Investigation and Analyzingof TIG Welding Parameters of 2205 Duplex Stainless Steel Using Design of Experiment Technique

*Mr. Ibrahem. A. Zoubi **Prof. Dr. Ezzeddin M. Anawa *Prof. Dr. Farag. M. Shuaeib

***Dr. A. R. H. Midawi **Mr. Thabet M. Elrabei

Abstract: The present research work deals with parametric study and optimization of tungsten inert gas welding process (TIG) on Duplex Stainless Steel (DSS2205).The present investigation is to find out the best influence of welding current, welding speed, and gas flow rate on mechanical properties more specifically the tensile strength.MINTAB software was used for designing, analyzing and optimization of the welding process.Taguchi L9 orthogonal array method was employed to optimize the welding process parameters for improvement of mechanical properties of weld bead such as tensile strength without any alteration of its corrosion resistance. Three welding parameters was selected as a study variablesand their three levels were selected and design of experiments was implemented as per Taguchi L9 array approach. Analysis of Variance (ANOVA) applied in investigation. Results have been analyzed using tensile strength as a response variable of the prepared welding jointsusing Taguchi L9 array approach The tensile strength test results showed that as welding current is increased the tensile strength was decreased, while increasing gas flow rate caused an increase in tensile strength up to rate of 13 L/min then decreased. Finally a regression model is developed which relate the TIG welding factors with the response variable which is the tensile strength which can be used in the future to predict the welding setting which would produce a joint with a specific strength.

Keywords:TIG Welding, Duplex Stainless steel, Tensile Strength and ANOVA.

1. INTRODUCTION

Duplex stainless steels consists of the two phases. Ferrite and Austenite and they are often termed Ferritic-Austenitic stainless steels. Typically, duplex stainless steels have a microstructure consisting of approximately 50% ferrite and 50% austenite.It is generally accepted that the favorable properties of the duplex stainless steels can be achieved with phase balances in the range of 30 % to 70% ferrite and austenite [1]. However, duplex stainless steels are most commonly considered to have roughly equal amounts of ferrite and austenite, with current commercial production just slightly favoring the austenite for best toughness and processing characteristics. The interactions between the major alloying elements, particularly the chromium, molybdenum, nitrogen, and nickel are quite complex. To achieve a stable duplex structure that responds well to processing and fabrication, care must be taken to obtain the correct level of each of these elements [2].

* Department of Mechanical Engineering, Bright Star University , Elbriga , Libya
Email: i.zobi@yahoo.com

** Industrial and Manufacturing Department, Faculty of Engineering, University of Benghazi, Benghazi, Libya, Email: ezzeddin.anawa@uob.edu.ly

* Mechanical Department, Faculty of Engineering, University of Benghazi, Benghazi, Libya, Email: farag.shuaeib@uob.edu.ly

*** University of Waterloo, Mechanical and Mechatronic Engineering Department, Waterloo, ON, Canada, Email: mr.bastoo@gmail.com

** Industrial and Manufacturing Department, Faculty of Engineering, University of Benghazi, Benghazi, Libya, Email:thabet.elrabei@uob.edu.ly

Besides the phase balance, there is a second major concern with duplex stainless steels and their chemical composition: the formation of detrimental intermetallic phases at elevated temperatures. Sigma and chi phases form of high chromium, high molybdenum stainless steels and precipitate preferentially in the ferrite. The addition of nitrogen significantly delays formation of these phases.

C.J. Mines et al. [3]A study on the pitting corrosion resistance of welded duplex stainless steel 2205.Joints were made using the GMAW process with different fillers: duplex ER 2209 and two austenitic fillers (ER 316LSi and ER 308LSi). J M Gomez De Salazar et al. [4] Investigated of two different duplex stainless steels. An arc was discharged on base metal plates using the TIG technique without filler material and with varying energy conditions. Mourad et al. [5]conducted a comparative study on the influence of gas tungsten arc welding (GTAW) and carbon dioxide laser beam welding (LBW) processes on the size and microstructure of fusion zone (FZ)and, on the mechanical and corrosion properties of duplex stainless steel DSS grade 2205 plates of 6.4 mm thickness. R Aristotile et al. [6]studied the effect of welding processes such as shielded metal arc welding, gas metal arc welding and gas tungsten arc welding on tensile and impact properties of the duplex stainless steel.Igual Muñoz et al. [7]investigatedthe effect of nitrogen content in the argon shielding gas of tungsten inert gas (TIG) welding on the corrosion resistance of a duplex stainless steel (DSS; AISI 2205). Vahid et al. [8]studied the effect of Nitrogen loss is an important phenomenon in the welding of super duplex stainless steels was autogenously TIG-welded with one to four bead-on-plate passes with low or high heat inputs using pure argon shielding gas. From all previous studies,it is found that DSS welding is still on active area of research. Also welding optimization, particularly using more advanced techniques such as design of experiment (DOE), is one of the important issues required (Controlling and Modeling Tig Welding of Duplex Stainless Steel Using Taguchi Method).

2.0 MATERIALS AND METHODS

2.1. Materials

In this work, the material used was duplex stainless steel 2205 (UNS S32205). Plates of 6 mm thick, 200 mm in width and 300 mm in length. The chemical composition and the mechanical property of typical as-received materials are shown in Table 1 and Table 2 below [9]. The material was welded using double pass butt weld joints using Tungsten Inert Gas Welding (TIG) process. Tungsten electrode class 2209-16 (AWS A5.4) and 2.4 mm diameter was used as filler metal wire.

Table:1 Typical Chemical Composition of Duplex Stainless Steels [9]

Component	C	Mn	Si	Cr	Ni	P	S	Mo	Cu	N	Bal.
Wt%	**0.029**	**1.20**	**0.28**	**22.04**	**5.03**	**0.017**	**0.014**	**2.21**	**0.22**	**0.12**	**Fe**

Table 2: Typical mechanical properties of the base material [9]

Material	0.2% Yield strength-MPa	Ultimate tensile strength -MPa	Total Elongation-%
AISI-2205	496	1076	31.0

2.2.Welding Process

The selected material was cut using an electrical shearing device to (9) samples in this study. Then the welding process was applied to join samples at different welding parameters (factors), which include: welding current, welding speed, and gas flow rate, The samples were welded in butt joint configuration with a size of (10 × 20 × 6 mm), which are shown in Fig.1 (a- before welding, b- after welding) using 100% argon in the welding machine with more than one pass which is shown in Fig. 2. The work is prepared as detailed by the experimental design (Taguchi technique) and butt joint welding configuration. The specimens were fixed during the welding process, and the semi-automatic TIG welding process was carried out. Welding operation was carried out in the welding lab. at the Benghazi university. Different currents ranged from 140 to 200 A. The processing parameters are shown in Table 4.

(a) (b)

Fig. 1. a- Welding fixture and equipment setup, b- Butt joint of DSS-2205

Fig. 2. Photographic view of the welded tensile test specimen

2.3. Design of Experiments

To find a correlation between the welding parameters, optimum parameters and reduce the number of the experiments, Taguchi's technique was adopted to plan the experiments in this work. L9 orthogonal array has been selected by considering three factors and three levels for each factor. The input parameters considered in the study are welding current, welding speed, and gas flow rate. Nine butt welded samples have been made using different welding currents, welding travel speeds, and gas flow rates. In this work, the measured response is the ultimate tensile strength. Based on the trial runs and literature review, the levels are shown in Table 3.

Table3:Process parameters and their levels

Process Parameters	Symbols	Unit	Values	Level 1	Level 2	Level 3
Welding Current	A	Ampere (Amp.)	Numerical	140	170	200
Welding Speed	B	mm/min	Numerical	137	174	213
Gas Flow Rate	C	liter/min	Numerical	7	10	13

3.0. RESULTS AND DISCUSSION

3.1. Tensile Test

Each welded sample was cut into five tensile coupons. The specimens for the tensile testing were prepared as per ASTM standard [10]. Tensile tests were performed using 100kN MTS hydrulic frame; the crosshead speed was 1 mm/min. Tensile strength samples and machine are shown in Fig.3.

Fig. 3: Photographic view of universal testing machine

The average ultimate tensile strength results with standard deviations are reported in Table 4. The results showed very relative tensile strength to the as-received base material. Experiment number 3 exhibited the highest tensile strength; the tensile strength of the joint matched the base material strength (1077 MPa).

Table 4. Welding parameters and the average tensile strength results.

Experiment Number	Welding Current (Amp.)	Welding Speed (mm/min)	Argon Flow Rate (liter/min)	Ultimate tensile Strength (MPa)
1	170	213	7	1055±3.0
2	200	137	13	1045±7.0
3	170	137	10	1077±2.5
4	200	213	10	1011±2.6
5	140	137	7	1056±2.0
6	170	174	13	1056±4.0
7	140	174	10	1066±2.0
8	140	213	13	1033±5.0
9	200	174	7	1067±6.0

3.2.The Effect of The Welding Parameters Variables on The Response:

This section makes main effect plots for (UTS) using the desgin of experiment software. To separate the effect of each input parameter on the response and analyze the result, the main effect plots for (UTS) have been generated. From these plots, one can predict the nature of the relationship between (UTS) and input parameters. Fig.4 shows the trend of (UTS) with welding current and welding speed. Fig.4 indicates that changes in the levels of the input parameters influence UTS, but not always in a consistent manner. Other factors, which have not been considred in this study, like environmental conditions and some base metal impurities may influence the process. Sgnal-to-Noise (S/N) ratio selection is based on Mean Squared Deviation (MSD) for analysis of repeated results. MSD expression combines variation around the given target and is consistent with Taguchi's quality objective. The relationships among observed results, MSD and S/N ratios are as follows (1 to 3):

$$MSD = \frac{\left((Y_1-\bar{Y})^2 + (Y_2-\bar{Y})^2 + \ldots.(Y_n-\bar{Y})^2\right)}{n}$$ for nominal is better ….. (1)

$$MSD = \frac{(Y_1^2 + Y_2^2 + \dots + Y_n^2)}{n} \quad \text{for smaller is better ….. (2)}$$

$$MSD = \frac{\left(\frac{1}{Y_1^2} + \frac{1}{Y_2^2} + \dots + \frac{1}{Y_n^2}\right)}{n} \quad \text{for bigger is better ….. (3)}$$

The signal-to-noise (S/N) ratio analysis for UTS was analyzed to maximize the response, following the criterion of the bigger is better [11-12]. The Taguchi experiment results obtained utilizing MINITAB 17 statistical software are summarized in Table 6 and presented in Fig.4. The obtained results show that the ultimate tensile strength is mainly affected by the welding speed, while the welding current and gas flow rate had a less effect on the response, as compared with the welding speed in the range of factors considred as shown in Table 5. The rank (1) in Table 5 indicates that the welding speed parameter has a stronger effect on the process, followed by rank (2) welding currentwhich has a less effect, while rank (3) gas flow rate parameter has the minimum effect on the process.

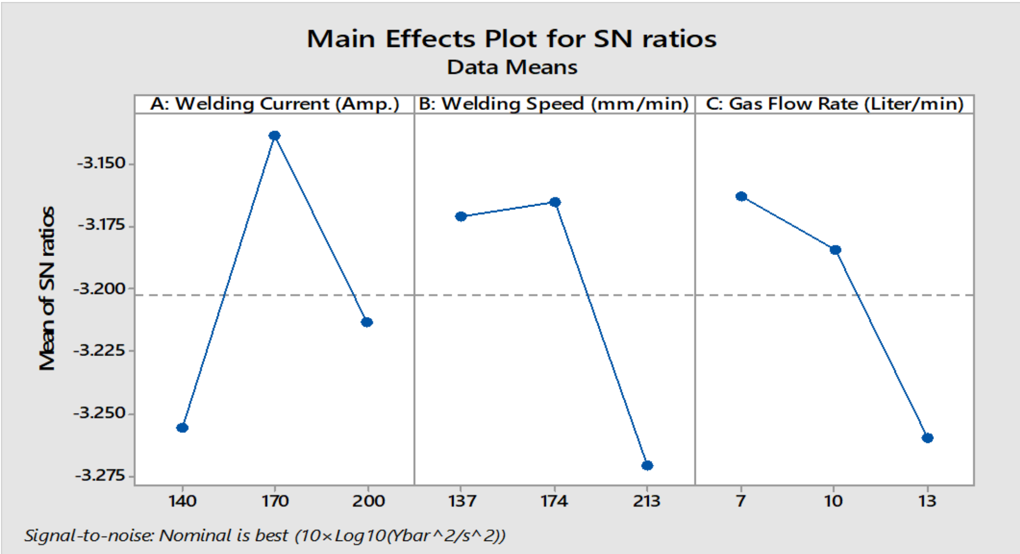

Fig.4. Effects of the parameters on the S/N ratio

Table 5: Experimental observations and S/N ratios for ultimate tensile strength

Level	A: Welding Current (Amp.)	B: Welding Speed (mm/min)	C: Gas Flow Rate (Liter/min)
1	55	55	55
2	55	55	55
3	55	54	54
Delta	0.15	0.21	0.08
Rank	2	1	3

3.3. Analysis of Variance (ANOVA) for UTS

Analysis of the effects on the welding parameters in more detail was carried out using analysis of variance (ANOVA) with the implementation of the regression method using MINITAB 17 software. The results for the reduced linear model suggested by the software for the calculated tensile values are shown in Table 6. If the "P" value is less than 0.05, the corresponding factor is said to influence the response at a 95% confidence level significantly. Other model adequacy measures R^2, and Adjusted R^2 are presented in the same Table. The determining factor (R^2) indicates the model's goodness of fit. The value of R^2 of this model is 99.9%, greater than 99.89%. The results showed least 99.9% of the variability in the data for the response is explained by the model, which emphasizes that the proposed model is adequate.

Table 6: Analysis of variance for ultimate tensile strength

Source	Sum of Square	df	Mean Square	F Value	Prob. > F
Model	3164.4	7	452.06	857.76	0.0263
A-Current	262.75	1	262.75	498.55	0.0285
B- Speed	145.49	1	145.49	276.06	0.0383
C- Gas Flow Rate	497.74	1	497.74	944.44	0.0207
AC	499.46	1	499.46	947.69	0.0207
BC	318.14	1	318.14	603.65	0.0259
A^2	114.81	1	114.81	217.85	0.0431
B^2	71.35	1	71.35	135.38	0.0546
Residual Error	0.53	1	0.53		
Cor.Total	3165.7	8			
R-Sq = 0.9998			R-Sq (adj) = 0. 9987		

3.4.Mathematical Model for UTS

Themathematical equation for ultimate tensile strength (UTS) has been developed by linear-interaction regression analysis using MINITAB software[12]. The mathematical equation for UTS has been expressed in terms of the process variables welding current (A), welding speed (B), and gas flow rate (C) in the form.

$$UTS = v_0 + v_1(A) + v_2\ (B) + v_3\ (C) + V_{11}\ (A*C) + v_{22}\ (B*C) + v_{33}\ (A^2) + v_{21}\ (B^2)$$
….. (4)

Where, v_0 is the constant coefficient, v_1, v_2, v_3 are the coefficients of welding current, welding speed, and gas flow rate, respectively, v_{11}, v_{22} , v_{33} ,v_{21} and the coefficients of A^2, B^2, respectively. The final mathematical model to estimate UTS in terms of an Actual factor is given as:

$$UTS = +256.145+4.961\ (A)+2.390(B)+54.867(C)-0.205(A*C)-0.128(B*C)-9.809*10^{-3}(A^2)-4.823*10^{-3}(B^2)$$
….. (5)

Where: UTS value is in MPa, welding current in A (ampere), welding speed in mm/minute, and gas flow rate in a litre/ minute.

3.5. Validation of Taguchi Model for UTS

The actual and predicted values of the ultimate tensile strength (UTS) are shown in Table 8 with a mean absolute error (MAE) and mean absolute percentage error (MAPE) for the developmental model of UTS. MAE and MAPE are calculated using equations 6 and 7 as in below. Fig. 6 shows the actual measurement of UTS versus predicted UTS values. From Fig. 6, it can be seen that the measured values tend to be close to the diagonal linear, indicating that the model can adequately describe the response within the limits of the factors being investigated herein. Furthermore, four extra experiment conformations were carried out using test conditions, which are selected within the considered range of the parameters.

Mean Absolute Error (MAE) = $((\Sigma|A-P|)/n) = ((\Sigma|E|)/n)$ ……. (6)

Mean Absolute Percentage Error (MAPE) = $(\Sigma\ (|\frac{A-P}{A}|\times 100)/n)$ ……. (7)

Where, A= Actual measured value, P= Predicted value and n= No. of experiments.

Table 7: Actual, Predicted, MAE, and MAPE for UTS using the Taguchi model

Run	Actual UTS (MPa)	Predicted UTS (MPa)	|E|	|E/A| (%)
1	1055	1032	23	2.18
2	1045	1033	12	1.15
3	1077	1070	7	0.65
4	1011	986	25	2.47
5	1056	1035	21	1.99
6	1056	1047	9	0.72
7	1066	1051	15	1.41
8	1066	1058	8	0.75
9	1067	1061	6	0.56
			$\sum$ = 126	**$\sum$ = 11.88**
			MAE = 14	**MAPE = 1.32**

3.5. 3D Surface and Contour Plots

The contour plots are two-dimensional (2D) plots and may be helpful in the same way as the response surface plots. Each line/contour in the contour plots represents a constant response line. The plots are essential when the stationary point is a saddle point or is remote from the design region. Contour and 3D surface plots for ultimate tensile strength are shown in Fig.5 and Fig.6. If these lines/contours are straight, the combined effect is negligible. The more the line bends or curves. The more is the combination effect. For example, Fig.7 indicates that a combination of welding current (A) and argon flow rate (B) has prominent effects on UTS.

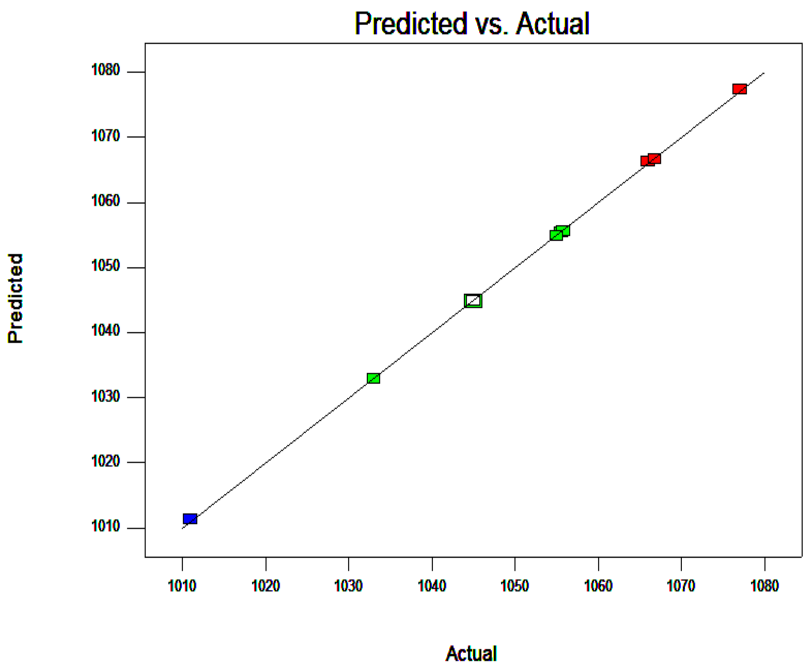

Fig.5. Predicted values of UTS (MPa) test vs. actual measured values using Taguchi

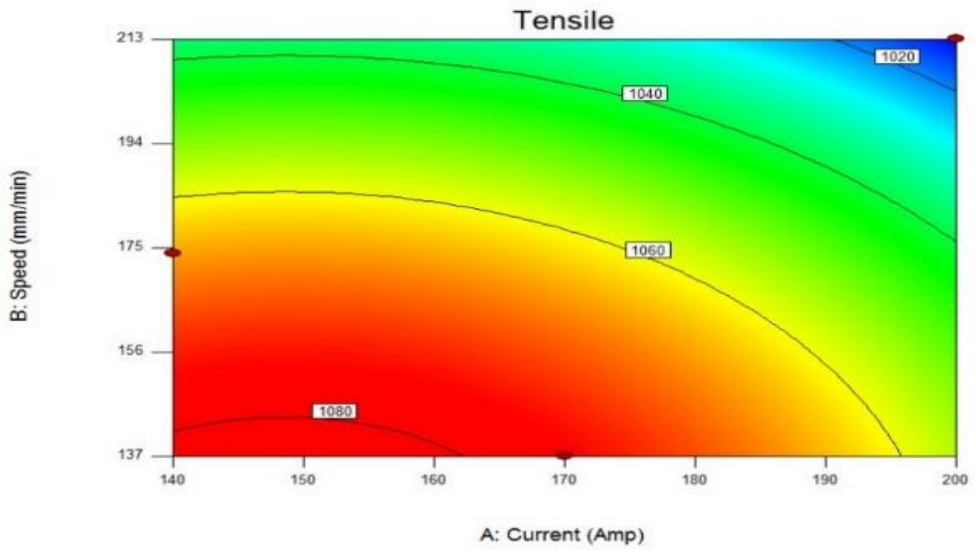

Fig.6. Contour plot showing the combined effects of A and C on UTS (MPa) when B is kept constant (10 Liter/min)

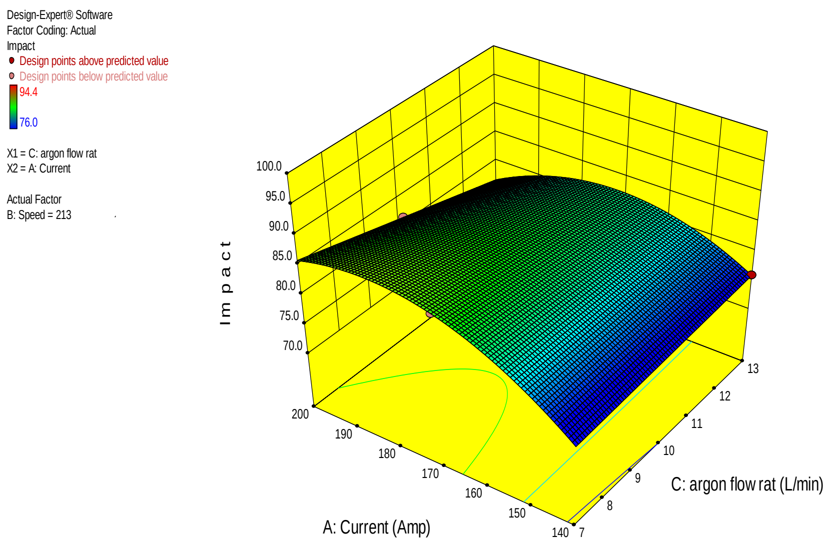

Fig.7. A 3D surface plot showing the combined effects of A and C on IE when B is kept constant (213mm/min)

4.0. CONCLUSIONS

Referring to the discussion and the results obtained, the following are concluded:

1) The welding parameters studied in this research article had a high effect on the quality of welding and the mechanical properties of the joints.

2) The main effect of welding parameters is welding speed.

3) The welding current parameter also significantly affected the weld quality. It is inversely proportional to tensile strength.

4) Increasing the electrical current resulted in a decrease in tensile strength and ductility. However, the increasing gas flow rate increased tensile strength with an improvement of toughness and ductility properties.

المستخلص: تعامل البحث الحالي مع دراسة العوامل وتحسين عملية اللحام بغاز التنغستن الخامل(TIG)على الفولاذ المقاوم للصدأ المزدوج (Duplex Stainless Steel DSS2205). يتمثل البحث الحالي في تحديد أفضل تأثير لتيار اللحام وسرعة اللحام ومعدل تدفق الغاز على الخواص الميكانيكية بشكل أكثر تحديدًا على قوة الشد. تم استخدام طريقة المصفوفة المتعامدة Taguchi L9 لتحسين معاملات عملية اللحام لتحسين الخواص الميكانيكية لوصلة اللحام مثل مقاومة الشد دون أي تغيير في مقاومتها للتآكل. تم استخدام برنامج MINTAB لتصميم وتحليل وتحسين عملية اللحام. تم اختيار ثلاثة متغيرات لحام كمتغيرات دراسة وتم اختيار مستوياتها الثلاثة وتنفيذ تصميم التجارب وفقًا لمنهج المصفوفة Taguchi L9. تم إجراء التجارب و استخلاص النتائج. تم تحليل التباين (ANOVA) حيث تم تحليل النتائج باستخدام مقاومة الشد كمتغير استجابة لوصلات اللحام المحضرة باستخدام طريقة مصفوفة Taguchi L9. أظهرت نتائج اختبار مقاومة الشد أنه كلما زاد تيار اللحام تقل مقاومة الشد ، بينما أدت زيادة معدل تدفق الغاز إلى زيادة مقاومة الشد حتى معدل 13 لتر / دقيقة ثم انخفضت. و في نهاية البحث تم استنتاج معادلة تربط متغيرات عملية اللحام بمقاومة الشد والتي من خلالها نستطيع الحصول على أفضل متغيرات التي تعطينا أعلى مقاومة ش

References

1. Lippold, John C., Kotecki, Damian J., Welding Metallurgy and Weldability of Stainless, Steels, John Wiley & Sons, Inc. (2005).
2. I. Varol, John C. Lippold, W.A. Baeslack, Welding of Duplex Stainless Steels ,Key Engineering Material Vols. 69-70 (1992) pp 217-252, Trans Tech Publications, Switzerland (2013).
3. C.J. Munez, M.V. Utrilla, andA. Otero E., Influence of the filler material on pitting corrosion in welded duplex stainless steel 2205, Welding International Otero (2006).
4. J M Gomez De Salazar, A Urema, M Cobollo, V Barrancoand M J Alvarez, TIG welding of 22-05 duplex stainless steels (Uranus 45N and Avesta) Microstructural studies and mechanical properties, Welding International (2010).
5. Mourad, A-H. I., Khourshid A., and Sharef T., Gas tungsten arc and laser beam welding process effects on duplex stainless steel 2205 properties Gas tungsten arc and laser beam welding process effects on duplex stainless steel 2205 properties, Materials Science and Engineering (2012).
6. R Aristotle, M Barteri MFersini Weldability of duplex stainless steel using tungsten inert gas (TIG) and submerged-arc welding, Welding International (2014).
7. A. Igual Muñoz, J. García Antón, J.L. Guiñón, and V. Pérez Herranz, Department de Engineer Qumica Nuclear, ETS Industrials, Universidad Polytechnic de Valencia (2005).
8. Vahid A. Hosseini, StenWessman, KjellHurtig and Leif Karlsson, Nitrogen loss and effects on microstructure in the Multipass TIG welding of a super duplex stainless steel, Accepted Manuscript,(2016).
9. Riad Badji, BellelCheniti, Charlie Kahloun, Thierry Chauveau, Mohammed Hadji BrigtteBacroix, (2021), Microstructure, mechanical behavior and crystallographic texture in a hot forged dual phase stainless steel, The International Journal of Advanced Manufacturing Technology, 116, 1115–1132 (2021). https://doi.org/10.1007/s00170-021-07502-8.
10. Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate، Sheet, and Strip for Pressure Vessels and for General Applications, (2012), ASTM A240/A240M-11a.
11. "Regression : A Second Course in Statistics . by Thomas H .Wonnacott ; Ronald J . Wonnacott Review by : Michael C . Costanza Published by : American Statistical Association Stable URL : http://www.jstor.org/stable/2287756 .," vol. 77, no. 379, pp. 694–695, 2014.
12. Minitab Statistical Software, https://www.minitab.com/en-us/products/minitab