Optimization Of GTAW Process Parameters For Joining Dissimilar Alloys, SS 202 And SS 304

Thanveer Ahamed S[1] , Siva Priya V[2], Umar Mohamed J[3] , Palaniappan PL. K[4]

[1]Deparment of Mechanical Engineering Thiagarajar College of Engineering Madurai, Tamil Nadu, India - 625 015 thanveer14am@gmail.com
[2]Deparment of Mechanical Engineering Thiagarajar College of Engineering Madurai, Tamil Nadu, India - 625 015
jopriyavenkatesan@gmail.com
[3]Deparment of Mechanical Engineering Annamalai Polytechnic College Chettinad, Tamil Nadu, India – 630 102
umarmjamaludeen@gmail.com
[4]Deparment of Mechanical Engineering Thiagarajar College of Engineering Madurai, Tamil Nadu, India - 625 015
kpal@tce.edu

Abstract - This research investigates the joining of two dissimilar stainless-steel alloys, SS 304 and SS 202, using Gas Tungsten Arc Welding (GTAW). SS 304 is widely recognized for its excellent intergranular corrosion resistance, making it suitable for applications such as pressure vessels and automotive components. In contrast, SS 202 is a cost-effective alternative with good tensile strength and toughness, commonly employed in structural applications and kitchenware. TIG welding, known for its precision and control, enhances productivity while reducing time and cost. The study utilizes Taguchi's Design of Experiments (DOE) methodology to determine the optimal welding parameters—including welding current, root gap, gas flow rate, groove angle, and filler material—to achieve uniform tensile strength and hardness in the dissimilar weld joint. Taguchi's orthogonal array design, combined with Analysis of Variance (ANOVA), was employed to analyze weld characteristics and optimize process parameters for improved joint performance. The optimal tensile strength (553.543 MPa) was achieved with a welding current of 160 A, gas flow rate of 3 l/min, groove angle of 60°, root gap of 1 mm, and filler material 308 L. The optimal hardness (284.99 BHN) was obtained with a current of 60 A, gas flow rate of 9 l/min, groove angle of 40°, root gap of 1 mm, and filler material 304 L. These results were further validated and compared using predictive modeling techniques, including Linear Regression, Random Forest, Artificial Neural Networks (ANN), and a Genetic Algorithm, which served as a confirmatory approach for the optimal parameter combinations. The predicted outcomes were then compared with experimental values to assess the accuracy and reliability of the models in enhancing weld joint performance

Keywords— Gas Tungsten Arc Welding, SS 202 and SS 304, Hardness, Ultimate tensile strength, Design of Experiments.

I. INTRODUCTION

Tungsten Inert Gas (TIG) welding is a versatile arc welding process that uses a non-consumable tungsten electrode and inert gas shielding (Argon or Helium majorly), making it ideal for joining metals like aluminum, stainless steel, and titanium [1,2]. SS 202 and SS 304 are frequently used materials in variety of industries, including automotive, household, petroleum and utensils, because of their low pitting corrosion resistance and particularly exhaust manifolds and tail pipes for automotive applications were joined using Tungsten Inert Gas (TIG) Welding in both similar and dissimilar combinations [1].

For Many Years, Chrome-Manganese Austenitic Stainless-Steel grades (also known as "Standard 200 – Series") with clearly defined technical features that has been accepted for various Purposes. In addition to that depending on their chemistry, 200 Stainless Steel series can provide good Strength from a material cost perspective and designers are able to reduce weight since some grades (Corresponding to the 201, 202 and 205 series) even give roughly 30% higher mechanical properties (Yield Strength) than the traditional 304 – series chrome nickel grade [3]

By combining Magnesium and Nitrogen with carbon, nickel can be nearly entirely replaced. More manganese and nitrogen are needed to stabilize the Austenitic phase when nickel addition is reduced. Lower Nitrogen additions may result in higher draw ability qualities. However, to stabilize the austenitic phase, the chromium concentration must be lowered to 14-15%. Because of its exceptional formability, AISI 304 Stainless Steel is frequently utilized in forming applications. An Inquiry into the viability of substituting AISI 202 for AISI 304 in applications needing similar mechanical qualities was spurred by the current high price of Nickel [3].

Aishna et al. examined how various Filler materials affect TIG welding of SS 304 attention to its Mechanical and Microstructural attributes with that Superior alloying Content and tensile strength were demonstrated by ER 316L and ER 308L [4]. Using the TLBO Algorithm Bishub et al. concentrated on GTAW Parametric optimization for Inconel 825 where Current found to be the important parameter for Predicted Weld penetration and Width using RSM [5]. Bharath et al. Examined the impact of welding parameters on Tensile Strength and Bend Strength on welded Joint, where the most important Variables according to ANOVA results were Current and Welding Speed [6]. Mayank et al. used the Taguchi approach for optimization to examine how process factors affected the weld distortion in Stainless Steel using Pulsed GTAW, where the most important element found to be welding Speed and Distortion [7]. Neeraj et al. Examined how TIG welding parameters affect hardness and tensile strength of SS 202 Weld and found Current as the most Influencing parameter and Under various Circumstances, weld quality was predicted and improved using empirical models and NSGA -II Optimization [8]. The Dissimilar Welding of Stainless Steels has drawn more attention in recent years. Nevertheless, Limited Research as been done on Optimizing the welding Parameters for Joining alloys of SS 202 and SS 304 for improved Mechanical Properties. This Study uses Taguchi's DOE Technique to examine the dissimilar TIG Welding of SS 202 and SS 304 with the goal of optimizing Parameters including Current, Groove Angle, Root Gap, Gas Flow Rate and Filler Material. To determine the best parameters for Optimal Weld strength and hardness, ANOVA and other Sophisticated prediction models – ANN, Genetic Algorithm were used as Confirmatory Test for the Optimal Values

II. METHODOLOGY

A. Materials and Experimental Setup

As Mentioned, the Base Material for the Research work was 4-mm thick plates of SS 202 and SS 304 was taken. To accommodate 18 distinct samples for Tensile and Hardness testing total material size were designed and compared to the standard market available size and then purchased (400 X 400 mm). The Chemical Composition of the Alloys in percentage was given in Table 1.

TABLE 1. The Chemical Composition of the Alloys Used

Materials	**C**	**Mn**	**Si**	**S**	**P**	**Cr**	**Ni**
SS 202	0.065	8.00	0.458	0.008	0.033	18.65	8.24
SS 304	0.031	1.521	0.199	0.005	0.021	18.79	8.31

For Tensile Testing, the Sample Specimens were fabricated as per ISO 4136:2001 (Destructive Tests on welds in Metallic Materials) for Experimentation. Figure 1 provides the Schematic of Standard Tensile Test Specimen whose Guage Length is 70mm.

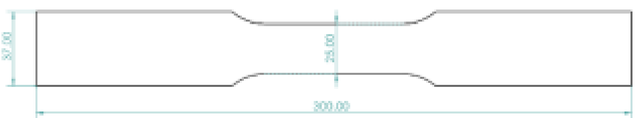


Fig. 1. Tensile Test Specimen according to ISO 4136:2001

(a)

(b)

Fig. 2. (a) Machined Tensile Test Specimen and (b) Machined Hardness Test Specimen

Sample Specimen were machined out of the Material using Precision Laser Cutting to the Standard Sizes for both Tensile and Hardness Testing which were shown in Figure 2. Once the Specimens were machined out of the material then they were grinded manually to their respective Groove angle using Angular Grinding machine and kept into welding fixture for further Joining Process. The Experiments were performed using Fronius MagicWave 2500 G/F TIG Welding Machine for all 36 Samples (18 – Tensile and 18 – Hardness) that were being Fabricated which is shown in Figure 3.

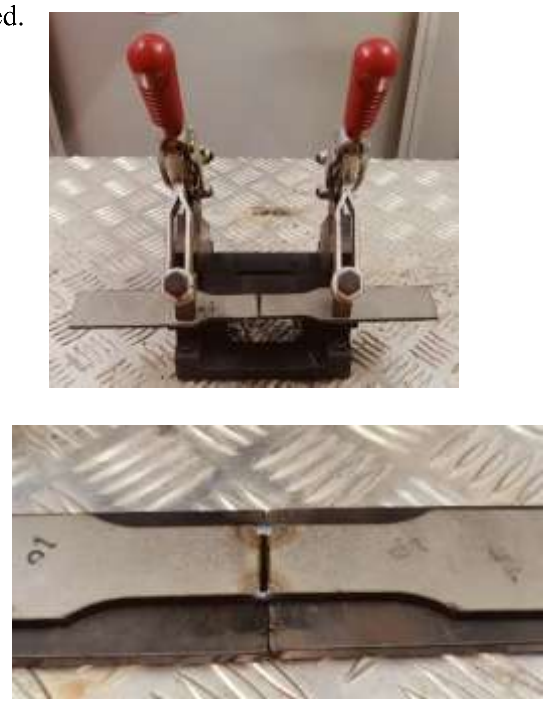
(a)

(b)

Fig. 3. (a) MagicWave 2500 G/F and (b) Experimental Setup – Welding Booth

At First, Machined Specimen Samples were kept at the respective Root Gap within the Fixture till the edges of the samples were tack welded after that they were taken out for the Complete welding of the Samples shown in Figure 4. To Create the Specimens of various factors and parameters for testing, the following experimental Procedure is followed.

(a)



(b)

Fig. 4. a) Edge Prepared Specimen Secured in Fixture and (b) Tack welded Specimen

B. Taguchi's Experimental Combination

A thorough Optimization Study was carried out considering five crucial parameters to attain the best values for Tensile Strength and Hardness.

TABLE 2. T Orthogonal Array for Experimentation using Taguchi's DOE

Experiment No	Current (A)	GFR (L/min)	Root Gap (mm)	Groove Angle (°)	Filler material

1	60	3	0.5	40	304L
2	60	6	1.0	50	304L
3	60	9	1.5	60	304L
4	110	3	0.5	50	304L
5	110	6	1.0	60	304L
6	110	9	1.5	40	304L
7	160	3	1.0	40	304L
8	160	6	1.5	50	304L
9	160	9	0.5	60	304L
10	60	3	1.5	60	308L
11	60	6	0.5	40	308L
12	60	9	1.0	50	308L
13	110	3	1.0	60	308L
14	110	6	1.5	40	308L
15	110	9	0.5	50	308L
16	160	3	1.5	50	308L
17	160	6	0.5	60	308L
18	160	9	1.0	40	308L

Of these, the four following were studied at three different levels: Current, Gas Flow Rate, Groove angle and Root Gap. The fifth parameter Filler Material was evaluated at two different levels. This setup produced a Mixed – level factorial design resulted in total of 162 experimental Runs. Finding the Ideal set of input Parameters to maximize Tensile Strength and Hardness was the main objective of this optimization. Using Taguchi's DOE Principle, MINITAB was employed to obtain the ideal setting with minimal runs (Optimized) to get the Best Experimental Results was L18 Orthogonal Array. The L18 orthogonal Array for the given Input Parameters was shown in Table 2.

(a)

(b)

Fig. 5. (a) Tensile Test Specimens and (b) Hardness Test Specimens

With the obtained Optimal Combination for Experimentation, the Sample specimen was fabricated for both Tensile and Hardness Testing as shown in Figure 5.

C. Testing and Results

Both the Sample Material and Welded Specimens were tested using TUF - C – 1000, a digital tensile testing machine that provides yield strength and Ultimate tensile Strength Values in addition to Load vs Deflection Graph shown in figure 6.

The Brinell Hardness Tester was used to measure the sample's hardness after a 750 kgf load was applied to the sample for dwell time of 10 seconds using a 5mm diameter intender. For both Tensile and Hardness 3 trails were taken overall and average of those values were taken for results and Calculation.

Fig. 6. Tensile Testing Setup

Fig. 7. Hardness Testing Setup

By conducting all these tests, the mechanical properties of the respective specimens were obtained and are Tabulated.

TABLE 3. Results for Tensile Strength and Hardness of Specimen

Experiment No	UTS (N/mm^2)	Hardness (BHN)
1	401.4	275.39
2	401.5	275.39
3	419.7	275.39
4	400.1	228.88
5	511.2	228.88
6	409.3	238.74
7	517.9	228.88
8	516.4	228.88
9	541.2	238.74
10	497.4	281.74
11	417.6	266.25
12	400.6	275.39
13	509.5	228.88
14	515.7	238.74
15	507.7	221.86
16	526.1	194.73
17	469.7	221.86
18	475.1	228.88

III. RESULTS AND DISCUSSION

A. MINITAB Analysis

Using MINITAB Software, the experimentally obtained Mechanical properties for welded Specimens were analyzed through Taguchi's method to determine the optimized Parameters which then validated Experimentally. The corresponding ANOVA (Analysis of Variance) and Signal to Noise Ratio Response Table for Tensile Strength is Provided Below.

From Table 4 it has been observed that Current is the most Significant factor influencing Tensile Strength, contributing 40.31% overall with a p value $0.022<0.05$, indicating its Statistical significance. Following that Gas flow rate has a moderate effect contributing 17.55% although its P-value is $0.12>0.05$ but still making it practically relevant. From table 5, Current has the Highest delta value followed by Gas Flow Rate, Groove Angle, Root Gap and Filler Material showing the parameters its significance in affecting Tensile Strength.

TABLE 4. ANOVA for Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
F M	1	0.4428	0.4428	0.4428	0.52	0.492	1.622
Current	2	11.0005	11.0005	5.5002	6.43	0.022	40.306
GFR	2	4.7906	4.7906	2.3953	2.8	0.12	17.553
Root Gap	2	2.0694	2.0694	1.0347	1.21	0.348	7.582
Groove Angle	2	2.1399	2.1399	1.07	1.25	0.337	7.840
Residual Error	8	6.8485	6.8485	0.8561			25.093
Total	17	27.2918					

TABLE 5. Response Table for S/N Ratio – Tensile Strength

Level	FM	Current	GFR	Root Gap	Groove Angle

1	52.94	52.2	53.48	52.62	53.13
2	53.25	52.99	53.43	53.38	52.65
3		54.1	52.37	53.29	53.5
Delta	0.31	1.91	1.12	0.76	0.84
Rank	5	1	2	4	3

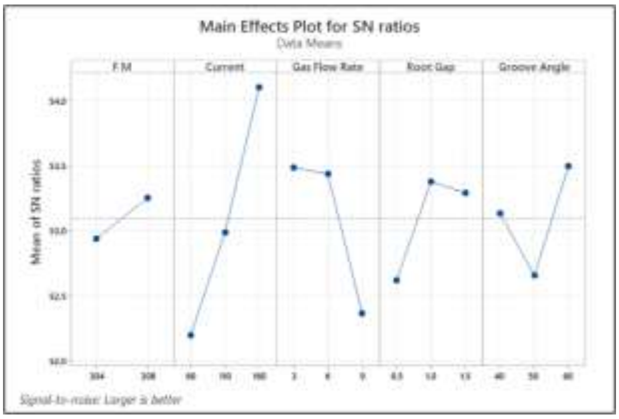


Fig. 8. Main effect plot for S/N Ratio – Tensile Strength.

The ideal Values of each Parameter to obtain Optimized Tensile Strength was displayed in figure 8's mean effect plot for S/N ratio. The table below provides the optimized parameters and their respective levels.

TABLE 6. Input Parameter levels for Max TS

Current	Level 3	160 A
Gas Flow Rate	Level 1	3 L/min
Groove Angle	Level 3	60°
Root Gap	Level 2	1.0 mm
Filler Material	Level 2	308L

Such that for hardness,

TABLE 7. ANOVA for Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
F M	1	0.3218	0.3218	0.32	2.02	0.1	2.361
Current	2	11.301	11.301	5.65	35.4	0	82.952
GFR	2	0.2353	0.2353	0.11	0.74	0.5	1.727
Root Gap	2	0.0246	0.0246	0.01	0.08	0.9	0.180
Groove Angle	2	0.4647	0.4647	0.23	1.46	0.2	3.410
Residual Error	8	1.2763	1.2763	0.15			9.367
Total	17	13.624					

TABLE 8. Response Table for S/N Ratio – Hardness

Level	FM	Current	GFR	Root Gap	Groove Angle

1	47.81	48.78	47.53	47.65	47.8
2	47.54	47.27	47.7	47.73	47.45
3		46.97	47.8	47.65	47.78
Delta	0.27	1.81	0.28	0.08	0.35
Rank	4	1	3	5	2

From Table 7 it has been observed that here also Current is the most Influencing factor contributing 82.95% overall with a p value less than 0.05, indicating its Statistical Significance other than this all-other parameter makes a minimal impact. Table 8 shows that the pattern of significantly affecting parameter begins with Current and moves on to Groove Angle, Gas Flow Rate, Filler Material and Root Gap.

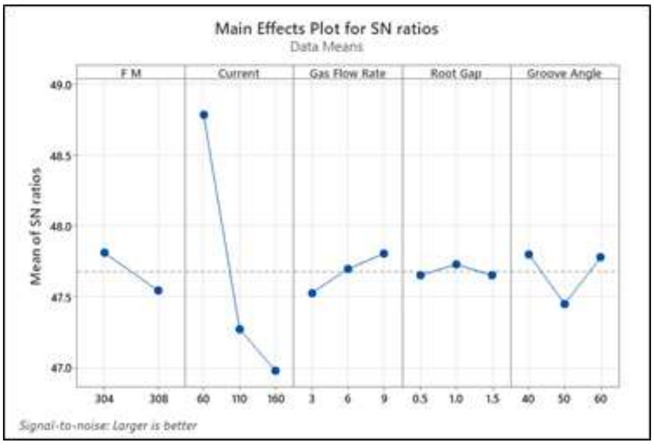


Fig. 9. Main effect plot for S/N Ratio – Hardness.

The table below provides the optimized parameters and their respective levels for Max Hardness

TABLE 9. Input Parameter levels for Max Hardness

Current	Level 1	60 A
Gas Flow Rate	Level 3	9 L/min
Groove Angle	Level 1	40°
Root Gap	Level 2	1.0 mm
Filler Material	Level 1	304L

B. Confirmatory Test Using Prediction Models

For the Selected Alloy weld, UTS is maximum at Particular setting, then at the same setting hardness will be minimum. Both Tensile Strength and hardness are maximum the better type of performance characteristics, but for the same parameter setting, both parameters exhibit opposite nature. Thus, various prediction models such as Linear Regression, Random Forest, ANN and Genetic Algorithm were employed to estimate the tensile Strength and Hardness for Optimized Parameters.

Initially, all these Prediction models were trained using the input and output of all 18 experimental Data and to identify the most reliable and accurate model for predicting mechanical properties these models were assessed based on its key performance metrics such as the Coefficient of determination (R^2) and error percentage

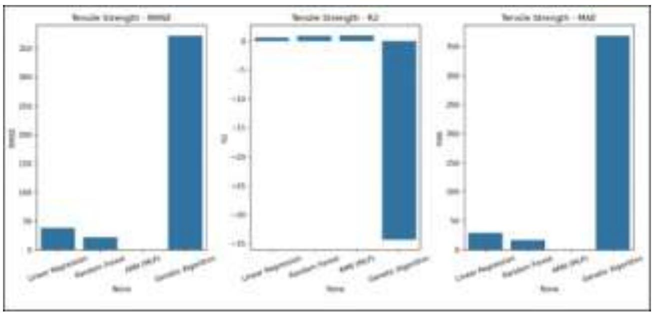


Fig. 10. Graphical Analysis of Tensile Strength Prediction Models

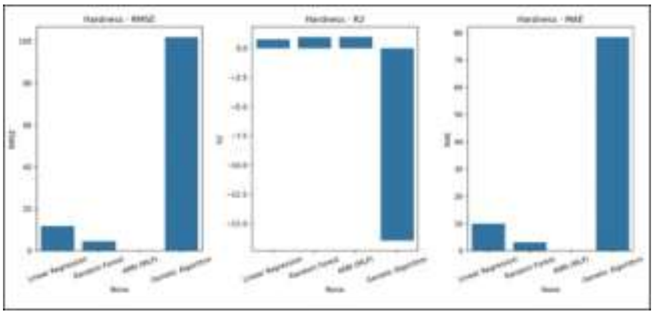


Fig. 11. Graphical Analysis of Haardness Prediction Models

From figure 10 and 11, it's been observed that for both Tensile Strength and Hardness ANN (MLP) is the most consistent and accurate model for predictive tasks in this domain. Now, the predicted value (ANN) is compared to the experimentally obtained value as an confirmatory test for the predicted Optimal Input parameters.

TABLE 10. Confirmatory test for Tensile Strength

Optimum Parameter Condition by Taguchi Method	Experimentally obtained Values	Predicted Value	Error Percentage
F M – 308L	553.543 N/mm^2	580.15 N/mm^2	4.80 %
Current – 160 A			
Gas Flow Rate – 3 L/min			
Root Gap – 1.0 mm			
Groove Angle - 60°			

TABLE 11. Confirmatory test for Hardness

Optimum Parameter Condition by Taguchi Method	Experimentally obtained Values	Predicted Value	Error Percentage
F M – 304L	284.99 BHN	285.18 BHN	0.06 %
Current – 60 A			
Gas Flow Rate – 9 L/min			
Root Gap – 1.0 mm			
Groove Angle - 40°			

The tensile strength and hardness predictions showed very small error percentages of 4.80% and 0.06%, respectively. These minimal deviations confirm the accuracy of the selected prediction model (ANN) and validate that the optimization procedure and parameter selection were appropriate and effective. Hence, the overall methodology adopted in this study can be confidently considered reliable for future applications in welding process optimization.

IV. CONCLUSION

The present research was done to investigate the effect of input parameters on weld joint quality during TIG welding of SS202 & SS 304. The following conclusions have been drawn from the experimental investigation:

1) Welding current was identified as the most significant factor affecting tensile strength, with a P-value of 0.022, indicating strong statistical relevance. While gas flow rate, groove angle, and root gap showed moderate to minor influence, their effects were not statistically significant. Based on the optimized parameter settings obtained through Taguchi analysis and ANOVA, the predicted Maximum tensile strength was approximately 553.543 N/mm², corresponding to optimal conditions including a welding current of 160 A, gas flow rate of 3 L/min, groove angle of 60°, Root Gap of 1.0mm and Filler Material of 308L.

2) The welding current was found to be the most significant factor with a P-value of 0.. The Max hardness at weld center using the optimal condition would be 284.99 BHN with welding current of 60 A, gas flow rate of 9 L/min, groove angle of 40°, Root Gap of 1.0mm and Filler Material of 304L.

3) Through confirmatory tests, it is shown that the errors associated with weld TS & hardness at weld center for dissimilar alloy joint were 4.80% and 0.06% respectively, which are under the acceptable range. The results revealed that the welding current was found to be the most significant factor that affects TS and hardness at weld center. Gas Flow Rate shows a significant effect on TS but not in hardness. Root Gap did not show any significant effect on hardness at weld center but had a minor effect on TS. The levels of different factors could be chosen to increase quality of weld and productivity through TIG welding.

REFERENCES

[1] Anand, Chaitanaya, et al. 2021. Activated flux TIG welding of dissimilar SS202 and SS304 alloys: Effect of oxide and chloride fluxes on microstructure and mechanical properties of joints, Materials Today: Proceeding, 2021.

[2] Gurmeet Kaur, et al., Effect of Filler Wire Composition on Joining Properties of GTAW Stainless Steel 202, Proceedings of the International Conference on Research and Innovations in Mechanical Engineering, 2014.

[3] Sahil Bharwal and Charit Vyas, Weldability Issue of AISI 202 SS (Stainless Steel) Grade with GTAW Process Compared to AISI 304 SS Grade, International Journal of Advanced Mechanical Engineering, 2014.

[4] Aishna Mahajan, et al., Mechanical properties assessment of TIG welded SS 304 joints, Materials Today: Proceedings, 2021.

[5] Bishub Choudhury, M, Multi optimization of weld bead characteristics during GTAW of Inconel 825 using TLBO, Materials Today: Proceedings, 2021.

[6] P. Bharath, et al, Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique, Procedia Engineering, 2014.

[7] Mayank Shrivastava, Rajeev Kumar, Optimization of GTA Welding Parameters for AISI 304 Stainless Steel using Taguchi Method, ICARI, 2020.

[8] Neeraj Sharma, et al, Optimization of TIG Welding Parameters for the 202 Stainless Steel Using NSGA-II, 2020.

[9] Saadat Ali, S.P Tewarib, Optimization of Welding Parameters by Using Taguchi Method and Study of Fracture Mode Characterization of SS304H Welded by GMA Welding. JJMIE, 2018.

[10] Sanjay, Pravin, et al., Optimization of welding parameters of GTAW using response surface methodology. U.P.B. Sci. Bull, Series D, 2017.

[11] Tunde Isaac, et al., Investigation of mechanical and parametric optimization of the dissimilar GTAW of AISI 304 stainless steel and low carbon steel. World Journal of Engineering, 2018.

[12] Vishal Chaudhari, et al., Parametric optimization of tig welding on SS 304 and MS using Taguchi approach, IRJET, 2019.

[13] Rekha Yadav, Gianender, Rinki Yadav, Process Parameter Selection for Optimizing the Weld Pool Geometry of Stainless Steel (SS 202 & SS 316) of the TIG Welding using Taguchi Method, IJRASET, 2018.

[14] Sathish, Naveen, et al, Weldability and Process Parameter Optimization of Dissimilar Pipe Joints Using GTAW, IJERA, 2012.

[15] R Sudhakaran, V Vel-Murugan and PS. Sivasakthivel, Effect of Process Parameters on Depth of Penetration in GTAW SS 202 Using RSM, TJER, 2011.