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Comparative Study on the Effects of TIG Welding Parameters on AISI 4130 and AISI 1018 Pipe Weldments

Ankush Sharma[1] and Shankar Singh[2]

[1,2]Department of Mechanical Engineering, Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab-148106, India
E-mail: [1]ankushaps@gmail.com, [2]singh.shankar@gmail.com

Abstract—*Pipes or tubes material namely AISI 1018(low carbon alloy steel) steel and AISI 4130 (chromium molybdenum steel) find use in variety of applications such as experimental airplanes , racing car frames, roll cages of All Terrain Vehicle (ATVs), Go Karts, bicycle and motorcycle frames. Other uses include petrochemical and steam tubing applications. The materials are noted for its high-strength properties at high temperatures.*
The welding of tubes is an essential requirement in the fabrication of components in many industries. Tungsten inert gas welding has become indispensable tool for many industries because of high quality welds produced and low equipment cost.
In the present study,TIG process is performed in manual mode with the application of filler metal. The effect of welding variables namely current, shielding gas flow rate, average welding speed has been observed. The experimental runs were performed using L18 Taguchi orthogonal array. Comparative study has been carried out on AISI 1018 and AISI 4130 pipe joints to study the effect of TIG parameters on the performance measures viz. strength, strain, and micro-hardnrss. The results shows that AISI 4130 has better mechanical properties having high strength, large strain and much micro-hardness. The results show that ultimate tensile strength and micro-hardness of steel pipes have been affected mainly by type of material as they are more significant determined by using ANOVA and also at same time shielding gas flow rate has maximum effect on strain.

Keywords*: ATV, Roll cage Material, Pipe weldments, TIG, Taguchi Methodology, Optimization.*

1. INTRODUCTION

Tubular products known as pipe or tubing, are hollow items, normally circular, used for transmitting gases or liquids, or for structural, mechanical, or decorative function. They can range from the smallest to over 60 inch in diameter. [1].

Structural pipe and tube are used for structural or load bearing purposes, for architectural or structural purposes, and can be of different shapes. Structural steel pipes and tube is made of low carbon weldable steels [1].

AISI 4130 steel and AISI 1018 steel find applications in structural parts of aircraft, race cars, bicycle frame, off road vehicles or All Terrain Vehicles (ATVs). They are used to make roll cage of ATVs which participate in Baja SAE (Society of Automotive Engineers) event.

Roll cage is specially engineered and constructed frame built in around the passenger compartment of vehicle to protect its occupant from being injured in an accident. It is situated within vehicle itself.

Fig. 1: ATV design fabricated by Team Junkyard Warriors[2]

TIG welding is popular for thin wall stainless steel tubing and tubing made of nonferrous alloys. TIG welding produces high quality weld in tube mills in square groove weld from 0.5mm to 3mm thick. It is used where max leak integrity, high performance, cleanliness is required. The quality of TIG arc welds ranks higher than the quality of any arc welding process [1].

2. LITERATURE REVIEW

Lee *et.al.* (2012) have studied on the effect of thermal refining on mechanical properties of annealed SAE 4130 by multilayer TIG welding. It was observed that drastic droppings in hardness appeared between the multilayer welds, but the values were still larger than the minimum value at HAZ [3].

Moslemi *et al.* (2015) have studied on the effect of current on characteristic for 316 stainless steel welded joint including microstructure and mechanical properties. It was observed that the increase of welding current led to large amount of heat input in the welding pool, the enlargement of width and deepness of the welding pool. . Arc current of 100 A has been identified as the most suitable arc current used to weld the two and half inches 316 stainless steel pipe [4].

Prabu *et al.* (2014) studied the Metallurgical and Mechanical Properties of SA 210 A1 Rifle Tubular Joints. Widmanstatten ferrite structure was observed at the HAZ of the SA 210 A1 steel. GTA weldments offer better mechanical properties as compared to SMA weldments since the fracture had occurred at the parent metal [5].

Owing to limited researches in the field of TIG welding of pipe joints, this present study has been conducted on TIG welding of AISI 4130 and AISI 1018 steel pipes and the results are compared to find out the better material suitable for its intended applications ie. for roll cage etc. Further, the effect of input parameters such as current, shielding gas flow rate (SGFR-l/min) and average welding speed (mm/min) have been studied and optimized to get best output responses selected accordingly namely strength (MPa), strain and micro-hardness (HV).

3. EXPERIMENTATION:

3.1 Material

SAE Baja rulebook specifies a standard tubing selection with 1- inch outside diameter and a wall thickness of 0.120-inch [6]. However, SAE does allow alternate selections as long as the team uses steel tubing and can prove that their selection has equivalent bending strength and stiffness. The tubing must have a minimum diameter of 0.5-inch and a minimum wall thickness of 0.065-inch. As per the constraint given in the rulebook, the roll cage material must have at least 0.18% carbon content. After an exhaustive market survey, the following materials which are commercially available and are currently being used for the roll cage of an "ATV" were shortlisted namely AISI 1018 and AISI 4130. The dimensions of material selected were:

Outer diameter- 25.4 mm, Wall thickness- 1.6 mm.

Filler wire (ER70S2) diameter-1.5 mm.

The composition after spectroscopy of the material selected and filler material are:

Table 1: Composition of material selected and filler

Material	AISI 1018	AISI 4130	Filler ER70S2	
Element	% Wt	% wt	Element	%
C	.201	0.350	Si	.45-.7
Si	.519	.226	Mn	.9-1.4
Mn	1.33	.537	Ti	.05-.15
P	.010	.014	Al	.05-.15
S	.003	.003	P	.025
Cr	.044	.900	C	.15
Mo	.002	.226	S	.035
Ni	.048	.065	Zr	.02-.12
Al	.022	.006		
Cu	.018	.099		
V	.001	.003		
Fe	98.02	97.47		

3.2. Design of Experiment

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.

The Taguchi method is a structured approach for determining the "best" combination of inputs to produce a product or service. It is used to investigate how different parameters affect the mean and variance of a process performance characteristic. The Taguchi formula is described as:

Smaller the better:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} y_i^2\right) \quad (1)$$

Larger the better:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} \frac{1}{y_i^2}\right) \quad (2)$$

3.3. Factors and their levels

The trial runs has been performed to select the level of factors by considering one factor at a time. Table 2 shows the input parameters and their levels.

Table 2: Process parameters and their levels.

Name of Factor	Symbol (Unit)	Levels		
		1	2	3
Material	-	AISI 1018	AISI 4130	
Current	I(A)	70	80	90
Shielding gas flow rate	SGFR (l/min)	8	10	12
Welding Speed	v (mm/min)	46	52	59

3.4. Experimental procedure

Taguchi's L18 orthogonal array was used to perform the experimental runs in this work. Table 3 shows the different combinations of parameters to weld specimens. Welding is carried out in 1G position i.e. pipe is rotating and depositing weld at top. The joint design was V groove butt joint with 60° included angle and a root gap of 1.5 mm.

Table 3: Input Parameters (L18 Orthogonal Array)

Number of Specimen	Material *	Current (A)	SGFR (l/min)	Avg Welding Speed (mm/min)
1	A	70	8	46
2	A	70	10	52
3	A	70	12	59
4	A	80	8	46
5	A	80	10	52
6	A	80	12	59
7	A	90	8	52
8	A	90	10	59
9	A	90	12	46
10	B	70	8	59
11	B	70	10	46
12	B	70	12	52
13	B	80	8	52
14	B	80	10	59
15	B	80	12	46
16	B	90	8	59
17	B	90	10	46
18	B	90	12	52

*** A**-AISI 1018, **B**-AISI 4130

Using the above parametric combinations, the pipe weldments are made and later testing were conducted.

3.5. Testing and Inspection of Weldments.

The specimens welded were then polished using different grades of emery papers and then etchant (Nital) was applied before testing is performed. Micro-hardness measurements were taken in the longitudinal direction of pipe i.e. perpendicular to the weld bead.The Vickers micro-hardness is measured using Vickers micro-hardness tester at incremental distance of 1 mm on either side of the mid-point of weld zone.

For tensile testing, mandrels are force-fitted to provide a grip in the UTM machine. The tensile testing is carried on hydraulic UTM machine make HEICO (Hydraulic & Engineering Instruments) having a maximum capacity of 50 tons.

Fig. 2: Tensile test specimens of pipe weldments.

The values of tensile testing are recorded in the monitor attached to it, which are further taken into consideration during optimization.

4. RESULTS AND DISCUSSION

The results obtained from the testing performed are analyzed using Minitab17® software. ANOVA table determines the input parameters which significantly affect the response variable. If P-value < 0.05 (at 95% confidence interval), null hypothesis is rejected and that factor has significant effect on the response

Table 4 shows the response variables considered for optimization.

Table 4: Results obtained for response variables

Number of specimen	Strength (MPa)	Longitudinal Strain	Avg Micro Hardness (HV)
1	530.45	0.0535	198.22
2	560.92	0.0592	204.22
3	531.08	0.0681	208.12
4	530.86	0.0534	218.80
5	603.80	0.0437	237.38
6	530.30	0.0529	221.00
7	556.90	0.0485	230.47
8	510.16	0.0514	247.38
9	470.31	0.0516	231.92
10	764.10	0.0614	295.65
11	775.20	0.0550	303.72
12	765.37	0.0759	283.38
13	729.63	0.0549	312.50
14	737.30	0.0479	312.07
15	730.71	0.0687	310.24
16	712.68	0.0470	326.41
17	698.14	0.0535	339.84
18	740.20	0.0689	317.04

The ANOVA table obtained for tensile strength is shown in Table 5.

Table 5: ANOVA Table for Strength

Source	DOF	SS	MS	F-Value	P- Value
Material	1	35.4003	35.4003	351.83	**0.000**
Current	2	1.0035	0.5017	4.99	**0.039**
SGFR	2	0.3313	0.1656	1.65	0.252
WS	2	1.0829	0.5414	5.38	**0.033**
Material * current	2	0.3307	0.1653	1.64	0.252
Error	8	0.8049	0.1006		
Total	17	38.9535			

From Table 5, it can be stated that type of material, welding current and welding speed have significant effect on the ultimate tensile strength of the joint.

From Figure 4, it can be noted that when material is selected as AISI 4130, current as 70 A, SGFR as 10 l/min and welding speed as 52 mm/min; we get maximum value of Strength.

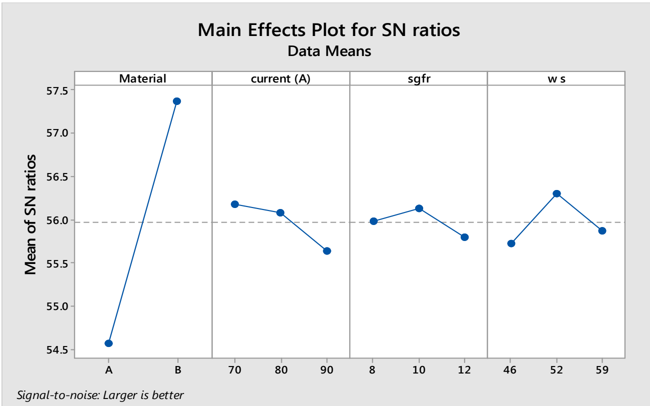

Fig. 3: Main effects plot of SN ratios for Strength

Further from SN ratios, it can be stated that apart from type of material, welding speed has more effect on the strength of the joint followed by welding current and SGFR.

It is observed that AISI 4130 pipe joints have higher tensile strength than AISI 1018. The reason for this, it contains chromium and molybdenum as strengthening agents.

The tensile results so obtained for both materials show that maximum tensile strength is possessed by the specimens made of low welding current combination followed by using medium current and high current input combination. High tensile strength and ductility is possessed by the joints at low heat input, which can be attributed to smaller dendrite sizes and lesser inter-dendritic spacing in the fusion zone [7].

Welding speed and welding current is found to have significant effect on the ultimate tensile strength of the joint due to the fact that welding current and welding speed directly affects the heat input which affects the tensile strength of the joint.

The ANOVA table obtained for strain is shown in Table 6.

Table 6: ANOVA table for strain

Source	DF	SS	MS	F-Value	P- Value
A	1	.000144	.000144	5.27	**0.045**
Current	2	.000299	.000150	5.48	**0.025**
SGFR	2	.000572	.000286	10.46	**0.004**
WS	2	.000044	.000022	.80	0.476
Material * current	2	0.2763	0.1382	.18	0.842
Error	10	.000273	.000027		
Total	17	.001332			

From Table 6, it can be stated that type of material, current and SGFR have significant effect on strain.

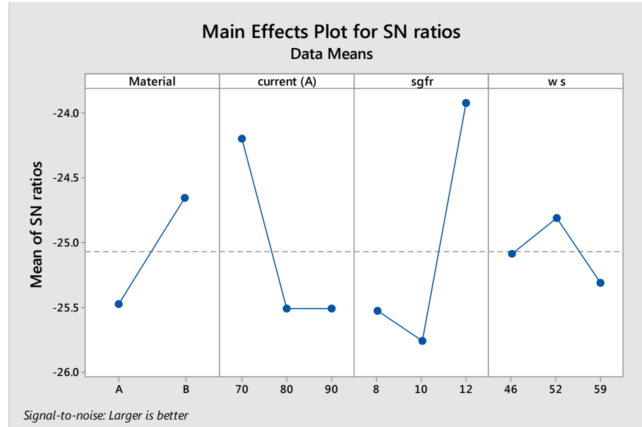

Fig. 4: Main effects plots of SN ratios for Strain

From Figure 4, it can be noted that when type of material as AISI 4130, current as 70 A, SGFR as 12 lt/min and welding speed as 52 mm/min; we get maximum value of strain.

Further from SN ratios, it can be stated that SGFR has the highest effect on strain followed by current, type of material and welding speed.

It was observed that strain is higher in AISI 1018 material as compared to AISI 4130 pipe. The reason to this can be less hardness of AISI 1018 pipe material.

The ANOVA table obtained for Vickers micro-hardness using Minitab software is shown in Table 4.

Table 4: ANOVA table for micro-hardness

Source	DF	SS	MS	F-Value	P- Value
Material	1	35853.1	35853.1	1005.4	**0.000**
Current	2	3364.3	1682.1	47.17	**0.005**
SGFR	2	518.7	259.4	7.27	**0.011**
WS	2	57.5	28.7	.81	0.474
Material * current	2	0.1459	0.0729	1.48	0.238
Error	10	356.6	35.7		
Total	17	40150.2			

From Table 4, it can be seen that type of material, welding current and SGFR have significant effect on the Vickers micro-hardness of the weld zone.

The analysis has been carried out using Taguchi technique and SN ratios graphs are plotted for the response variables. Further the graphs are studied to find the optimal parametric combinations.

From Figure 5, it can be noted that when material is selected as AISI 1018, current as 80 A, SGFR as 12 l/min and welding speed as 52 mm/min; we get minimum value of micro-hardness.

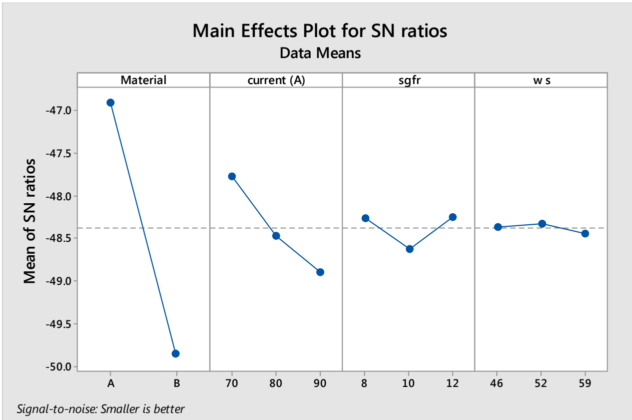

Fig. 5: Main effect plots of SN ratios for micro-hardness

It is observed that AISI 4130 has higher micro-hardness as compared to AISI 1018 because it has higher carbon content and carbon content is in direct proportion to hardness.

With increase in current, hardness value for both the material decreases. The reason being due to increase in heat input, time required to solidify weld pool increases which may lead to little coarse microstructure.

With increase in SGFR, the hardness of weld pool increases because cooling rate increases.

Further from SN ratios, it can be stated that apart from type of material, current is a dominant factor when micro-hardness of the joint is considered, followed by SGFR and lastly welding speed.

5. CONCLUSION

The following conclusions can be drawn from the analysis of the results obtained from the present work:

- Both AISI 1018 and AISI 4130 pipe material, when joined by TIG process using ER70S2 filler rod shows good weldability and very good joint strength as the fracture has taken place from the base metal nearer to the HAZ and not from the weld.
- It is found that maximum tensile strength is possessed by the specimens made using low welding current.
- The optimized parameters for better ductile joints viz. lesser micro-hardness are found to be current as 80 A, SGFR as 12 l/min and welding speed as 52 mm/min considering AISI 1018 as the base material.
- The optimized parameters for better ultimate tensile strength are found to be current as 70 A, SGFR as 10 lt/min and welding speed as 52 mm/min considering AISI 4130 as the base material.
- The optimized parameters for maximum strain are found to be current as 70 A, SGFR as 12 lt/min and welding speed as 52 mm/min considering AISI 4130 as the base material.

Based upon the present study it is recommended that AISI 4130 is better material for Roll Cage fabrication because it have better mechanical properties and good weldability.

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