Weldability Study of Aluminium Alloy AA6063 by Tungsten Inert Gas Welding and Optimization of Weld Conditions by Analytical Hierarchy Process

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Abstract - Welding of aluminium alloys and composites is interesting research subject due to the many challenges encountered during the process. As aluminium finds several applications due to its lightness and high strength-to-weight ratio, thus welding of the same with improved weldability has remained an important area of research. Among the several welding processes, Tungsten Inert Gas (TIG) welding is widely used for welding of aluminium. In this work, AA6063 aluminium alloy samples were TIG welded using ER4043 filler material of diameter 2 mm. Central Composite Design (CCD) of Response Surface Methodology (RSM) was the design of experiment. Heat Input (kJ/mm) and Gas flow rate (l/min) were input factors of two levels each. Responses were measured as bead geometry (depth of penetration, bead width and height of reinforcement), hardness and visual impressions (cracks, blowholes and pinholes). Heat input values of 0.355kJ/mm,0.408kJ/mm, 0.48kJ/mm and gas flow rates of 8l/min, 12l/min and 16l/min were considered. In this research work, Analytical Hierarchy Process (AHP) was utilised to optimize the TIG welding process parameters to obtain the best combination for sound weldability. It was observed that optimal weld condition was obtained at heat input of 0.702 kJ/mm and gas flow rate, 14 l/min.

Key Words: Tungsten Inert Gas welding, aluminium alloy, bead geometry, visual impressions, optimize

1.INTRODUCTION

Over the years, aluminium and its alloys and composites have found several applications in different industries such as aerospace, robotics and manufacturing sector. Thus, fabrication of these parts becomes an integral subject of research. Welding is one of the most important fabrications and joining technique. Aluminium alloys and composites are mostly joined by TIG welding. During welding process, heat input and shielding gas flow rate have significant influence on weld quality. The optimization of TIG welding process parameters is very essential in selection of appropriate process parameter combination for yielding good quality weld. Analytical Hierarchy Process (AHP) is one of the optimization tools used. It is an efficient multi-criteria decision-making tool that can be utilized for the selection of welding processes for the right parameter of welding.

Influence of interfacial reactions between matrix and reinforcement on the fracture behaviour of arc welded aluminium alloy reinforced with SiC was investigated by Urena et. al [1]. TIG welding was conducted on sheets (4 mm thick) of AA2014/SiC/Xp (X indicate 6, 13 and 20 vol%, respectively). Tensile test was performed on welded samples. Results revealed that failure in weld metal had tensile strength lower than 50% of parent metal. Comparison of welded parts with parent metal w.r.t. fracture was analyzed. SEM analysis of the welded parts was conducted. Interfacial failures increased due to formation of $Al4C3$which reduced the strength of weldment. Wang Xi-he et. al [2] investigated the weldability of SiCp/6061 Al composites using He–Ar mixture as shielding gas. Welding was performed under autogeneous condition and using Al–Si filler metal. Welded samples using filler metals were subjected to microstructure analysis. Addition of 50% volume helium in shielding gas enhanced the arc stability and resulted in weldments with improved appearance. Weld centre exhibited distribution of SiC particles at the centre. Also, welded joints using filler metals were 70% more than composite metals under annealed conditions. Mechanical properties and wear characteristics of TIG welded dissimilarAA6061-T6 and AA7075-T6aluminium alloys were examined by Reyaz and Sinha [3]. Both micro and macrographic examinations were conducted to study the changes in terms of heat input. Strength of welded joints were examined by tensile, impact, residual and wear tests. Results showed that joints with increased heat input exhibited improved tensile strength, impact toughness, residual stress and wear resistance. However, excess heat input was undesirable as it produced coarser grains and porosities. Highest ultimate tensile strength of 178 MPa, largest elongation of 12.6% and highest impact toughness of 13 J were obtained at welding current of 145 A, torch travel speed of 78 mm/min and heat input of 1.67 kJ/mm. Pulsed TIG welding was used to improve grain structure and mechanical properties of AA6061-T6 and AA7075-T6 dissimilar aluminium welds by Reyaz et. al [4]. Peak currents of 110, 120, 165, and 175 A and pulse frequencies of 4, 8, 12, and 16 Hz were used at constant base current, pulse on time and shielding (argon)gas flow rate. Optimum void free joint was obtained with maximum tensile strength of 201 MPa, elongation of 17%, microhardness of 101 HV and compressive residual stresses of 76 MPa. Microstructure study showed that with increasing pulsed current and pulse frequency, there was more grain refinement and grain boundary transformation around the fusion zone. Jayashree et. al [5] investigated on sliding wear characteristics of TIG-welded Al6061 reinforced with SiC. TIG welding was performed using ER5356 as filler material. Weld current used were 150, 170 and 200A. Effect of TIG welding on hardness and wear resistance were examined. Hardness test was conducted on base metal, weld bead and heat affected zone. Results showed that hardness increased with increased weld current. Decrease in wear rate and weight loss resulted due to increased weld current. SEM was performed to study the microstructure of welded and unwelded parts. In another experimental investigation by Jayashree et. al [6], fractography analysis and improvement of mechanical properties, such as hardness and tensile strength of Al6061-SiC reinforced composites were examined during artificial aging at 100, 150 and 200 °C. The composite with 0, 8, 10 and 12 wt.% fractions of silicon carbide grits were TIG welded using ER5356filler material. Results showed higher hardness and lower tensile strength for the composite under non-homogenized and artificially aged condition. Microstructure study showed dendritic segregation in non-homogenized specimen and after homogenization reduction in dendritic segregation, resulting in enhanced hardness and tensile strength. Also, improvement in properties was obtained due to the combined effect of homogenizing and lower temperature aging. Raj et. al [7] investigated on effect of various factors on TIG welded dissimilar aluminium magnesium alloy AA5083-H111 and AA5052-H32 by using ER5356 filler rod and scandium added ER5356 composites. These alloys have wide application in aerospace and automobile sectors and thus reduction of micro-pores was an objective. Weld current, gas flow rate and wt% of Scandium were the input parameters of three levels each. Microstructure, macrostructure and mechanical properties of welded joints were examined. Gray relation analysis was used to optimize the process parameters to obtain enhanced mechanical properties. It was observed that optimal weld condition was obtained at 190 A weld current, gas flow rate of 10 l/min and 0.50% scandium added ER5356. In another experiment on dissimilar welding of Al 7075 alloy to Al 6061 alloy, Raju et. al [8] investigated on hot crack behaviour of weldment by finding a relationship between welding current and Ultrasonic Vibration Technique (UVT) input power. Central composite design of Response surface methodology was used as design of experiment to find a relationship among the parameters. Effect of each parameter was obtained by analysis of variance (ANOVA) and UVT had the maximum influence on weld quality. Optimal parametric condition was obtained at weld current of 90 A welding current and 1.25 kW UVT input power, resulting in hot crack behaviour of -0.897 mm. Optimal process parameters for low hot cracking susceptibility and improved microhardness of ultrasonic-assisted tungsten inert gas welding of AA7075 joints was investigated by Annamalai et. al [9]. Response surface methodology with Genetic algorithm was used as design of experiment. Process parameters considered were weld current, gas flow rate, presence and absence of ultrasonic vibration. Hot crack sensitivity and microhardness of the weldment were the responses. Optimal condition was obtained at weld current of 120 A, gas flow rate of 13 l/min with Ultrasonic vibration and filler material with hot cracking sensitivity of 0 % and microhardness of 117.76 HV. Jayashree et. al [10] investigated on mechanical properties and microstructure of TIG welded Al6061 MMC containing 6% weight SiC using ER5356 filler material. Three levels of welding current of 150, 170 and 200A were used. Improvement in ultimate tensile strength was observed at 150 A weld current with decrease in UTS values and elasticity for corresponding increase in weld current. Also, compared to unwelded samples, there was an increase in impact strength at 150 A weld current.

Analytical Hierarchy Process (AHP) was applied by Faleh and Doos [11] to select the optimal weld condition in an experimental investigation involving previously obtained data. The process is a multi-criteria decision-making process and it was observed that the result obtained matched with the previous results. Ahsan et. al [12] compared the prediction of detecting weld defects in ship construction using a rejection ratio method and a demerit chart. The latter was based on application of Analytical Hierarchy Process. Results suggested that demerit chart was more effective in proper detection of weld defects compared to rejection ratio. Application of AHP was made by Jayant and Singh [13] to select the appropriate welding process for high pressure welding application. Twelve parameters were considered for selection of the best welding process from a range of five processes. In a similar investigation by Capraz et. al [14], AHP helped in deciding suitable welding process for plain carbon steel storage tank. Sarkar et. al [15], applied AHP to find the optimal weld condition for submerged arc welding of plain carbon steel. Input factors considered were wire feed rate, stick out and traverse speed. Bead geometry (depth of penetration, bead width and height of reinforcement) was the response considered. Taguchi was used as design of experiment. The technique of AHP helped to optimize process parameters in gas metal arc welding of austenitic stainless steel which involved butt joint of 4mm thick plates as investigated by Gope et. al [16]. In an attempt to analyze and minimize defects in bridges, Rashidi et. al [17] developed a model based on simplified AHP which applied a multi criteria decision making technique.

Investigation on process parameters for obtaining good quality weld in Gas Tungsten Arc Welding of Aluminium Alloy AA6063using Analytic Hierarchy Process was made.

2. Development of Analytical Hierarchy Architecture

Analytic hierarchy Process is a simple but powerful Multi Criteria Decision Making (MCDM) process for taking any logical decision in wide variety of field of application. Thomas L. Saaty introduced this mathematical model in 1970s. Both qualitative and quantitative factors or multi criteria are used in this analytical hierarchy process.

The hierarchy structure visually depicts the relationship between the goal, criteria, sub-criteria (if applicable), and alternatives, with the goal at the top and alternatives at the bottom. Decision-makers use this hierarchical structure to systematically evaluate and compare the importance of criteria, sub-criteria, and alternatives through pairwise comparisons, ultimately leading to informed decision-making. The weights are assigned as number from one to nine with preferential parameters assigned to each number. These numbers are known as ratio scale of the comparative matrix. The structure is shown in Table 1, which was developed by Thomas L. Saaty [11].

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Table -1: Ratio Scale of Comparison Matrix

Scale Value	Qualitative Comparison
9	Extremely Preferred
8	Very strongly to extremely Preferred
7	Very strongly Preferred
6	Strongly to very strongly Preferred
5	Strongly Preferred
4	Moderately to strongly Preferred
3	Moderately Preferred
2	Equally to moderately Preferred
1	Equally Preferred

This scale helps decision-makers assign numerical values to pairwise comparisons between criteria, sub-criteria, or alternatives. These values are utilized to construct comparison matrices, which are key components of the AHP methodology. By applying the preference parameters consistently, decision-makers can quantify their subjective judgments and derive weighted scores for each criterion or alternative in the decision hierarchy.

Complete the pairwise comparisons and assign weights to each criterion and alternative. Calculate the Consistency Ratio (CR) for each pairwise comparison matrix using the formula, CR=RI/CI, where CI indicates Consistency Index and RI indicates Random Index obtained from Table 2.

Table -2: Value of Random Index corresponding to the Rank of Matrix

Rank of matrix	Random Index
3	0.58
4	0.89
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.58

Once consistency is confirmed (if $CR < 0.1$ for all matrices), determine the overall importance of every alternative, by aggregating the weights according to the hierarchy. Choose the alternative with the highest overall priority as the optimum parameter.

This process ensures that the decision-making in the Analytical Hierarchy Process (AHP) is not only systematic but also consistent, leading to a reliable selection of the best alternative.

3. Methodology

In this study, the analytical hierarchy process is utilized for the selection of optimum conditions for the welding process. For the construction of the mathematical model experimental data obtained from autogeneous TIG welding process of AA6063 Aluminium Alloy is considered. A combination of quantitative criteria (depth of penetration, bead width, height of reinforcement and hardness) and qualitative elements (presence of cracks, blowholes and pinholes) were considered that affect the quality of the weld.

Table -3: Criteria chosen to determine the best quality weld

Symbol	Criteria
C1	Depth of Penetration
C2	Bead Width
C3	Reinforcement Height
C4	Hardness
C5	Presence of Blow hole and Pin Hole

Five criterions were selected for selection of optimal condition for the TIG welding process as shown in Table 3. Based on Central Composite Design (CCD) of Response Surface Methodology (RSM) design of experiment, thirteen number of experiments were conducted which are considered as alternatives.

3.1 Identifying the limits of the GTAW process parameters

Autogenous TIG welding was performed on AA6063 aluminium alloy samples using Heat Input (kJ/mm) and Gas Flow Rate (l/min) as input factors of three levels each. Trial runs were performed for determining the range of values for the above-mentioned factors. Finally, the following levels were considered for experimentation as shown in Table 4.

Table -4: Welding Factors and their levels

Factors	Level 1 (-1)	Level 2 (0)	Level 3 (+1)
Heat Input (kJ/mm)	0.355	0.408	0.48
Gas flow rate (l/min)	8	12	16

3.2 Developing the experimental design matrix

Experimental runs using three factors and two levels were undertaken, using Response Surface Methodology (RSM) design of experiment. Various combinations of input factors are shown in Table 5.

Table -5: Combination of Input Factors for GTAW

Sl. No.	Heat input (Coded Value)	Gas flow rate (Coded Value)	Heat input (Coded Value)	Gas flow rate (Coded Value)
1.	-1	-1	0.355	8
2.	+1	-1	0.48	8
3.	-1	+1	0.355	16
4.	+1	+1	0.48	16
5.	-1	0	0.355	12
6.	+1	0	0.48	12
7.	0	-1	0.408	8
8.	0	+1	0.408	16
9.	0	0	0.408	12
10.	0	0	0.408	12
11.	0	0	0.408	12
12.	0	0	0.408	12
13.	0	0	0.408	12

3.3 Performance of TIG welding experiment

TIG welding using argon (99.99% pure) as shielding gas was performed on AA6063 aluminium alloy of 10 mm plate thickness. ER4043 rods of 2 mm diameter were used as filler material. The machine setup is shown in Figure 1 with the following specification:

i) Type- E 400

ii) Maximum Continuous Hand Welding- 8 KVA

iii) Welding Current Range at 55 OCV - 60 to 400 AMPS

iv) Maximum Continuous Hand welding Current- 55 OCV- 200 AMP

v) Input (Primary) Current at Rated Output- 22 AMPS

vi) Secondary OCV- 55 Volts

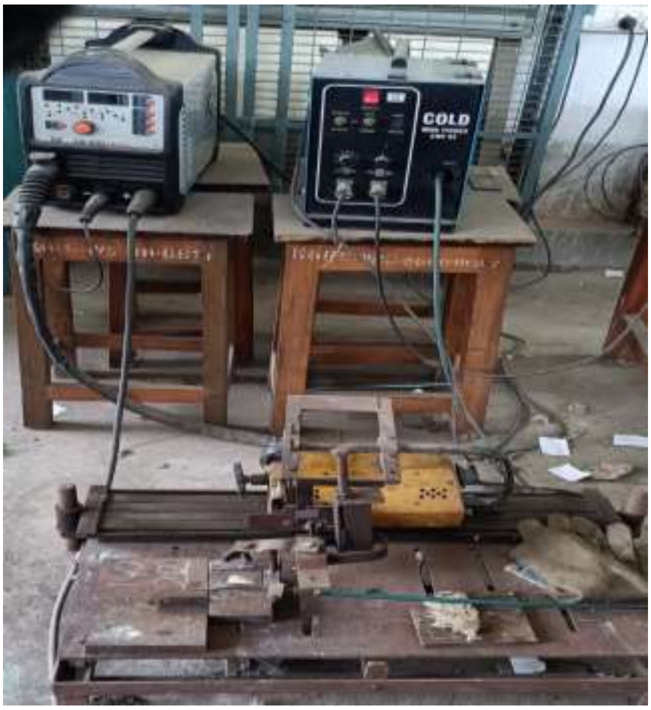

Fig -1: GTAW Welding Machine

AA6063 aluminium alloy samples of dimensions 40 mm x 50 mm x15 mm, were cut into 26 pieces. Cleaning of base material was performed and followed by edge preparation of the samples. After that, GTAW is done resulting in 13 pairs of weldments. During welding, two factors were considered as input, i.e. Heat Input and Gas Flow Rate. After welding, we check the output parameters of the material in the form of weld bead geometry. The visual inspection results of TIG welding have been summarized in Table 6.

Table -6: Typical visual inspection results of welded samples

Sl. No.	Weld Picture	Inspection Remarks
1.		Minute pin holes on bead surface.
2.		Even weld profile throughout.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

3.		Minute pin hole on bead surface.
4.		Smooth weld profile throughout.

4. Results and Application of Analytical Hierarchy Process

The results of TIG welding, i.e. bead geometry and hardness measurement are summarized in Tables 7 and visual inspection results in Table 8.

Good weldability	C1	C2	C3	C4	C5	Geometric Mean	Criteria Weight
C1	1	3	5	1/3	1/2	1.2011	0.186
C2	1/3	1	2	1/2	1/5	0.5818	0.0901
C3	1/5	1/2	1	1/4	1/6	0.3342	0.0517
C4	3	2	4	1	1/3	1.5157	0.2347
C5	2	5	6	3	1	2.8252	0.4375
Λ_{max}=5.312	n=5	**C.R.=0.0696**					

Table -7: Experimental results of TIG welding on AA6063 aluminium alloy

Symbol	Heat Input (kJ/mm)	Gas Flow Rate (l/min)	DOP (mm)	Bead width (mm)	Reinforcement Height (mm)	Hardness (HRB)
E1	0.355	8	1.676	5.118	0.126	51
E2	0.48	8	1.893	5.221	0.096	53
E3	0.355	16	1.749	5.955	0.128	64
E4	0.48	16	2.238	7.086	0.201	63
E5	0.355	12	1.596	6.025	0.14	58
E6	0.48	12	1.797	6.094	0.144	62
E7	0.408	8	1.642	4.985	0.112	46
E8	0.408	16	1.852	6.312	0.145	58
E9	0.408	12	1.412	6.082	0.122	55
E10	0.408	12	1.44	6.092	0.12	56
E11	0.408	12	1.357	6.107	0.121	55
E12	0.408	12	1.328	6.107	0.12	55
E13	0.408	12	1.398	6.02	0.122	56

Table -8: Visual inspection results of TIG welding on AA6063 aluminium alloy

Symbol	Visual Inspection
E1	Weld is uniform with small pinholes open to the surface
E2	Weld is uniform with one/ two pinhole and one/ two blowhole
E3	Weld is uniform with two blow holes on surface
E4	Weld is uniform with increasing weld width towards the end.
E5	Weld is uniform with few pinholes at the middle
E6	Weld is uniform with small pinholes open to the surface
E7	Weld is uniform with one/ two pinhole.
E8	Weld is uniform with two blow holes on surface
E9	Weld is uniform with increasing weld width towards the end.
E10	Weld is uniform with few pinholes at the middle
E11	Even welding with good weld profile seven pin holes
E12	Weld is uniform and smooth throughout.
E13	Weld is uniform with some pinholes on the surface

The comparative matrix for criteria is tabulated in Table 9. It is generated to solve the issue of the selection of optimum conditions for the welding process. For each criterion (C) preferences of all the alternatives (E) from Table 1 is tabulated.

Table -9: Comparison Matrix of Criteria

Table -10: Comparison Matrix of Alternatives with regards to Depth of Penetration from E1 to E7 [C1]

C1	E1	E2	E3	E4	E5	E6	E7
E1	1	1/3	1/2	1/4	2	1/2	1
E2	3	1	3	1/2	4	2	3
E3	2	1/3	1	1/3	3	1	2
E4	4	2	3	1	4	3	4
E5	1/2	1/4	1/3	1/4	1	1/3	1/2
E6	2	1/2	1	1/3	3	1	3
E7	1	1/3	1/2	1/4	2	1/3	1

E8	3	1	2	1/2	4	2	1
E9	1/3	1/4	1/3	1/5	1/2	1/4	1/2
E10	1/3	1/5	1/4	1/5	1/2	1/4	1/3
E11	1/3	1/5	1/4	1/6	1/3	1/4	1/3
E12	1/3	1/5	1/4	1/6	1/3	1/4	1/3
E13	1/3	1/4	1/3	1/5	1/2	1/3	1/2
Λ_{max}=13.936		n=13			C.R.=0.05004		

Table -11: Comparison Matrix of Alternatives with regards to Depth of Penetration from E8 to E13 [C1]

C1	E8	E9	E10	E11	E12	E13	GM	CW
E1	1/3	3	3	3	3	3	1.0981	0.0643
E2	1	4	5	5	5	4	2.5724	0.1506
E3	1/2	3	4	4	4	3	1.5805	0.0926
E4	2	5	5	6	6	5	3.4647	0.2029
E5	1/4	2	2	3	3	2	0.766	0.0449
E6	1/2	4	4	4	4	3	1.7199	0.1007
E7	1	2	3	3	3	2	1.2886	0.0755
E8	1	4	4	5	5	4	2.2524	0.1319
E9	1/4	1	1	2	2	1	0.5419	0.0317
E10	1/4	1	1	3	2	2	0.5495	0.0322
E11	1/5	1/2	1/3	1	2	1/2	0.3716	0.0218
E12	1/5	1/2	1/2	1/2	1	1/2	0.3446	0.0202
E13	1/2	1	1/2	2	2	1	0.5252	0.0308
Λ_{max}=13.936			n=13		C.R.=0.05004			

Table -12: Comparison Matrix of Alternatives with regards to Bead width from E1 to E7 [C2]

C2	E1	E2	E3	E4	E5	E6	E7
E1	1	1	2	6	3	4	1/2
E2	1	1	2	5	3	3	1/2
E3	1/2	1/2	1	4	2	3	1/3
E4	1/6	1/5	1/4	1	1/4	1/3	1/6
E5	1/3	1/3	1/2	4	1	2	1/3
E6	1/4	1/3	1/3	3	1/2	1	1/4
E7	2	2	3	6	3	4	1
E8	1/5	1/4	1/4	2	1/3	1/2	1/5
E9	1/3	1/3	1/2	3	1/2	2	1/4
E10	1/4	1/3	1/3	2	1/2	1	1/4
E11	1/4	1/4	1/3	2	1/3	1/2	1/5
E12	1/4	1/4	1/3	2	1/3	1/2	1/5
E13	1/2	1/2	1/2	3	1	2	1/3
Λ_{max}=13.426		n=12			C.R.=0.0875		

Table -13: Comparison Matrix of Alternatives with regards to Bead width from E8 to E13 [C2]

C2	E8	E9	E10	E11	E12	E13	GM	CW
E1	5	3	4	4	4	2	2.4856	0.1513
E2	4	3	3	4	4	2	2.305	0.1403
E3	4	2	3	3	3	2	1.6822	0.1024
E4	1/2	1/3	1/2	1/2	1/2	1/3	0.3398	0.0207
E5	3	2	2	3	3	1	1.2377	0.0753
E6	2	1/2	1	2	2	1/2	0.7425	0.0452
E7	5	4	4	5	5	3	3.2848	0.1999
E8	1	1/3	1/2	1/2	1/2	1/3	0.4171	0.0254
E9	3	1	2	2	2	1/2	0.9481	0.0577
E10	2	1/2	1	2	2	1	0.7591	0.0462
E11	2	1/2	1/2	1	1	1/2	0.5419	0.033
E12	2	1/2	1/2	1	1	1/2	0.5419	0.033
E13	3	2	1	2	2	1	1.1478	0.0698
Λ_{max}=13.426			n=12		C.R.=0.0875			

Table -14: Comparison Matrix of Alternatives with regards to Reinforcement Height from E1 to E7 [C3]

C3	E1	E2	E3	E4	E5	E6	E7
E1	1	1/4	1	3	2	3	1/3
E2	4	1	4	6	4	5	2
E3	1	1/4	1	3	2	3	1/3
E4	1/3	1/6	1/3	1	1/2	1/2	1/5
E5	1/2	1/4	1/2	2	1	2	1/4
E6	1/3	1/5	1/3	2	1/2	1	1/5
E7	3	1/2	3	5	4	5	1
E8	1/3	1/5	1/3	2	1/2	1	1/5
E9	2	1/4	2	4	2	3	1/4
E10	3	1/3	3	4	3	4	1/2
E11	2	1/3	3	4	3	4	1/3
E12	3	1/3	3	4	3	4	1/2
E13	2	1/4	2	3	2	3	1/4
Λ_{max}=13.699		n=13			C.R.=0.0373		

Table -15: Comparison Matrix of Alternatives with regards to Reinforcement Height from E8 to E13 [C3]

C3	E8	E9	E10	E11	E12	E13	GM	CW
E1	3	1/2	1/3	1/2	1/3	1/2	0.8079	0.0483
E2	5	4	3	3	3	4	3.4058	0.2038
E3	3	1/2	1/3	1/3	1/3	1/2	0.7831	0.0469
E4	1/2	1/4	1/4	1/4	1/4	1/3	0.3323	0.0199
E5	2	1/2	1/3	1/3	1/3	1/2	0.5944	0.0356
E6	1	1/3	1/4	1/4	1/4	1/3	0.4043	0.0242
E7	5	4	2	3	2	4	2.7133	0.1623
E8	1	1/4	1/4	1/3	1/3	1/4	0.4043	0.0242
E9	4	1	1/3	1/2	1/2	1	1.0548	0.0631
E10	4	3	1	2	1	3	1.9308	0.1155
E11	3	2	1	1	1/2	2	1.4	0.08
E12	3	2	1	2	1	2	1.8306	0.1095
E13	4	1	1/3	1/2	1/2	1	1.0317	0.0617
Λ_{max}=13.426		n=12		**C.R.=0.0875**				

Table- 16: Comparison Matrix of Alternatives with respect to Hardness from E1 to E7 [C4]

C4	E1	E2	E3	E4	E5	E6	E7
E1	1	2	5	5	4	5	1/2
E2	1/2	1	4	4	4	4	1/3
E3	1/5	1/4	1	1	1/2	1/2	1/6
E4	1/5	1/4	1	1	1/2	1	1/6
E5	1/4	1/4	2	2	1	2	1/5
E6	1/5	1/4	2	1	1/2	1	1/6
E7	2	3	6	6	5	6	1
E8	1	2	5	5	4	5	1/2
E9	1/2	1	4	4	4	4	1/3
E10	1/5	1/4	1	1	1/2	1/2	1/6
E11	1/5	1/4	1	1	1/2	1	1/6
E12	1/4	1/4	2	2	1	2	1/5
E13	1/5	1/4	2	1	1/2	1	1/6

Λ_{max} =13.422	n=12	**C.R.=0.0873**

Table- 17: Comparison Matrix of Alternatives with respect to Hardness from E8 to E13 [C4]

C3	E8	E9	E10	E11	E12	E13	GM	CW
E1	1/4	1/4	2	2	1	2	1/5	1
E2	1/3	1/2	3	4	3	3	1/3	3
E3	1/3	1/3	3	3	2	2	1/4	2
E4	1/2	1/2	3	2	3	3	1/3	3
E5	1/3	1/2	3	3	3	2	1/4	3
E6	1/3	1/3	3	2	2	2	1/4	2
E7	1/4	1/4	2	2	1	2	1/5	1
E8	1/3	1/2	3	4	3	3	1/3	3
E9	1/3	1/3	3	3	2	2	1/4	2
E10	1/2	1/2	3	2	3	3	1/3	3
E11	1/	1/	3	3	3	2	1/4	3
E12	1/3	1/3	3	2	2	2	1/4	2
E13	1/4	1/4	2	2	1	2	1/5	1
Λ_{max} =13.422		n=12		**C.R.=0.0873**				

Table- 18: Comparison Matrix of Alternatives with respect to Visual Inspection from E1 to E7 [C5]

C4	E1	E2	E3	E4	E5	E6	E7
E1	1	5	4	1/2	2	1	5
E2	1/5	1	1/2	1/6	1/4	1/4	1
E3	1/4	2	1	1/5	1/4	1/4	2
E4	2	6	5	1	3	2	6
E5	1/2	4	4	1/3	1	1/2	5
E6	1	4	4	1/2	2	1	5
E7	1/5	1	1/2	1/6	1/5	1/5	1
E8	1	5	4	1/2	2	1	5
E9	1/5	1	1/2	1/6	1/4	1/4	1
E10	1/4	2	1	1/5	1/4	1/4	2
E11	2	6	5	1	3	2	6
E12	1/2	4	4	1/3	1	1/2	5
E13	1	4	4	1/2	2	1	5

Λ_{max} =13.331	n=12	**C.R.=0.08175**

Table- 19: Comparison Matrix of Alternatives with respect to Visual Inspection from E8 to E13 [C5]

C3	E8	E9	E10	E11	E12	E13	GM	CW
E1	E8	1/4	2	1	1/5	1/3	1/4	2
E2	E9	2	6	5	1	3	2	6
E3	E10	1/2	4	3	1/3	1	1/2	2
E4	E11	1/2	3	2	1/3	1/2	1/2	3
E5	E12	2	5	6	1	3	2	5
E6	E13	1	5	5	1/2	2	1	4
E7	E8	1/4	2	1	1/5	1/3	1/4	2
E8	E9	2	6	5	1	3	2	6
E9	E10	1/2	4	3	1/3	1	1/2	2
E10	E11	1/2	3	2	1/3	1/2	1/2	3
E11	E11	2	5	6	1	3	2	5
E12	E13	1	5	5	1/2	2	1	4
E13	E8	1/4	2	1	1/5	1/3	1/4	2
Λ_{max} =13.331			n=12		**C.R.=0.08175**			

Global weights are shown in Table 20, which is the combination off all the pair-wise matrices for criteria and alternatives. From table, it can be observed that alternative E4 has the highest global weight. So, it can be said that heat input of 0.48 kJ/mm and gas flow rate, 16 l/min used in experiment No. 4 is the optimum condition for good weld quality.

Table-20: Global Weight For the selection of input parameter for good weld

Alternatives	Experimental condition		Global weight
	Heat Input	Gas Flow Rate	
E4	0.48	16	0.1138
E1	0.355	8	0.1074
E7	0.408	8	0.1003
E9	0.408	12	0.1003
E12	0.408	12	0.0949
E2	0.48	8	0.0884
E6	0.48	12	0.0718
E13	0.408	12	0.0692
E10	0.408	12	0.0551
E5	0.355	12	0.0533
E11	0.408	12	0.052
E8	0.408	16	0.0481
E3	0.355	16	0.0456

5. Conclusions

TIG welding was performed on AA6063 aluminium alloy samples using ER4043 filler material of diameter 2 mm. Central Composite Design (CCD) of Response Surface Methodology (RSM) was the design of experiment. Heat input (kJ/mm) and Gas flow rate (l/min) were the input factors of three levels each. Also, hardness was measured on Rockwell hardness tester of B-scale. Visual inspection, i.e. presence of cracks, pinholes, blowholes was made. Analytical Hierarchy Process (AHP) was used to find the optimal weld condition.

The following inferences were concluded-

i) The criteria selected to determine the best quality weld were depth of penetration, bead width, height of reinforcement, hardness, presence of pinhole and blowhole.

ii) Heat input values of 0.355kJ/mm,0.408kJ/mm, 0.48kJ/mm and gas flow rates of 8l/min, 12l/min and 16l/min were considered.

iii) Consistency ratio for each alternative w.r.t. other was calculated as 0.0696.

iv) Consistency ratio of Alternatives with regards to Depth of penetration was calculated as C.R.=0.05004.

v) Consistency ratio of Alternatives with regards to Bead width was calculated as C.R.= 0.0875.

vi) Consistency ratio of Alternatives with regards to Height of reinforcement was calculated as C.R.= 0.0373.

vii) Consistency ratio of Alternatives with regards to Hardness was calculated as C.R.= 0.0873.

viii) Consistency ratio of Alternatives with regards to Visual inspection was calculated as C.R.= 0.08175.

ix) Global weight for each experiment was calculated and it was observed that highest global weight of 0.1138 was obtained at heat input of 0.48 kJ/mm and gas flow rate of 16 l/min. Thus, it was inferred that optimal weld condition was obtained at this combination of input parameters.

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