ANALYSIS OF DEFECTS IN GAS SHIELDED ARC WELDING OF AISI1040 STEEL USING TAGUCHI METHOD

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ABSTRACT

Research on welding of materials like steel is still critical and ongoing. An attempt has been made to analyze the effect of process parameters in qualitative manner for welding of AISI1040 steel using processes of Shielded Metal Gas Welding (MIG and TIG). Taguchi method is used to formulate the experimental layout. Exhaustive survey suggest that 5-7 control factors viz., arc voltage, arc current, welding speed, nozzle to work distance and gas pressure predominantly influence weld quality, even plate thickness and backing plate too have their own effect. Design of experiments based on orthogonal array is employed to develop the weldments. The weldments are subjected to testing to find the qualitative properties. The data obtained is checked for adequacy based on ANOVA. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for minimum defects. The data in the present work is collected using ultrasound testing (UT), in which angle beam technique is adopted for the testing of weldments and results are quantified accordingly. The testing of specimens indicated, the presence of defects like LOP, LOF, Blowhole, and Cracks

Keywords: steel, gas welding, welding defects, analysis, MIG, TIG, ultrasound test.

1. INTRODUCTION

The weldability of ferrous metals is inversely proportional to a property known as the hardenability of the steel, which measures the probability of martensite formation in welding. Ferrous metals such as AISI1040 are susceptible to distortion due to their high coefficient of thermal expansion. Some alloys of this type are prone to cracking and reduced corrosion resistance as well. Hot cracking is possible if the amount of ferrite in the weld is not controlled. Alleviating the problem when an electrode is used for deposition the weld metal contaminates with a small amount of ferrite.

Gas tungsten arc welding (TIG) is most commonly used to weld non-ferrous materials, but it can be applied to nearly all metals. Its applications involving carbon steels are limited not because of process restrictions, but because of the existence of more economical steel welding techniques, such as gas metal arc welding (MIG) and shielded metal arc welding (SMAW). This technique can produce strong, ductile corrosion resistant welds. The material considered for the present investigation is AISI1040 steel, with composition C 0.37-0.44; Mn 0.60-0.90; P 0.40(max); S 0.50 (max). This is widely used in manufacture of Axles, Shafts, Lightly stressed gears and Components of agricultural, earth moving and material handling equipments.

In the present work ultrasonic testing is used for the non destructive evaluation of weld defects. Ultrasonic flaw detection has long been the preferred method for non-destructive testing in welding applications. This safe, accurate, and simple technique has pushed ultrasonic to the forefront of inspection technology. On line weld pool monitoring for various defects such as lack of fusion (LOF), porosity, under cutting, inclusion, which are caused by in correct TIG and MIG conditions are highlighted by using ultrasonics, how ever this study was carried out on mild steel and stainless steel by Stares [1]. Selection of process parameters for optimum weld pool geometry for stainless steel is reported by Jung [2]. Taguchi methods are applied for detecting TIG welding process parameters by Tarng [3] this study is carried out on mild steels for predicting optimal setting for each welding process parameters. Giridharan [4] carried out optimization of bead Geometry of pulsed TIG welding applied for 304L stainless steel, mathematical models are developed and they are checked for adequacy. The lucid explanation by Ross [5] on Taguchi method formed a fundamental back bone for this present work.

The literature revealed works carried out by various investigators on stainless steel using different gas shielded arc welding techniques, however there is a short fall of work carried out on AISI 1040 steel by using Taguchi method and detection of defects by using ultrasound testing

2. EXPERIMENTATION

The base materials employed in this study are 3mm and 5mm thick plates of AISI 1040 steel joined by TIG and MIG welding processes using DCSP (Direct Current Straight Polarity). Sizes of the specimens are 100mm x 64mm x 3mm and 100mm x 64mm x 5mm. Process parameters selected for the investigation are arc voltage (x_1), arc current (x_2), welding speed (x_3), Nozzle to work distance (x_4), gas pressure (x_5), plate thickness (x_6) and backing plate (x_7). Optimal ranges for the parameters are selected from the renowned books of welding [7, 8] values in between the ranges are selected viz. 2 values (2 level) are needed. An L8 orthogonal array is selected for experimentation. The total variables are seven hence 2^7 experiments are required for perfect analysis, however it is impractical, time consuming and expensive to conduct such large number of experiments. Obeying the principal of experimentation, the analysis is carried out using an L8 orthogonal array, which required a set of 16 experiments

VOL. 5, NO. 1, JANUARY 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

hence a set of 16 experiments are conducted to evaluate TIG welding. Similarly another 16 experiments for evaluation of MIG welding.

Selection of process variable for TIG welding of AISI 1040, two levels are required for the experimentation and welding of the coupons is completed by choosing these limits from standard data available in literature (Table-1).

Table-1. Selection of levels for TIG welding.

Thickness	3mm	5mm
Groove type	sq	v
Tungsten electrode size	3 mm	3 mm
Filler rod size	1.5 mm	3.2 mm
Nozzle size	9.5 mm	9.5 mm
Gas flow rate	9 l/min	10 l/min
Shielded gas	Argon	Argon
Current I	58 A	75 A
No of passes	1	1
Travel speed	As required	As required

Responses are obtained using NDT method-Ultrasound testing. The test is performed on the welded coupons (work pieces). Primarily the calibration of the instrumentation is performed and the Distance Amplitude Curve (DAC) is drawn with the help of Notch plate of same material and DAC is drawn at 80 % echo level then at 40 % and then at 20%. If the echo crosses the curve then it means that it is a defect which needs to be investigated. To get echo and to know the presence of defect the angle probe is to be located in such a manner that the crystal faces the weld area. The probe is moved in zig-zag manner from the weld center line to heat affected zone (HAZ), the distance on the RHS and LHS sides of the weld. The values of surface distance (SD), Beam path (BP/SP) and depth (D) are measured. The data relating to the defect(s) is checked for adequacy using ANOVA and the effects of parameters are known in form of contribution, as shown in Tables 2 and 3.

3. TEST RESULTS OF AISI 1040-TIG COMBINATION

Table-2. ANOVA for lack of penetration in TIG welding.

Para-meters	**Sum of squares** (SSxi)	**DOF** (n-1)	**Mean of SSxi M. SSxi = SSxi/D.O.F**	**Fisher ratio F=M. SSxi/ M. SSE**	**Contri-bution** (%)
x_1	105.06	1	105.06	21.0125	-
x_2	45.56	1	45.56	9.1120	0.245
x_3	2678.06	1	2678.06	535.6125	-
x_4	7.5625	1	7.5625	1.5125	-
x_5	1785.06	1	1785.06	357.0125	9.63
x_6	13398.06	1	13398.06	2679.6125	72
x_7	473.06	1	473.06	94.6125	2.55
SSE = 37.5025		8	SSE/8 = 5		Total = 84.42
SST= 18529.93					Others = 16.58

Table-3. ANOVA for under fill in TIG welding.

Para-meters	**Sum of squares** (SSxi)	**DOF** (n-1)	**Mean of SSxi M. SSxi =SSxi /D.O.F**	**Fisher Ratio F=M. SSxi/ M. SSE**	**Contri-bution** (%)
x_1	60.06	1	60.06	136.5056	-
x_2	189.06	1	189.06	429.6875	45.50
x_3	39.06	1	39.06	88.7784	-
x_4	18.06	1	18.06	41.0511	-
x_5	10.56	1	10.56	24.0056	2.54
x_6	95.06	1	95.06	216.0511	22.88
x_7	0.062	1	0.062	0.1420	0.015
SSE = 3.5		8	SSE/8 = 0.435		Total= 70.93
SST = 415.4375					Others = 29.07

The distribution of lack of penetration (LOP) and under fill for different conditions of L_7 orthogonal array are presented in Figures 1 and 2.

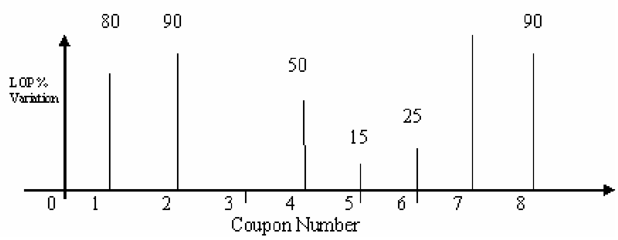

Figure-1. Distribution of LOP for different experimental conditions.

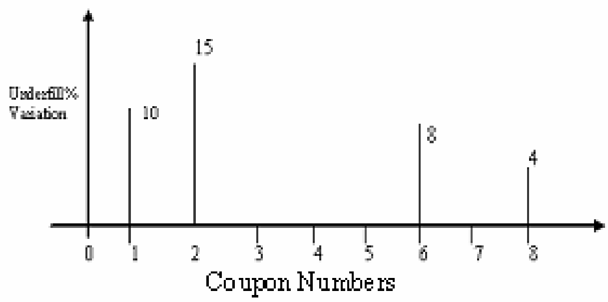

Figure-2. Distribution of under fill for different conditions.

VOL. 5, NO. 1, JANUARY 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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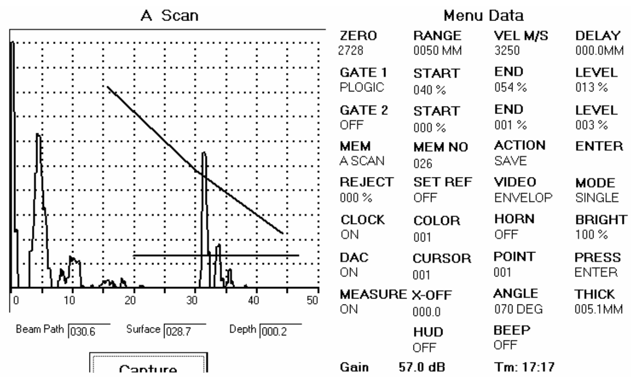
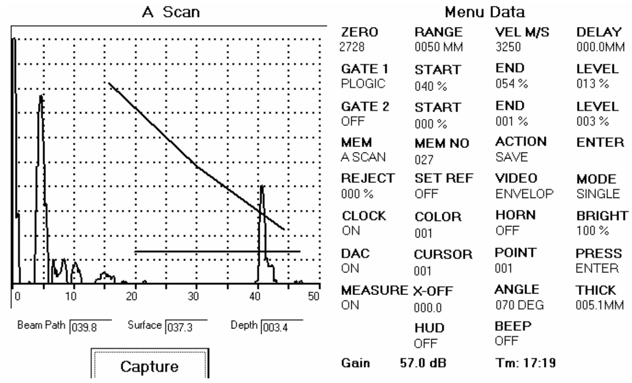
Figure-3. Typical TIG welded coupon with overlap and porosity.

Typical test result of ultra sound scan of TIG welded coupons of 5mm AISI1040 steel plate is shown below. Under fill in TIG welding, echo indicating at a distance of 32mm from the edge of the work piece.



Lack of penetration in TIG welding, echo indicating at a distance of 41mm from the edge of the work piece.



4. TEST RESULTS OF AISI 1040-MIG COMBINATION

Two levels are required for the experimentation and welding of the coupons is completed. By choosing these limits from standard data available in literature (Table-4).

Table-4. Selection of levels for MIG welding of AISI 1040.

Thickness	3mm	5mm
Groove type	sq	V
Electrode diameter	0.9 mm	0.9 mm
Voltage	22 V	26 V
Gas flow rate	9 l/min	10 l/min
Shielded gas	CO_2	CO_2
Current I	120 A	140 A
Passes	1	1
Travel speed	20 ipm	14 ipm
Nozzle to work distance	11	14

In the similar lines of TIG welding ANOVA is also carried out on MIG welded coupons and the results of LOP and under fill are shown in Tables 5 and 6.

Table-5. ANOVA lack of penetration in MIG welding.

Para-meters	Sum of squares (SSxi)	DOF (n-1)	Meanof SSxi M. SSxi = SSxi/ D.O.F	Fisher ratio F = M. SSxi/ M. SSE	Contribution (%)
x_1	45.56	1	45.56	22.0876	0.17
x_2	8602.5	1	8602.5	4170.3315	32.47
x_3	68.06	1	68.06	32.9952	0.25
x_4	1.56	1	1.56	0.7574	0.006
x_5	9168.06	1	9168.06	4444.4747	34.6
x_6	264.06	1	264.06	128.0116	0.99
x_7	8326.56	1	8326.56	4036.5340	31.43
SSE = 16.5025		8	SSE/8 = 2.06		Total = 99.91
SST = 26493					Others = 0.09

Table-6. ANOVA for under fill in MIG welding.

Para-meters	Sum of squares(SSxi)	DOF (n-1)	Mean of SSxi M. SSxi = SSxi/ D.O.F	Fisher Ratio F=M. SSxi/ M.SSE	Contribution (%)
x_1	11.73	1	11.73	316.5991	20.65
x_2	5.4056	1	5.4056	145.9001	9.50
x_3	2.8056	1	2.8056	75.7246	4.93
x_4	2.8056	1	2.8056	75.7246	4.93
x_5	5.4056	1	5.4056	145.9001	9.50
x_6	11.73	1	11.73	316.5991	20.65
x_7	16.6056	1	16.6056	448.1943	29.23
SSE = 0.2964		8	SSE/8 = 0.03705		Total = 99.39
SST = 56.7844					Others = 0.61

The distribution of lake of penetration (LOP) and under fill for different conditions of L_7 orthogonal array are presented in Figures 4 and 5.

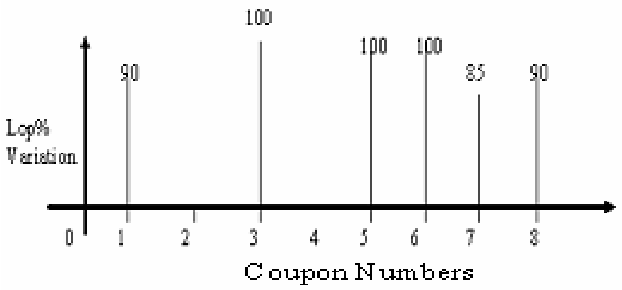


Figure-4. Distribution of lack of penetration in MIG welding.

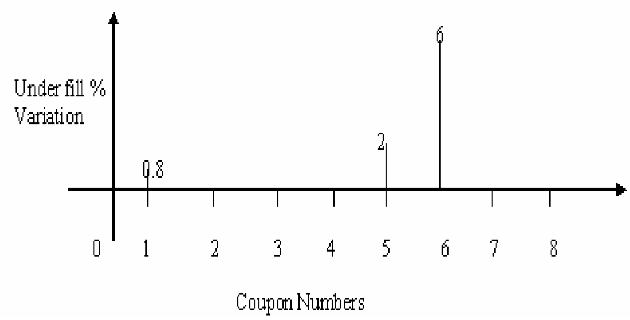
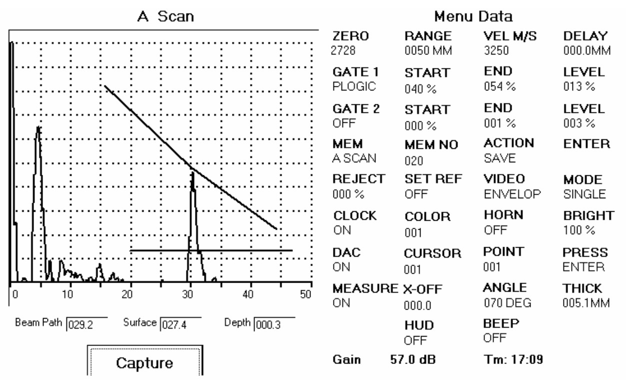


Figure-5. Distribution of under fill in MIG welding.

Figure-6. Typical MIG welding with under fill and porosity.

Typical test result of ultra sound scan of MIG welded coupons on 5mm AISI1040 steel plate is shown below. Under fill in MIG welding, echo indicating at a distance of 30mm from the edge of the work piece.



Lack of penetration in MIG welding, echo indicating at a distance of 45mm from the edge of the work piece.

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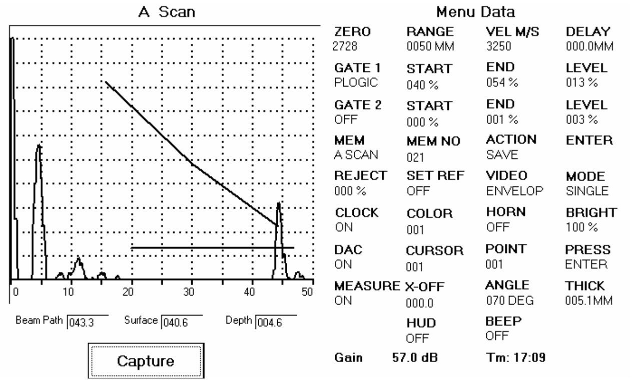

5. ANALYSIS OF TEST RESULTS

- The experiments with low current has increased the % of variance of LOP in both TIG and MIG welding;
- High welding speed resulted in under fill; it is as high as 8mm2 in TIG welding;
- Lack of penetration is also observed in experiments performed with low nozzle tip distance in MIG welding;
- Under fill is not observed in all experiments with high current values;
- Over lap compared with blow holes and porosity are observed in MIG welding at low speeds and at low current values;
- AISI 1040 has excellent weldability for both TIG and MIG welding procedures;
- The operator skill is found to be more dominant when compared with the process variables in TIG welding;
- Perfect shielding can be obtained with a gas flow rate 9-10 l/min;
- Lack of penetration is largely influenced by the plate thickness in TIG welding; current has an influence of about 45 % on under fill;
- Influenced of upto 35% is contributed by gas pressure for lack of penetration and 31% is contributed by current for LOP in MIG welding;
- Voltage, thickness and backing plate have large influence on under fill in MIG welding.

6. CONCLUSIONS

- To avoid LOP the optimum current values are 150A and 180A for 3mm and 5mm plate for MIG welding;
- Similarly for TIG the current values are 65A and 80A for3mm and 5mm plates, respectively;
- The weld speed should be less than 0.45 m/min for 3mm plate and 0.35 m/min for 5mm in MIG welding;
- To avoid LOP the optimum velocity of nozzle tip distance about 10mm for 3mm plate and 12mm for 5mm plate;
- Taguchi method proved to be robust in design of experiments for evaluation of the quality;
- The cost of experiments can be reduced by selecting proper orthogonal array;
- Ultrasonic testing is rapid and effective NDT method. However, skill is required in interpreting the results.

ACKNOWLEDGEMENTS

The authors are sincerely thankful to the Principal and management of Vasavi College of Engineering for extending their support in carrying out this work. The cooperation extended by Mr. T. Ratanaiah, Lab Technician, during experimentations is highly appreciated.

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