisth,' Metal Inert Gas Welding', International Journal of Innovative Research in Technology, 2 (7) 2015. ISSN: 2349-6002.