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Effect of GTAW-SMAW hybrid welding process parameters on hardness of weld

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Abstract

This paper presents effect of welding parameters viz. Gas Tungsten Arc Welding (GTAW) current, Shielded Metal Arc Welding (SMAW) current, gas flow rate and inter pass temperature between GTAWand SMAW processes on hardness of weld and heat affected zone (HAZ). Taguchi based experimentation with L9 array was used to carry out hybrid weldingon low carbon steel material with GTAW process for root pass and SMAW process for subsequent passes. Confirmation experiments were carried out where ever necessary and it was found that Inter pass temperature dominated the hardness of both i.e. hardness of weld and hardness of HAZ. It was also found that weld hardness was affected by GTAW current whereas SMAW current affected the HAZ hardness.

Keywords:SMAW, GTAW, Multi pass welding, Hybrid welding, Hardness, Taguchi

Introduction

SMAW and GTAW are common arc welding processes in which heat required to melt parent and filler material is generated by an arc established between an electrode and the workpiece. In SMAW, flux covered consumable electrode is used whereas in GTAW non consumable Tungsten electrode is used and consumable filler wire is supplied externally. In case of GTAW and SMAW hybrid welding both processes are used to complete the weld, such that root pass is done by GTAW process and subsequent passes are made by SMAW process. Since GTAW and SMAW have their own advantage [1], objective of hybrid welding is to aggregate advantage of both processes in enhancing productivity and work quality.

Any production or manufacturing process has process parameters which if controlled properly, gives desired output. Similarly SMAW and GTAW welding processes has controlling parameters such as welding current, voltage, welding speed and electrode polarity. In addition GTAW process also requires control over shielding gas composition, shielding gas flow rate and electrode tip angle. From previous researches it is evident that welding current plays major role in deciding mechanical properties of weld [2,3, 4,5,6, 7, 8].

Depth of penetration depends upon welding voltage and it decreases as voltage increases [9].

S. P. Tiwari *et al*. during their research found that depth of penetration also depends on welding speed [10].

Riyadh Hamaza*et al*. during their study of effect of welding polarity on hardness of weld, concluded that the Direct current Electrode Negative (DCEN) polarity produces welds with highest hardness as compared to Direct Current Electrode Positive (DCEP) and Alternating Current (AC) polarity [11].

In case of GTAW process, researchers noted that increase in current is directly proportional to increase in heat generated and generated heat is utilized to melt externally supplied filler wire.Increase in current results in increase in weld deposition rate and weld bead height[12, 13].

Shielding gases used in GTAW influences the amount of heat actually entering the work piece. High thermal conductivity of Carbon dioxide and low electrical conductivity of helium gas as compared to the argon increases the amount of heat entering the work piece [14].

Shanping Lu *et al.* stated that Argon ionization energy is much lower than the Helium ionization energy due to which with argon, ignition can be achieved at higher (up to 13 mm) tip to work distance [15].

During their experimentation Abid *et al*.found that arc temperature near the electrode tip is the maximum for the sharp tip and decreases as the electrode tip angle increases. It is because sharper electrodes have hotter tips due to the reduced cross section as compared to the blunt tips [16].

From the preceding literature it is clear that welding parameters have considerable effects on weld quality, weld geometry and mechanical properties.

Design of Experiments

From the various parameters described above, welding current plays a major role in deciding mechanical properties of the weld and hence SMAW welding current and GTAW welding current were selected as factors for experimentation. Gas flow rate was selected as another factor for experimentation as it can be controlled easily with gas flow meter. Many researchers selected welding voltage and welding speed as separate factors in their experimentation. However one must note that GTAW and SMAW are manual processes and precise control over speed and voltage is not practical. Due to this reason these parameters are not selected for experimentation. Practically when hybrid welding is carried

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out it was found that welders are reluctant to carry out SMAW passes immediately after GTAW root pass. Many times it is observed that all available GTAW roots are first completed and then welder performs SMAW passes. Hence it becomes important to study inter pass temperature between GTAW root and SMAW hot passes. For this reason inter pass temperature was selected as factor of experimentation. All factors were tested for three levels i.e. low- medium- high. By using Taguchi factorial design for 4 factor 3 levels, L9 orthogonal array was established and experiments were performed accordingly.

Table 1: Table indicating different levels of factors

Factor	Level I	Level II	Level III
GTAW Current (amp)	100	110	120
Gas Flow Rate (lpm)	10	12	15
SMAW Current (amp)	90	100	110
Inter pass Temperature (^{0}c)	Room temperature	100	150

Table 2: Table indicating experiments conducted with different levels of factors

Expt no	GTAW current	Gas flow rate	SMAW current	Inter pass temperature
1	I	I	I	I
2	I	II	II	II
3	I	III	III	III
4	II	I	II	III
5	II	II	III	I
6	II	III	I	II
7	III	I	III	II
8	III	II	I	III
9	III	III	II	I

Experimentation

A 516 Gr 70 material was selected for experimentation as it is commonly used low temperature pressure vessel material.

Table 3: Key material composition of base plate (%)

C 0.0520	Si 0.297	Mn 1.20	P 0.0149	S 0.0035
Cr 0.118	Mo 0.0063	Ni 0.111	Al 0.0345	Co 0.0086

Edge preparation was done as per Figure 1. and hybrid welding was carried out with GTAW for root pass and SMAW for subsequent passes. This is shown in Figure 2.

For GTAW, ER70S-2 1/8 in. filler wire and DCEN polarity was used. For SMAW E7018 1/8 in electrode and DCEP polarity was used. Welding so carried out was photographed and shown below.

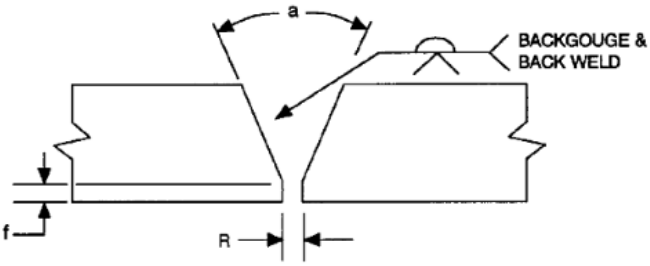


Figure 1: Edge preparation for welding [17]

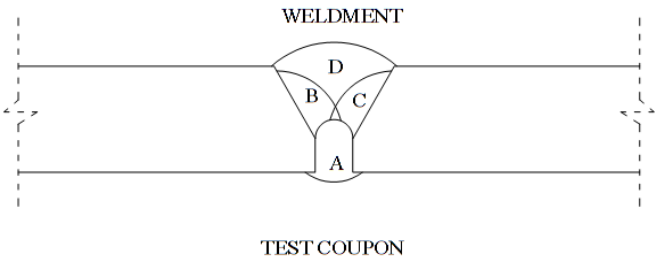
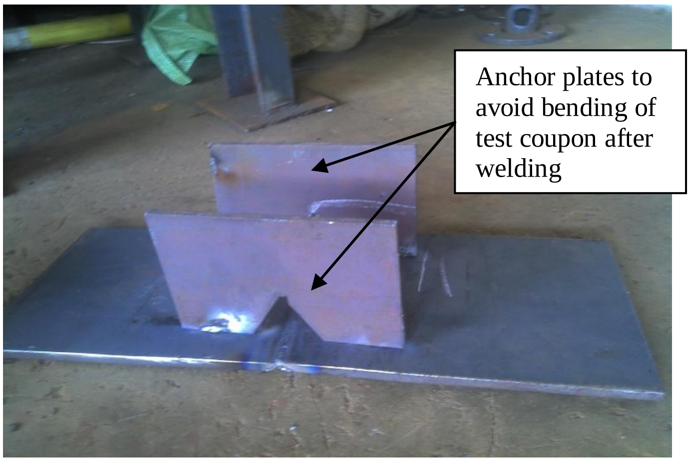


Figure 2: Welding sequence (Pass A- GTAW, Pass B,C,D- SMAW)



Photograph 1: Test Coupons with anchor plates

Welded pieces were tested with Vickers's hardness tester at weld and at HAZ. Results so obtained are tabulated below.

Table 4: Hardness results

Experiment No.	Weld Hardness (Vickers's no)	HAZ Hardness (Vickers's no)
I	186.5	181.0
II	193.0	186.0
III	185.5	198.5
IV	178.5	183.0
V	179.5	184.0
VI	190.5	186.0
VII	186.0	192.5
VIII	181.0	190.5
IX	175.5	181.0

Result Analysis

Above results were analyzed to find the optimum levels of factors which if applied will give most desired hardness value. To do this exercise, Minitab version 17 software was used. Main Effect plot of S-N ratio so obtained are shown in figure 3 and figure 4. These plots were used to find the optimum level of factors. In obtaining these plots, logic of "Larger is Better" was used.

Signal to Noise Ratio calculations were further analyzed to identify dominant factor affecting the responses. Results are tabulated in Table 5 and Table 6.

For "Higher is Better" characteristic

S-N Ratio = $-10 \times log_{10}\left[\left(\sum \frac{1}{y^2}\right)/n\right]$

Where y is hardness values for a particular level of factor
n is number of hardness values under considerations. n = 3

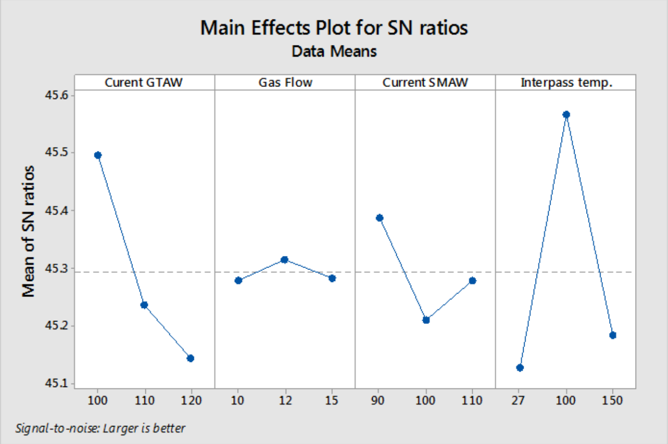


Figure 3: S-N Ratio plots for weld hardness

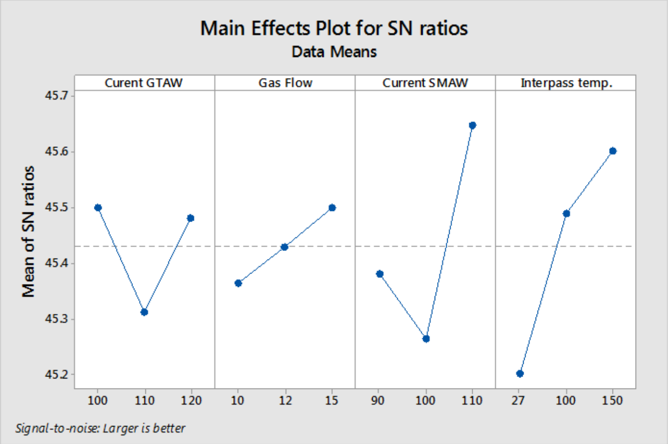


Figure 4: S-N Ratio plot for HAZ hardness

Table 5: S-N Ratio for weld hardness results

	S-N RATIO			
Level	GTAW Current	Gas Flow Rate	SMAW Current	Inter pass Temp.
Level 1	45.50	45.28	45.39	45.13
Level 2	45.24	45.32	45.21	45.57
Level 3	45.14	45.28	45.28	45.18
Delta	0.35	0.04	0.18	0.44
Rank	2	4	3	1

Table 6: S-N Ratio for HAZ hardness results

	S-N RATIO			
Level	GTAW current	Gas flow rate	SMAW current	Interpass temp.
Level 1	45.50	45.36	45.38	45.20
Level 2	45.31	45.43	45.26	45.49
Level 3	45.48	45.50	45.65	45.60
Delta	0.19	0.14	0.38	0.40
Rank	3	4	2	1

From all S-N ratio plots (i.e. Figure 3 and Figure 4) it is evident that larger values ofhardnessshall be achieved at following combinations of factor levels

Table 7: Optimized levels of factors

Response	**Weld hardness**	**HAZ hardness**
Factors	Levels in terms of values	
GTAW Current (amp)	100	100
Gas Flow Rate (lpm)	12	15
SMAW Current (amp)	90	110
Inter pass Temperature (^{0}c)	100	150

Optimum combination of factor Levels for response "weld hardness" was not a part of L9 experiment design hence validation for thisresponse requires actual experimentation with optimum levels of factors mentioned in Table 7. For this reason confirmation experiment was again carried out physically in the welding workshop and Vickers hardness test was again carried out on test coupon. Response value of 192.5 Vickers was recorded through test.

However for a response "HAZ hardness"; factor levels proposed in Table 6 were already been experimented through L9 array (refer Table no. 1 & 2) and the response value received through experimentation was 198.5 Vickers. This is largest of all results obtained through L9 array. This confirms that L9 array result for response "HAZ hardness" validates the S-N ratio results of the same response. And hence no special validation experiment was carried out for the response "HAZ hardness".

Table 5 and Table 6 indicates the dominant factors who has effect on respective response i.e. weld hardness was dominated by Inter pass temperature then by GTAW current then by SMAW current and least by Gas flow rate. Similarly HAZ hardness was dominated by Inter pass temperature then by SMAW current then by GTAW current and least by Gas flow rate. However these results requires confirmation and it was done by statistical method called Analysis of Variance (ANOVA). Results of one way ANOVA calculations for individual factors are summarized below in Table 8& Table 9.

Table 8: ANOVA for weld hardness

	DOF	SS	V	Percent Contribution	Rank
GTAW Current	2	90.50	45.25	33.83	2
Gas Flow Rate	2	1.167	0.5833	0.004	4
SMAW Current	2	20.67	10.33	7.727	3
Inter pass Temp	2	155.2	77.58	58.02	1
Total	8	267.50		100	

Table 9: ANOVA for HAZ hardness

	DOF	SS	V	Percent Contribution	Rank
GTAW Current	2	31.06	15.53	11.34	3
Gas Flow Rate	2	13.56	6.78	4.95	4
SMAW Current	2	109.7	54.86	40.08	2
Inter pass Temp	2	119.4	59.69	43.62	1
Total	8	273.73		100	

ANOVA results used to decide dominating factor; confirms the results of S-N ratio.

To validate results of confirmation experiments, means and confidence intervals were calculated. For this analysis, factors with lesser percent contribution were considered as noise factors and their variances were pooled in to error variance.

For weld hardness, variances caused by SMAW current and Gas flow rate were pooled in to the error variances where as for HAZ hardness variance due to Gas flow rate was pooled. Mean and confidence interval so obtained are mentioned below. Experimentation results falls within the confidence interval. This validates the optimized combination of factor levels (refer Table 7) required to provide higher hardness values.

Table 10: Validation of optimized factor level combination (90% CI)

Response	μ_{mean}	USL-LSL	Response value through Confirmation experiment
Weld Hardness	194.16	187.96-200.36	192.5
HAZ Hardness	196.98	186.84-207.12	198.5

Inferences

1) Inter pass temperature dominantly affected the hardness of weld and HAZ.
2) Change in Gas flow rate had very less effect on hardness of weld and HAZ.
3) Second dominant factor in case of weld hardness was GTAW current where as in HAZ hardness second dominant factor was SMAW current.
4) 100 amps of GTAW current, 12 lpm gas flow rate, 90 amps of SMAW current and 100^0c inter pass temperature gave the highest weld hardness values.
5) 100 amps of GTAW current, 15 lpm gas flow rate, 110 amps of SMAW current and 150^0c inter pass temperature gave the highest HAZ hardness values.

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