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Analyzing the Best Arc Welding Parameters Following The Best Edge Joint Using Taguchi And Grey Fuzzy Method

Md. Riafedul Islam Rifat, Md. Saiful Islam Safi,
Md. Ahamed Hossain Yousuf, Md. Ariful Islam
Department of Industrial & Production Engineering
Rajshahi University of Engineering & Technology,
Rajshahi-6204, Bangladesh
rifat1805060@gmail.com, safisaiful99@gmail.com

Shukdev Bhowmick
Department of Mechanical Engineering
Rajshahi University of Engineering & Technology,
Rajshahi-6204, Bangladesh
shukdev.me.ruet@gmail.com

Abstract

Welding is a process where two similar or dissimilar metals are joined to create a complex joint used in various fields. Among the many welding methods, arc welding stands out as one of the best. In arc welding, two metals are brought into contact, and the junction is heated, causing the metal to melt and fill the gap between the parent metals. This study aims to identify the most effective edge joint for arc welding and optimize the process parameters for welding BSRM A 415 square bars. Optimizing welding parameters is crucial because they significantly influence the quality of the weld. Without determining the optimal values, the experiment cannot be accurately completed, and the resulting products may lack long-term sustainability. BSRM A 415 square bars were chosen due to their quality billets, guaranteed strength, safe welding properties, and ISO certification. They are ideal for intricate structural designs and offer both strength and cost efficiency. Four input parameters were selected for the welding process: welding current, voltage, travel speed, and electrode diameter, with hardness and ultimate tensile strength as output responses. The study used the Taguchi orthogonal array and Grey Fuzzy methods to analyze and optimize the parameters. These methodologies, along with various tools and techniques, helped achieve the desired outcomes effectively.

Keywords
Edge Joint, Arc Welding, Taguchi Method, Grey Fuzzy Method.

1. Introduction
Bangladesh is developing day by day in many sectors. Specially in technological development is one of the best achievements. To make the structural development in any building and construction site welding is must even we used it in our practical daily life so. So each and every work field welding is very much important (Srivastava 2017). The history of fusing metals through welding goes back as far as 3000 B.C. when humans first started working with bronze. The oldest known examples of welding are small golden boxes that date back to the Bronze age over 2,000 years ago. During the Middle Ages, the art of blacksmiths was developed and many items of iron were produced that were welded by hammering. It was not until the 19th century that welding as we know it today was invented.in modern age developed in the Soviet Union, friction welding uses rotational speed and upset pressure to provide friction heat. It is a specialized process and has applications only where a sufficient volume of similar parts is to be welded because of the

initial expense for equipment and tooling. This process is called inertia welding. Laser welding is one of the newest processes. The Bell Telephone Laboratories originally developed the laser as a communications device. Because of the tremendous concentration of energy in a small space, it proved to be a powerful heat source. Operations use lasers or cutting metals and nonmetals. Continuous pulse equipment is available (Osayi 2015). The laser is finding welding applications in automotive metalworking operations. Welding joint is directly influenced by input parameters therefore welding can be called as multi input multi output process. But there is a big problem in welding joint, the problem is to control the input parameters which are mostly used to influence the output parameters. To eliminate this problem various researcher developed various techniques. Someone proposed Taguchi design, someone response surface methodology, someone genetic algorithm and so on. In two or three decades ago welding was used in small area but now a days welding used in vast area. So welding demand increasing day by day. From household work to industrial work welding used very easily and that’s why lots of welding worker needed not only our country but also all over the world. So, welding impact is huge in all areas. Some potential applications of welding are: household work, industrial instruments, construction sites, bridges and rails (Ahire 2018).

1.1 Objectives
The objectives of the study are to find out the best edge joint in terms of maximum Ultimate Tensile Strength and maximum Hardness and to find out the best optimal solution for that edge joint by the process of parameters optimize.

2. Literature Review
Benyounis (2008) optimized different welding process techniques in the welding industry. This evaluation was categorized based on the weld's output characteristics, such as bead geometry and the welds' mechanical characteristics. Zoalfakar (2008) performed Tensile and micro-hardness tests at room temperature to assess the mechanical properties. The Taguchi technique was utilized to identify the key control variables that will improve the mechanical characteristics of the joints, and Taguchi's instruments. V. (2011) optimized the process parameters by using GA. The optimization of the depth-to-width ratio was done using Turbo C source code, with penetration and bead width serving as restrictions. Umrigar (2014) shows experiment design and experimental data to optimize using various optimization approaches where the hardness, tensile strength, and microstructure of the material are the output parameters. Srivastava (2017) addresses that Bead geometry factors, the heat-affected zone, bead width, bead height, penetration, and area of penetration are all significantly impacted by the welding process parameters, such as voltage, arc travel, speed, and current. Ahire (2018) developed (GA)-based technique is successful. Adin (2022) examined distortion behaviors, such as global girder bending and local plate bending and buckling, employing the method of finite elements. According to the findings, buckling doesn't happen in buildings.

Panin (2022) improved the welding groove to improve the mechanical properties of medium carbon steel joints welded by MIG welding by applying the Taguchi method. Adekola (2022) developed the central composite face-centered design technique of the response surface methodology was used to arrange the experiments. ANOVA was used to assess the experimental results, and regression equations were created for each of the output values. Adin (2022) used the genetic algorithm method to find out the optimal solution in welding. Welding current, arc voltage, and welding speed are used as input parameters and the welding bead ultimate tensile strength are used output parameters. Auddy (2022) given an overview of the Taguchi method and the steps of the method are briefly described. Overall, the Taguchi method is a powerful tool for simultaneously improving quality and cost. In addition, the method can help integrate costing and engineering activities through simultaneous engineering, which is necessary for cost estimation during experimental design. S. and Baghe l(2023) demonstrated that structural features of the created USW joints had to be taken into account and the developed optimal criterion was insufficient. Singh (2023) developed gray fuzzy multi-objective optimization. Prerequisite background Andale’s definitions of gray systems are presented. A gray fuzzy-optimization formulation is discussed starting from a general fuzzy optimization problem. Vijayakumar (2024) examined the tensile strength of medium carbon steel (CS), mild steel (MS), and SMAW dissimilar steel (MS) using a range of process factors, including electrode angle (EA), root face (RF), and welding current (WC).

3. Methods
Taguchi and Grey Fuzzy methods are employed to analyze arc welding parameters effectively. The Taguchi method optimizes process settings by minimizing variability, while the Grey Fuzzy approach evaluates multiple performance characteristics simultaneously. Together, these methods ensure precise parameter optimization, leading to improved welding quality and enhanced mechanical properties of welded joints.

Research Methodology

Methodology has been conducted by some steps. These are given below.

- First, collect the welding material (BSRM A 415 square bar) and electrode (T 421 E 6013 mild steel).
- Cut metal properly and made different types of edge joint and then welded by selecting the input parameters.
- Grinding these welding joints properly.
- Selection of process parameters and dividing the process parameters into suitable levels as per design software requirements.
- Design the selected welding parameters by using L9 orthogonal array for Taguchi design of experiment first of all and then in the second attempt used L27 orthogonal array design.
- Completion of welding process with designed process parameters.
- Ultimate Tensile Strength and Rockwell Hardness Testing For 36 joints (4 multiplied by 9).
- Apply the Taguchi method orthogonal array to determine the optimal combination of welding process parameters.
- Applying the grey fuzzy method to determine the optimal combination of welding process parameters. .
- Confirmation test to validate the result.

Material Selection

BSRM 415 SQUARE BAR was selected because it is most commonly used in low-stress and less demanding applications which means its simplicity. It is an economical choice where a tremendous level of tensile strength is not necessarily needed.

Welding Electrode Selection

There are lots of welding electrodes used for welding operations depends on the type of welding materials. The E 6013 mild steel electrode is selected.

Confirmation Test

After identifying the optimal parameters, a confirmation test will be made. The accuracy of the optimal solution can be measured by the following formula.

$$\eta\ (\text{predicted}) = \eta_1 + \sum_{i=1}^{n}(\eta_2 - \eta_1)$$

Here,

η_1 = total mean of grey fuzzy reasoning grade

η_2 = mean of grey fuzzy reasoning grade at the optimum level of significant parameter.

η = no of significant parameter.

4. Data Collection

Fig 2 shows the different angles of our selected edge joints. The minimum angle is 60 degrees and the maximum angle is 120 degrees (considering both sides of these joints).

Table 1. Control factor and levels

Factor	Symbol	Unit	Level 1	Level 2	Level 3
Welding current	I	Ampere	170	186	202
Voltage	V	volt	16	20	24
Travel speed	TS	mm/min	11	18	25
Electrode diameter	D	mm	2.5	3.2	4

Table 1 shows the control factor and level.

Table 2. Control factors and their levels

Factor	Symbol	Unit	Level 1	Level2	Level3
Welding current	I	Ampere	202	186	170
Welding voltage	V	voltage	24	20	16
Travel speed	TS	mm/min	25	18	11
Electrode diameter	D	mm	4	3.2	2.5
Groove angle	α	Degree	120(60+60)	90(45+45)	`60(30+30)

Table 2 shows the combination of new control factor and old factor and their levels. Each factor has 3 levels and for this 2nd attempt we want to set our levels in descending order because we want to see is there any difference create between our first design with this design and we want to are we get minimum or maximum ultimate tensile strength and hardness rather than previous gotten value.

4.1 Data Analysis

We analyzed our data by using two software. One is taguchi orthogonal array and other is grey fuzzy tool. In orthogonal array analyses we covered some steps such as SN analysis, ANOVA analyses. In grey fuzzy method we covered four steps sequentially, these are data normalization, deviation sequence, grey relational coefficient and finally grey fuzzy reasoning grade.

Design of experiment

For experimental design, we used the L9 orthogonal array because we have four (4) input parameters and every parameter has 3 levels so for that combination L9 orthogonal design is suitable.

Table 3. Design of Experiment with Actual Values

Exp no	Coded values				Actual values			
	I	V	TS	D	Current	Voltage	Travel speed	Electrode diameter
1	1	1	1	1	170	16	11	2.5
2	1	2	2	2	170	20	18	3.2
3	1	3	3	3	170	24	25	4
4	2	1	2	3	186	16	18	4
5	2	2	3	1	186	20	25	2.5
6	2	3	1	2	186	24	11	3.2
7	3	1	3	2	202	16	25	3.2
8	3	2	1	3	202	20	11	4
9	3	3	2	1	202	24	18	2.5

Table 3 shows the design of the experiment with actual values

We used 4 types of welding edge joints. These are Single bevel joint, Double bevel joint, Single v joint, Double v joint.

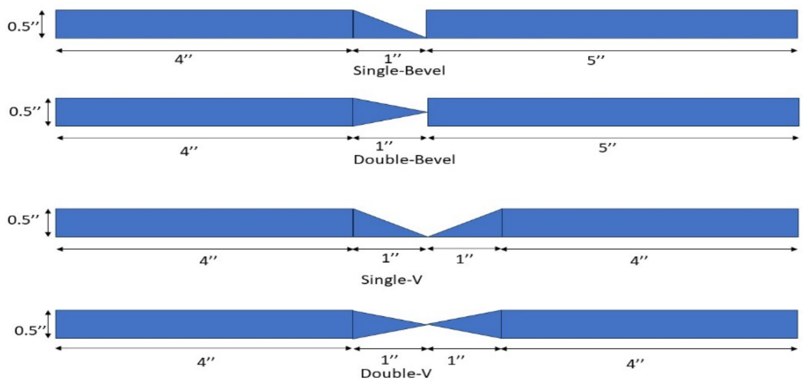

Figure 1. Four Types of Edge Joint

Figure 1 illustrates four weld joint designs: Single-Bevel, Double-Bevel, Single-V, and Double-V, detailing dimensions for bevel angles and root spacing in inches.Our first target was to find the best edge joint with the optimal condition of input parameters. Since we have 4 joints and we used L9 orthogonal array we must conduct a (4*9=36) experimental run and after testing the hardness and ultimate tensile strength we will find out our best edge joint with the suitable combination of input parameters.

Table 4. Response Table

S Trial no	Joint name	Set No.	Current (A)	Voltage (volt)	Travel speed (mm/min)	Electrode diameter (mm)	Tensile Strength (MPA)	Hardness (HRC)
1	Single bevel	1	170	16	11	2.5	405.47	24
2	Double bevel		170	16	11	2.5	505.56	23.9
3	Single v		170	16	11	2.5	497.5	27
4	Double v		170	16	11	2.5	502.05	26
5	Single bevel	2	170	20	18	3.2	452.63	23.5
6	Double bevel		170	20	18	3.2	377.27	27.46
7	Single v		170	20	18	3.2	592.99	25.5
8	Double v		170	20	18	3.2	426.67	26.4
9	Single bevel	3	170	24	25	4	395.94	24.8
10	Double bevel		170	24	25	4	473.54	25.7
11	Single v		170	24	25	4	518.15	28.2
12	Double v		170	24	25	4	577.43	27.15
13	Single bevel	4	186	16	18	4	376.83	29.46
14	Double bevel		186	16	18	4	487.1	27.26
15	Single v		186	16	18	4	538.06	24.5
16	Double v		186	16	18	4	599.33	35
17	Single bevel	5	186	20	25	2.5	430.35	28.25
18	Double bevel		186	20	25	2.5	482.25	24.5
19	Single v		186	20	25	2.5	475.58	27.92
20	Double v		186	20	25	2.5	499.43	31.5
21	Single bevel	6	186	24	11	3.2	414.09	27.9
22	Double bevel		186	24	11	3.2	302.93	28.5
23	Single v		186	24	11	3.2	372.47	29.5
24	Double v		186	24	11	3.2	416.41	31.2

25	Single bevel	7	202	16	25	3.2	422.13	23.79
26	Double bevel		202	16	25	3.2	360.55	24.98
27	Single v		202	16	25	3.2	387.95	29.63
28	Double v		202	16	25	3.2	543.04	30.21
29	Single bevel	8	202	20	11	4	416.44	32.23
30	Double bevel		202	20	11	4	276.37	33.63
31	Single v		202	20	11	4	380.48	24.56
32	Double v		202	20	11	4	397.73	28.67
33	Single bevel	9	202	24	18	2.5	389.6	29.47
34	Double bevel		202	24	18	2.5	386.61	30.85
35	Single v		202	24	18	2.5	441.48	31.21
36	Double v		202	24	18	2.5	490.6	32.29

Table 4 shows that in experiment no 16 in trial no 4 we got our optimal solution (current=186A, voltage=16V, welding speed=18mm/min, and electrode diameter=4mm) and the selected welding edge joint is double v in terms of highest ultimate tensile strength 599.33 M pa and highest Rockwell hardness (35 HRC. Now we incorporate one new input parameter which is the Groove angle. Groove angle is one of the highly impracticable parameters. So from the point of view, we want to select this parameter. In our selected double v joint we make this joint into three different joints in terms of groove angle.

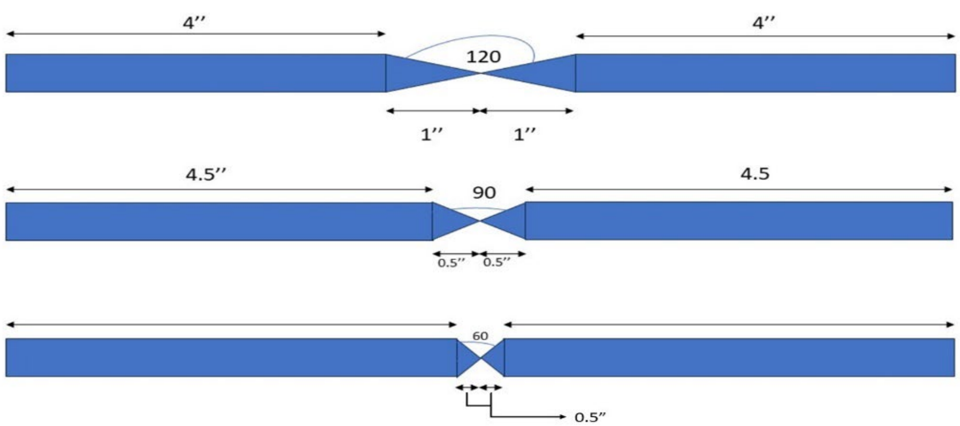

Figure 2. Groove angles in double V joints

Fig 2 shows the different angles of our selected edge joints. Groove angles are 60 degrees, 90 degrees, and 120 degrees. The minimum angle is 60 degrees and the maximum angle is 120 degrees (considering both sides of these joints).

Our input parameters are 5. These are:

- Welding Current
- Welding Voltage
- Welding Speed
- Electrode Diameter
- Groove Angle

The output responses are Ultimate Tensile Strength and Rockwell Hardness. Since each parameter has 3 levels. So, our experimental design will be an orthogonal array L27 model.

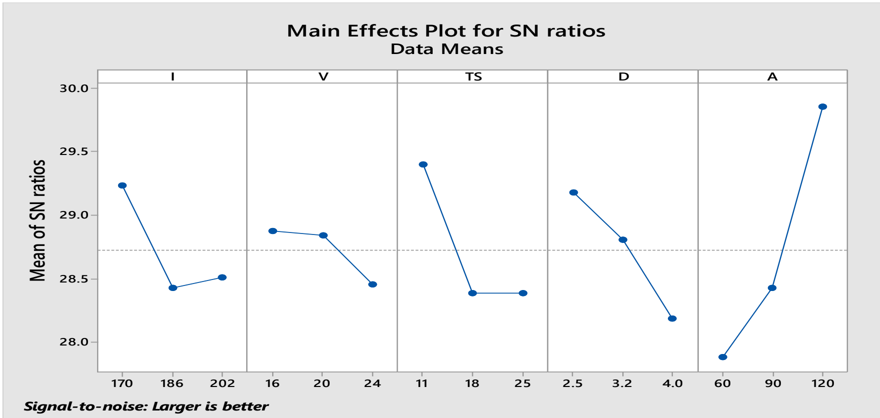

Figure 3. SN ratio plot for HRD

Fig 3 shows that we got maximum hardness for the current 170A . For voltage 16V, welding speed 11mm/min, electrode diameter 2.5mm and groove angle 120 degree we got the maximum signal-to-noise ratio.

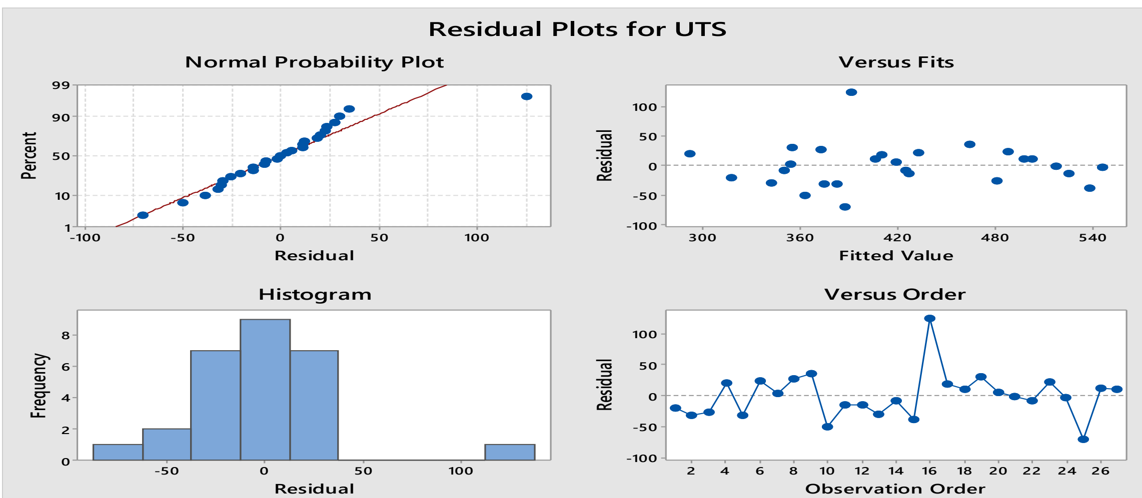

Figure 4. Residual plot for UTS

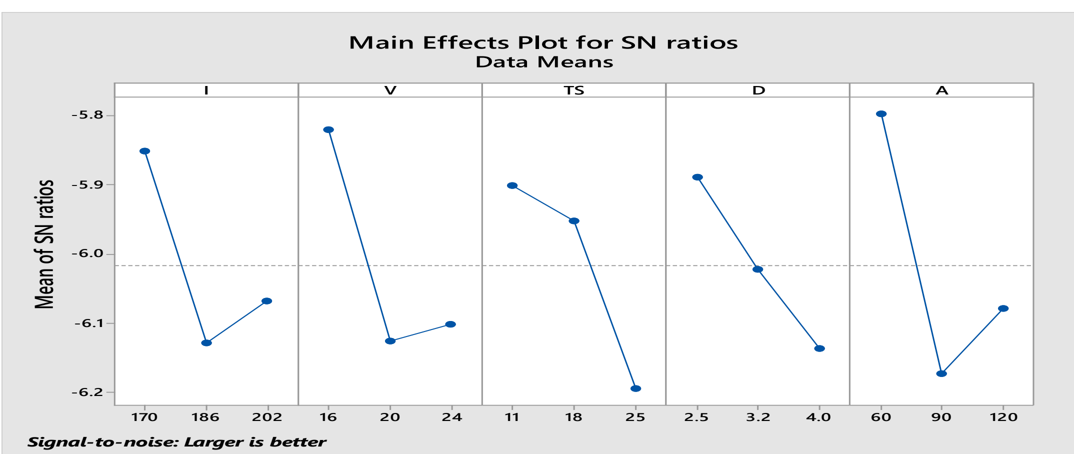

Figure 5. SN ratio plot for GFRG

Table 5. Experimental Result according to Design of Experiment (DOE)

Exp no	Coded Value					Actual Value				
	I	V	TS	D	α	Current (Amp.)	Voltage (V)	Speed (mm/min)	Welding Diameter (mm)	Groove Angle (deg.)
1	1	3	2	1	1	202	16	18	4	120
2	1	1	3	1	2	202	24	11	4	90
3	1	2	1	1	3	202	20	25	4	60
4	1	1	1	2	1	202	24	25	3.2	120
5	1	2	2	2	2	202	20	18	3.2	90
6	1	3	3	2	3	202	16	11	3.2	60
7	1	2	3	3	1	202	20	11	2.5	120
8	1	3	1	3	2	202	16	24	2.5	90
9	1	1	2	3	3	202	24	20	2.5	60
10	2	3	2	3	1	186	16	18	2.5	120
11	2	1	3	3	2	186	24	11	2.5	90
12	2	2	1	3	3	186	20	25	2.5	60
13	2	1	1	1	1	186	24	25	4	120
14	2	2	2	1	2	186	20	18	4	90
15	2	3	3	1	3	186	16	11	4	60
16	2	2	3	2	1	186	20	11	3.2	120
17	2	3	1	2	2	186	16	25	3.2	90
18	2	1	2	2	3	186	24	20	3.2	60
19	3	3	2	2	1	170	16	20	3.2	120
20	3	1	3	2	2	170	24	11	3.2	90
21	3	2	1	2	3	170	20	25	3.2	60
22	3	1	1	3	1	170	24	25	2.5	120
23	3	2	2	3	2	170	20	20	2.5	90
24	3	3	3	3	3	170	16	11	2.5	60
25	3	2	3	1	1	170	20	11	4	120
26	3	3	1	1	2	170	16	25	4	90
27	3	1	2	1	3	170	24	18	4	60

Table 5 shows the Experimental Result according to the Design of Experiment (DOE). Here, we got the groove angle.

Table 6. Output Response

Exp no	Coded value					Actual value					Response	
	I	V	TS	D	α	Current (A)	Voltage (V)	Speed Mm/m	Welding Diameter (mm)	Groove angle (degree)	UTS (MPA)	HR (HRC)
1	1	3	2	1	1	202	16	18	4	120	297	25.5
2	1	1	3	1	2	202	24	11	4	90	350	30.05
3	1	2	1	1	3	202	20	25	4	60	455	25.06
4	1	1	1	2	1	202	24	25	3.2	120	312	34.03
5	1	2	2	2	2	202	20	18	3.2	90	344	29.04
6	1	3	3	2	3	202	16	11	3.2	60	512	24.04
7	1	2	3	3	1	202	20	11	2.5	120	357	34.02
8	1	3	1	3	2	202	16	25	2.5	90	400	28.03
9	1	1	2	3	3	202	24	18	2.5	60	500	23.02
10	2	3	2	3	1	186	16	18	2.5	120	312	35.01
11	2	1	3	3	2	186	24	11	2.5	90	413	25.02
12	2	2	1	3	3	186	20	25	2.5	60	512	22.04
13	2	1	1	1	1	186	24	25	4	120	312	21.5
14	2	2	2	1	2	186	20	18	4	90	416	35
15	2	3	3	1	3	186	16	11	4	60	500	27
16	2	2	3	2	1	186	20	11	3.2	120	317	24
17	2	3	1	2	2	186	16	25	3.2	90	429	26.5
18	2	1	2	2	3	186	24	18	3.2	60	514	23.02
19	3	3	2	2	1	170	16	18	3.2	120	385	35
20	3	1	3	2	2	170	24	11	3.2	90	425	25.02
21	3	2	1	2	3	170	20	25	3.2	60	518	20
22	3	1	1	3	1	170	24	25	2.5	120	342	33.99
23	3	2	2	3	2	170	20	18	2.5	90	455	28
24	3	3	3	3	3	170	16	11	2.5	60	544	35.52
25	3	2	3	1	1	170	20	11	4	120	517	35
26	3	3	1	1	2	170	16	25	4	90	418	27.03
27	3	1	2	1	3	170	24	18	4	60	510	24

Table 6 shows that in response column the maximum ultimate tensile strength 544 M pa, and maximum hardness 35.52 HRC. So, we got it 24 no experiment (I=170A, V=16V, TS=11mm/min, D=2.5mm, α=60 degree).

5. Results and Discussion

Best welding Edge Joint with Optimal Input Parameter
Trial no. 16

- Set no. 4
- Joint name: Double V
- Optimal setting: current 186A, voltage 16V, welding speed 18mm/min, electrode diameter 4mm.
- Maximum ultimate tensile strength: 599.33 M pa
- Maximum Rockwell hardness:35 HRC

Optimal Solution of our selected Edge Joint
Trial no 24

- Current 170A, voltage 16V, welding speed 11mm/min, electrode diameter 2.5mm, and groove angle 60 degrees.
- Hardness 35.52 HRC, ultimate tensile strength 544 M pa

Confirmation Test
After identifying the optimal parameters, we should confirmation test in our experiment to enhance the accuracy of the optimal solution.

The Double-V edge joint (Trial 16) achieved optimal tensile strength (599.33 MPa) and hardness (35 HRC) at 186A, 16V, 18mm/min, and 4mm electrode. Trial 24 (170A, 16V, 11mm/min, 2.5mm electrode, 60° groove) confirmed 35.52 HRC, 544 MPa. Confirmation tests ensure accuracy.

5.1 Numerical Results

Table 7. Result of optimal solution

Level	Grey fuzzy approach
Control factor setting	$I_3V_3TS_3D_3\alpha_3$
UTS	544
HRD	35.5
GFRG	0.582

Table 7 shows the optimal solution that has been got by the Grey fuzzy approach.

5.2 Proposed Improvements

Table 8. Result of welding performance with the initial and optimal solution and the improvement

Level	Initial condition	Grey fuzzy approach	Improvement
Control factor setting	$I_1V_3TS_2D_1\alpha_1$	$I_3V_3TS_3D_3\alpha_3$	%
UTS	297	544	45%
HRD	25.5	35.5	28%
GFRG	0.495	0.582	14.94%

Table 8 shows the Grey Fuzzy approach improved UTS by 45%, hardness by 28%, and GFRG by 14.94% compared to the initial condition, showcasing significant enhancements in welding performance and quality.

5.3 Validation

After identifying the optimal welding parameters, a confirmation test was conducted to validate the solution. The estimated GFRG was calculated as 0.539, while the experimental GFRG was slightly higher at 0.582. This positive deviation confirms the accuracy and reliability of the optimization process, demonstrating that the experimental results align well with the predicted outcomes, ensuring improved welding performance.

6. Conclusion

Taguchi method used signal to noise ratio, ANOVA analysis. From SN analysis we see that Groove angle is the highly impact parameter and voltage is less important parameter in terms of ultimate tensile strength, for hardness groove angle is also very high significant parameter and voltage is very low significant parameter. From ANOVA testing we see that groove angle has highest contribution on the output parameters for ultimate tensile strength and for hardness groove angle has also highest contribution on the output parameters. For grey fuzzy method to find out the optimal solution we followed some steps, these are data normalization, deviation sequence, grey relational coefficient and finally Grey fuzzy reasoning grade. From each and every step we noticed that in experiment no 24 we got our optimal solution. The solution is current(I)= 170A, voltage(V)= 16V, Travel speed (TS)= 11mm/min, welding diameter (D)= 2.5mm, groove angle = 60 degree. This research opens several avenues for further exploration. Future studies could focus on a broader range of material types, including advanced alloys and composites, to assess how different welding edge configurations affect performance across various industries. Additionally, examining the impact of dynamic welding conditions, such as temperature and humidity, on edge types and joint angles could yield valuable insights for real-world applications. Long-term performance analysis of welded joints with optimized edge configurations is another important area for future research. Conducting durability and fatigue tests will help understand how these joints perform over time. Furthermore, exploring the effects of modern welding techniques, like laser welding and friction stir welding, on edge performance can lead to innovative solutions and applications.

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Biographies

Md. Riafedul Islam Rifat is a student of the Department of Industrial & Production Engineering at Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh. Major academic courses include Operations Research, Probability and Statistics, CAD/CAM, Computer Integrated Manufacturing (CIM), Environment and Project Management, Measurement and Instrumentation, Project Management and Legal Issues, and Industrial Management.

Md. Saiful Islam Safi is a student of the Department of Industrial & Production Engineering at Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh.

Md. Ahamed Hossain Yousuf is a student of the Department of Industrial & Production Engineering at Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh.

Md. Ariful Islam is an Associate Professor in the Department of Industrial & Production Engineering at Rajshahi University of Engineering & Technology (RUET). He has contributed significantly to academic research, authoring 7 journal articles and presenting 14 conference papers, showcasing his expertise and dedication to advancing knowledge in his field.

Shukdev Bhowmick is a student of the Department of Mechanical Engineering at Rajshahi University of Engineering & Technology (RUET), Rajshahi-6204, Bangladesh. His major academic courses include Thermodynamics, Heat Transfer, Fluid Mechanics, Strength of Materials, Solid Mechanics, Machine Design, Mechanical Vibrations, Mechatronics, and Control Engineering.