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Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique

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Abstract

Welding is one of the most popular methods of metal joining processes. The joining of the materials by welding provides a permanent joint of the components. The objective of this research is used to determine the influence of various welding parameters on the weld bead of AISI 316 welded joint. In this research work the ANOVA technique is used to identify the influence of the welding speed, current, electrode, root gap on the strength of the material. The result shows that speed is most influencing factor to have highest bend strength and current that is to be used while welding is the most influencing factor to get higher tensile strength.

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Keywords: ANOVA; Tensile Strength; Bend Strength.

1. Introduction

Welding is one of the fabrication processes that is used for joining the metals, by causing coalescence which replaces other joining processes like bolting, riveting [1, 2]. A good joint will be obtained through TIG welding and a preferred by most of the manufactures for mechanical assemblies [3]. Generally filler material is used in metal joining processes, even in TIG welding. The acceptance of the welded samples is most important. In order to meet its requirements and standards, non destructive evaluation of these materials is done in various stages to evaluate weld quality [4, 5]. The weld joint inspected found that it does not meet its requirements due to lack of

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penetration, under cuts, cracks etc. even though necessary precautions were taken during welding process. Some of the techniques used in non destructive evaluation are Radiography, Ultrasonic tests, Acoustic testing. These tests can be done in a simpler way to find out the defects in the weldment [6]. Mostly these tests are preferably done on the products that are produced using casting process. Now a day's welding is mostly used in fabrication of many components including critical shapes and structures. TIG welding is also known as Gas Tungsten Arc Welding (GTAW) in which an arc is maintained between the base metal and the non consumable tungsten electrode. The heat affected zone, tungsten electrode, molten metal are shielded by a blanket of inert gases fed through GTAW torch which protects atmospheric contamination [7]. In TIG welding inert gases like argon, helium are used which acts as shielded gases because they prevent atmospheric contamination of molten weld pool and also they do not react with the base metal. This shielding gas acts as a blanket to the weldment and excludes active properties surrounded in the air [8, 9]. TIG welding results in increase in the weld penetration in the austenitic stainless steel and penetration overcomes as a result of chemical composition [10].

Taguchi method is a powerful tool that uses a special design to study the parameter space with small number of experiments through orthogonal arrays [11, 12]. In the factorial design, the number of levels and factors increases the number of factors and levels increases exponentially. This technique provides an efficient, simple and systematic approach to optimize design for quality, performance and cost. Large number of experiments has to be done, when the factors and levels increases. To solve the problem, an orthogonal array is developed in Taguchi method to study entire parameters. These results are transformed by using S/N (signal to noise) ratio. This S/N ratio can be characterized into three categories i.e., nominal-the better, lower-the better, larger-the better. In this research larger-the-better is chosen to get the final strength that should be maximum. Then a statistical analysis of Variance (ANOVA) is performed to check the statistical process parameters. Optimal combination of the parameters were be predicted by ANOVA and S-N analysis.

This research studies the influence of various input parameters on the tensile strength and bending strength of AISI 316 welded joint. The influence of speed, current, electrode, root gap is identified by ANOVA method

2. Methodology

2.1Material selection

316stainless steel is selected over other materials because of its distinct properties, cheaper cost and its availability in the market. 316stainless steel used is a boiler grade steel used in pressure vessels. This grade has high corrosion resistance and can be operated at elevated temperature. The chemical composition of SS316 is shown in Table 1. Fig.1. shows the sample of TIG welded joint.

Fig.1. Sample piece welded using TIG welding with 2.0 mm root gap

Table 1. Chemical Composition of 316 stainless Steel

Elements	Weight percentage
Carbon	0.08
Manganese	2.00
Phosphorus	0.045
Sulphar	0.030
Silicon	0.75
Chromium	16.0-18.0
Nickel	10.0-14.0
Nitrogen	0.10
Molybdenum	2.0-3.0

The material specifications are

Material : 316 Austenitic stainless steel
Thickness : 3 mm
Length : 100mm
Number of samples : 27

1.1.1. Taguchi method analysis

In Taguchi method first optimal parameters were determined by using L27 (3^5) orthogonal array. L27 (3^5) means that it will investigate for 3 levels and 5 factors on qualitative index for each factor. Table2 gives the levels and factors which are employed for welding the samples. Table 3 gives the experimental data that is taken for analysis.

Table 2. Critical Parameters and Levels

LEVELS	1	2	3
Speed (mm/min)	50	65	80
Current(Amps)	60	80	100
Electrode	316	309L	347
Operator	1	2	3
Root gap (mm)	1.0	1.5	2.0

2. ANALYSIS OF VARIATIONS (ANOVA)

The observed values for speeds, and current were determined as the influencing factors in welding process. The parameters influencing tensile strength and bending strength were found out by using ANOVA technique. From the Table 4, 5 and 6 the influencing factors for bending strength is speed of welding and current for tensile strength.

Table 3. Experimental Data

Sample number	Electrode	Current (Amps)	Speed (mm/min)	Operator	Root gap (mm)
1	316	60	50	1	1
2	316	60	50	1	1.5
3	316	60	50	1	2
4	316	80	65	2	1
5	316	80	65	2	1.5
6	316	80	65	2	2
7	316	100	80	3	1
8	316	100	80	3	1.5
9	316	100	80	3	2
10	309L	60	65	3	1
11	309L	60	65	3	1.5
12	309L	60	65	3	2
13	309L	80	80	1	1
14	309L	80	80	1	1.5
15	309L	80	80	1	2
16	309L	100	50	2	1
17	309L	100	50	2	1.5
18	309L	100	50	2	2
19	347	60	80	2	1
20	347	60	80	2	1.5
21	347	60	80	2	2
22	347	80	50	3	1
23	347	80	50	3	1.5
24	347	80	50	3	2
25	347	100	65	1	1
26	347	100	65	1	1.5
27	347	100	65	1	2

The percentage contribution of the welding parameters for tensile strength and bending strength calculated are shown in Table 4 and 5. In the very first step over all mean is calculated as the average of the tensile strength measured during trails. Grand total sum of squares is given as the sum and square of each trail value. Sum of squares due to mean is given as the number of experiments multiplied by the square of the overall mean. The calculated total sum of squares is given as the difference between grand total sum of squares and sum of squares due to mean. Sum of squares for each parameter is given as $3[(A_1\text{-m})^2 + (A_2\text{-m})^2 + (A_3\text{-m})^2]$ where, A_1, A_2, and A_3 are the average value of each assigned parameters at levels 1, 2, 3 respectively. Degree of freedom (DOF) error is given by the difference between the DOF for the total sum of squares and sum of DOF for various factors. Mean square is given as the ratio of sum of squares due to each factor to DOF for each factor. Variance ratio is given by the ratio of mean squares due to the factor to mean squares error. Percentage of contribution is the ratio of sum of squares to the total sum of squares [13, 14]. All the values for each parameter were calculated and shown.

Similarly the percentage of contribution was calculated for parameters speed and current. The results of ANOVA for bending strength and tensile strength are summarized in Table 4 and Table 5 respectively.

Table 4. ANOVA for Bend Strength

Factors	Degrees of Freedom	Sum of squares	Mean	variance	% contribution
Root gap	2	5428.135	2714.07	0.1418	0.593
Speed	2	24333.73	12166.7	0.6357	2.658
Current	2	885652.9	442826.5	23.139	96.75
Total	6	915414.8	_	_	_
Error	20	382751.4	19137.57	_	_

Table 5. ANOVA for Tensile Strength

Factors	Degrees of Freedom	Sum of squares	Mean	variance	% contribution
Root gap	2	41735.55	20867.8	0.2204	19.85
Speed	2	97795.83	48897.9	0.5164	46.51
Current	2	70729.91	35364.9	0.3734	33.63
Total	6	210261.3	–	–	_
Error	20	1893814.3	94690.7	_	–

3. Mathematical Modeling

Multiple linear regression models were developed for tensile strength and bend strength by using Minitab17 software. The responsible variables are tensile strength, bend strength whereas the predictors are speed, root gap, current. The equations of the fitted model for tensile strength, bend strength are given below

- Tensile Strength = 218 + 0.29 Current + 3.07 Speed - 20.7 Root Gap
- Bending strength = 1374 - 5.34 Current - 3.44 Speed+ 149 Root Gap

Table 6. Experimental Observations

S. No	Tensile Strength N/mm^2	Bending Strength N/mm^2
1	335.97	1004.37
2	264.756	1095.06
3	307.853	1515.65
4	438.339	1240.19
5	579.473	525.498
6	506.289	621.32
7	640.076	954.286
8	639.75	552.13
9	287.18	920.924
10	538.486	815.853
11	328.486	926.185
12	274.738	810.25
13	197.722	487.868
14	526.853	1124.47
15	569.149	752.656
16	510.443	845.257
17	367.439	779.406
18	263.508	1119.86
19	570.44	1021.33
20	259.992	845.13
21	525.898	1805.92
22	332.843	916.068
23	524.32	900.586
24	479.786	1218.49
25	239.403	970.054
26	160.093	945.711
27	402.692	830.835

5. RESULTS AND DISCUSSION

5.1 Bend test

This test is used to determine the ductility of the weldment. The specimen is made to bend into U-shape by applying load on the welded area on the flat surfaces using 3 point bend test in UTM. In this research on studying different parameters specimen 21 has highest bend strength as observed in Table.6. The stress- strain curve of specimen-21 is shown in fig.2 and distributions of stress for different specimens are shown in Fig.3. The bending strength of the specimen – 21 can resist load up to 1805.92 N/mm^2. The bending strength increases as the root gap between the specimens varies.

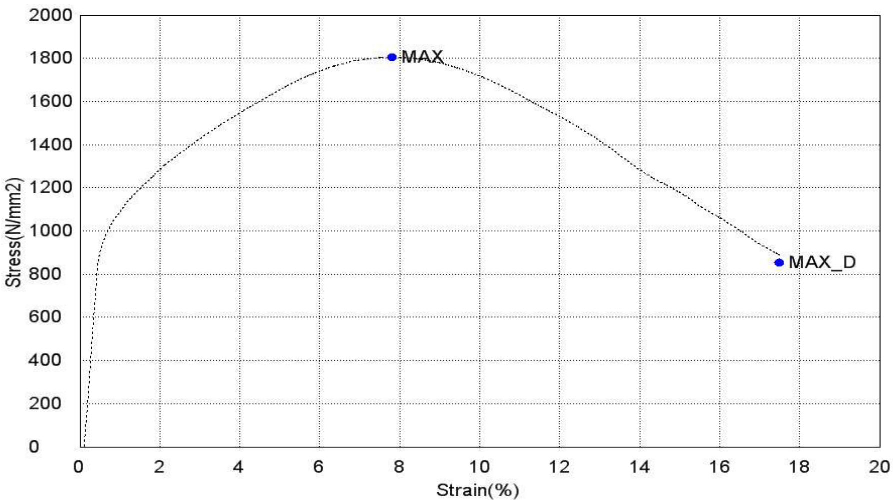


Fig.2. Stress-Strain curve of specimen-21

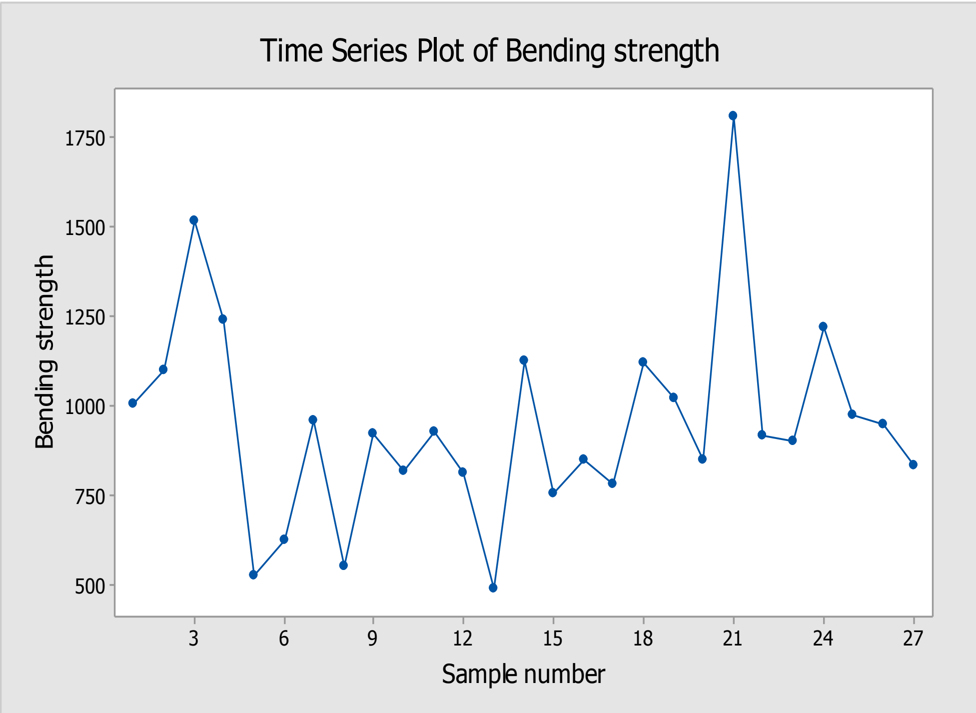


Fig.3. Time series plot for bending strength

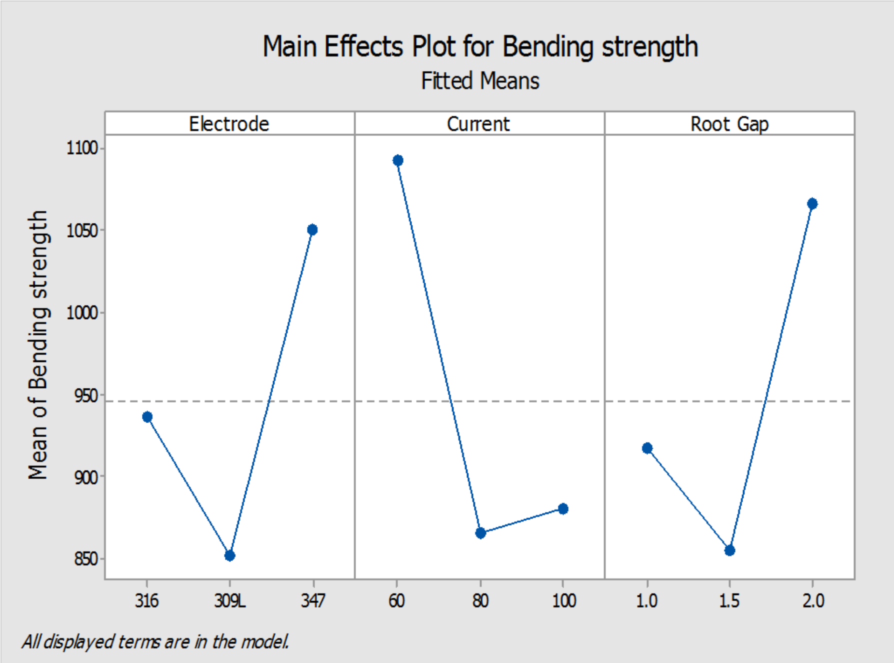


Fig.4. Effect plots for bending strength

5.2. Tensile test

This test is used to determine the modulus of elasticity (E), ultimate tensile strength (UTS). The tensile test was conducted on UTM and their results were studied. The tensile strength of all the specimens are shown in Table.6 and Fig.6 shows distribution of stress for different specimens. The Time series plot for tensile strength confirms that specimen 7 has highest tensile strength and its stress-strain plot is shown in Fig.5. The tensile strength of the specimen varies with the speed of the welding. The speed increases within the range of the root gap, which in turn increases the better tensile strength. The specimen-7 exhibited a tensile strength of 640N/mm^2.

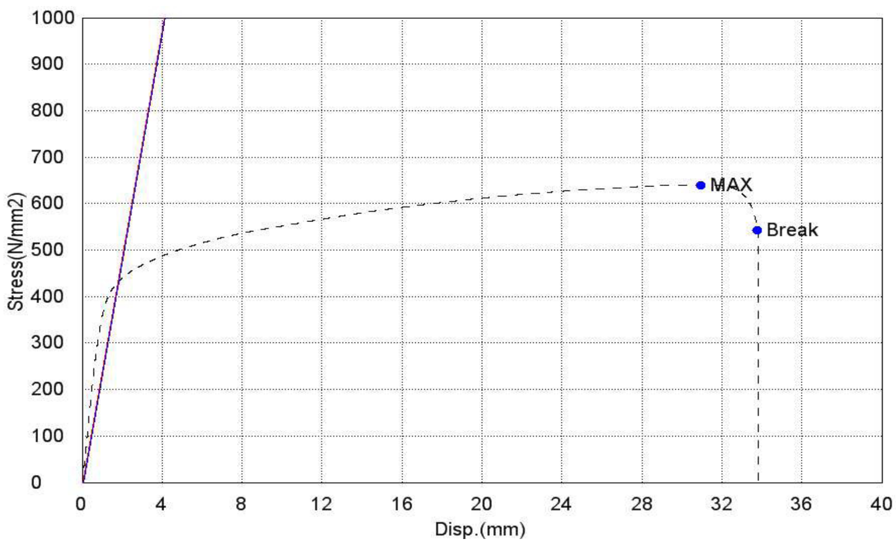


Fig.5. Stress-Strain curve for specimen-7

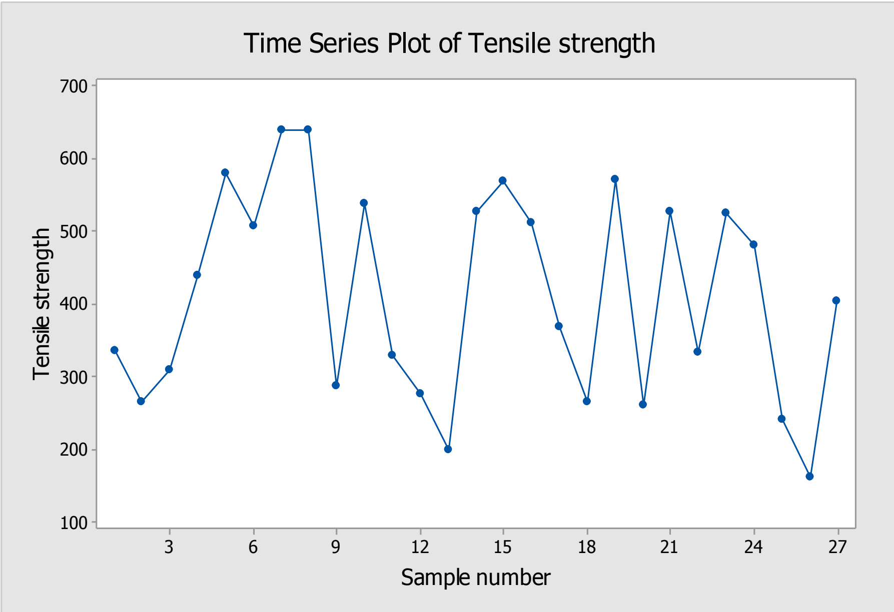


Fig.6. Time series plot for Tensile strength

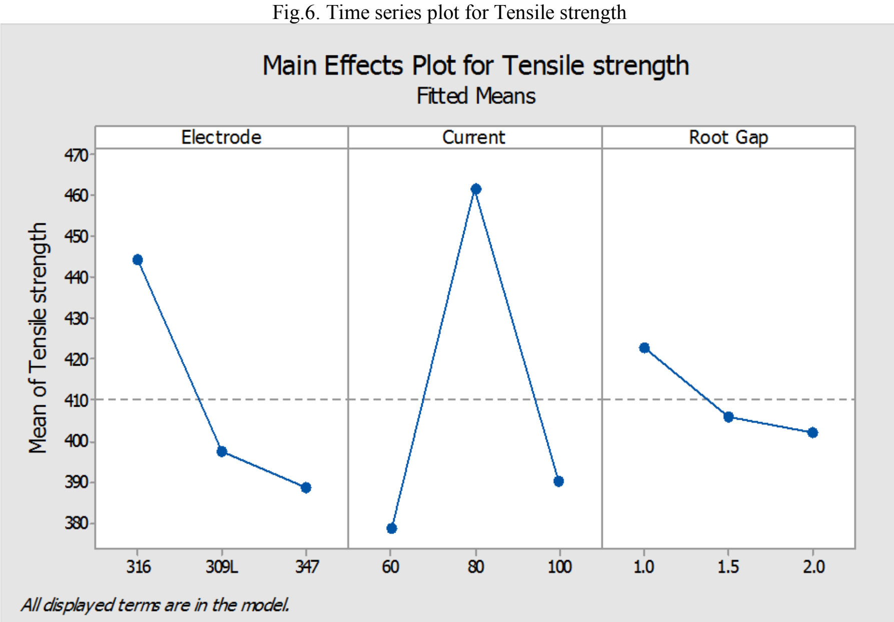


Fig.7. Effects plot for Tensile strength

6. Confirmative tests

6.1. Ultrasonic testing

Ultra sonic testing is one of the non- destructive testing processes. In this process, the work piece is tested without destructing. The welded samples were subjected to ultra sonic testing and found that there is no significant defect on all the test specimen.

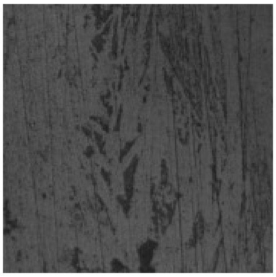
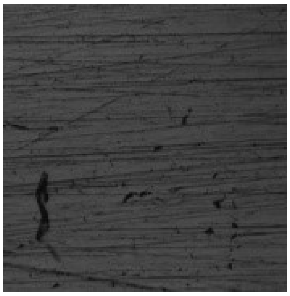
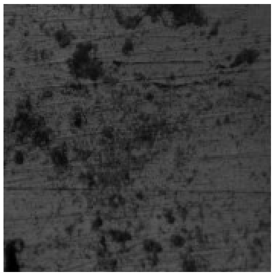
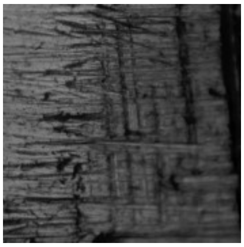
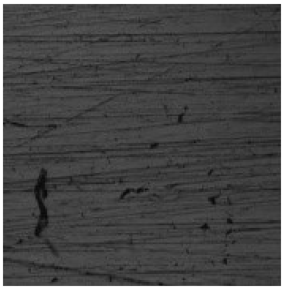
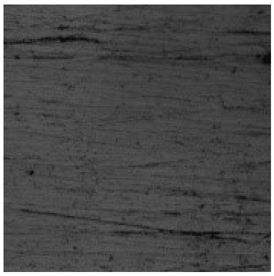
6.1. 1. Micro structure study

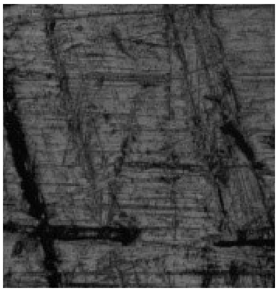
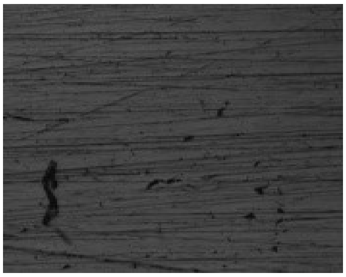
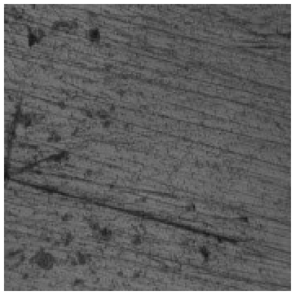
This study is to make a view of the material properties in the grain growth at the welded area, HAZ and the base metal. The microstructures were taken only for those samples which have high, medium and low tensile strength. The microstructures are shown in Fig 8. The results of the microstructure revealed in Table 7 shows the properties of the specimens at different regions like welded zone, HAZ and the base metal.

Table 7. Micro structure Analysis

Specimen	Area	Microstructure properties
specimen 4	Weld zone	This microstructure shows dendrites structure
	Heat affected zone	This microstructure shows austenite/ferrite dark structure
	Base metal	This microstructure shows light structure of austenite
Specimen 13	Weld zone	This microstructure shows dendrites structure
	Heat affected zone	This microstructure shows dark structure of austenite/ferrite
	Base metal	This microstructure shows light structure of austenite
Specimen 18	Weld zone	This microstructure shows coarse structured austenite + second phase
	Heat affected zone	This microstructure shows coarse structured of austenite + second phase.
	Base metal	This microstructure shows light structure of austenite

Table 8. Micro structures of different specimens

Sample	Welded zone	Base metal	Heat affected Zone
Sample-4			
Sample-13			

Sample-18			

7. Conclusion

It has been observed that current, speed, root gap has some influence on the tensile strength and the bending strength of the material.

Based on Analysis of variance (ANOVA) it is found that welding speed (46.51% contribution) has greater influence on bend strength and current (96.75%) has highest influence on tensile strength. Further it has found that root gaps has some influence on both tensile and bend strengths.

Micro structure study shows some inclusions near the heat affected zone due to change in weld material and also change in grain sizes that are developed during welding process.

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