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Experimental Investigation for Welding Aspects of Stainless Steel 310 for the Process of TIG Welding

V.Anand Rao[a] , Dr.R.Deivanathan[b*]*

[a]*M.Tech student, SMBS, VIT University, Chennai-600127, India*
[b]*Associate Professor, SMBS, VIT University, Chennai-600127, India*

Abstract

This work aims at the analysis and optimization of joining similar grades of stainless steel by TIG welding. The parameters like current, filler materials, welding speed are the variables in the study. The mechanical properties and microstructure of 310 austenitic stainless steel welds are investigated, by using stainless steel filler material of different grades. Higher tensile strength was achieved with a current 120A and 309L filler rod and also the weld has fewer defects.

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Keywords:tensile strength, bend strength, ultrasonic testing;

1. Introduction

Stainless steel or corrosion resisting steels are a family of iron base alloys having excellent resistance to corrosion. Because of high corrosion resistance, stainless steel sheets are progressively used for kitchen, transportation, building constructions, etc. Austenitic steels are one of the best choices, as they combine good mechanical properties and corrosion performance[10]. As they have low carbon percentage, intergranular corrosion can be prevented. Stainless steel sheets are the preferred material of use in many areas like automotive exhaust systems, steel pipes, chemical industrial equipments, etc.

310SS is selected for fabrication works mainly because the material contains low carbon and good weldability factor and also because it has high temperature service factor with good ductility. It resists oxidation in continuous

* *Corresponding author. Tel:+919677108743, +919789092344; fax: 044 3993 2555.*
E-mail address:anandraov.mech@gmail.com, deivanathan.r@vit.ac.in

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service at temperature up to 1150^{O}C, provided the reducing sulphur gases are not present. It is also used for intermittent service at temperatures up to 1040°C. Further, 310SS grade is resistant to sulphidation and carburization.

Until the end of the 19th century, forge welding was the only welding process the blacksmith had used years together, to join iron and steel by heating and hammering. Arc welding, oxy fuel welding and electric resistance welding processes followed soon after. Due to technology advance, several modern techniques were developed by welding engineers, such as semi automatic and automatic processes, gas metal arc welding, submerged arc welding, and electro slag welding. Among them one of the best welding technique is gas tungsten arc welding[11], commonly referred as TIG welding.

Gas Tungsten Arc Welding (GTAW) is a process in which an electric arc is produced and maintained between non consumable tungsten electrode (DCEN) and the part to be welded. The inert gas which passes from GTAW torch acts as a shield from atmospheric contamination for the heat affected zone, molten metal and tungsten electrode. Generally Argon and Helium are the preferred inert gases in TIG welding as they do not react with metals being joined. The shielding gas serves as a blanket to the weld and excludes the active properties in the surrounding air[1,5]. MIG welding of austenitic steels was attempted with proportion of H-Ar as the gas shielding[10].

The weld quality is dependent on the right choice of key welding parameters like the welding current, filler material, welding speed[7,11]. An attempt to increase the mechanical properties by initially annealing can be significant when the welding parameters i.e. groove design, filler angle etc. are considered[3]. Based on the literature survey, many researchers have worked on welding of 310 stainless steels, but were conservative in choosing the same 310SS as the filler material. Now in this work, different filler materials viz., 309L, 347 and 316L are tested to investigate the better filler material for welding 310SS and to determine the best mechanical properties in severe conditions.Austenitic stainless steels are particularly prone to the hot cracking phenomenon. It has been determined however, that hot cracking may be reduced in austenitic stainless steel weldments by using filler materials that contain a small percentage of retained ferrite [4].

2. Experimental procedure

310 austenitic steel with a chemical composition presented in Table1 was used to conduct the test. Specimen of 50 x 50 x 3 mm dimension, were prepared and welded in butt joint configuration with single groove of 45^{O}C groove angle. The root gap was kept at 1mm uniformly for all specimens.

Table 1.Chemical compositions of base metals and filler materials

Elements(%wt)	Base metal(310SS)	316L(filler)	347(filler)	309L(filler)
C	0.07	0.03	0.08	0.02
Mn	0.95	2.0	2.0	1.8
P		0.045	0.045	0.045
S	0.03	0.03	0.03	0.03
Cr	24-26	16-18	17-19	24
Mo	0.25	2-3		0.15
Ni	18.96	10-14	9-13	13.0
N	-	0.1		
Si	1.58		0.75	0.5
Al	0.68			

Welding was performed in single pass by the manual gas tungsten arc welding procedure with direct current electrode negative (DCEN), using Argon gas shielding. For this study, a total of 9 specimens were prepared. Each one of the three different stainless steel filler rods, namely 316L, 347 and 309L were used to weld three pairs of SS310 plates respectively. The welding current was the other parameter varied for each experiment thus giving a range of heat input for welding.

The weld quality was assessed using ultrasonic flaw detector (across the thickness of the specimen) as well as through microstructure study using optical microscope[8,9]. For microscopic observation, the specimen was carefully cut into 10mm width, polished and then etched with picric acid. Further, in order to determine the mechanical properties of the welded plates, all the specimens were subjected to tensile strength test and three point bend test[6].The specimen was further cut into 10mm width for tensile testing and the remaining 30mm width of specimen was used for the bend test. A 310SS welded specimen is shown in Fig.1(a) and the tensile test specimen is prepared as shown in Fig.1(b).

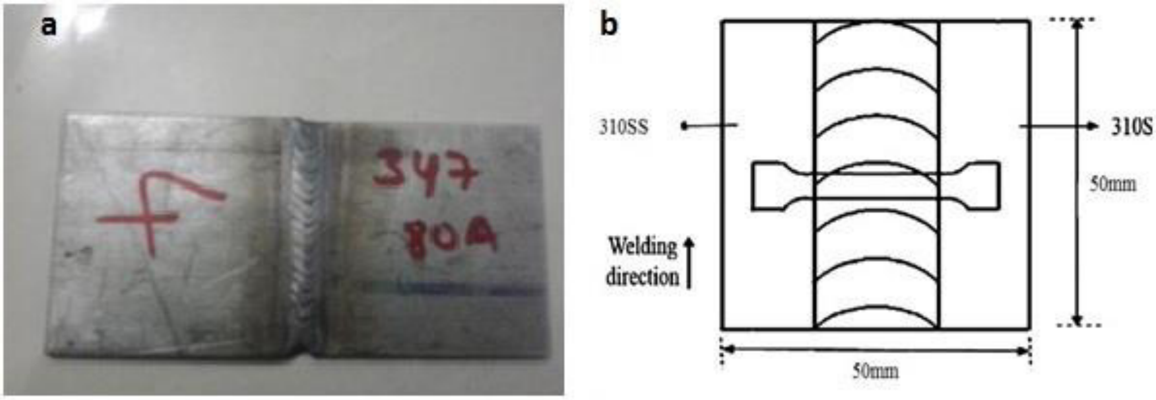


Fig 1. (a)Alignment of specimens in welding; (b) specimen for tensile test.

Heat input at the weld zone is calculated by the formula, $Q= (V*I*60)/(S*1000)$, where Q is the heat input (KJ/mm), V is the applied voltage(V), I is the current(Ampere) and S is the welding speed (mm/min).

Speed of welding, S, varies with the change in root gap; for 1.0mm root gap, the welding time is 50sec. Thus, as per the experimental conditions for specimen A, $Q = (19*80*60)/(50*1000) = 1.824$ KJ/mm. The heat input and welding parameters values are given in Table 2 for all the 9 specimens named A through I.

Table 2. Experimental data regarding the TIG welding process

Specimens	Current,*I* (amperes)	Electrodes	root-gap (mm)	Heat input (J/mm)
A	80	316L	1.00	1824
B	100	316L	1.00	2280
C	120	316L	1.00	2736
D	80	347	1.00	1824
E	100	347	1.00	2280
F	120	347	1.00	2736
G	80	309L	1.00	1824
H	100	309L	1.00	2280
I	120	309L	1.00	2736

3. Results and discussions

3.1. Tensile test

The welding process was analyzed using the test pieces with respect to parameters incurred in Table 2. The tensile strength of the specimen was determined by UTM (Universal Testing Machine) as shown in Fig.2 and the corresponding stress-strain graph for 'specimen I' is given in Fig.3. The tensile strength of specimen A through H are tabulated in Table 3.

Ductility of the material can also be determined by the tensile test. It can be seen that, the tensile strength of specimen welded with 316L filler rod is low compared to that welded with 347 or 309L. Further, 309L yielded the best joint in terms of tensile strength. Strength of weld is proportionately increasing with the welding current while using 316L and 347 filler rods. Whereas the said effect is absent in case of 309L filler rod (having Cr content same as base metal) which gives better fusion of weldment.

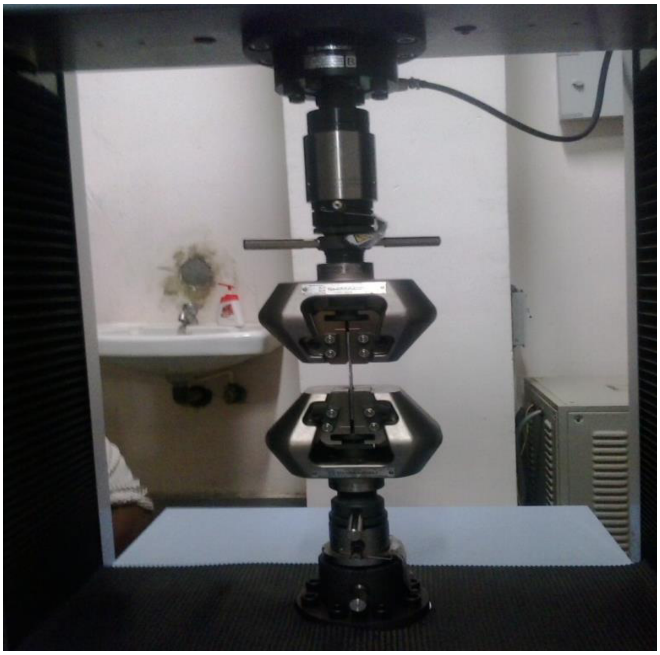


Figure 2. Specimen under a Tensile Test

Table 3. Tensile strength and bending strength of different specimens

Specimen	Tensile strength(MPa)	Bending Strength(MPa)
A	51.79	369.23
B	110.66	519.88
C	146.55	646.55
D	71.33	572.92
E	309.22	319.18
F	350.6	211.37
G	401.12	427.58
H	327.07	449.83
I	454.6	373.70

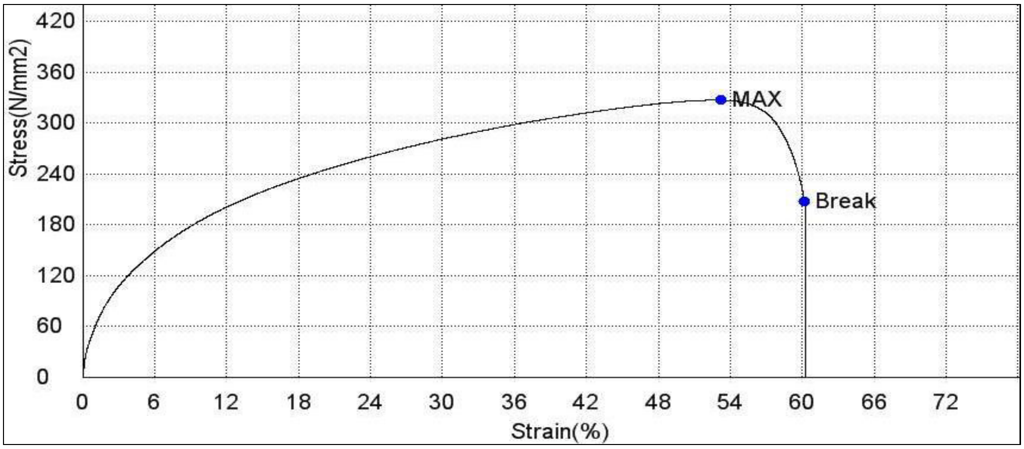


Figure 3. Tensile graph for specimen I

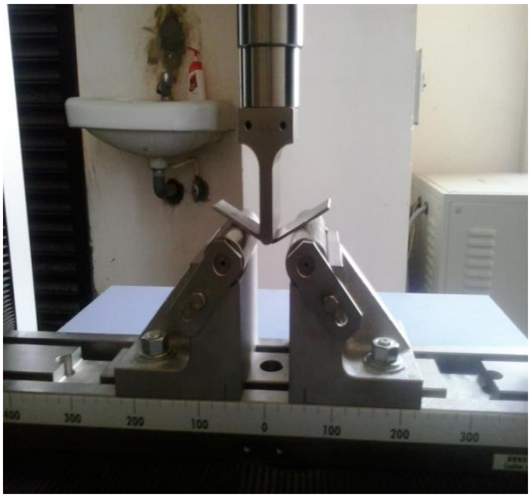


Figure 4. Specimen under a Bend Test

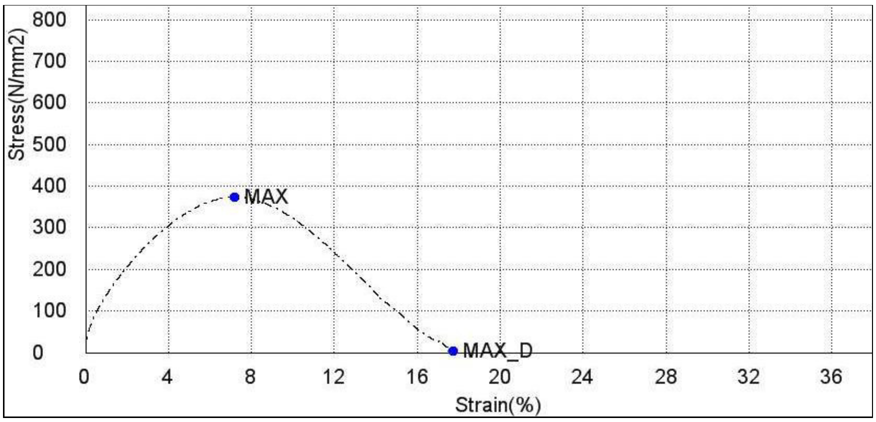


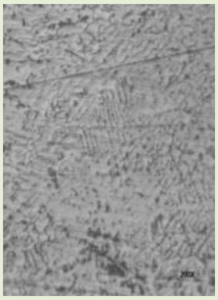
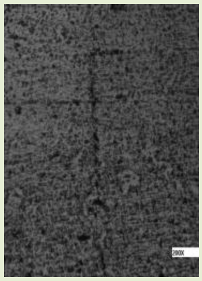
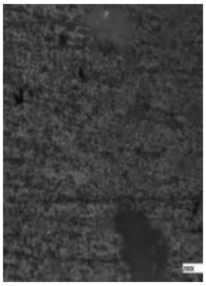
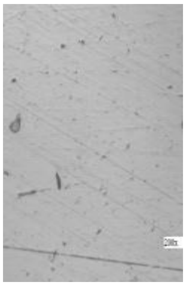
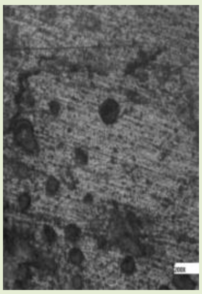
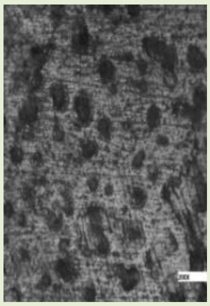
Figure 5. Bend test graph for specimen I

3.2. Bend test

Bending strength of the material can be determined by using 3 point bend test. The specimens are made into U shape by the bend test as shown in Fig.4. The results were analyzed and tabulated in the Table 3. The bend test graph corresponding to 'specimen I' is shown in Fig.5. Specimen welded with 316L and 309L produced joints of good quality with bending strength over 370 MPa, whereas the filler material 347SS is seen to give lower bending strength and are associated with surface cracking.

3.3. Micro structural study

Table 4. Micro structure of three regions of the SS310 weldment at 200X

Specimen	Weld zone	Base metal	Heat affected zone
Specimen C Filler rod (316L)	 Dendritic structure	 Light structure (austenite)	 Darkstructure (austenite/ferrite)
Specimen F filler rod (347)	 Dendritic structure	 Light structure (austenite)	 Dark structure (austenite/ferrite)
Specimen I Filler rod (309L)	 Coarse structured (austenite + 2^{nd} phase)	 Light structure (austenite)	 Coarse structured (austenite + 2^{nd} phase)

After the welding operation was performed on the specimen, the micro structural study was made in order to understand the effect of welding heat across the specimen. The equipment used is optical microscope with a magnification is 200X. The three main zones of microstructure of specimens C, F, I are presented in Table 4, i.e. the structure of heat affected zone, weld zone and base metal respectively. Dark microstructure could be due to the presence of delta ferrite in the material after high temperature welding. According to Schaeffler diagram 5-15% ferrite has been forecast for the given compositions.

3.4. Ultrasonic testing of defects

This test was conducted to determine the welding defects more accurately and to know whether any other flaw exists in the welded specimens[2]. The ultrasonic test was performed using the Ultrasonic Flaw Detector. The ultrasonic test results showed defects of penetration, even though delta ferrite in 309L could dissolve Sulphur which causes the penetration defects. From the images shown in Table 6, the specimens G& H are observed to have fewer defects when compared to other specimens.

4. Conclusions

Experiments were carried out with accuracy in order to keep the error minimum and determine the results appropriately. The results are prone to deviations due to some uncontrolled conditions, but are not taken into consideration during this work.

- Welding current 120A and electrode 309L has produced greater tensile strength of 454.6MPa while a welding current 80A and electrode 316L has produced minimum tensile strength of 51.79MPa for the specimen studied.
- In bend test the welding current with 120A and electrode 316L has produced maximum bending strength of 646.55MPa while the same welding current with electrode 347 has produced minimum bending strength of 211.37MPa for the specimen studied.
- The filler material 309L has produced better tensile and bending strength.
- The ultrasonic test results showed defects of penetration, but in general results indicate that the defect does not create much impact.
- Microstructure images show that 309L has prominent second phase formation because of varying chromium percentage retarded transformation and uncontrolled heat input.

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