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Experimental investigation of GTA Welded SS316L plates using shape memory alloy as a filler material

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Abstract

Parameter optimization is the active subject of research, and in this current work the ferrite number and gas tungsten arc (GTA) welding SS. Filler material. Models have been developed by welding SD316L slab with NiTinol wire (shape memory alloy) as a filler material by conducting experiments using three-factor, three level factorial designs. Tests have been conducted for various models at UTM and the results are scheduled. The final models were upgraded using the design expert method. It can be seen from the investigation that the interactive effect of the process parameters has a significant effect on the tensile strength and the ferrite number.

Keywords: NiTinol; SS316L; GTA welding; Design Expert Optimization.

1. Introduction

Case tungsten arc welding (GTAW), often referred to as TIG welding, has become a popular choice of welding processes when high quality, precision welding is required. An arc is formed between the tungsten electrode, which is not consumed in TIG welding, and the metal is welded. Gas is supplied via a torch to protect the electrode and the molten weld pool. If filler wire is used, it is added separately to the weld pool. The SS31L material is low carbon and has a good weld strength factor. The ductility may decrease due to the increase in the carbon content of the steel, which improves the tensile strength and toughness of the steel. [1]. Buehler et al. [2] Alloy nitinol, first discovered, is named after the filler material used to make steel 316L alloy welding, based on NI for nickel, DI for titanium and NOL from the *Naval Ordnance Laboratory*. Nitinol presents many good properties such as superficiality, corrosion resistance and bio-compatibility. Also the shape, stiffness and other properties of nitrite can be controlled by chemical composition, heat treatment and temperature [3] and Shabalovskaya et al., [4] Explored bio-compatibility and found its application in the form of stents and guide wires in medical devices. In recent years, nitinol has seen significant growth in eyeglass frames, cellular phone antenna, high pressure seal plug for diesel fuel injectors, and high temperature protection device for lithium ion battery. Although the possibility of its application in the welding medical equipment of the NiTi SMA has been extensively explored, research on the coupling of the NiTi SMAwith steel is currently limited. Li et al [5-6] conducted laser brazing of NiTi SMA and stainless steel with Ag-based filler metal, Capacitor discharge welding, micro-plasma arc welding done by Qiu [7] and laser welding done by Li [8] of NiTi SMA to stainless steel wires were investigated. However, further investigation on the dissimilar metal joining of NiTi SMA to stainless steel is necessary to explore the wider application of joint design. The two allotrophic changes of nitinol are martensitic and austenitic. The phases depend on the chemical composition, temperature and pressure. Chemical composition of steel 316L and

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nitinol are given in Table 1. Thus the stainless steel with low carbon content is selected in order to have better parameters in welding.

Table 1 Chemical composition of SS316L and NiTinol

	C	**Co**	**`Cr**	**Cu**	**Mn**	**Ni**	**Fe**	**Ti**
SS 316 L[wt%]	0.008	0.06	18.5	0.1	1.28	10	Res	-
Nitinol[wt %/at%]	-	-	-	-	-	56/51	-	44/49

In this paper, an attempt has been made to explore the precision welding process of TIGs with their tensile properties and ferrite number as a filler material for welding steel 316L slab with nitinol wire.

2. Experimentation

In the present study, different models are produced by different combinations of welding process parameters, i.e., welding current, welding speed and tip plate distance. The tests were performed on SS316L slabs with a thickness of 3 mm, which were welded with 0.8 mm diameter NiTinol wire as a filler material between the butt joints. Important process control variables were identified and their upper and lower limits were identified. Selected values with units and symbols are given in Table 2.

Table 2 Process variables and their bounds.

	units	**notation**	**-1**	**0**	**1**
Welding current	amp	I	100	125	150
Welding speed	mm/min	S	140	160	180
Nozzle to plate distance	mm	N	12	15	18

Table 3 Design matrix and their responses

Experiment runs	**Process variables**			**Ferrite Number**	**Tensile strength (MPa)**
	N(mm)	I(amps)	S(mm/min)		
1	-1	-1	-1	0.54	389.98
2	-1	1	-1	0.36	404.89
3	-1	-1	1	0.51	388.76
4	-1	1	1	0.38	402.34
5	1	-1	-1	0.52	389.23
6	1	1	-1	0.34	393.7
7	1	-1	1	0.53	388.54
8	1	1	1	0.34	392.56
9	0	-1	0	0.55	388.89
10	0	1	0	0.38	394.87
11	0	0	-1	0.41	391.32
12	0	0	1	0.42	390.34
13	-1	0	0	0.44	391.34
14	1	0	0	0.4	390.09
15	0	0	0	0.45	390.78
16	0	0	0	0.39	392.34
17	0	0	0	0.45	391.34
18	0	0	0	0.46	393.45
19	0	0	0	0.37	390.54
20	0	0	0	0.47	390.87

Three-factor, three-level test designs were selected to conduct the tests as shown in Table 3. Twenty test runs were conducted according to the design matrix. Traction strength FIE was measured with the help of a universal test machine and the ferrite number was measured with the help of FERITSCOPE FMP30 MACHINE and the relevant results were given using the design expert method for each process variables as shown in Table 3.

3. Results and discussion

In the present work, Models have been developed by welding SD316L plates using nitinol as a filler material by conducting experiments using three-factor, three-level factorial designs. Various samples were tested and the results are tabulated. An attempt has been made to investigate TIG's precision welding process for their tensile strength and ferrite number. Variation analysis (ANOVA) is performed to determine the significance of the process parameters for tensile strength and ferrite number. A mathematical model for tensile strength and ferrite number is developed and parameter optimization is performed. Finally the intermediate strength effects of the welding speed and the welding current are generated for the tensile strength and the ferrite number.

3.1. Analysis of variance (ANOVA) of Tensile strength and Ferrite number

The adequacy of the model so developed was then tested by using analysis of variance (ANOVA). The ANOVA table was constructed for both tensile strength and ferrite number as shown in Table 4 and 5.

Table 4 Analysis of variance for tensile strength.

Source	**Sum of squares**	**Df**	**Mean squares**	**F- value**	**p- value prob>F**	
Model	318.25	9	35.36	15.31	<0.0001	Significant
A-welding current	184.56	1	184.56	79.9	<0.0001	
B-welding speed	4.33	1	4.33	1.87	0.2009	
C-nozzle to plate distance	53.78	1	53.78	23.28	0.0007	
Residual	23.10	10	2.310			
Lack of fit	16.74	5	3.35	2.64	0.1556	Not significant
Cor total	341.35	19				

Table 5 Analysis of variance for Ferrite number.

Source	**Sum of squares**	**Df**	**Mean squares**	**F- value**	**p-value prob>F**	
Model	0.073	3	0.024	29.52	<0.0001	Significant
A-welding	0.072	1	0.072	87.34	<0.0001	
B- welding	1.000E-005	1	1.000E-005	0.012	0.9138	
C- nozzle to plate distance	1.000E-003	1	1.000E-003	1.21	0.2878	
Residual	0.013	16	8.272E-004			
Lack of fit	4.725E-003	11	4.320E-004	0.25	0.9276	Not significant
Cor total	0.086	19				

The ANOVA analysis for tensile strength is given in Table 4. The model F-value of 15.31 indicates that the model is significant and the lack of fit is found to be insignificant. Welding current could be seen to have a major influence on tensile strength from tip to plate distance. The welding current shows a maximum contribution of 54.06%, a welding speed of 1.26%, and a tip-to-plate distance of 15.75%. The p-value was also found to be less than 0.05 for welding reactions to current-tip plate distance. They account for 14.64%. This gives a clear indication that the sample is adequate and can be associated with test data. This analysis was done with a 95% confidence level. The "Lack of Fit F-value" of 2.64 indicates that the incompatibility is not significant compared to the pure error. There is a 15.56% chance of this major "Lack of Fit F-value" due to noise.

The ANOVA analysis for the ferrite number is given in Table 5. The f-value of 29.52 indicates that the sample is significant and the inconsistency is found to be negligible. Welding current could be seen to have a major influence on the ferrite number. The welding current shows the maximum contribution of 83.72%, 0.01% for the welding speed and 1.16% for the tip-to-plate distance. This gives a clear indication that the sample is adequate and can be associated with test data. This analysis was done with a 95% confidence level. A "Lack of Fit F-value" of 0.25 indicates that the incompatibility is not significant compared to the pure error. There is a 97.26% chance of this major "Lack of Fit F-value" due to noise.

4. Development of mathematical model for Tensile strength and Ferrite number

The final mathematical models in coded form is determined with the help of DESIGN EXPERT 7.0 and are presented below :

T = 407.90636 + 0.11322*I - 0.45754*S + 1.38185*N - 4.45000E-004*I*S - 0.033333*I*N + 4.04167E- 003*S*N + 2.51927E-003*I2 + 1.31136E-003*S2 + 0.045505*N2

Fn =0.90250 - 3.40000E-003*I + 5.00000E-005*S - 3.33333E-003*N

5. Optimization of process parameters

The optimization of the model is done using a design expert. A diagram for improving the answers Figure 1. Predictive values for welding current, welding speed and plate distance are found to be 1. Since these values are similar, sample optimization is satisfactorily justified. The predictive value for tensile strength and ferrite number are found to be 0.933 and 0.907, respectively. Because these values are close to similarity, model optimization is satisfactorily justified. The ten optimal solutions of the model and the associated factors are given in Table 6. High welding current of 150 amps, low welding speed of 140 mm / min and low tip first plate distance of 12 mm. Optimal values are appropriate for all work models.

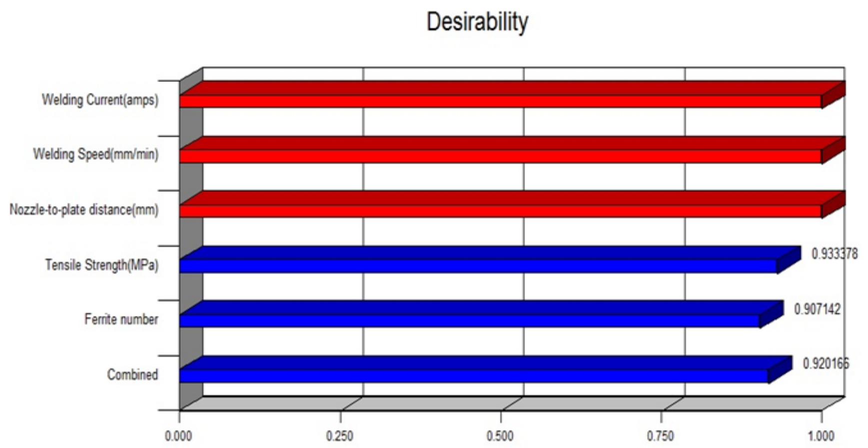

Figure 1 Optimization histogram of response

Based on these results, confirmation runs are made and the measured values of the answers are shown in Table 6. An average percentage error was calculated between the results of the optimal sample solutions and the stabilization runs. An error of 0.5% and 0.7% was found for the tensile strength and the ferrite number, respectively. Since these error values are less than uniform, the sample optimization is satisfactory and they can be used accurately to predict the answers.

Table 6 Optimal solutions and confirmatory runs.

Number	Welding current	Welding Speed	Nozzle-to-plate distance	Model tensile strength	Exp tensile strength	Model ferrite number	Exp ferrite number	Desirability
1	150	140	12	403.801	401.781	0.359	0.34	0.93
2	150	140.09	12.04	403.714	402.623	0.359	0.34	0.92
3	149.61	140	12	403.64	401.92	0.360	0.35	0.904
4	149.20	140	12	403.47	403.12	0.362	0.35	0.904
5	149.98	140	12.31	403.186	402.64	0.358	0.36	0.902
6	150	145.63	12	403.23	401.24	0.359	0.36	0.90
7	150	149.85	12	402.858	404.57	0.359	0.36	0.89
8	150	152.04	12	402.68	405.76	0.360	0.37	0.884
9	150	152.74	12	402.63	404.88	0.360	0.37	0.883
10	150	155.42	12	402.43	404.24	0.37	0.36	0.876

6. Inter strengthation effects

6.1. Inter strengthation effects of welding speed and welding current on Tensile strength

Figure 2 depicts the effect of welding speed (mm / min) and tensile strength of the welding current (A). From this figure it is clear that the tensile strength increases with increasing welding speed with all levels of welding current. The tensile strength for different combinations of welding current and speed is shown in Figure 2, which shows that there is an increase in tensile strength when the welding current and speed increase together.

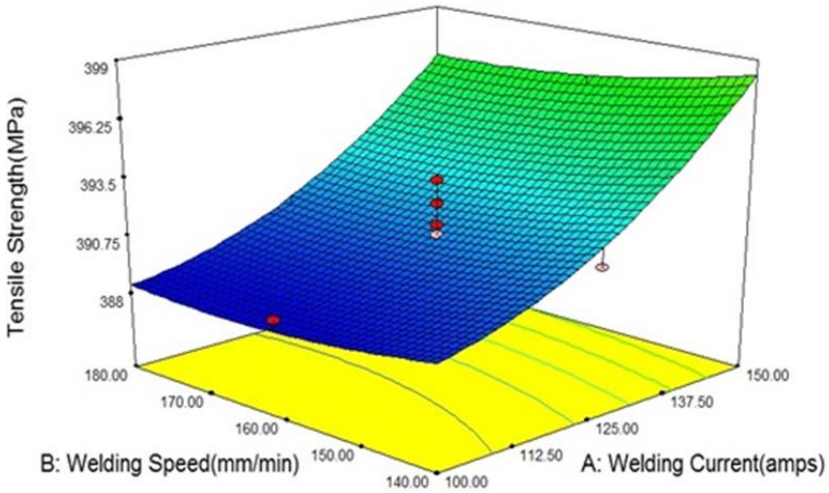

Figure 2 Surface plot for interaction effects of welding speed (mm/min) and welding current (amps) on Tensile strength (Mpa)

6.2. Inter strengthation effects of welding speed and welding current on Ferrite number

Figure 3 depicts the effect of welding speed (mm / min) and tensile strength of the welding current (A). From this figure it is clear that the ferrite number decreases with increasing level of welding speed with all level welding current. The ferrite number for different combinations of welding current and speed is depicted in Figure 3, which shows that the ferrite number decreases as the welding current and speed increase together.

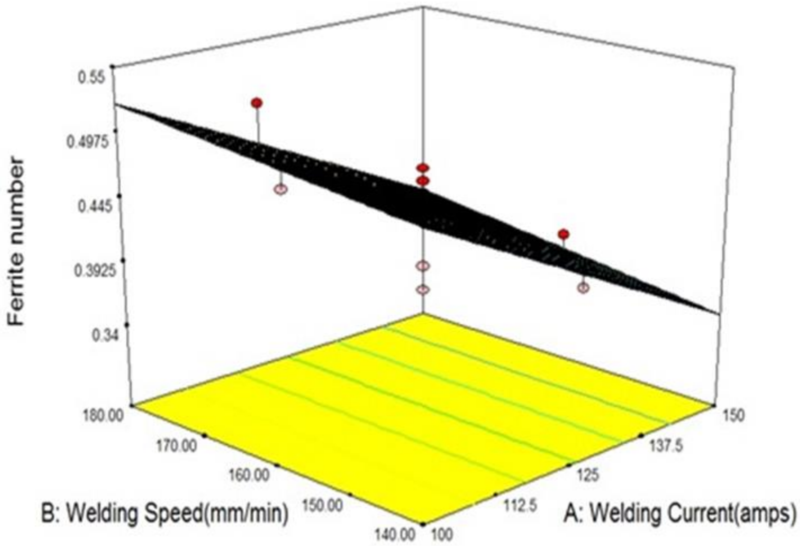

Figure 3 Surface plot for interaction effects of welding speed (mm/min) and welding current (amps) on ferrite number.

7. Conclusion

- Experiments were conducted using the concept of DOE, and were used to create regression models using the response surface method with the help of Design Expert 7.0 software to find the optimal set of process parameters.
- Tensile strength was found to increase with increasing welding speed (mm / min) and welding current (amps).
- The ferrite number was found to decrease with increasing welding speed (mm / min) and welding current (amps).
- The optimization of the selected design is shown in the ten best solutions and stabilizing runs. The average error percentage between the model and the test runs was found to be less than the similarity.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

All authors declare that they have no conflict of interest.

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Author’s short biography

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