Effect of GTAW Process Parameters on Weld Bead Geometry of AA 7075-T6 Weldments

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Abstract:- **Gas tungsten arc welding (GTAW) is mainly characterized by the weld pool geometry. This is because the weld pool geometry plays an important role in determining the mechanical properties of the weld. In this paper, the selection of process parameters for obtaining optimal weld pool geometry in the AC Pulse GTAW of AA 7075-T6 Aluminium alloy is presented. The traditional Taguchi method is widely used for optimizing the process parameters of a single response problem. Optimization of a single response results the non-optimum values for remaining responses. But, the performance of the manufactured products is often evaluated by several quality characteristics. Under such circumstances, multi-characteristics response optimization may be the solution to optimize multi-responses simultaneously. In the present work, a multi-characteristics response optimization model based on Taguchi and Utility concept is used to optimize GTAW process parameters, such as Peak current, Base current, Frequency, Pulse on time, Gas flow rate and welding speed on multiple performance characteristics, namely, weld pool geometry characteristics such as Penetration, Face width, and Back width. Taguchi's L_{27} orthogonal array (OA) was selected for experimental planning. The experimental result analysis showed that the combination of higher levels of Peak current, Base current, Gas flow rate and lower level of welding speed and intermediate level of Pulse on time and Frequency is essential to achieve simultaneous maximization of Penetration and minimization of Face width and Back width. The ANOVA is used to analyze the results. Further, the confirmation tests are conducted for validation.**

Keywords: Al-Zn-Mg-Cu alloy; GTAW; Multi response Optimization, Taguchi method, Utility concept,

1. INTRODUCTION

In manufacturing, quality is measure of fineness or a state of being free from defects, deficiencies and significant variations. Weld quality mainly in the field of welding depends on the mechanical properties of the weld metal zone (WZ) and heat affected zone (HAZ), which consecutively is influenced by metallurgical uniqueness and chemical compositions of the weld. Furthermore, these mechanical and metallurgical features of the weldment depend on the weld bead geometry, which are directly related to welding process parameters. In other terminology, weld quality depends on welding process parameters [1, 2, 16].

Gas Tungsten Inert Gas Welding GTAW was a multi objective and multi process parameter metal fabrication technique. Several process parameters interact in a complex manner resulting direct or indirect influence on weld bead geometry. Basically, GTAW quality is strongly characterized by the weld bead geometry [1].Welding is one of the most used methods for joining aluminium and its alloys especially in aerospace and nuclear industry. (GTAW) process and Gas Metal Arc Welding (GMAW) are the welding processes which are used the most. Conversely, GMAW offers excessive heat input imposes the problems such as melt and distortion specially in welding of thin aluminium sheets. Therefore, to produce high quality weldments, GTAW process is preferred over GMAW [3].

Theoretically, an extremely thin fused layer might be sufficient for connecting the parts to be joined. The fusion layer should also not be thicker than necessary in order to avoid wasting of energy, edge burn-off, sagging of the weld pool and deep weld end craters. Control of weld-bead shape is essential as the mechanical properties of welds are affected by the weld-bead shape. Therefore, it is clear that precise selection of the process parameters is necessary [4].Usually, the welding conditions can been determined by welding engineers on the basis of information obtained from experience. Knowledge of the heat input intensity and the temperature gradients in the work piece are extremely important for welding process studies. The important problem to be solved in welding engineering is to develop a model for determining the optimal responses.

Search for optimal solutions by a suitable optimization technique based on input–output and in-process parameter relationship or objective function formulated from models with or without constraints, is a critical and difficult task for researchers and practitioners [5]. In this paper we made ample literature review of the application of different optimization techniques. This review shows the optimization of the different welding processes parameters through the mathematical models.

The investigators [4,19] stated in his paper that the application of DOE, evolutionary algorithms and computational network are widely used now-a-days to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint. Jeng et.al.[19] have used both BPN and learning vector quantization neural networks to predict the laser welding parameters for butt joints. Parikshit Dutta.et.al.[20] conducted experiments and carried out conventional regression analysis on some experimental data of a TIG welding process, to find its input and output relationships.

Y.Cho.et.al.[21] studied the effects of various process conditions on weld quality for aluminum using resistance spot welding, mathematical models were established, based on which the influences of the welding parameters were studied. G.Casalino[22] investigated the innovative arc-laser welding process by means of a regression model and a full factorial experiment and analyzed effect of process parameters. The results showed the significance of some parameters and indicated the way to maximize the weld penetration. D.Kim.et.al.[23] proposes a method for determining the near-optimal settings of welding process parameters using a controlled random search (CRS) where in the near-optimal settings of the welding process parameters are determined through experiments. U.Esme.et.al. [24] developed nonlinear and multi-objective mathematical models to determine the process parameters corresponding to optimum weld pool geometry. KondapalliSiva Prasad.et.al. [13] have made study on factors effecting weld pool geometry of pulsed current Micro plasma arc Welding of AISI 304L Austenitic stainless steel sheets using statistical approach. By the developed mathematical models, weld pool geometry parameters can be predicted.

D.S.Nageshaet.al.[26] explained an integrated method with a new approach using experimental design matrix of experimental designs technique on the experimental data available from conventional experimentation, application of neural network for predicting the weld bead geometric descriptors and use of genetic algorithm for optimization of process parameters. Cemal Meran [26]have used stochastic search process that is the basis of genetic algorithms (GAs), in developing estimation of the welding parameters for the joined brass plates. S.C. Juang et.al. [27] have used neural networks to model TIG welding process for preding weld pool geometry. V. Gunaraj and N.Murugan [28] developed mathematical models for the submerged arc welding of structural steel plates. The models were developed using the factorial technique to relate the process control variables. G.Padmanaban.et.al.[30]developed an empirical relationship to predict tensile strength of pulsed GTAW AZ31B magnesium alloy. Incorporating process parameters the developed empirical relationship effectively used to predict the tensile strength of pulsed current GTAW joints.

M.Balasubramanian et.al. [30] has been conducted an experiments to understand the effect of process parameters of pulsed GTAW on titanium alloy weldments and experimental results coupled with ANOVA results. N.B. Mostafa et.al.[31] described prediction of weld penetration as influenced by Flux core arc welding (FCAW) process parameters. It deals with the statistical technique to develop a mathematical model for predicting weld penetration. K. Elangovan et.al. [32] developed a mathematical relationship to predict the tensile strength of friction stir welded AA2219 aluminum alloy joints.

A. Kumar.et.al.[10] was employed Taguchi method to optimize the pulsed TIG welding process parameters of AA 5456 Aluminum alloy welds for increasing the mechanical properties. S.C. Juang, and Y.S. Tarng [12] adopted the modified Taguchi method to solve the optimal weld pool geometry with four smaller the better quality characteristics. Experimental results have shown that the front height, front width, back height and back width of the weld pool in the TIG welding of stainless steel are greatly improved by using this approach.

Dr.Taguchi employed DOE, which is one of the most important and efficient tools of total quality management (TQM) for designing high quality systems at reduced cost. This approach helps to reduce the large number of experimental trials when the number of process parameters increases. Most of the works have been published so far focused on single response performance characteristic optimization by using Taguchi approach. But the Taguchi approach is designed for optimizing the single response problems. It is not fit for optimizing the multi response problems [6].Optimization of a single response results the non-optimum values for remaining responses. In solving many problems in engineering, it is necessary to consider the application of multi-response optimization, because the performance of the manufactured products is often evaluated by several quality characteristics. Though the Taguchi approach is used for a single response problem, most of the researchers proposed various methods for multi-response problem by modifying it. Some of the researchers has been efficiently utilized the Taguchi method and utility concept for multi-response optimization for various welding, and metal cutting processes such as Laser welding, Sub merged arc welding, face milling, magnetic-field-assisted abrasive flow machining-process casting, electro-chemical honing, thermoforming process of polymeric foams, turning of Free-machining and Gas tungsten arc welding, etc. [5].

The main weld bead geometry variables are heat affected zone, bead width, bead height, penetration and area of penetration. These are greatly influenced by welding process parameters; welding speed, welding current, shielding gas flow rate and gap distance. It is necessary to find an optimal GTAW process condition capable of producing desired weld quality. In the present study optimization was performed in such a way that all the objectives should fulfill simultaneously. Such an optimization technique is called multi-response optimization. Senthil Kumar et.al. [8] investigated that the use of pulsed current parameters has been found to improve the mechanical properties of the welds compared to those of continuous current welds of AA 6061 aluminium alloy due to grain refinement occurring in the fusion zone. Many considerations come into the picture and one need to carefully balance various pulse current parameters to arrive at an optimum combination.

As per the literature review lot of research work was done on GTAW of steel alloys and aluminium alloys such as 5xxx series and 6xxx series. But research work on AC pulse GTAW on high strength aluminium alloys 2xxx series and 7xxx series is very less. Because of some particular problems in weldability they include: solidification cracking within the fusion zone, and loss of alloying elements due to the formation of groove this in turn related to weld bead, loss of strength and poor corrosion performance. Still lot of research work required on these high strength aluminium alloys. And also it was found that no work has been reported in the literature on multi-response optimization of weld pool geometry in GTAW of AA7075-T6 aluminium alloy. Hence, in this investigation an attempt has been made to study the influence of AC pulsed current GTAW process parameters on weld pool geometry of AA 7075-T6 aluminium alloy weldment. In the present investigation, a multi characteristics optimization model based on Taguchi method and utility concept has been employed to determine the best combination of the AC Pulsed GTAW process parameters such as Peak current (Ip), Base current (Ib), Welding speed (S), Frequency (F), Pulse on time (Pon), and Gas flow rate (GF) to attain the minimum Face width (B), Back width (C) and maximum Penetration (A). The predictive models obtained for performance measures. Confirmation tests are also conducted to verify the results. Heat treatable aluminium alloy AA7075-T6, with 5.10-6.10% of Zinc as the main alloying element is widely used for aerospace applications. Such as transportable bridge girders, military vehicles, road tankers and railway transport systems [7].

2. MATERIALS.

The base material used in this study was AA7075-T6 it is in the form rolled sheet of thickness 3.46mm.The welding of AA7075-T6 usually involves using a non-heat-treatable filler metal such as ER5356 to increase the hot-cracking resistance of the weld fusion zone [9]. So in this study selected a commercially available filler wire ER5356.The chemical composition of both base metal and filler wire measured by the method of spectrospark emission (ASTM-E1251-07) using a Spark Analyzer Spectromax as given in theTable1.

Table1.Composition of Base material, filler wire, aluminium alloys

Al-alloy	Zn	Mg	Mn	Cr	Cu	Fe	Ti	Al
7075-T6	5.28	2.15	0.04	0.23	1.31	0.21	0.05	Bal
ER 5356	---	5.56	0.12	0.10	0.05	0.09	0.08	Bal

3. EXPERIMENTAL DETAILS.

The schematic diagram of the GTAW welding process is shown in Fig.1 [12]. A non-consumable tungsten electrode, shielded by inert gas, is used to strike an electric arc with the base metal. The heat generated by the electric arc is used to melt and join the base metal. The traveling speed of the electrode is controlled by a DC motor, filler wire pre placed in to the groove of 30^0 and root gap 2mm the whole experimental set up is shown in the Fig.2. In the experiments, the welding power source is provided by a GTAW welding machine “Master TIG MLS™ 3003 ACDC”. The shielding gas is 99.99% argon and the flow rate of the shielding gas is controlled by a valve meter. The base metal is AA 7075-T6 aluminium alloy plates. A single-pass welding process is performed because the thickness of AA 7075-T6 aluminium alloy plates is 3.46 mm.

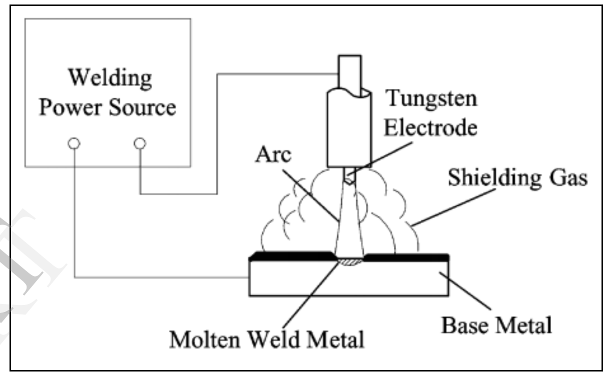

Fig. 1. Schematic diagram of the TIG welding process

Fig. 2: Experimental set up for GTAW.

From the literature review [9,10] it was found that, the most important process parameters which are having greater influence on the weld pool geometry and fusion zone grain refinement of AC pulsed GTAW process are: Peak current (Ip),Base current (Ib), Welding speed (S),Frequency (F),Pulse on time (Pon), and Gas flow rate (GF).

A large number of trials have been conducted by varying one of the process parameters and keeping the others constant. The working range of Peak current (Ip),Base current (Ib), Welding speed (S),Frequency (F),Pulse on time (Pon), and Gas flow rate (GF) has been explored by inspecting bead appearance, bead contour, and for any visual defects [11].The working range of the process parameters selected under the present study and its levels are shown in Table 2.

Table.2 Process parameters and their levels

Symbol	Unit	Level 1	Level 2	Level 3
Ip	A	195	200	205
Ib	A	93	98	103
S	mm/min	200	300	400
F	Hz	4	6	8
Pon	%	40	50	60
GF	L/min	9	10	11

The GTAW experiments are conducted as per the Taguchi orthogonal array (OA) L_{27}. The rolled plates of AA7075-T6 aluminium alloy were cut in to the required size (300x150x3.46mm) by using a Jig saw cutting and grinding. It was investigated by Leijun Li et.al [9] that, the joint strength of the AL7075-T6 plate when welded with ER5356 filler wire with a 0°groove angle gives higher strength compared to 60^0 and 90^0 groove this is because the loss of Zn elements is less in making the groove. In this study we used single butt joint with 30^0 groove and 2mm root gap to fabricate AL7075-T6 plate. The plates to be welded were kept on steel temporary backing plate which having groove of size 7x0.9 mm and ends were clamped to maintain the alignment and gap. High purity (99.99%) argon gas was used as shielding gas.

Initially aluminium plates pickled with NaOH for 10 minutes to remove any grease, dust particles following by HNO_3 for 15 minutes to remove the oxide layer. The initial joint configuration was obtained by securing the plate in position by tack welding. The direction of welding was normal to the rolling direction. Single pass welding procedure was applied to fabricate the joints.

To evaluate the quality of TIG welds, the measurements of the weld bead geometry are performed as shown in Fig.3. In this study, the Penetration (A), Face width (B), and Back width (C) of the weld bead are used to describe the weld pool geometry. The weld bead geometries were measured using Up-right reflected and transmitted metallurgical microscopy system; Make: VT Vacuum Technologies Pvt. Ltd; Model No. EQ-MSXJM213H-3M. Typical weld bead geometry is shown in Fig.3 and measured by a Metallurgical Microscope. Sample preparation and mounting was done as per ASTM E 3-11standard [13]. Two samples at a distance of 15 mm to each other are cut at the middle of the welded joint [14]. Samples being located at 15 mm behind the trailing edge of the crater at the end of the weld to eliminate the end effects (Fig.4). The samples are mounted using cold setting binder and cold setting compound as shown in Fig 5. The etching reagent Keller's was made by using chemicals 2 ml HF,3ml HCl, 20ml $HNO_3$and 175ml H_2O with an etching time of 30 sec. Weld pool geometry parameters were observed and recorded using a metallurgical microscope. The recorded specimen weld pool geometry quality characteristics namely Penetration (A), Face width (B), and Back width (C) are as shown in the Table 3.

4.2 The Utility concept.

A client evaluates a product on a number of diverse quality characteristics. To be able to make a rational choice, these evaluations on different characteristics should be combined to give a combined index. Such a combined index represents the utility of a product. The overall utility of a product measures the usefulness of that product in the view of the client. The utility of a product on a particular characteristic measures the usefulness of that particular characteristic of the product. The overall utility of a product is the sum of utilities of each of the quality characteristics.

Table.3 Experimental layout using an L_{27} orthogonal array and Experimental results for the weld pool geometry

Expt.No	GTAW Process Parameters						Weld pool geometry (mm)					
	Ip	Ib	S	F	Pon	GF	A1	A2	B1	B2	C1	C2
1.	195	93	200	4	40	9	4.5	4.3	7.0	6.8	3.5	3.6
2.	195	93	300	6	50	10	5.0	4.6	8.5	8.6	5.0	4.9
3.	195	93	400	8	60	11	4.5	4.2	7.0	7.2	3.0	3.1
4.	195	98	200	6	50	11	4.5	4.6	7.0	6.9	5.0	4.9
5.	195	98	300	8	60	9	4.5	4.2	8.0	8.1	3.0	3.1
6.	195	98	400	4	40	10	2.0	2.1	6.0	6.2	1.0	1.2
7.	195	103	200	8	60	10	5.0	4.9	8.5	8.2	3.5	3.4
8.	195	103	300	4	40	11	2.0	1.9	6.5	6.3	0.1	0.2
9.	195	103	400	6	50	9	4.5	4.3	6.5	6.3	0.1	0.1
10.	200	93	200	6	60	10	4.6	4.4	7.0	6.8	6.5	6.3
11.	200	93	300	8	40	11	2.0	1.9	6.0	5.9	0.2	0.2
12.	200	93	400	4	50	9	1.5	1.4	7.0	6.9	0.3	0.2
13.	200	98	200	8	40	9	2.0	1.8	7.0	6.8	0.5	0.4
14.	200	98	300	4	50	10	5.0	4.8	8.0	7.8	2.0	2.2
15.	200	98	400	6	60	11	4.5	4.3	6.5	6.4	3.5	3.4
16.	200	103	200	4	50	11	4.6	4.7	6.0	6.0	3.0	3.2
17.	200	103	300	6	60	9	5.0	4.8	5.5	5.5	4.0	4.5
18.	200	103	400	8	40	10	3.0	2.9	6.5	6.3	0.1	0.2
19.	205	93	200	8	50	11	4.5	4.4	5.5	5.5	4.0	3.8
20.	205	93	300	4	60	9	4.5	4.4	7.5	7.2	6.0	6.1
21.	205	93	400	6	40	10	4.3	4.2	6.0	5.9	3.0	3.1
22.	205	98	200	4	60	10	4.0	3.9	9.0	8.8	6.5	6.4
23.	205	98	300	6	40	11	4.5	4.4	7.0	6.8	1.5	1.4
24.	205	98	400	8	50	9	5.0	4.9	6.0	5.9	3.5	3.3
25.	205	103	200	6	40	9	4.5	4.6	7.5	7.4	4.5	4.4
26.	205	103	300	8	50	10	4.5	4.6	8.5	8.4	6.5	6.3
27.	205	103	400	4	60	11	4.0	3.9	8.0	7.9	6.5	6.3

Thus if xi is the measure of effectiveness of the attribute i and there are n attributes evaluating the outcome space, then the joint utility function can be expressed as:

$$U(X_1, X_2, X_3, X_4, X_5, \dots \dots \dots X_n) = [fU_1(X_1), U_2(X_2), \dots \dots \dots, U_n(x_n)] \quad \dots.(1)$$

In linear case, the function becomes:

$$U(X_1, X_2, X_3, X_4, X_5, \dots \dots \dots X_n) = \sum_{i=1}^{n} W_i \, U(X_i) \quad \dots. (2)$$

where, *Wi*, is the weightage assigned to the attribute *i* and the sum of the weightage for all attributes is equal to 1. If the overall utility is maximized the quality characteristics considered for evaluation of utility will automatically be optimized maximized or minimized whatsoever the case may be.

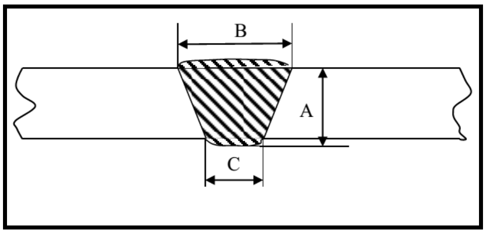

Figure 3: Weld pool geometry; Penetration (A), Face width (B), Back width (C)

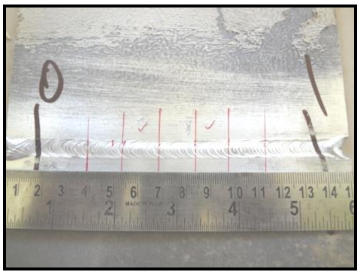

Fig. 4. Marking for cutting specimen

In this study for optimizing the process parameters, three quality characteristics were considered as a single characteristic by using above mentioned utility concept.

Fig. 5. Specimens for measuring weld pool geometry

The utility value (Single characteristics response) of each GTAW specimen has been calculated using the following relation:

$$U(n,R) = P_A(n,R) x W_A + P_B(n,R) x W_B + P_C(n,R) x W_C \quad \dots..(3)$$

Where, n = trial number

n = 1,2, . . ., 27

R = repetition, R = 1, 2,

W_A, W_B, W_C are the weightage for weld pool geometry Penetration (A), Face width (B),Back width (C) respectively. From the previous literature survey it has been found that the quality characteristics Penetration (A), Face width (B), and Back width (C) are not equally important [12] and hence unequal weightage has been assigned but summation of all weightage must be equal to 1[12]. The weights assigned are:

$W_A = 0.50$, $W_B=0.35$, $W_C=0.15$

P_A, P_B , P_C are the preference scale for weld pool geometry Penetration (A), Face width (B),Back width (C) respectively. These values calculated as given below;

If a log scale is chosen the preference (P_i) is given by Equation

$$P_i = K \log \frac{x_i}{x_i^{/}} \quad \text{.... (4)}$$

Where X_i = any value of quality characteristic or attribute i

$X_i^{/}$ = minimum acceptable value of quality characteristic or attribute i $\quad K$ = a constant

At optimum value (X_i^{*}) of attribute i, Pi= 9 So, K at optimal value of X_i^{*} is given by

$$K = \frac{9}{\log \frac{x_i^{*}}{x_i^{/}}} \quad \text{.... (5)}$$

Preference scale calculation for A

X_i^{*}= Maximum acceptable value considering the 27 experiments =4.5 mm (assumed)

$X_i^{/}$= Minimum acceptable value considering the 27 experiments =2 mm (assumed)

(All the A values in Table 3 are in between 1.5 to 5)

Using these values and the Equations 4 & 5, the following preference scale for A has been constructed;

$$P_A = 25.55 \log \frac{x_i}{2} \quad \text{.... (6)}$$

Preference scale calculation for B

X_i^{*}= Minimum acceptable value considering the 27 experiments =6.0 mm (assumed)

$X_i^{/}$= Maximum acceptable value considering the 27 experiments =8.0 mm (assumed)

(All the B values in Table.3 are in between 6 to 9.0)

Using these values and the Equations 4 & 5, the following preference scale for B has been constructed;

$$P_B = -72.03 \log \frac{x_i}{8} \quad \text{..... (7)}$$

Preference scale calculation for C

X_i^{*}= Minimum acceptable value considering the 27 experiments =0.1 mm (assumed)

$X_i^{/}$= Maximum acceptable value considering the 27 experiments =6.0 mm (assumed)

(All the C values in Table.3 are in between 0.1 to 6.5)

Using these values and the Equations 4 & 5, the following preference scale for C has been constructed;

$$P_C = -5.06 \log \frac{x_i}{6.0} \quad \text{.... (8)}$$

The utility values with mean are calculated and given in Table 4.

4.3 Results and discussion.

4.3.1 Single response optimization and its confirmation. Effect on penetration (A)

The penetration (A) was considered as the quality characteristic with the concept of "the larger-the-better". The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB 15. The average values of penetration (A) for each parameter at levels 1, 2 and 3 for raw data are plotted in Fig.6 From the this Fig. it clears that peak current (Ip), frequency (F), and pulse on time (Pon) are the most significant process parameters compared to other process parameters.

Fig.6 shows that as the increase in Peak current (Ip) up to 200A the penetration (A) value decreases and penetration (A) value increases with further increase in Ip value. This is because at low Ip up to 200 Amp the heat input is less and it is not sufficient to melt base metal with the filler material. The Peak current (Ip) more than 200A gives more heat and it melts the base metal with filler metal completely and gives full penetration (A). So Peak current (Ip) plays an important role in the determination of penetration (A) value. As the base current (Ib) increases the up to 98 A the penetration (A) value go on increasing and after 98 A further increase in Ib value there is decrease in penetration (A) value. As the base current (Ib) increases higher the value of penetration (A). This is because the Ib is mainly helpful in maintaining continuous arc during welding [13], so it melts more base metal and filler material in narrow direction so penetration (A) increases. Though from Fig.7 Ib process parameter not as significant as other parameters. As the welding speed (S) decreases the penetration (A) value go on increasing this is mainly because, lesser the speed complete melting of submerged filler material and base metal leads to complete diffusion of filler metal in to base metal and forms a perfect joint. As the Frequency (F) increases penetration (A) go on increasing proper diffusion of filler metal in to the base metal so the penetration (A) value increases. But further increase in the F from 6Hz more penetration than required leads to undercut and decrease in penetration (A) value.

Table. 4 Utility Data Based on Quality Characteristics A,B and C with its Mean.

Expt.no	Utility 1	Utility 2	Mean Utility
1.	6.13881	6.19467	6.16674
2.	4.48002	3.89601	4.18801
3.	6.18962	5.48759	5.83861
4.	6.02124	6.30738	6.16431
5.	4.72761	4.19801	4.46281
6.	3.74038	3.59197	3.66618
7.	4.59759	4.88847	4.74303
8.	3.62301	3.45213	3.53757
9.	8.12215	8.21209	8.16712
10.	6.05669	6.13775	6.09722
11.	4.27090	4.17034	4.22062
12.	0.85340	0.76181	0.80760
13.	2.28110	2.08749	2.18430
14.	5.44582	5.46512	5.45547
15.	6.95020	6.87728	6.91374
16.	7.99932	8.09737	8.04835
17.	9.31977	9.05446	9.18712
18.	5.87258	5.79819	5.83538
19.	8.73522	8.62745	8.68133
20.	5.20575	5.52257	5.36416
21.	7.62515	7.66781	7.64648
22.	2.52969	2.64039	2.58504
23.	6.41810	6.63354	6.52582
24.	8.41112	8.50245	8.45678
25.	5.30058	5.57689	5.43874
26.	3.80898	4.07080	3.93989
27.	3.81927	3.82683	3.82305

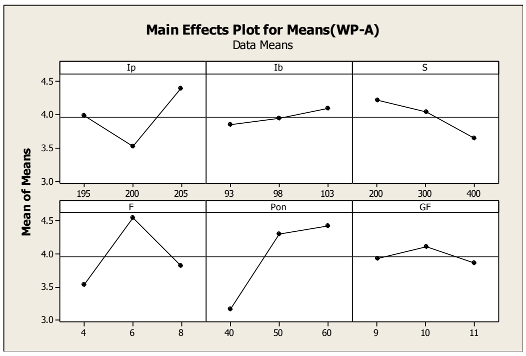

Fig.6 Effects of Process Parameters on WP-A (Raw Data)

Though from Fig.6 Ib process parameter not as significant as other parameters. As the welding speed (S) decreases the penetration (A) value go on increasing this is mainly because, lesser the speed complete melting of submerged filler material and base metal leads to complete diffusion of filler metal in to base metal and forms a perfect joint. As the Frequency (F) increases penetration (A) go on increasing proper diffusion of filler metal in to the base metal so the penetration (A) value increases. But further increase in the F from 6Hz more penetration than required leads to undercut and decrease in penetration (A) value.

From the Table 4 it was found that Gas flow rate (GF), Base current (Ib) and welding speed (S) are lesser percentage of contribution (P%) i.e. non significant process parameters for penetration (A). As penetration (A) is the 'higher the better' type quality characteristic, it can be seen from Fig.6 that the III level of Ip , III level of Ib, I level of S, II level of F, III level of Pon and II level of GF provide maximum value of penetration (A).

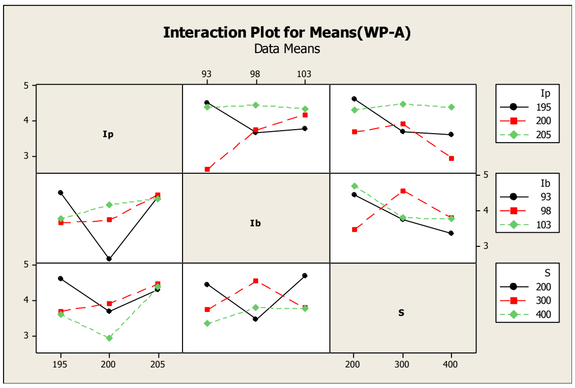

Fig. 7 Effects of Interactions on WP-A (Raw Data)

The optimal GTAW process parameters for maximum penetration (A) are Ip-205A , Ib-103A, S-200mm/min, F-6Hz, Pon=60%, and GF-10 lit/min. Fig. 7 reveal that the interactions between Peak current (Ip), Base current (Ib), Welding speed (S) affect highly the output responses since the responses are not parallel to each other. So our suspected interactions are significant on responses.

Effect on Face width (B)

The face width (B) was considered as the quality characteristic with the concept of "the smaller-the-better". The average values of face width (B) for each parameter at levels 1, 2 and 3 for raw data are plotted in Fig.8. From this Fig it clears that Peak current (Ip), welding speed (S), pulse on time (Pon) and gas flow rate (GF) are the most significant process parameters compared to other process parameters. Fig.8. shows that as the increase in Peak current (Ip) up to 200A the face width (B) value decreases and face width (B) value increases with further increase in Ip value. This is because at low Ip up to 200 Amp the heat input is less and it is not sufficient to melt base metal with the filler material. The Peak current (Ip) more than 200A gives more heat and it melts the base metal with filler metal completely and increases face width (B). So Peak current (Ip) play an important role in the determination of face width (B) value. As the base current (Ib) increases the up to 98 A the face width (B) value go on increasing and after 98 A further increase in Ib value there is decrease in face width (B) value. As the base current (Ib) increases higher the value of face width (B). This is because the Ib is mainly helpful in maintaining continuous arc during welding [13], so it melts more base metal and filler material in narrow direction so face width (B) increases. On the other hand from Fig. 8 Ib process parameter not as significant as other parameters.

As the higher welding speed (S) lesser the time for the contact between arc and base material with submerged filler material, this leads to lesser face width (B). The decrease in welding speed (S) increases the face width (B) this is because more time for contact between arc and face of base metal with submerged filler material. As the frequency (F) increases face width (B) go on decreasing this is because more pulse rate and more heat contact in narrow direction. Similar observation made by investigators [13] in welding of AISI 304L.

Table 4 Analysis of Variance for Means (A)

Source	DF	Seq SS	Adj SS	Adj MS	F	P %
Ip	2	3.5150	3.5150	1.7575	2.78	**11.2563**
Ib	2	0.2850	0.2850	0.1425	0.23	0.9126
S	2	1.5439	1.5439	0.7719	1.22	4.9441
F	2	4.8106	4.8106	2.4053	3.81	**15.4054**
Pon	2	8.7072	8.7072	4.3536	6.89	**27.8838**
GF	2	0.2839	0.2839	0.1419	0.22	0.9091
Ip*Ib	4	4.8067	4.8067	1.2017	1.90	**15.3929**
Ip*S	4	2.0311	2.0311	0.5078	0.80	6.5043
Ib*S	4	3.9794	3.9794	0.9949	1.57	**12.7435**
Residual Error	2	1.2639	1.2639	0.6319		4.0474
Total	26	31.2267				100
S = 0.7949 R^2 = 96.0%						

From the Table 5 it was found that Ip,Ib,S, and F are lesser percentage of contribution (P%) i.e. non significant process parameters for face width (B). From these tables, it is also clear that pulse on time (Pon), and interaction factors are more significant compare to individual process parameters. These are significantly affected both the mean and the variation in the face width (B) values. As face width (B) is the 'lower the better' type quality characteristic, it can be seen from Fig.9 that the II level of Ip , I level of Ib, III level of S, II level of F, I level of Pon and III level of GF provide minimum value of face width (B). The optimal GTAW process parameters for minimum face width (B) are Ip-205A , Ib-103A, S-200mm/min, F-6Hz, Pon=60%, and GF-10 lit/min. Fig.9 reveal that the interactions between Peak current (Ip), Base current (Ib), Welding speed (S) affect highly the output responses since the responses are not parallel to each other. So our suspected interactions are significant on responses.

Effect on Back width (C)

The back width (C) was considered as the quality characteristic with the concept of "the smaller-the-better". The average values of back width (C) for each parameter at levels 1, 2 and 3 for raw data and S/N data are plotted in Fig. 10. From the Fig.10 it clears that Peak current (Ip), welding speed (S), pulse on time (Pon) are the most significant process parameters compared to other process parameters.

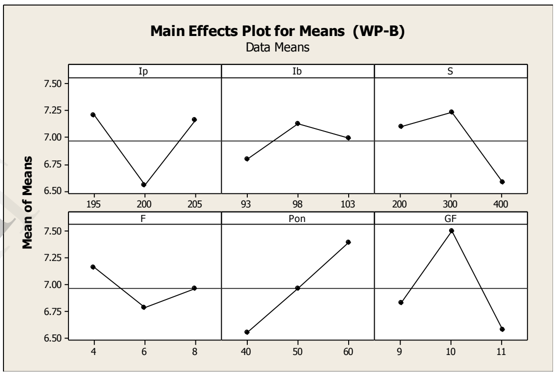

Fig. 8 Effects of Process Parameters on WP-B (Raw Data)

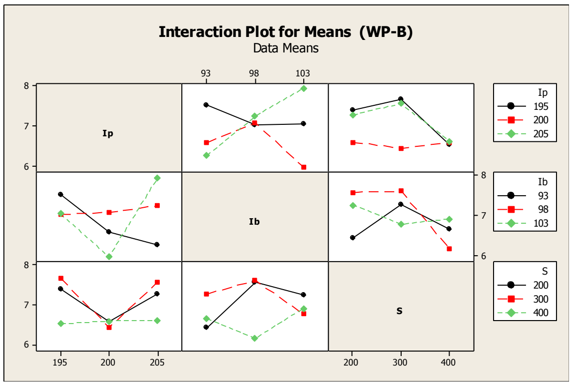

Fig.9 Effects of Interactions on WP-B (Raw Data)

Fig.10 shows that as the increase in Peak current (Ip) up to 200A the back width (C) value decreases and back width (C) value increases with further increase in Ip value. This is because at low Ip up to 200 Amp the heat input is less and it is not sufficient to melt the metal and reach the root. The Peak current (Ip) more than 200A gives more heat and it melts the base metal with filler metal completely and reach the root with more back width (C). So Peak current (Ip) play an important role in the

determination of back width (C) value. As the base current (Ib) increases the up to 98 A the back width (C) value go on increasing and after 98 A further increase in Ib value there is decrease in back width (C) value. As the base current (Ib) increases higher the value
of back width (C). This is because the Ib is mainly helpful in maintaining continuous arc during welding [13], so it melts more base metal and filler material towards the root so back width (C) increases. However from Fig.10 Ib process parameter not so significant as other parameters. As the higher welding speed (S) lesser the time for the contact between arc and base material with submerged filler material, this leads to lesser back width (C).

Table 5 Analysis of Variance for Means (WP-B)

Source	DF	Seq SS	Adj SS	Adj MS	F	P %
Ip	2	2.3735	2.37352	1.18676	100.92	**9.8462**
Ib	2	0.4891	0.48907	0.24454	20.80	2.0289
S	2	2.0830	2.08296	1.04148	88.57	8.6411
F	2	0.6430	0.64296	0.32148	27.34	2.6674
Pon	2	3.2096	3.20963	1.60481	136.47	**13.3146**
GF	2	4.0946	4.09463	2.04731	174.10	**16.9860**
Ip*Ib	4	6.1348	6.13481	1.53370	130.43	**25.4495**
Ip*S	4	1.4959	1.49593	0.37398	31.80	6.2055
Ib*S	4	3.5587	3.55870	0.88968	75.66	**14.7628**
Residual Error	2	0.0235	0.02352	0.01176		0.0974
Total	26	24.1057				100
S = 0.1084 R^2 = 99.9%						

The decrease in welding speed (S) increases the back width (C) this is because more time for contact between arc and face of base metal with submerged filler material. As the frequency (F) increases back width (C) go on decreasing this is because more pulse rate and more heat contact in narrow direction. Similar observation made by investigators [13] in welding of AISI 304L.

From the Table 6 it was found that gas flow rate (GF), base current (Ib) and frequency (F) are lesser percentage of contribution (P%) i.e. non significant process parameters for back width (C). From these tables, it is also clear that pulse on time (Pon), welding speed (S), and peak current (Ip), and interaction (Ip*Ib) significantly affect both the mean and the variation in the back width (C) values.

As back width (C) is the 'smaller the better' type quality characteristic, it can be seen from Fig.10 that the II level of Ip , II level of Ib, III level of S, III level of F, I level of Pon and I level of GF provide minimum value of back width (C). The optimal GTAW process parameters for minimum back width (C) are Ip-200A , Ib-98A, S-400mm/min, F-8Hz, Pon=40%, and GF-9 lit/min. Fig.11 reveal that the interactions between Peak current (Ip), Base current (Ib), Welding speed (S) affect highly the output responses since the responses are not parallel to each other. So our suspected interactions are significant on responses.

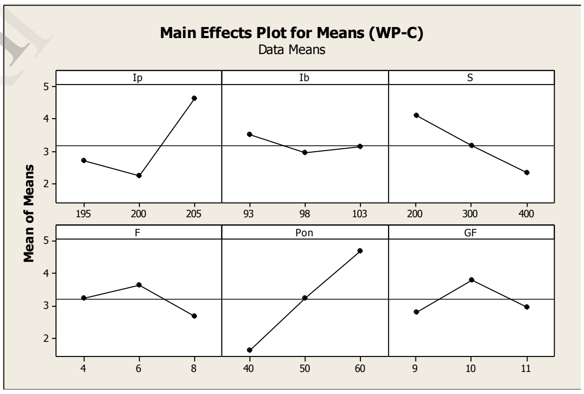

Fig. 10 Effects of Process Parameters on WP-C (Raw Data)

4.3.2 Multi response optimization using Taguchi and Utility concept and its confirmation.

Fig. 12 and 13 show graphically the effect of the six GTAW Process Parameters and its interactions on, Utility (A,B,C). The data from Table 4 are plotted in Fig.12 it is clear from the Fig. that GTAW process parameters at level Ip-3,Ib-3,S-1, F-2, Pon-2 and GF-3 yield best performance in terms of Utility value within the selected range of process parameters. Fig.13 reveal that the interactions between Peak current (Ip), Base current (Ib), Welding speed (S) affect highly the output responses since the responses are not parallel.

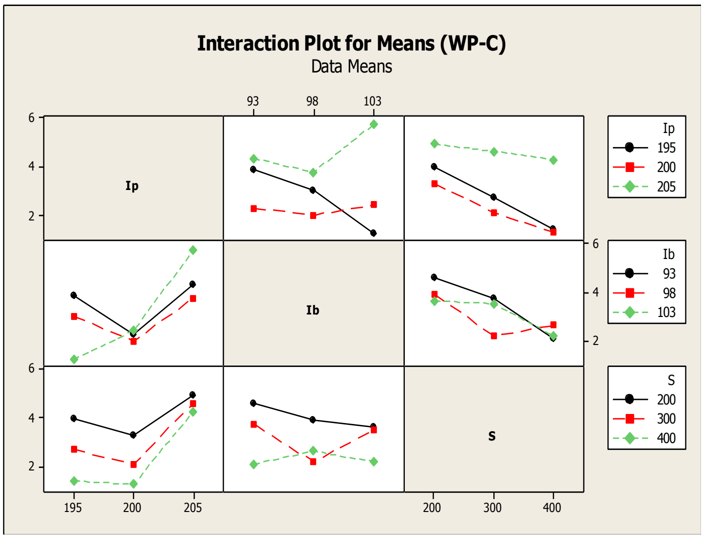

Fig.11` Effects of Interactions on WP-C (Raw Data)

Table 6 Analysis of Variance for Means (WP-C)

Source	DF	Seq SS	Adj SS	Adj MS	F	P %
Ip	2	28.572	28.572	14.2859	21.96	**23.6468**
Ib	2	1.420	1.420	0.7101	1.09	1.1752
S	2	13.795	13.795	6.8973	10.60	**11.4170**
F	2	4.339	4.339	2.1693	3.33	3.5910
Pon	2	42.972	42.972	21.4859	33.02	**35.5646**
GF	2	4.894	4.894	2.4470	3.76	4.0503
Ip*Ib	4	15.886	15.886	3.9715	6.10	**13.1476**
Ip*S	4	2.991	2.991	0.7479	1.15	2.4754
Ib*S	4	4.658	4.658	1.1645	1.79	3.8550
Residual Error	2	1.301	1.301	0.6506		1.0767
Total	26	120.828				100
S = 0.8066 R^2 = 98.9%						

The Analysis of Variance (ANOVA) for mean of Utility values (A, B and C) is given in Table 7. By observing percentage of contribution in the Table 7 it clears that, among all the process parameters Frequency (F) 21.351% is the most significant parameter. And also it is found that interactions, especially (Ip*Ib) 31.465% and (Ib*S) 18.755% are most significant, in determining Utility values, so selected interaction is most affective in analysis. And for Residual Error percentage of contribution is 4.537%. The percent of contribution due to error provides an estimate of adequacy of the experiment and should not be more than 50%. If the percent contribution due to error is low (15% or less), then it is assumed that no important factors were omitted from the experiment [15].Although factors Ip,Ib and S do not show significant effect but significant interaction (Ip*Ib), (Ip*S) and (Ib*S) is observed for Utility values (A, B and C) as shown in Table 7 and Fig.13.So, it is recommended to use the process parameters at level Ip_3, Ib_3, S_1, F_2, P_{on2} and GF_3 yield best performance in terms of Utility value i.e. to get maximum penetration (A), minimum face width (B) and minimum back width (C).

4.4 Confirmation of experiments

The optimal combination of GTAW process parameters has been determined in the previous analysis. Still the final step is to predict and verify the improvement of the observed values through the use of the optimal combination level of GTAW process parameters. In the WP-A response Ib, S, and GF are least significant compared to other process parameters. But the interactions Ip*Ib and Ib*S are significant so process parameters Ib and S also considered in prediction equation.

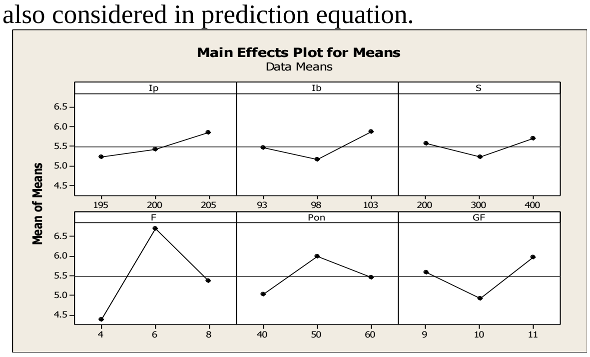

Fig. 12 Effect of GTAW process parameters on Utility values (A,B &C) Raw Data

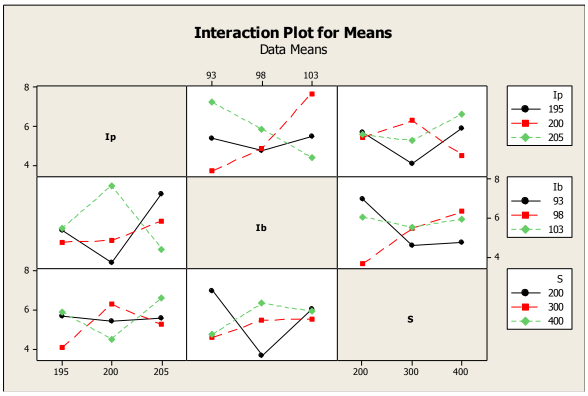

Fig. 13 Effects of GTAW Interactions on Utility values (A,B &C) Raw Data

Considering significant factors the predicted optimal value calculated by the following equations:

$$\mu_A = \bar{T} + (\bar{I}_{p3} - \bar{T}) + (\bar{I}_{b3} - \bar{T}) + [(\bar{I}_{p3}\bar{I}_{b3} - \bar{T}) - (\bar{I}_{p3} - \bar{T}) - (\bar{I}_{b3} - \bar{T})] + (\bar{S}_1 - \bar{T}) + [(\bar{I}_{b3}\bar{S}_1 - \bar{T}) - (\bar{I}_{b3} - \bar{T}) - (\bar{S}_1 - \bar{T})] + (\bar{F}_2 - \bar{T}) + (\overline{P_{on3}} - \bar{T})$$

…. (9)

By combining like terms, the prediction equation reduces to

$$\mu_A = \bar{I}_{p3}\bar{I}_{b3} + \bar{I}_{b3}\bar{S}_1 - \bar{I}_{b3} + \bar{F}_2 + \overline{P_{on3}} - 2\bar{T} \quad \ldots (10)$$

Where,

$\bar{T}$= overall mean of WP-A = 3.96mm

And remaining values are determined from the plot as shown in Fig.6 and Fig.7.Substituting the values of various terms in the above equation no.10 and its values are given in Table 9. A experimental set up with GTAW process parameters levels are III level of Ip , III level of Ib, I level of S,II level of F, and III level of Pon provide maximum value of WP-A, non significant process parameters considered at economical value. Above prediction equation is considered to predict the WP-A value.

The predicted optimal value for the remaining weld pool geometry responses (WP-B, WP-C) calculated by the following equations:

$$\mu_B = \bar{T} + (\bar{I}_{p2} - \bar{T}) + (\bar{I}_{b3} - \bar{T}) + [(\bar{I}_{p2}\bar{I}_{b3} - \bar{T}) - (\bar{I}_{p2} - \bar{T}) - (\bar{I}_{b3} - \bar{T})] + (\bar{S}_3 - \bar{T}) + [(\bar{I}_{b3}\bar{S}_3 - \bar{T}) - (\bar{I}_{b3} - \bar{T}) - (\bar{S}_3 - \bar{T})] + (\overline{P_{on1}} - \bar{T}) + (\overline{GF_3} - \bar{T})$$

…. (11)

By combining like terms, the prediction equation reduces to

$$\mu_B = \bar{I}_{p2}\bar{I}_{b3} + \bar{I}_{b3}\bar{S}_3 - \bar{I}_{b3} + \overline{P_{on1}} + \overline{GF_3} - 2\bar{T} \quad \ldots (12)$$

Where,

$\bar{T}$= overall mean of WP-B = 6.97 mm

All remaining values are determined from the plot as shown in Fig.8 and Fig. 9.

Similarly for predicted optimal value for WP-C

$$\mu_C = \bar{T} + (\bar{I}_{p2} - \bar{T}) + (\bar{I}_{b2} - \bar{T}) + [(\bar{I}_{p2}\bar{I}_{b2} - \bar{T}) - (\bar{I}_{p2} - \bar{T}) - (\bar{I}_{b2} - \bar{T})] + (\bar{S}_3 - \bar{T}) + (\overline{P_{on1}} - \bar{T})$$

…(13)

By combining like terms, the prediction equation reduces to

$$\mu_C = \bar{I}_{p2}\bar{I}_{b2} + \bar{S}_3 + \overline{P_{on1}} - 2\bar{T} \quad \ldots (14)$$

Where,

$\bar{T}$= overall mean of WP-C=6.87mm

All values are determined from the plot as shown in Fig.10 and Fig. 11.

Table 9 Optimal value as per prediction equation

Optimum condition	**Responses**	**Optimum value**
Ip-205A, Ib-103A, S-200mm/min, F-6Hz, Pon-60%,	Penetration (A)	5.8mm
Ip-200A, Ib-103A, S-400mm/min, Pon-40%, GF-11lit/min	Face width(B)	5.08mm
Ip-200A, Ib-98A, S-400mm/min, Pon-40%	Back width (C)	0.1mm

Table 7. Analysis of Variance (ANOVA) for Means of Utility values (A, B and C)

Source	DF	Seq SS	Adj SS	Adj MS	F	P%
Ip	2	1.764	1.764	0.8818	0.34	1.544
Ib	2	2.232	2.232	1.1160	0.43	1.954
S	2	1.103	1.103	0.5514	0.21	0.965
F	2	24.381	24.381	12.1904	4.71	**21.351**
Pon	2	4.215	4.215	2.1075	0.81	3.691
GF	2	5.238	5.238	2.6189	1.01	4.587
Ip*Ib	4	35.931	35.931	8.9826	3.47	**31.465**
Ip*S	4	12.729	12.729	3.1823	1.23	**11.147**
Ib*S	4	21.417	21.417	5.3543	2.07	**18.755**
Residual Error	2	5.181	5.181	2.5904		4.537
Total	26	114.190				100
S =1.609 R^2 = 95.5%						

The optimum combination is observed in weld pool geometry responses i.e. A, B, and C are given in the following Table 9. For validations of the optimum results, experiments are conducted as per the optimum conditions and weld pool geometry are evaluated and the averages of

Optimum condition	Responses	Optimum value	Expt. value
Ip-205A, Ib-103A, S-200mm/min, F-6Hz, Pon-60%, GF-10lit/min	Penetration (A)	5.8mm	5.1mm
Ip-200A, Ib-93A, S-400mm/min, F-6Hz, Pon-40%, GF-11lit/min	Face width(B)	5.08mm	5.2mm
Ip-200A, Ib-98A, S-400mm/min, F-8Hz, Pon-40%, GF-9 lit/min	Back width (C)	0.1mm	0.5mm

two test results are presented in Table 10. It is observed that, experimental values were closer to the optimum values.

The predicted mean for Utility value can be calculated with the help of following prediction equation

$$\mu_{ABC} = \bar{T} + (\bar{I}_{p3} - \bar{T}) + (\bar{I}_{b3} - \bar{T}) + [(\bar{I}_{p3}\bar{I}_{b3} - \bar{T}) - (\bar{I}_{p3} - \bar{T}) - (\bar{I}_{b3} - \bar{T})] + (\bar{S}_1 - \bar{T}) + [(\bar{I}_{b3}\bar{S}_1 - \bar{T}) - (\bar{I}_{b3} - \bar{T}) - (\bar{S}_1 - \bar{T})] + (\bar{F}_2 - \bar{T}) + (\overline{P_{on2}} - \bar{T}) + (\overline{GF_3} - \bar{T}) + [(\bar{I}_{p3}\bar{S}_1 - \bar{T}) - (\bar{I}_{p3} - \bar{T}) - (\bar{S}_1 - \bar{T})] \quad \text{.... (15)}$$

By combining like terms, the prediction equation reduces to

$$\mu_{ABC} = \bar{I}_{p3}\bar{I}_{b3} + \bar{I}_{b3}\bar{S}_1 + \bar{I}_{p3}\bar{S}_1 - \bar{I}_{b3} + \bar{F}_2 + \overline{P_{on2}} + \overline{GF_3} - \bar{I}_{p3} - \bar{S}_1 - 2\bar{T} \quad \text{.... (16)}$$

Above values are determined from the Table. 4 and plot as shown in Fig.13 and 14. Substituting the values of various terms in the above equation no. 10 and it is found to be

Prediction Utility $(\mu_{ABC}) = 8.293$. Two confirmation experiments have been conducted at the optimum settings of the process parameters i.e. Ip=205A, Ib=103A, S=200mm/min, F=6Hz, Pon=50% and GF=11 lit/min. Two specimens at optimal condition as shown in the Fig.15.The average values for weld pool geometry are A=3.7mm, B=5.2mm, and C=2.5mm.

The actual Utility value of the weld pool geometry has been calculated using the equation 3 and it is found that μ_{ABC} =8.390. The predicted utility value and actual utility values are very close together so the adequacy of the Utility value model of GTAW specimen as given below (Eqn.3) is justified and the results are validated.

U (n, R) = P_A (n, R) x W_A + P_B (n, R) x W_B + P_C (n, R) x W_C

As per the trial and data hand book the usual GTAW process parameters (Initial process parameters) for welding GTAW of AA 7075-T6 alloys are Ip-200A,Ib-93A,S-200mm/min, F-4Hz,Pon-50%,GF-9 lit/min . With these process parameters the average values for weld pool geometry are A=4.7mm, B=6.2mm, and C=3.5mm. And the utility value is μ_{ABC} =6.030. So by comparing utility values with initial and optimal process parameters it can be seen that weld pool geometry are greatly improved by optimization technique.

5 CONCLUSIONS

The present work is concerned to determine the optimum setting of process parameters for multi-response optimization during GTAW of AA7075–T6 Aluminium alloy. On the basis of Taguchi approach and Utility concept, a model was developed to attain this. The L_{27} OA was used for experimental planning. In multi-response, the analysis of means establishes that a combination of higher levels of Peak current, Base current, Gas flow rate and lower level of welding speed and intermediate level of Pulse on time, and Frequency is essential to achieve simultaneous maximization of Penetration and minimization of Face width and Back width. Based on the ANOVA the most statistical significant

Table 10 Validation of optimum results

and percent contribution of the process parameters for multiple performances is, Frequency (F) is the most significant parameter. And also it is found that interactions, especially (Ip*Ib) and (Ib*S) are most significant, in determining Utility values, so interaction consideration is most affective in analysis. The validation experiment confirmed that the adequacy of Utility value model is justified. It is found that the proposed model based on Taguchi approach and Utility concept is useful and provides an appropriate solution for multi-response optimization problems.

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