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AN EXPERIMENTAL INVESTIGATION ON THE INFLUENCE OF ROOT GAP AND GROOVE ANGLES ON 304 STAINLESS STEEL WELDING USING TUNGSTEN INERT GAS (TIG) WELDING.

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Abstract : The purpose of this experimental investigation is to determine how the root gap and groove angles affect the tensile strength of TIG-welded SS304 weld joints. The welding parameters for connecting 304 stainless steel using Gas Tungsten Arc Welding (GTAW) were extensively studied using the Taguchi method and a l9 orthogonal array. The evaluation of the mechanical properties of the welded joints is the main goal of this study. The analysis specifically looks at the effect of the Root Gap and Groove Angles on the response variable, which probably represents the tensile strength of the TIG-welded SS304 joints. The analysis specifically looks at the effect of the Root Gap and Groove Angles on the response variable, which probably represents the tensile strength of the TIG-welded SS304 joints. According to the results, Root Gap has a greater percentage of contributions (64.22%) than Groove Angles (43.64%), indicating that it dominates the response. The optimal root gap and V-groove angle for producing the highest tensile strength (621.06 MPa) were found to be 1 mm and 45°, respectively. These findings contribute to improvements in welding procedures for numerous industrial applications by providing useful information on boosting the mechanical performance of TIG-welded SS304 joints and optimizing welding parameters.

Keywords – TIG welding, tensile strength, Taguchi method.

1 INTRODUCTION

A process of uniting two metals, with or without filler material, that are similar or dissimilar is welding. TIG welding, also referred to as standard Arc welding, is one of the widely used methods. This technique is employed because it has strong controlling qualities to locally deliver heat to the welding line [1]. By inducing coalescence, welding, one of the fabrication processes, is used to unite metals, taking the role of other joining techniques like bolting and riveting. TIG welding creates strong joints and is preferred by the majority of manufacturers for mechanical assembly. Even in TIG welding, filler material is typically employed in metal joining procedures. The most crucial factor is if the welded samples are approved. Non-destructive testing of these materials is done at different stages to gauge the quality of the welds in order to match their specifications and norms. Even though the appropriate precautions were taken throughout the welding process, the weld joint inspection found that it does not fulfil its standards owing to lack of penetration, under cuts, cracks, etc. Radiography, ultrasonic testing, and acoustic testing are a few of the non-destructive examination procedures. To identify the weldment faults, these tests can be carried out more easily. The majority of the time, these tests are performed on casting-produced goods. The majority of components today, including crucial forms and structures, are made via welding.

The Taguchi technique is an effective technique that employs a unique design to analyze the parameter space with few experiments using orthogonal arrays. In a factorial design, both the number of levels and the number of factors rise exponentially. This method offers an effective, straightforward, and systematic approach to design optimization for cost, performance, and quality. It becomes necessary to conduct a large number of experiments as the factors and levels rise. An orthogonal array is created in the Taguchi method to investigate all parameters in order to solve the issue. The S/N (signal to noise) ratio is used to transform these data. Three categories nominal-the better, lower-the better, and larger-the better can be used to describe this S/N ratio [2]. An electric arc is created and maintained between a non-consumable tungsten electrode (DCEN) and the component to be welded during the process of gas tungsten arc welding (GTAW). The heat-affected zone, molten metal, and tungsten electrode are protected from ambient contamination by the inert gas that exits the GTAW torch. Since they don't react with the metals being connected, Argon and Helium are often the preferred inert gases for TIG welding. The shielding gas acts as a blanket over the weld, keeping out the air's active components [3]. The best welding technique for stainless steel is TIG. "Tungsten Inert Gas Welding" is what this acronym stands for. Early in the development of these steels for cutlery applications, the name "stainless" was developed. It was used as a generic name for these steels and is currently used to refer to a variety of steel kinds and grades for applications requiring resistance to corrosion or oxidation. Stainless steels are used because of their great toughness and general corrosion resistance. The most common stainless steels are austenitic (300 series), which are ductile and easy to shape into the necessary geometries. For applications requiring great toughness and resistance to surface wear, they can also be casehardened to generate alternating layers of martensitic and austenitic structures. However, because of their higher initial cost and susceptibility to pitting and inter granular (IGC) corrosion, their use is restricted in comparison to that of other ferrous alloys. A cell was created to investigate these localized corrosion events in structural locations of interest by conducting polarization (spot) tests on metallic surfaces in precisely specified areas [4].

The introduction provides a brief overview of the significance of SS 304 and TIG welding and the purpose of the study. The thesis statement is clearly stated, which is to investigate the mechanical properties (tensile strength and Hardness) of SS 304 weld joints produced by TIG welding.

1.1 TIG welding process

A non-consumable tungsten terminal is used to provide the weld in gas tungsten circular segment welding, also known as tungsten latent gas (TIG) welding. An external source supplies the filler metal, usually in the form of an exposed metal filler bar. A shielding latent gas, such as argon, protects the weld pool area from the environment and any contaminants. Despite the fact that some welds, known as autogenous welds, don't require it, filler metal is frequently used. Welding small pieces of tempered steel and light metals like aluminum, magnesium, and copper compounds is best done using TAW. The interaction gives the welding supervisor greater control over the welding cycle than other methods, resulting in more solid, high-upright welds. The drawbacks of GTAW include that it is slower and more complicated than many other welding techniques.

TIG welding follows the same rules as bent welding. The severe focus curve between the tungsten anode and work piece is delivered during TIG welding. The curve generates a significant amount of heat energy, which is used to attach the metal plate. The weld surface is protected from oxidation by the safeguarding gas, which is used. The TIG welding process makes use of the heat produced by an electric bend between the metals that need to be welded and a tungsten-based terminal that is positioned inside the welding lamp. To protect the tungsten terminal and weld pool, a dormant or declining gas shield is placed over the curve area. The welder physically inserts a bar of filler metal into the weld pool [5].

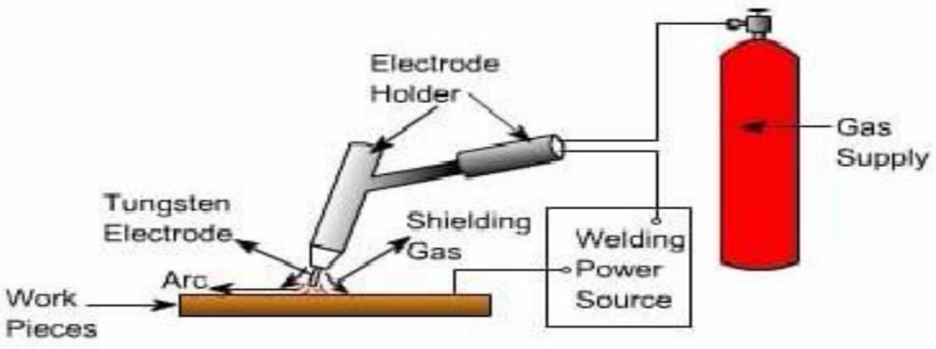

Fig. 1: TIG welding A process of uniting two metals, with or without filler material, that are similar or dissimilar is welding. TIG welding, also referred to as standard Arc welding, is one of the widely used methods. This technique is employed because it has strong controlling qualities to locally deliver heat to the welding line [1]. By inducing coalescence, welding, one of the fabrication processes, is used to unite metals, taking the role of other joining techniques like bolting and riveting. TIG welding creates strong joints and is preferred by the majority of manufacturers for mechanical assembly. Even in TIG welding, filler material is typically employed in metal joining procedures. The most crucial factor is if the welded samples are approved. Non-destructive testing of these materials is done at different stages to gauge the quality of the welds in order to match their specifications and norms. Even though the appropriate precautions were taken throughout the welding process, the weld joint inspection found that it does not fulfil its standards owing to lack of penetration, under cuts, cracks, etc. Radiography, ultrasonic testing, and acoustic testing are a few of the non-destructive examination procedures. To identify the weldment faults, these tests can be carried out more easily. The majority of the time, these tests are performed on casting-produced goods. The majority of components today, including crucial forms and structures, are made via welding.

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2 LITERATURE SURVEY

Table 1: Literature survey

Sr. No.	Title of Research Paper	Author Name	Year	Remark
1	Experimental and numerical analysis on tig arc welding of stainless steel using RSM approach	Sattarpanah Karganroudi, S. Moradi, Aghaee Attar, Rasouli, Ghoreishi, Lawrence, Ibrahim,	2021	increasing the current and decreasing scanning speed, causes the weld bead width to widen and the depth of penetration extended.
2	Optimization of 316 stainless steel weld joint characteristics using Taguchi technique	P. Bharatha, V.G. Sridharb, M. Senthil kumarb	2014	It has been noted that the root gap, current, and speed all have some bearing on the material's tensile and bending strengths.
3	Experimental investigation for welding aspects of stainless steel 310 for the process of TIG welding.	V.Anand Raoa, Dr.R.Deivanathan	2014	Better tensile and bending strength was obtained with the filler material 309L.
4	Effect of tig welding parameter of welded joint of stainless steel ss304 by TIG welding	Manabendra Saha, S. S. Dhami	2019	When stainless steel SS304 was welded utilising optimised settings, joint tensile strength and hardness increased by 10.56% and 7.36%, respectively. Ultrasonic testing was also used to assess the weld joints for interior defects.
5	A review on experimental investigation of autogenous tungsten inert gas (TIG) welding on mild steel	Sourabh Raikwar, Arun Patel	2021	The anticipated outcomes of the standard TIG welding procedure demonstrate that the maximum depth of penetration was intended to be attained with the parametric combination of the minimum welding speed and the maximum current.
6	Experimental studies on high thickness welding of ss316L using TIG-MIG welding	Mohammad Kamran Habeeb	2022	The high thickness SS materials in the range of 20-60 mm based on the required protocols are mainly used for the fabrication of sub components in vacuum vessel. Therefore, the Combination of TIG-MAG is proposed
7	Studies on mechanical properties, microstructure and fracture morphology details of laser beam welded thick ss304l plates for fusion reactor applications	Ramesh Kumar Buddua, N. Chauhana, P.M. Raolea, Harshad Natu	2015	Weld microstructures with narrow HAZ show combined characteristics of dendritic and cellular structures, and delta ferrite is present in the welds, which is further supported by increased Ferrite Number data.
8	Multi-objective optimization of process parameters in TIG-MIG welded AISI 1008 steel for improved structural integrity	Cynthia Samuel Abimaa, Stephen Akinwale Akinlabib, Nkosinathi Madushelea, Olawale Samuel Fatobac, Esther Titilayo Akinlabid	2021	This study demonstrates the value of the grey relational grading system in accomplishing a multi-objective TIG-MIG welding process optimisation.

9	Optimization of process parameters in tig welding of AISI 4140 stainless steel using Taguchi technique	L. Natrayan, R. Anand, S. Santhosh Kumar	2020	The welding current at level 1 (A1), weld speed at level 3 (B3), and filler diameter at level 3 (C3) are the best process parameters for tensile strength. According to ANOVA results, welding speed is the biggest factor in reaching tensile strength.
10	Investigation on the process parameters of TIG-welded aluminium alloy through mechanical and microstructural characterization	Jing-long Li, Muhammad Taimoor, Mohammad Nouman Siddiqui, Sumair Uddin Siddiqui, Jiang-tao Xiong	2020	The optimum heat input value to weld a thick plate of Al-5083 alloy was found to be 1e2 kJ/mm with 270e320 A welding current and 2e4 mm/s torch traveling speed. Above and below these parameters, joint properties were declined
11	Mechanical properties and microstructural investigations of tig welded 40 mm and 60 mm thick ss 316l samples for fusion reactor vacuum vessel applications	Ramesh Kumar Buddu, N. Chauhan, P.M. Raole	2014	High-thickness SS316L plates were successfully TIG welded using a multi-pass process, with no weld flaws found. The welded samples were then further characterised for their mechanical properties and microstructure.
12	Mechanical properties assessment of TIG welded SS 304 joints	Aishna Mahajan, Harvinder Singh, Satish Kumar, Santosh Kumar	2022	The current study's objective is to determine how the filler material composition affects the welding characteristics of stainless steel (SS) 304 when it is welded using a semi-automatic TIG welding procedure.
13	Mechanical Assessment of SS 304 & SS316L by using Pulsed TIG Welding Process	Darbha Rohit, Kunapuli Naga Sriranga Abhiram, Boppidi Sumanth Reddy , Valaboju Anvesh	2021	Tensile testing was done both before and after the post-welding heat treatment process, and microstructure analysis was done.
14	Characterization and analysis of TIG welded stainless steel 304 alloy plates using radiography and destructive testing techniques	Ajay Prakash Pasupulla, Habtamu Abebe Agisho, Suresh Seetharaman, S. Vijayakumar	2021	examining the mechanical behaviours of a welded joint and flaws caused by these mechanical behaviours, such as tensile testing, bending, hardness testing, and impact testing performed on a work specimen in destructive testing.
15	Influences of Groove Angles and Filler Metals on 304L Stainless Steel to AISI 1040 Carbon Steel Dissimilar Joint by Gas Tungsten Arc Welding	Eriek Wahyu Restu Widodo, Vuri Ayu Setyowati, Suheni, and Ahmad Rilo Hardianto	2019	With ER 308L-16 filler metal, the groove angle of 60° produced the highest tensile strength (614.54 MPa). The lowest tensile strength, 578.66 MPa, was attained with a 45° groove angle and ER 70S-6 filler metal.

3 METHODOLOGY

3.1 Experimental Setup for TIG welding

The experimental setup incorporates the Taguchi method with a L9 orthogonal array for TIG welding of SS304. The preparation and cleaning of SS304 specimens with predetermined dimensions. There are specified welding specifications, such as a 130 Amp current and an argon gas flow. According to the Taguchi array, the welding operation is carried out with different groove angles and root gaps. The welded specimens are subjected to tensile strength testing, and the data is statistically analysed to identify the key variables influencing tensile strength. This method enables TIG-welded SS304 joints to have superior mechanical performance and optimised welding settings.

Fig. 2: TIG welding Machine

Fig. 3: Performing TIG Welding

3.2 Material selection

SS304 is frequently utilized in welding-related applications, including the fabrication of structural elements, tanks, and pipes. Due to its exceptional weldability, components can be joined seamlessly, resulting in strong and trustworthy connections. The material's ability to resist corrosion makes it appropriate for welding in challenging conditions, and its sanitary qualities have uses in the manufacturing of pharmaceuticals and food processing equipment. standard procedure-prepared for TIG welding was the material utilized in the experiment. The substance is grade ss 304. Tables 2 demonstrate the SS 304's chemical composition.

Table 2: Chemical properties of SS304 [7]

C%	Si%	Mn%	S%	Cr%	Ni%	N%	P%	Fe%
0.03	1.00	2.0	0.03	17.5-19.5	8.00-10.50	0.11	0.05	Balanced

3.3 Sample preparation

AISI steel 304 plates are manufactured with a 30°, 45°, 60° angle and have the following dimensions: 200x 25 x 6. Following that, these specimens are welded with a root gap distance of 1 mm, 2 mm, and 3 mm.

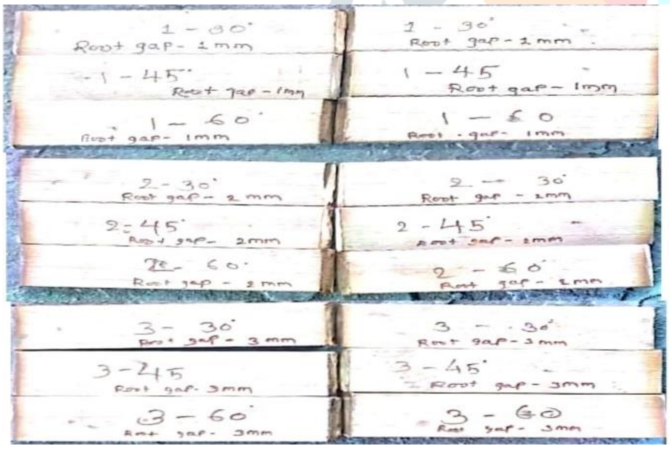

Fig. 4: Specimen before welding

Fig. 5: Specimen After welding

3.4 Parameter considered for experiment:

Table 3: Parameter considered for experiment.

Sr. No.	Input Parameters
1	Root gap (mm)
2	Grove Angle (degree)
	Constant Parameters
1	Current (amp)
2	Gas flow rate (l/min)
3	Filler material
4	Filler Material Diameter (mm)
	Output Parameters
1	Ultimate strength (KN)

3.5 Analytical methods

By minimizing variability in the robust design of tests for the creation of high-quality products, the statistical Taguchi technique has been demonstrated to be an effective tool for optimizing the TIG welding procedure. The signal to noise ratio (S/N) and the best process parameter combination from the nine sample runs that maximize the output response according to the higher-is-better criteria were calculated using the Minitab 17 Software. The observed root gap and groove Angle values were identified as the welding process's impacting variables. Using the ANOVA approach, the variables affecting tensile strength and yield strength were identified [8]–[11].

3.6 Orthogonal Array Levels

Stainless steel sheet TIG welding is influenced by a variety of variables. two characteristics were taken into account during the experimental inquiry due to practical limitations. The parameters' values were chosen based on the properties of the materials and the machinery employed in the sector. Using the Taguchi system, which has three tiers and two parameters, nine combinations of experiments can be run. As a result, the L9 orthogonal array was chosen for the current work. Table 3 lists the welding parameters and their levels for experimentation.

Table 3 The values of the variables

Sr. No.	Factors	Notation	Levels		
			1	2	3
2	Grove Angle	B	30	45	60
3	Root Gap	C	1	2	3

3.6.1 Orthogonal array Taguchi level

Taguchi experimental designs, often known as orthogonal arrays (OA's), are a collection of fractional factorial designs that focus on main effect estimation rather than interaction. Though two and three level designs are the most frequent, designs can have multiple levels of factors. The L9 design is presumably the most well-liked. The levels of each factor can be recorded in the current spreadsheet along with the design, replacing any existing data when the design is constructed. The orthogonal array and its welding parameters are shown in Table 4. Design Summary

Table 4: Experiment design L9 orthogonal array

Sample Run	Input process parameters	
	Root Gap	V- Groove angle
1	1	30
2	1	45
3	1	60
4	2	30
5	2	45
6	2	60
7	3	30
8	3	45
9	3	60

3.6.2 Constant Parameters and their value:

Table 5: Constant parameters and their values

Sr. No.	**Parameters**	**Values/ Type**
1	Current (amp)	130 (Amp)
2	Gas flow rate	9 l/min
3	Filler material	SS304
4	Filler Material Diameter	0.8 mm

3.7 Tensile Test of Welded joint

A crucial test to determine the mechanical integrity and strength of the welded connection is the tensile test for TIG-welded SS304 joints. In this test, samples that have been taken from welded joints are put under axial tension until they break. The test determines the ultimate tensile strength of the material by calculating the greatest force applied during tension and measuring how much pulling force the material can withstand before breaking.

Fig. 6. Tensile tested Specimens

4 RESULTS AND DISCUSSION

The ultimate tensile strength (UTS) measured using this test. UTM underwent the tensile test, and the findings were examined. Table.6 displays the tensile strength and S/N ratio of each specimen.

4.1 S/N ratio for Tensile Strength

To maximize the tensile strength of the welded joints is the goal of this study on tungsten inert gas (TIG) welding. We'll use the Taguchi approach and the Signal-to-Noise (S/N) ratio; a higher S/N ratio is preferred because it implies better performance. The groove angle and root gap are the two welding factors that are taken into account. To promote TIG welding techniques for better mechanical performance in welded joints, the study conducts tests based on the Taguchi L9 orthogonal array to determine the ideal combinations of groove angle and root gap that produce greater tensile strength.

Table 6: Experiment design L9 orthogonal array

Expt. No.	Root Gap	Groove Angle	UTS (MPa)	S/N Ratio
1	1	30	564.47	55.03281730677247
2	1	45	621.06	55.86267117938252
3	1	60	493.62	53.86785495379676
4	2	30	598.34	55.538960742068994
5	2	45	544.21	54.71533035581772
6	2	60	545.3	54.732709953736425
7	3	30	607.68	55.67349886113847
8	3	45	604.58	55.62907552526784
9	3	60	613.67	55.7586978558394

Signal to Noise (S/N) ratio is a statistical performance metric that is used in single-objective hardness optimization utilizing the Taguchi technique. The S/N ratio, which is determined using MINITAB 17 software, is the ratio of mean (signal) to standard deviation (noise). The quality of the product or procedure will determine this. The typical S/N ratio applied is as follows; Nominal is the better, Higher is the better and Lower is the better. Response Table for Signal to Noise Ratios & mean on tensile Strength is shown in table 7 and 8 respectively.

Table 7:Response Table for Signal to Noise Ratios

Larger is better

Level	Root Gap	Groove Anglele
1	54.92	55.42
2	55.00	55.40
3	55.69	54.79
Delta	0.77	0.63
Rank	1	2

Table 8: Response Table for Means

Level	Root Gap	Groove Anglele
1	559.7	590.2
2	562.6	589.9
3	608.6	550.9
Delta	48.9	39.3
Rank	1	2

The primary results for the method the values in the table represent the degree of correlation between the produced sequence and the reference sequence. There is a larger link when the value is higher. The delta rankings of the parameters are also shown in Table 7. The responses were most affected by the root gap, which was followed by the groove angle.

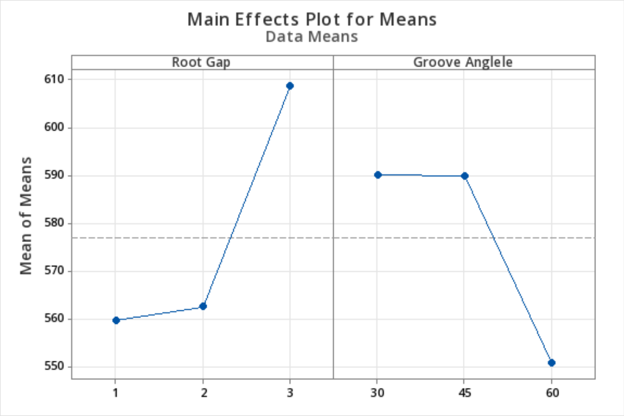

Fig.7:Effect of welding parameters on tensile strength for means

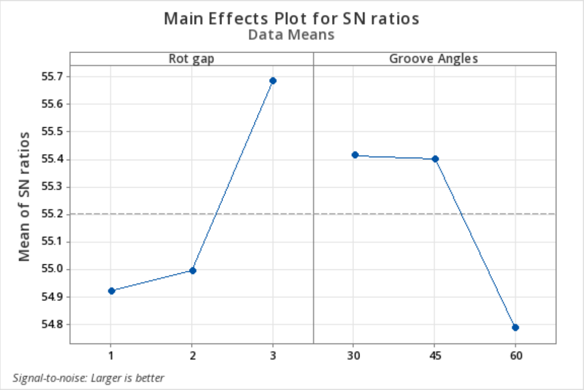

Fig.8: Effect of welding parameters on tensile strength for SN Ratios

Root Gap and Groove Angle alterations at various levels of the process have a big impact on the reaction. The root gap and groove angle mean values exhibit unique trends at various levels, demonstrating the influence of these variables on the weld quality and mechanical characteristics of TIG-welded joints. The observed variations in Root Gap and Groove Angle settings between the levels highlight the significance of doing so carefully in order to optimize the welding process and achieve excellent weld integrity

4.2 Analysis of Variance (ANOVA)

To ascertain the influence of each input process parameter in terms of their respective percentage contributions and level of significance at a given confidence level, analysis of variance (ANOVA) is used. The ANOVA results are displayed in Table 9.

Table 9: Analysis of variance for Tensile Strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %
Rot gap	2	4521	2260	1.28	0.371	64.21875
Groove Angles	2	3072	1536	0.87	0.485	43.6363
Error	4	7040	1760			100.00
Total	8	14633				

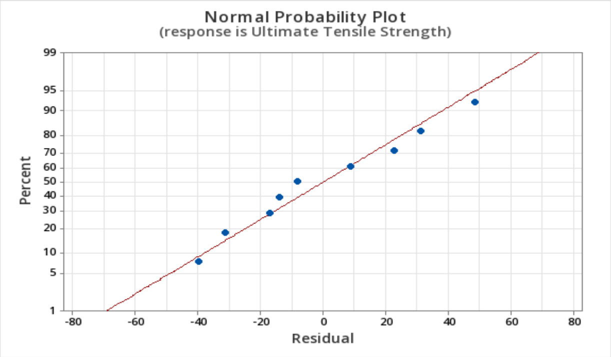

Fig.9:normal probability plot for tensile strength

The Root Gap and Groove Angles' impact on the response variable is shown in the ANOVA table and is probably connected to the mechanical characteristics, such as tensile strength, of TIG-welded SS304 joints. The table clearly shows that Root Gap contributes more by a factor of 64.22% than Groove Angles, which contribute by a factor of 43.64%. The p-values (0.371 for Root Gap and 0.485 for Groove Angles) suggest that the variations in means may not be statistically significant even if both factors appear to have an impact on the response. The variation in the response that cannot be accounted for by the elements under examination is represented by the word "Error."

5 CONCLUSION

In this work, several welding parameters were investigated when joining 304 stainless steel using gas tungsten arc welding (GTAW). The investigation's main focus was on the welded joints' mechanical characteristics. The study specifically evaluated how Root Gap and Groove Angles affected the response variable, which is probably a good indicator of the tensile strength of SS304 joints that were TIG-welded. The research showed that Root Gap had a higher percentage of contributions (64.22% vs. 43.64% for Groove Angles), highlighting its bigger influence on the response. A root gap of 1 mm and a V-groove angle of 45° were found to be the ideal conditions for producing the highest tensile strength (621.06 MPa). These results contribute to the improvement of welding procedures in many industrial applications by offering useful insights for boosting the mechanical performance of TIG-welded SS304 joints and optimizing welding settings.

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