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RESEARCH ARTICLE

Optimization of MIG welding process parameters with grey relational analysis for AL 6061 alloy

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ABSTRACT
Aluminum alloy Al 6061 alloy has a good combination of mechanical properties. It has wide applications in the aerospace and marine industries. However, welded part of the alloy differs in properties which intern depends on welding input parameters. The proper selection of welding parameters plays an important significance in improvement in weld bead geometry. This present research focused on the study of welding parameters of MIG welding of alloy Al 6061 by Taguchi's GR analysis using L32 orthogonal array. The angle of torch, Wire feed rate, Standoff distance, Welding speed, and Welding current are different parameters considered for analysis. AN0VA method was used to obtain the importance of each parameter on the weld bead. From ANOVA it was found that welding current plays a significant role and followed by wire feed rate, welding speed, angle of torch, and least influenced by standoff distance.

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KEYWORDS
MIG welding; Taguchi technique; grey relational analysis

1. Introduction

Al 6061 aluminum alloy had a good combination of all mechanical properties with excellent weldability, which can replace choices for fabrication like giant structures, pipes, thick plate wings, pressure vessels, marine vessels, and large structures in the industry. However mechanical properties of each fabrication result are good when all combinations of welding parameters are optimized. Since in welding process a parameters of welding influence directly or indirectly on Mechanical properties, Weld bead geometry, and Micro structure. In this view, many researchers concentrated on the study of the effect of welding parameters in welding on mechanical properties and on weld bead geometry. The authors Zhang et al. [1] applied the dual torch method to study the influence of welding speed on cracking and it was said that cracking was found to be more at the Centre and inclines with an increase in speed and also causes porosity in weldments. Zhang et al. [2] authors' investigation was done through two alternative methods of welding, such as Plasma welding for the study of micro structure of Al 6061 alloy. It reveals that micro structure is cast columnar at boundary and growth of nucleation was towards the centre of the specimen. And also, a fine equiaxed grain structure was caused which improved mechanical properties and cracking sensitivity. Anjaneya Prassad et al. [3] The mechanical properties of aluminum alloys were compared using MIG and FSW welding processes. The process reveals porosity in MIG welding compared to FSW welded elements. In comparison, the MIG welding has the same surface on both sides and FSW has a different. The author observed that the microstructure was found to be crystalline in MIG and fine microstructure in FSW. In a comparison of tensile strength, the property was found to be less in MIG welded joints compared to base metal and the FSW process. The hardness level of the zone of heat affected (HAZ) in FSW is narrower than the MIG welded joints. Abbasi et al. [4] The input variables considered are welding current, welding voltage, welding speed, and heat input. From research, it is observed that as speed and heat input increase the depth of penetration also increases. The shape factor is found to be good at the greater speed of welding. Beyond the optimum values of welding speed and temp, penetration of depth decreases.

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Lingaraju and Narasa Raju [5] made an effort to study the influence of welding voltage, current, and speed of welding Al 6061 on tensile strength and penetration of depth and reported that current is the most important factor compared to voltage and welding velocity on tensile strength, depth of penetration and toughness. From the above literature survey, many investigations are carried out to know the effect of welding process parameters on properties of mechanical, such as tensile strength, Heat input, Hardness nearer to HAZ, and weld bead geometry using different welding methodologies. The effect of parameters can be carried out by parameters, but it consumes time and material waste. But this can be easily overcome by using Taguchi's Technique which provides a logical and efficient method to determine optimum parameters among the selected level parameters. Aliakbari and Baseri [6] made an effort to work on various parameters like peak current, pulse on time, and rotational speed of tool in case of electrical discharge machining (EDM) considering output like mrr, wear rate of electrode, surface roughness using Taguchi's technique. Vijian and Arunachalam [7] studied squeeze casting of LM 24 aluminum alloy, i.e. combining a process of casting and forging for the preparation of solid cylindrical object using Taguchi's technique. It was reported that the pressure of squeeze and the die-pre heating temp were the parameters made an important influence on the mechanical properties of squeeze cast LM24 al alloy. Manihar et al. [8] utilized Taguchi's philosophy to get the required combinations of parameters to get better weld bead geometry, heat-affected zone, and quality of improvement in outlets by submerged arc welding. The study focused on process parameters, such as arc voltage, current, electrode, and welding speed considered for bead widths on the plates of mild steel. Finally, it was observed that a setting of the optimal parameter of the width of the weld bead has been obtained.

Senthil Kumar et al. [9] focused their work on the occurrence of imperfections in weld bead geometry by using shielding gases as one of the parameters and reported that the intervals of imperfections followed Gaussian distribution and artificial neural network with back propagation adopted during the process. The fitness of curve is reported to be 96.25 overall adequacy is achieved. Deepak Kumar et al. [10] utilized gas arc welding to study the effect of process parameters on the bead of welded joints using Taguchi's technique and reported how each parameter affects the output. The authors put an effort to optimize the level of gas flow rate, welding current, and voltage for increased tensile strength. Vikas Chauhan et al. [11] worked to improve the quality of weld beads due to wide applications of welding through adaptation of Taguchi's technique for optimization of tensile strength using three input parameters like welding speed, current, and voltage considering higher—the—better—quality and stated that significant effect of all process parameters was observed by ANOVA. Natrayan et al. [12] studied the effect of TIG welding parameters using Taguchi grey relational analysis of AISI 4140 stainless steel and it was concluded that the prediction of output responses is more accurate using mentioned analysis. From the literature, it can be concluded that welding parameters and their effects on weld bead geometry can be studied using the design of experiments. So, Kulkarni [13] in this view experiments are carried out through the Taguchi technique and predicated using grey rational analysis.

2. Experimental setup

Welding: Al 6061 aluminum alloy of the plate of $100 \times 40 \times 6$ mm is welded to have weld bead geometry. The plates are rigidly mounted on the fixture to maintain a good fit and avoid the gap between plates due to residual stresses during welding. To vary welding parameters following setup was fabricated (Figure 1). The welding parameters considered are Angle of torch, Wire feed rate, Standoff distance, Welding speed, and Welding current. The following Table 1 gives the information of parameters with two levels and Table 2 gives the chemical composition of base and filler materials.

3. Plan of conducting experiment

To achieve desired results, the selection of process parameters plays a significant role which intern nullifies the effect of noise factors. In this regard, Taguchi's technique is helpful for the proper identification of control factors to obtain optimum results of the process and is implemented through proper selection of

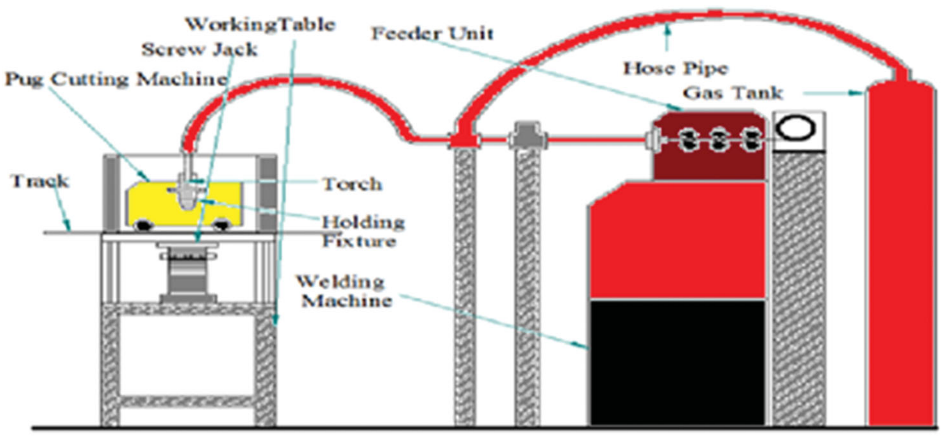

Figure 1. Schematic diagram of the experimental setup.

Table 1. Welding parameters with levels.

Sl. No	MIG welding parameters	Unit	Lower limit	Upper limit	Notation for parameter
01	Angle of torch	Degree	60	90	A
02	Wire feed rate	mm/s	55	65	W
03	Standoff distance	mm	8	12	SD
04	Welding Speed	mm/s	8.5	11.5	S
05	Welding Current	Amps	120	150	I

Note. Standoff distance is between workpiece and filler material.

Table 2. Chemical composition of base and filler material.

Chemicals	Base material in % (Al 6061)	Filler material in % (Al 4043)
Manganese (Mn)	0.083	0.05
Iron (Fe)	0.301	0.08
Magnesium (Mg)	0.809	0.05
Copper (Cu)	0.164	0.3
Zinc (Zn)	0.044	0.1
Silicon (Si)	0.550	5
Titanium (Ti)	0.077	0.2
Chromium (Cr)	0.059	–
Aluminum (Al)	97.913	94.22

orthogonal array. In the present research work, Taguchi's technique is applied to plan experiments for the study of the effects of parameters and their combined effects on weld bead geometry. The Taguchi's technique was initially used for manufacturing goods to reduce costs now the techniques are applied in almost all the fields since it provides a strategy for improvement in implementing the process for desired characteristics. Taguchi's methodology provides a mechanism for evaluating input, output, or process parameters. The techniques enable us to achieve desired characteristics and reduced the number of experiments. In the present study orthogonal array of L32 was applied and the following Table 1 gives an experimental layout with all input parameters.

4. Grey relational analysis (GRA)

It is the commonly used method for optimization. Parameters are processed, observed the outputs, and tabulated. This system gives conditions for data and enables the decision-making process. GRA method is used for solving complicated problems. In this method, through the procedure of the GRA process, we will get a GR grade, which is used for the evaluation of problems. In our work Taguchi L32 orthogonal array is used for analyzing varying five process parameters, i.e. Angle of torch, Wire feed rate, Standoff distance, Welding speed, and Welding current (Table 1).

4.1. Plan of investigation

The Experiment is investigated by considering two levels and five process parameters. The observations are recorded are five factors. As per Taguchi's array, L32 satisfy the requirements of DOF, i.e. Angle of torch, Wire feed rate, Standoff distance, Welding speed, and Welding current. The observations are listed in Table 3.

Table 3. Actual values of weld bead geometry along with normalization of GRA.

	Parameters					Experimental results					Normalization				
Trial No	A	W	SD	S	I	BH_A	BW_A	FH_A	FW_A	D_A	BH_A	BW_A	FH_A	FW_A	D_A
1	60	55	8	8.5	120	8.98	7.38	9.78	7.92	1.52	0.6993	0.3257	0.0719	0.5314	0.0794
2	60	55	8	8.5	150	8.96	8.4	8.95	8.8	2.44	0.7124	0.5211	0.6691	0.7099	0.3228
3	60	55	8	11.5	120	8.71	6.66	8.93	6.58	3.18	0.8758	0.1877	0.6835	0.2596	0.5185
4	60	55	8	11.5	150	8.89	6.78	8.91	6.98	3.06	0.7582	0.2107	0.6978	0.3408	0.4868
5	60	55	12	8.5	120	8.86	7.06	9.3	7.15	3.34	0.7778	0.2644	0.4173	0.3753	0.5608
6	60	55	12	8.5	150	9.71	7.41	9.17	8.11	2.4	0.2222	0.3314	0.5108	0.5700	0.3122
7	60	55	12	11.5	120	9.41	5.68	9.47	5.3	2.57	0.4183	0.0000	0.2950	0.0000	0.3571
8	60	55	12	11.5	150	8.71	6.15	8.9	6.89	2.16	0.8758	0.0900	0.7050	0.3225	0.2487
9	60	65	8	8.5	120	9.75	7.79	9.64	7.2	2.97	0.1961	0.4042	0.1727	0.3854	0.4630
10	60	65	8	8.5	150	9.59	7.59	9.06	8.9	3.71	0.3007	0.3659	0.5899	0.7302	0.6587
11	60	65	8	11.5	120	8.52	7.19	9.41	7.65	1.4	1.0000	0.2893	0.3381	0.4767	0.0476
12	60	65	8	11.5	150	9.42	8.2	9.42	8.22	3.74	0.4118	0.4828	0.3309	0.5923	0.6667
13	60	65	12	8.5	120	9.2	9.21	9.48	8.96	2.87	0.5556	0.6762	0.2878	0.7424	0.4365
14	**60**	**65**	**12**	**8.5**	**150**	**8.65**	**9.55**	**9.09**	**10.23**	**3.81**	**0.9150**	**0.7414**	**0.5683**	**1.0000**	**0.6852**
15	60	65	12	11.5	120	9.36	7.51	8.99	6.9	2.12	0.4510	0.3506	0.6403	0.3245	0.2381
16	60	65	12	11.5	150	8.68	7.63	9.12	8.01	1.98	0.8954	0.3736	0.5468	0.5497	0.2011
17	90	55	8	8.5	120	9.68	8.15	9.7	7.12	2.55	0.2418	0.4732	0.1295	0.3692	0.3519
18	90	55	8	8.5	150	9.44	9.52	8.91	8.55	3.53	0.3987	0.7356	0.6978	0.6592	0.6111
19	90	55	8	11.5	120	10.05	6.35	9.84	6.4	1.22	0.0000	0.1284	0.0288	0.2231	0.0000
20	90	55	8	11.5	150	9.41	6.62	9	6.65	2.19	0.4183	0.1801	0.6331	0.2738	0.2566
21	90	55	12	8.5	120	9.28	6.71	9.88	7.19	1.25	0.5033	0.1973	0.0000	0.3834	0.0079
22	90	55	12	8.5	150	9.31	7.04	8.98	6.77	2.09	0.4837	0.2605	0.6475	0.2982	0.2302
23	90	55	12	11.5	120	9.61	6.3	9.34	6.24	1.28	0.2876	0.1188	0.3885	0.1907	0.0159
24	90	55	12	11.5	150	8.8	7.13	8.49	6.8	1.8	0.8170	0.2778	1.0000	0.3043	0.1534
25	90	65	8	8.5	120	9.39	10.9	9.25	9.57	2.72	0.4314	1.0000	0.4532	0.8661	0.3968
26	90	65	8	8.5	150	9.27	10.01	9.75	9.34	3.01	0.5098	0.8295	0.0935	0.8195	0.4735
27	90	65	8	11.5	120	9.26	7.16	9.51	7.78	2.51	0.5163	0.2835	0.2662	0.5030	0.3413
28	90	65	8	11.5	150	9.59	8.03	9.13	7.91	3.75	0.3007	0.4502	0.5396	0.5294	0.6693
29	90	65	12	8.5	120	9.66	8.75	9.05	8.11	3.53	0.2549	0.5881	0.5971	0.5700	0.6111
30	90	65	12	8.5	150	9.68	9.74	9.5	8.68	3.85	0.2418	0.7778	0.2734	0.6856	0.6958
31	90	65	12	11.5	120	9.2	7.37	9.22	7.19	4.7	0.5556	0.3238	0.4748	0.3834	0.9206
32	90	65	12	11.5	150	9.38	7.28	9.22	7.45	5	0.4379	0.3065	0.4748	0.4361	1.0000

BH_A: actual back height; BW_A: actual back width; FH_A: actual front height; FW_A: actual front width; D_A: depth of penetration.

4.2. Grey relational analysis process

Signal to Noise Ratio.

Greater—the—better S/N ratio

$$\mu = -10\ \log 10\ (1/m)\sum_{i=1}^{m}\frac{1}{x_{ij}^2} \tag{1}$$

Where m = number of experiment performance

x_{ij} = response that is considered.

Where $i = 1, 2, \ldots m$; $j = 1, 2 \ldots k$

The above formula is used for the calculation of the S/N ratio of the factor which is having more value to be the best

Lesser—the—better S/N ratio

$$\mu = -10\ \log 10\ (1/m)\sum_{i=1}^{m} x_{ij}^2 \tag{2}$$

where m = number of experiment performance

x_{ij} = response that is considered.

where $i = 1, 2, \ldots m$; $j = 1, 2 \ldots k$

The above formula is used for the calculation of the S/N ratio of the factor which is having less value to be the best.

4.3. Pre-calculation of GRA process

Pre-Calculation of the GRA process is performed to obtain a comparable sequence by its original value. Experimental values are normalized between 0 and 1, based on greater or lower the best. For normalized calculation of BH_A, FH_A which are lesser-the-better can be calculated by.

$$pij = \frac{\mathrm{Max}(qij) - qij}{\mathrm{Max}(qij) - \mathrm{Min}(qij)} \tag{3}$$

Performance and BW_A, FW_A which are Greater-the-better calculated by:

$$pij = \frac{qij - \mathrm{Min}(qij)}{\mathrm{Max}(qij) - \mathrm{Min}(qij)} \tag{4}$$

The normalized values of BH_A, FH_A, BW_A, and FW_A rates are shown in Table 3. Result j of observation i, if the value Pij operated by Pre-Calculation of GRA process is equal/close to 1, then the observed experiment i is selected as the best for the result j. The order of reference $P0$ is described as ($P01$, $P02, \ldots,$ $P0$j$, \ldots,$ $P0n$) (1, 1, …, 1, …, 1), jth answer is the reference value of $P0j$, it directs to observe the experiment whose comparability order is the nearest to the reference order. Then the coefficient of grey relational analysis is calculated for the nearest Pij is for $P0j$. The larger the coefficient of grey relation, the nearer Pij, and

Table 4. Grey relational analysis.

Deviation sequence					GR coefficients						
BH_A	BW_A	FH_A	FW_A	D_A	BH_A	BW_A	FH_A	FW_A	D_A	Grade	Rank
0.3007	0.6743	0.9281	0.4686	0.9206	0.6245	0.4258	0.3501	0.5162	0.3520	0.4537	24
0.2876	0.4789	0.3309	0.2901	0.6772	0.6349	0.5108	0.6017	0.6329	0.4247	0.5610	7
0.1242	0.8123	0.3165	0.7404	0.4815	0.8010	0.3810	0.6123	0.4031	0.5094	0.5414	10
0.2418	0.7893	0.3022	0.6592	0.5132	0.6740	0.3878	0.6233	0.4313	0.4935	0.5220	15
0.2222	0.7356	0.5827	0.6247	0.4392	0.6923	0.4047	0.4618	0.4445	0.5324	0.5071	18
0.7778	0.6686	0.4892	0.4300	0.6878	0.3913	0.4279	0.5055	0.5376	0.4209	0.4566	23
0.5817	1.0000	0.7050	1.0000	0.6429	0.4622	0.3333	0.4149	0.3333	0.4375	0.3963	30
0.1242	0.9100	0.2950	0.6775	0.7513	0.8010	0.3546	0.6290	0.4246	0.3996	0.5218	16
0.8039	0.5958	0.8273	0.6146	0.5370	0.3835	0.4563	0.3767	0.4486	0.4821	0.4294	27
0.6993	0.6341	0.4101	0.2698	0.3413	0.4169	0.4409	0.5494	0.6495	0.5943	0.5302	14
0.0000	0.7107	0.6619	0.5233	0.9524	1.0000	0.4130	0.4303	0.4886	0.3443	0.5352	13
0.5882	0.5172	0.6691	0.4077	0.3333	0.4595	0.4915	0.4277	0.5508	0.6000	0.5059	20
0.4444	0.3238	0.7122	0.2576	0.5635	0.5294	0.6070	0.4125	0.6600	0.4701	0.5358	12
0.0850	**0.2586**	**0.4317**	**0.0000**	**0.3148**	**0.8547**	**0.6591**	**0.5367**	**1.0000**	**0.6136**	**0.7328**	**1**
0.5490	0.6494	0.3597	0.6755	0.7619	0.4766	0.4350	0.5816	0.4254	0.3962	0.4630	21
0.1046	0.6264	0.4532	0.4503	0.7989	0.8270	0.4439	0.5245	0.5261	0.3849	0.5413	11
0.7582	0.5268	0.8705	0.6308	0.6481	0.3974	0.4869	0.3648	0.4422	0.4355	0.4254	28
0.6013	0.2644	0.3022	0.3408	0.3889	0.4540	0.6541	0.6233	0.5947	0.5625	0.5777	4
1.0000	0.8716	0.9712	0.7769	1.0000	0.3333	0.3645	0.3399	0.3916	0.3333	0.3525	32
0.5817	0.8199	0.3669	0.7262	0.7434	0.4622	0.3788	0.5768	0.4078	0.4021	0.4455	26
0.4967	0.8027	1.0000	0.6166	0.9921	0.5016	0.3838	0.3333	0.4478	0.3351	0.4003	29
0.5163	0.7395	0.3525	0.7018	0.7698	0.4920	0.4034	0.5865	0.4160	0.3938	0.4583	22
0.7124	0.8812	0.6115	0.8093	0.9841	0.4124	0.3620	0.4498	0.3819	0.3369	0.3886	31
0.1830	0.7222	0.0000	0.6957	0.8466	0.7321	0.4091	1.0000	0.4182	0.3713	0.5861	3
0.5686	0.0000	0.5468	0.1339	0.6032	0.4679	1.0000	0.4777	0.7888	0.4532	0.6375	2
0.4902	0.1705	0.9065	0.1805	0.5265	0.5050	0.7457	0.3555	0.7347	0.4871	0.5656	6
0.4837	0.7165	0.7338	0.4970	0.6587	0.5083	0.4110	0.4052	0.5015	0.4315	0.4515	25
0.6993	0.5498	0.4604	0.4706	0.3307	0.4169	0.4763	0.5206	0.5152	0.6019	0.5062	19
0.7451	0.4119	0.4029	0.4300	0.3889	0.4016	0.5483	0.5538	0.5376	0.5625	0.5208	17
0.7582	0.2222	0.7266	0.3144	0.3042	0.3974	0.6923	0.4076	0.6139	0.6217	0.5466	9
0.4444	0.6762	0.5252	0.6166	0.0794	0.5294	0.4251	0.4877	0.4478	0.8630	0.5506	8
0.5621	0.6935	0.5252	0.5639	0.0000	0.4708	0.4189	0.4877	0.4700	1.0000	0.5695	5

P0j.The coefficient of grey relational analysis is calculated as:

$$(p0j,\ pij) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}} \text{for } i = 1, 2 \ldots m \text{ and } j = 1, 2 \ldots n \quad (5)$$

(P_{0j}, P_{ij}) GRC between P_{0j}, P_{ij}

$\Delta_{ij} = |\ p_{0j} - p_{ij}\ |$

$\Delta_{min} = \min\ \{ij,\ i = 1,2 \ldots m \text{ and } j = 1,2 \ldots n\}$

$\Delta_{max} = \max\ \{ij,\ i = 1,2 \ldots m \text{ and } j = 1,2 \ldots n\}$

ξ is determine the coefficient, $\xi \in [0,1]$. In this work, the ξ is considered as 0.5. The smaller ξ, the higher its distinguish ability. The quantity of the GR coefficient is measured by GR grade.

it is calculated by:

$$\delta\ P0 = \sum_{j=1}^{n} w_j \eta(p_{oj},\ p_{ij}) \text{ for } i = 1,\ 2 \ldots m \quad (6)$$

Where $\sum_{j=1}^{n} w_j = 1$

$\delta(P0, Pi)$ is the GRG between comparable order *Pi* and reference order *P*0. The reaction j is wj and normally depends on judgment. The GRG tells the similarity between comparable and reference. If any of the experiment values is having highest grade means it shows a similarity. and that experiment will be the best. The grade 1 will be allotted for a maximum value of the grey relational coefficient. Observation number 14, blue in color in Table 3, is the best closest combination for our experiment.

Table 5. Response table using grey relational grade.

Parameters	Level 1	Level 2	Max–Min	Rank
A	0.5145938	0.4989247	0.0156691	4
V	0.4746438	0.5388688	0.064225	2
SD	0.5025438	0.5109688	0.008425	5
S	0.521175	0.4923375	0.0288375	3
I	0.4743188	0.5391938	0.064875	1

Torch angle of Gun of 90-degree (level 1), Wire feed rate of 65 mm/s (level 2), Standoff distance of 12 mm (level 2), Welding Speed of 8.5 mm/s (level 1), and Welding Current of 150 rpm (level 2).

GRG means are evaluated for all levels and tabulated. The greater the GRG, Highlighted, the better the multiple performance characteristics.

5. Results and discussion

In our work Taguchi's L32 array is used for the optimization of output parameters of weld bead geometry. By GRA. All combinations of welding parameters of Grades of grey Relation give acceptable weld bead. The input parameters are related to output parameters.

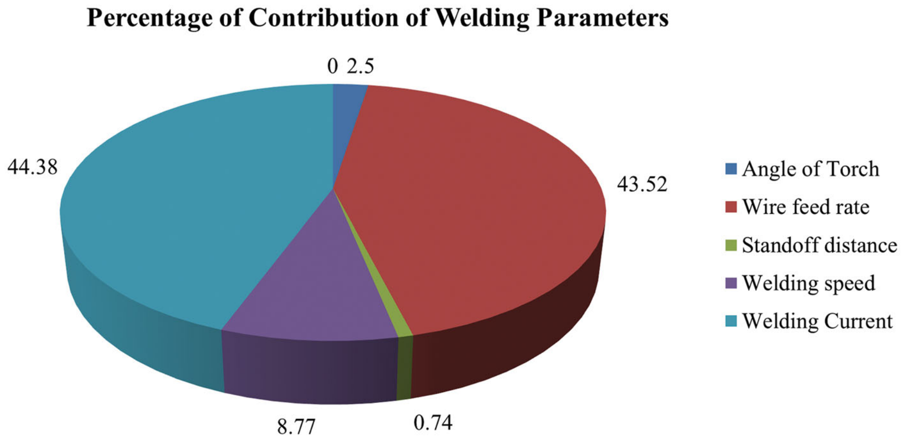

Figure 2. Welding percentage of all parameters over weld bead geometry.

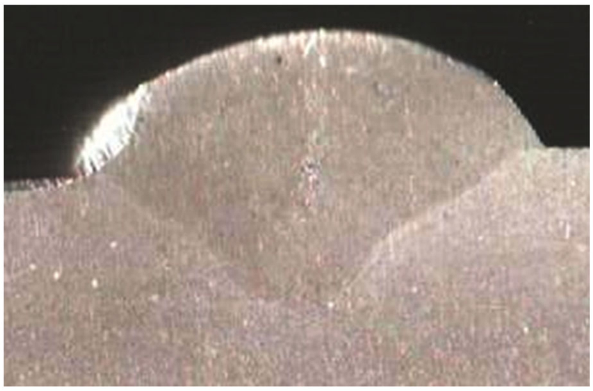

Figure 3. Weld bead geometry.

Table 6. Welding parameters and their significance effect over output responses.

Welding parameters	DF	Seq SS	Adj SS	Adj MS	*F*	*p*	% Contribution of welding parameters
Angle of Torch	1	0.001965	0.001965	0.001965	0.45	0.507	2.50
Wire feed rate	1	0.032992	0.032992	0.032992	7.59	0.011	43.52
Standoff distance	1	0.000567	0.000567	0.000567	0.13	0.721	0.74
Welding speed	1	0.006659	0.006659	0.006659	1.53	0.227	8.77
Welding current	1	0.033672	0.033672	0.033672	7.74	0.010	44.38
Residual error	26	0.113061	0.113061	0.004348			
Total	31						

5.1. Multiple response models using GRA

By Grey Relational Analysis all complex optimized problems will be solved efficiently. Greater multi-response characteristics were obtained by the better grey relational grade. In Table 4 grades of all parameters are tabulated. Fourteenth observation of all five combinations of process parameters suits best for our work. Back height, Back width, Front height, Front width, and Depth of penetration.

5.2. Response table for GRG using S/N ratio

Table 5 indicates the average of all the levels of grey relational grades. For each process parameter, the average of all levels is taken depending on combinations. This data represents the relation between reference order and observed order. The greater the difference between maximum and minimum averages will give more impact on our study. A4 V2 SD5 S3 I1 is the order obtained from Table 5.

5.3. ANOVA table for MIG welding process parameters

It is one of the best methods for evaluating all parameters. This method is adopted for the calculation of the consequence of all input parameters. The significance of welding parameters is obtained by Mini tab 17.0 Software, namely Torch angle, wire feed rate, Standoff distance, Welding speed, and Welding current. From grades that are obtained from the analysis of the GRA process are used for ANOVA. From this process, the Angle of torch (2.50), Wire feed rate (43.52), Standoff distance (0.74), Welding speed (8.77), and Welding current (44.38). ANOVA table shows nearest data which is related to grey relational analysis. The pie graph (Figure 2) presents the distribution of the Welding percentage of all parameters over weld bead geometry. And Figure 3 shows the weld bead geometry of the material.

5. Conclusion

The following conclusions can be drawn from the present investigation In this present research, the model considered for investigation is adequate to predict the weld bead geometries and properties of the welded bead with a confidence level of 95%. Taguchi L32 array with grey relational analysis has been used to optimize the multiple Performance characteristics, such as Angle of torch, wire feed rate, Standoff distance, Welding speed, and Welding current.

The optimized parameter found using GRA are Angle of torch = 60°, Wire feed rate = 55 mm/s, standoff distance = 12 mm, Welding speed = 8.5 mm/s, and Welding current = 150 Amps. From Table 6, it can be concluded that welding current has a significant role and standoff distance has the least influence on weld bead geometry.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

It is available in my thesis which has been cited in the paper [13].

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