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EFFECT OF FILLER ELECTRODES ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF DISSIMILAR WELD SS 316L AND SDSS 2507

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Abstract - *The goal of this work is to do optimization of dissimilar weld of Stainless Steel 316L and Duplex Stainless Steel 2507 specimen of each size 50mm × 25mm × 5mm. Here welding is done using Shielded Metal Arc Welding by varying filler electrodes. The electrodes used are E316L and E308L. The various parameters for which optimization is done are welding current, travel angle and welding speed by creating a Taguchi design of L9 orthogonal array (3 level, 3 factor) for each electrode. So the values selected to do the experimental procedure using Taguchi design are current of 50 Amps, 70 Amps and 90 Amps, travel angle of 10°, 20° and 30° and welding speed of 2.50 mm/s, 1.66 mm/s and 1.25 mm/s. Tensile test was used to find out the tensile strength of the welded specimens and thereby optimization is done based on the tensile values. Based on the optimized parameter values welding is again done and microstructural analysis was carried. Hardness test and bend test was used to find the hardness and weld properties for the optimized parameter welded specimen.*

Key Words: **SS 316L, SDSS 2507, SMAW, Tensile strength, Taguchi design**

1.INTRODUCTION

Shielded metal arc welding (SMAW) is the manual arc welding process using either bare coated electrode. It is also called stick welding. The process consists of establishing an electric arc between a metallic electrode and the work piece to be welded. The heat of the arc melts the core wire and the flux covering at the electrode tip into metal droplets and joins the weld pool. Molten metal in the weld pool solidifies into the weld metal while the lighter molten flux floats on the top surface and solidifies as a slag layer. Therefore the process is also considered as consumable arc welding process. Bare wire electrodes are used only rarely. The coated electrode was invented by Kjellberg, a Swedish engineer[1].

The coating on the electrode burns, producing a dense covers smoke which or shields the metal drops during their transfer from electrode to weld pool. This shielding is important to prevent oxidation and absorption of nitrogen by the metal. Here the shielding gas obtained from the flux is the mixture of hydrogen, carbon monoxide, and water and carbon di oxide. This shielding gas provides the protection of the molten metal from air. At the same time the coating melts forming a slag cover on the molten pool. During welding the parent metal also melts to particular depth, forming a crater. This depth is called depth of penetration. The weld metal deposited is therefore derived partly from parent metal and the rest from the electrode. The electrode holder is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely. Both AC and DC power can be used equally effectively[2].

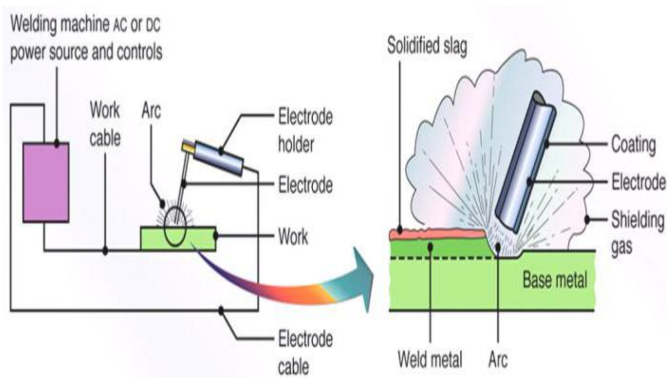

Fig -1: SMAW Welding

Fig. 1 shows the SMAW circuit diagram for the process. The weld pool is produced depends on the size of the covered electrode and the welding current used and may vary from very small to fairy large sizes.

1.1 Stainless Steel 316L

The material selected was SS316L grade. SS 316L is a austenitic stainless steel which usually contains a combined total of Cr, Ni, and MN content of 24% or higher with Cr content more than 16% and Ni content more than 7%. The Cr gives the oxidation and corrosion resistance while the Ni and Mn stabilize the austenite phase sufficiently to retain most or all of it when the steel is cooled rapidly to room temperature[3]. Austenitic stainless steel is the most corrosion resistant and because of that reason it has lots of applications in chemical plants. The austenitic steels generally have low yield strength and high ultimate tensile strength that is why they are often very ductile. They have excellent properties at cryogenic temperature and have higher strengths at 540°c than the 400series. The microstructures of these steels are either all austenite, or ferrite in a matrix of austenite[4].

1.2 Super Duplex Stainless Steel 2507

The material selected was SDSS 2507 grade. Duplex stainless steel stands for the steel which has two phases both, austenite and ferrite phase. Because of that reason it has the good properties of both austenite and ferrite which makes it different from other materials. These materials have higher strength and ductility. Nitrogen is added to increase the strength and also the weldability. It has an excellent corrosion resistance and pitting resistance equivalent number is more than 40 which makes it super duplex.

2. METHODOLOGY

The base materials selected for this are duplex stainless steel 2507 and stainless steel 316L. Both the material was available in the market as plates and has the thickness of 5mm each. Its chemical compositions are given in Table 1 and mechanical properties are given in Table 2[3]. The base metals were machined to get the dimension of each specimen as 50 mm × 25 mm ×5 mm likewise total 18 specimens of each base metal were prepared for optimization. The surface of the plates was cleaned and grinded to remove the dust and other foreign particles from it. In order to obtain a strong bonded joint the properties of the base metal and the welding electrode must comply with each other, therefore both the base metals and electrodes used was of low carbon. SS 316L and SDSS 2507 are selected over other materials because of its distinct properties like high corrosion resistance, weldability, strength and also due to its availability in the market. These are used as boiler grade steel in pressure vessels. It can be operated at elevated temperatures.

To study the weldment characters of the weld beads, welding of two dissimilar materials is done by SMAW by varying the filler electrodes. Butt welded joints were made on plates using SMAW. The filler electrodes selected are E316L and E308L. Its chemical composition is given in the table 3. E316L welding wire of 3.15 mm diameter was used for 9 experiments. E308L welding wire of 3.15 mm diameter was used for another set of 9 experiments.

Table -1: Chemical compositions of the base metals

MATERIALS (%)	SS 316L	SDSS 2507
C	0.03	0.03
Cr	16 - 18	24 – 26
Ni	10-14	6-8
Mo	2-3	3-5
N	0.10	0.24-0.32
Mn	2	1.20
Cu	-	0.5-1
Fe	Balance	Balance

Table -2: Mechanical properties of the base metals

Material	Min Tensile Strength (MPa)	Min Yield Strength (MPa)	Max Brinell Hardness (HB)
SS 316L	485	170	217
SDSS 2507	795	551	310

Table -3: Chemical composition of electrodes

MATERIALS	E316L	E308L
C	0.03	0.03
Cr	18	21
Ni	12	9.2
Mo	2.8	0.75
N	0.10	0.10
Mn	1.9	1.6
Cu	0.75	0.75
Fe	BALANCE	BALANCE

Here welding of the samples are done based on the Taguchi's design. Taguchi's design of L9 orthogonal array was made for 3 levels and 3 parameters. The parameters selected are welding current, travel angle and welding speed[5]. The values selected for the parameters are given in the table 4. Now using these parameters design matrix of L9 orthogonal array is made so that optimization of the parameters can be done which is given in the table 5.

Table -4: Parametrs and factors

FACTOR	LEVEL 1	LEVEL 2	LEVEL 3
CURRENT (Amps)	50	70	90
WELDING SPEED (mm/sec)	2.50	1.66	1.25
TRAVEL ANGLE (deg)	10	20	30

Table -5: Design matrix

Sl. No	Current (Amps)	Travel Angle (Deg)	Welding Speed (mm/sec)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The table 6 shows the experimental data used for welding the specimens for both the electrodes. So welding is carried out using this data values for both the electrodes E308L and E316L, which means the total number of experiments are 18.

Table -6: Experimental data

Sl. No	Current (Amps)	Travel Angle (Deg)	Welding Speed (mm/sec)
1	50	10	2.50
2	50	20	1.66
3	50	30	1.25
4	70	10	1.66
5	70	20	1.25
6	70	30	2.50
7	90	10	1.25
8	90	20	2.50
9	90	30	1.66

Here the transformer used for welding is Ador Welding Transformer which is shown in the Fig. 2. The specification of the ador welding transformer is given in the table 7. DCEP is used here to perform the welding so that the melting rate of electrode should decrease and depth of penetration should be increase which leads to the less consumption of electrodes and also increases the strength of the joint since it has greater depth of penetration compared to that of the DCEN.

Table -7: Specifications of Ador transformer

Phase	3phase, 50 cycles/sec
Current	50 A to 400 A
Open circuit voltage	80 volts
Efficiency	0.85%
Power factor	0.4
Energy consumption	4kWh/kg of Metal deposit

Fig -2: Ador welding transformer

3. RESULTS AND DISCUSSIONS

3.1 Tensile Test

After performing the welding operation using the parameters incurred by Taguchi's orthogonal array, machining has been done so as to take the tensile test as per ASTM standard A370. The test was conducted using a tensometer of 20KN capacity. Results of the tensile tests are given in the table 8 and table 9 for the specimens welded using the electrodes E308L and E316L respectively. The specimens before testing and specimens after testing is shown in the Fig. 3 and Fig. 4 respectively.
The specimen reaches its ultimate tensile load slightly losses their strength and after the ultimate load suddenly curve propagation goes on opposite direction. Then it will break at certain load rate on the load scale which is called as fracture load or strength of the specimen [5].

Table -8: Tensile strength using E308L

Sl. No	Tensile Strength (MPa)
1	631.378
2	466.128
3	469.401
4	548.785
5	498.586
6	591.930
7	560.137
8	685.766
9	646.402

Table -9: Tensile strength using E316L

Sl. No	Tensile Strength (MPa)
1	534.788
2	468.450
3	434.813
4	492.980
5	614.655
6	421.473
7	649.301
8	653.249
9	617.424

For both the electrodes, the fractures has been occurred in the SS 316L sides, weld metals and in the HAZ sides of SS 316L. It is because the tensile strength of the SDSS 2507 is far greater than that of the base metal SS 316L, electrodes used E316L and E308L. From the tensile results for both the electrodes it is clear that the value of tensile strength is more for electrode E308L for the given parameters.

Fig -3: Specimens before testing

Fig -4: Specimens after testing

3.2 Probability plot

Probability plots are used to check whether the given distribution fits the data given. It finds the confidence intervals (CI) and cumulative distribution function (CDF) based on the parameters from the data given [6].

If the distribution fits the data:

- The plotted points will be in the form of a straight line
- The plotted points will fall near to the fitted distribution line.

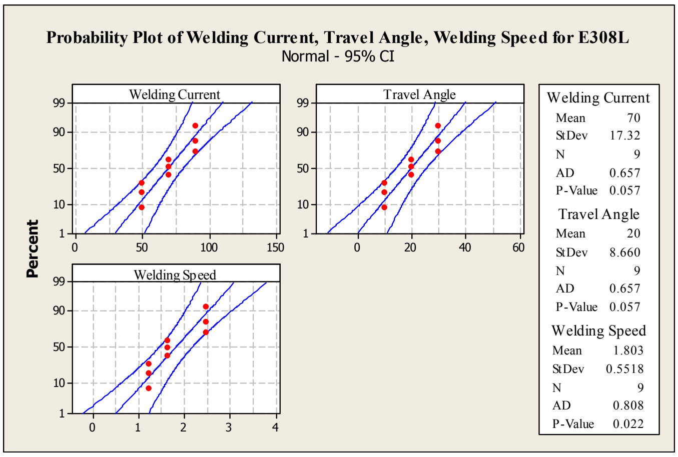

Fig -5: Probability plots for E308L

Here the Fig. 5 and Fig. 6 show the probability plots of the welded specimens using E308L and E316L respectively. Since the plotted lines roughly comes in a straight line and fallen near to the fitted distribution line for all the parameters used, we can say that the given data is fitted in the distribution.

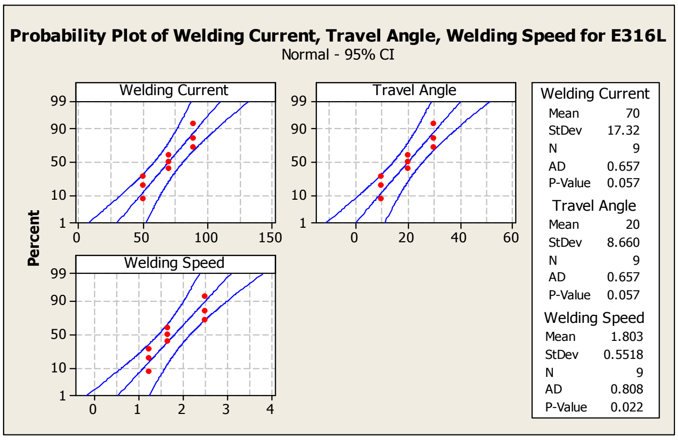

Fig -6: Probability plots for E316L

3.3 Main effect Plot for means

Main effect plot for means shows the average result for each value of each variable and also by combining the effect of all other independent variables[5].

Here the Fig. 7 is the specimen welded using E308L electrode which shows optimum parameters as the peak value in the main effect plot for mean. The optimum parameters are, welding current of 90Amps, Travel angle of 10° and welding speed of 2.5 mm/sec.

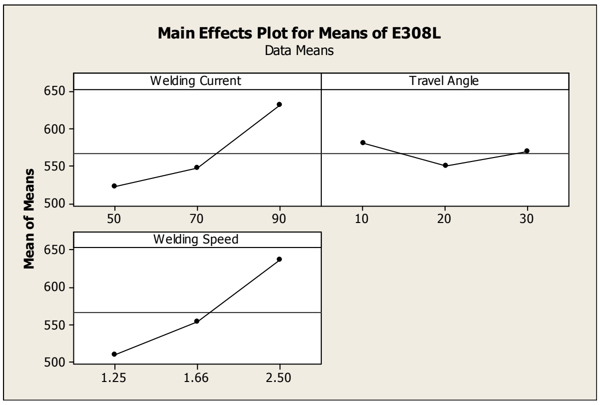

Fig -7: Main effect plots for means of E308L

Here the Fig. 8 is the specimen welded using E316L electrode which shows optimum parameters as the peak value in the main effect plot for mean. The optimum parameters are, welding current of 90Amps, Travel angle of 20° and welding speed of 1.25 mm/sec.

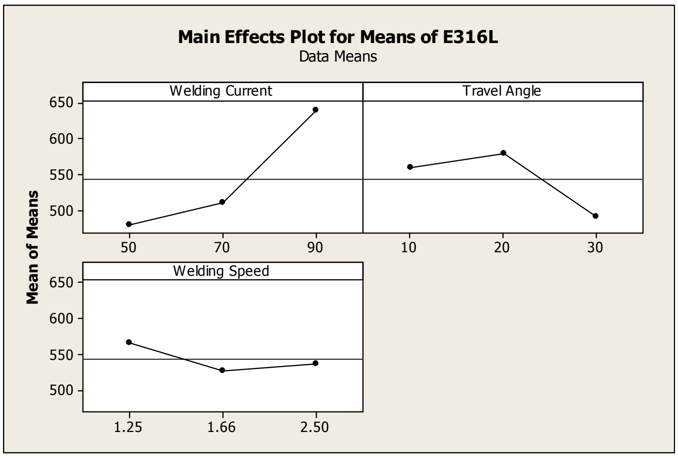

Fig -8: Main effect plots for means of E316L

So from the Fig. 7 and Fig. 8, we got the optimized parameters for both the electrodes E308L and E316L out of which E308L was chosen as our optimized electrode since the value of tensile strength is more for E308L. And for further confirmation we did the prediction of the results using predict taguchi results for the optimized parameters of both the electrodes. The prediction result shows that, the tensile strength for the optimized parameter of E308L is 714.223 MPa and that of the E316L is 699.003 MPa. So we have taken E308L as our optimized electrode based on the tensile values and using the optimized parameters for E308L a specimen is also welded so that the further tests can be carried out.

3.4 Microstructural Analysis

Here we have used the equipment METAVIS image analyzer with a magnification of 100x. The microstructure was taken only for the sample which is welded using the optimized parameter for the filler electrode E308L. The microstructural analysis of the five main zones of the welded specimen is done which are base metal zone of SDSS 2507and SS 316L, heat affected zone of SDSS 2507 and SS 316L and weld metal zone as shown in Fig. 9, Fig. 10, Fig. 11, Fig. 12 and Fig. 13 respectively.

The micro structure of base metal SDSS 2507 shows fine grains of ferrite and austenite grains with dark and light shades respectively with some amount of slag inclusions as dark spots. The micro structure of base metal SS 316L shows coarse grains of austenite along with some slag inclusions as dark spots. The Heat Affected Zone of SS 316L shows coarse grains of austenite, while the heat affected zone of SDSS 2507 shows thin fusion line with coarse grains of ferrite as dark zones and coarse grains of austenite as light zones. The Weld metal is showing the structure of widemanstaten ferrite with fine grains.

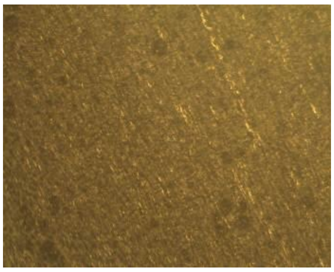

Fig -9: Base metal SDSS 2507

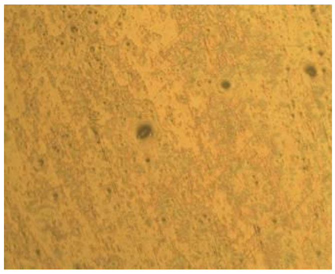

Fig -10: Base metal SS 316L

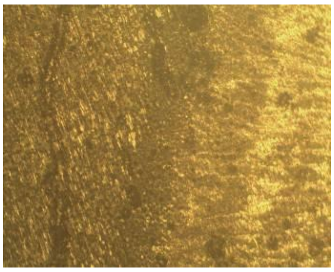

Fig -11: HAZ of base metal SDSS 2507

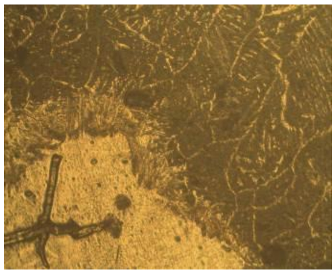

Fig -12: HAZ of base metal SS 316L

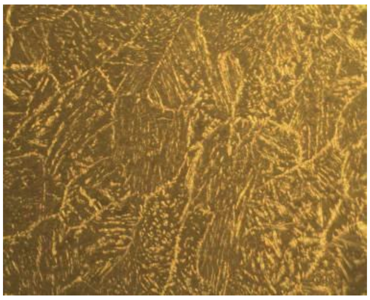

Fig -13: Weld Zone

3.5 Microhardness Test

Microhardness test was carried out using Vickers hardness testing machine for the optimized parameter weld as per the ASTM standard E384. The test results show that the base metal SS 316L has the least hardness and the hardness is increasing from the base metal SS 316L up to the base metal SDSS 2507 which is shown in the table 10. Therefore the hardness value of the weld metal is in between the hardness values of base metal SS 316L and SDSS 2507.

Table -10: Microhardness test

SL. No.	Sample Id	Observed Values, HV 10			Average, HV 10
		1	2	3	
1	Base metal SS 316L	168	169	169	169
2	HAZ of SS 316L	171	176	177	175
3	Weld Metal	192	199	197	196
4	HAZ of SDSS 2507	258	254	253	255
5	Base Metal SDSS 2507	258	256	254	256

So the hardness obtained for the weld metal is satisfactory since its hardness is more than that of the base metal SS 316L. The HAZ of SS 316L is coarse grained therefore its hardness is less than that of the weld metal.

3.6 Bend test

Bend test was carried out for the optimized parameter weld using the Ultimate tensile Machine as per the ASTM standard E190. Here the specimen has bended up to an angle of 135° which is shown in the Fig. 14 and there is no sign of cracks in the specimen which means the result is positive. Here the load applied for the bend test is compression load. And from the result, the compression strength of the tested specimen is 35.642 N/mm^2. So from the bend test it is clear that the optimized parameter weld has a good ductility.

Fig -14: Bend test

4. CONCLUSION

- From the probability plot with confidence limit 95%, we can say that process parameters are significant.
- Both the electrodes (E308L, E316L) showed good weldability for the dissimilar weld of SS 316L and SDSS 2507.
- From the tensile tests, it is clear that the fracture happens in the SS 316L side since it has low tensile strength.
- E308L has providing the greater tensile strength at the optimized parameters than that of the E316L optimized parameters.
- For E308L, the welding speed has the major impact on tensile strength and travel angle has the least impact on tensile strength.
- The optimum parameters for E308L are current of 90A, travel angle of 10° and welding speed of 2.5 mm/sec.
- The micro structure of Weld Zone showed Widemanstatten ferrite with fine grains, HAZ of SS 316L showed coarse grains of austenite and HAZ of SDSS 2507 showed coarse grains of ferrite as dark zones and coarse grains of austenite as light zones.
- Hardness test for the optimized parameter reveals that hardness in the base metal SDSS 2507 is more than that of the weld zone but the hardness of the base metal SS 316L is less than that of the weld zone.
- From the bend test for the optimized parameter, it was clear that the specimen was free from cracks which mean that the result was positive. So it has good ductility.

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