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An Experimental Investigation of Shielded Metal Arc Welding processes on Duplex Stainless Steel to control and correction of distortion in Weldments

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Abstract— The present work deals with optimization of Shielded Metal Arc Welding process on Duplex Stainless steel (DSS 2205). Welding is an important technology in Duplex Stainless steel alloy application where the quality control is too important. Taguchi L9 orthogonal array method was employed to optimize the welding process parameters of DSS 2205 weld for minimizing the angular distortion after weld and improving equal percentage of ferrite and austenite content in weld metal. Four variable welding parameters and their three levels were selected and design of experiment (DOE) was implemented as per Taguchi L9 array. Descriptions of angle of deviation measurement techniques and data analysis are presented. The present investigation is to find out the best influence of welding current, Welding Speed, Welding Position and filler material on angular distortion.
Keywords—Shielded Metal Arc Welding, Angular Distortion, Taguchi technique, Duplex Stainless Steel.

I. Introduction

Duplex Stainless steel DSS typically comprises of microstructure consisting approximately equal proportion of ferrite(δ) and austenite (γ).DSS is a commonly used structural material in the oil, gas ,manufacturing industries and has special application in chemical ,wastewater, marine engineering field [i]. In manufacturing, welding distortion can cause assemble related problems by adversely affecting the dimensional tolerances required. Joint misalignments and increased root gap would make manufacturing more difficult. I may also adversely affect further operation like machining. Presence of distortion may adversely affect the load carrying capacity and buckling strength of the weld structures.

The distorted component may lead to the following detrimental effects:

- May affect the load carrying capacity or the functional requirements.
- Leads to miss matching problems.
- Aesthetics loss.

The correction of distortion after fabrication would involve financial as well as production loss. Distortion in a weldment results from the non uniform expansion and contraction of the weld and adjacent regions of the base metal during the heating and cooling cycle associated with welding process. The expansion and contraction movements of the heated metal can be simply illustrated by considering the movements of a metal bar.If a steel bar at room temperature is uniformly heated throughout it will expand in all directions. Since the bar is unrestrained, it will contract uniformly to its original dimensions when allowed to return to room temperature. But if the bar is retrained before heating such that the expansion along the horizontal axis is prevented, high expansion takes place in thickness and width directions. When the heat is removed and the deformed bar returns to room temperature it will still tend to contract or shrink uniformly in all directions. The bar is now shorter in length and but large in width and thickness. It has been permanently deformed or distorted [ii].Influence of chemical composition of electrode on distortion is negligible. Experimental three-point bending corrosion fatigue tests were carried out in a normalised seawater on welded Duplex stainless with four experimental electrodes varying percentage of Ni content [iii].In this paper, Shielded Metal Arc welding were selected to investigate the effect of process parameters on angular distortion of DSS plate after welding. The Heat Affected Zone of the AISI 444 stainless steel welded with the AWS E309Mol-16 covered electrode exhibited significant grain growth with respect to the base metal in the partially-melted zone [iv].

1.1 Types of Distortion:

It is not always possible to keep the distortion with in acceptable limits. especially when dealing with a new design for the first time. The following are the types of distortion

1.1.1 Longitudinal Distortion: The amount of longitudinal shrinkage in a butt weld is in the order of 1/1000 of the weld width. The longitudinal shrinkage in fillet welds is primarily a function of the total cross section of the joints involved. The total cross section in the transverse section is therefore called as resisting cross section. When the weld line does not coincide with the neutral axis of the structure, longitudinal shrinkage of the weld metal induces bending moments and bending distortions are cambering of the structure. The amount of the distortion is related to the shrinkage moment and the resistance of the member to the bending indicated by the moment of inertia. The following formula may be used to calculate the amount of distortion or bending resulting from longitudinal shrinkage.

$\Delta L = 0.127.A_w.L^2 d / I.$ -------- (1)

Where, ΔL = Longitudinal bending distortion in mm, A_w=Total cross sectional area in mm^2 within the fusion line of the welds, d = Distance in mm between the center of gravity of the weld group and the neutral axis of the member. I= Moment of inertia in mm^4 of the member, L= Length of the member assuming welding of the full length in mm.

1.1.2 Transverse Distortion: Various theoretical models have been suggested by investigators for calculating the transverse distortion.

$$S = 5.17\ (A/t) + 1.17.d \quad \text{----------- (2)}$$

Where, S=Transverse shrinkage in mm, A= Cross sectional area of weld in mm^2.t= Thickness of plate in mm, d= Free distance of root opening in mm.

Transverse shrinkage = 0.1A/t. …….. (3)

Where, A= Cross section area of weld in square inches (cross section of entire fused part),t = Thickness of weld in inches. Welding input parameters plays an important role in determining the quality of a weld joint and distortion. The Taguchi method is applied to analyze the effect of each welding process parameter (arc gap, flow rate, welding current and speed) on the weld pool geometry[v].

1.1.3 Angular Distortion: Angular change occurs in a butt weld when transverse shrinkage is not uniform in the thickness direction. Welding procedures, parameters including the shape of the groove and degree of restraint have significant effect on angular change. In double V joint the angular change after completion of the welding depends on the ratio of the volume of weld metal deposited on the two sides of the plate. In the case of fillet welds the angular change varies directly with flange width W and weld size Z and inversely with flange thickness t.

The equation for angular change = 0.02 W (Z) $1^{/3}$/ t^2........ (4)

1.1.4 Buckling and Twisting: When thin plates are welded, residual compressive stresses occur in areas away from the weld and cause buckling. Buckling distortion increase as the thickness decreases. Buckling distortion differs from bending distortion in that

- There is more than one stable deformed shape.
- The amount of deformation in buckling distortion is much greater.

Stiffeners can be added to the member for minimizing buckling but the best remedy for controlling buckling is to increase the plate thickness and decrease the amount of welding. Twisting may be a problem with thin material because of its low torsional resistance. When a weld is made along the center line of a member, the center line tends to shrink and become shorter.To satisfy the condition ie. outer edges are longer than the center line, the member must twist.The prevention of twisting resolves itself to minimizing shrinkage force by good welding practice which decreases the amount of weld metal or by designing so that the member is short in length. The torsional resistance of a rectangular cross section of steel plate is a function of the cube of the thickness. So any increase in the plate thickness will help in minimizing the twisting distortion. Doubling the thickness will increase the torsional resistance eight times more. When design permits, torsional resistance can be increased by the e use of closed box sections or through diagonal bracing.

The welding process was carried out by using two passes and as per the design of experiments (DOE) as given in table 3. The welded specimens as per the DOE are shown in figure 4. After performing the SMA Welding process as per the DOE, the specimens were placed on the fabricated stand set up for measuring the angular distortion. The vertical displacements were measured on the surface of the welded plates using dial gauge and sprit level.

Table 3: Design of Experiments as per Taguchi L9 orthogonal array.

II. Material and Methodology

The Shielded Metal Arc Welding (SMAW) was used for welding of 2304 duplex stainless steel (DSS) plates of 150 mm x 100 mm x 6 mm plate dimensions. The welding process parameters, which could influence the Angular Distortion, were selected to be weld current (A), weld time (T), Electrode Material (F) and position of welding (Z). The materials for filler rods were 316 L, 308L and 310 L [vi]. The chemical composition of the base metal and filler rods are given in table 1. The weld joint design is shown in figure 1. The experiments were conducted using arc gap 2 mm, V-groove angle of 60^o, root gap of 3 mm. The direct current electrode negative DCEN (Straight polarity) was employed during SMA Welding process to provide deeper weld penetration and optimal angular distortion..

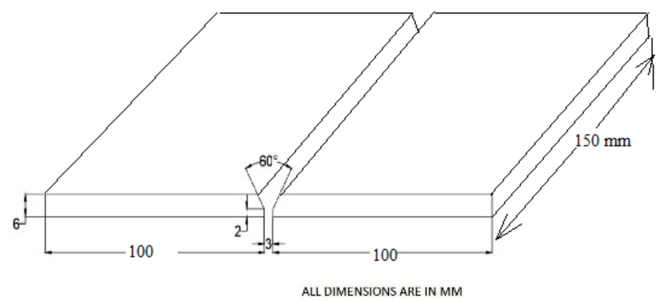


Figure 1. Weld joint Design (Edge Preparation).

The Taguchi optimization method was selected to minimize the distortion of welded plates. The four variable parameter Welding Current (A), Welding Time(T), Welding Position(Z), Filler Material(F) and their three levels were selected, the SMAW process parameter are given in the Table 2. The two plates were held as per the design using C-Clamping fixtures for the flat, horizontal and vertical position of welding with 3 mm root gap between the welding plates as shown in figure 2. A grooved copper back up plate having dimensions 2mm x 5mm was fixed below the welding plates to avoid the flow-off of weld metal from the weld joint. The electrode diameter used was 3 mm for all experiments. Two and half electrode was consumed for each 150 mm weld length.

Table 2: SMA Welding process parameter and three levels

	Parameters	Level-1	Level-2	Level-3
A	Weld Current, Amps	75 Amps	85 Amps	95 Amps
T	Weld Time , mint	1:45 mints	2:10 mints	2:35 mints
Z	Weld Position	Flat	Horizontal	Vertical
F	Filler Material	316 ER	308 ER	310 ER

Exp . No	Welding current (Amps)	Welding Time (mints)	Weld Position	Filler Wire Material
1	75	1.45	Flat	316 ER
2	75	2.10	Horizontal	308 ER
3	75	2.35	Vertical	310 ER
4	85	1.45	Horizontal	310 ER
5	85	2.10	Vertical	316 ER
6	85	2.35	Flat	308 ER
7	95	1.45	Vertical	308 ER
8	95	2.10	Flat	310 ER
9	95	2.35	Horizontal	316 ER

After conducting nine welding processes as per DOE, the experiments were carried out to measure the angular distortion in a bead on welded plates, the mean vertical displacement method was adopted to measure the distortion. A stand was fabricated with mild steel material for measuring distortion as show in the figure 3(a). On top surface of stand frame, three pillars (one fixed and two adjustable) were arranged to adjust the horizontal level of the welded plate with the help of sprite level. Eight points were marked on A & B sides of welded plate at 5 mm from both edges and eight points were marked nearer to weld bead 8 mm from the center line of weld bead as show in the figure 3(b). The dial gauge readings were taken from reference point to all nine points vertically at A, B, C and D respectively. One complete revolution of dial gauge indicator indicates 1 mm vertical displacement.

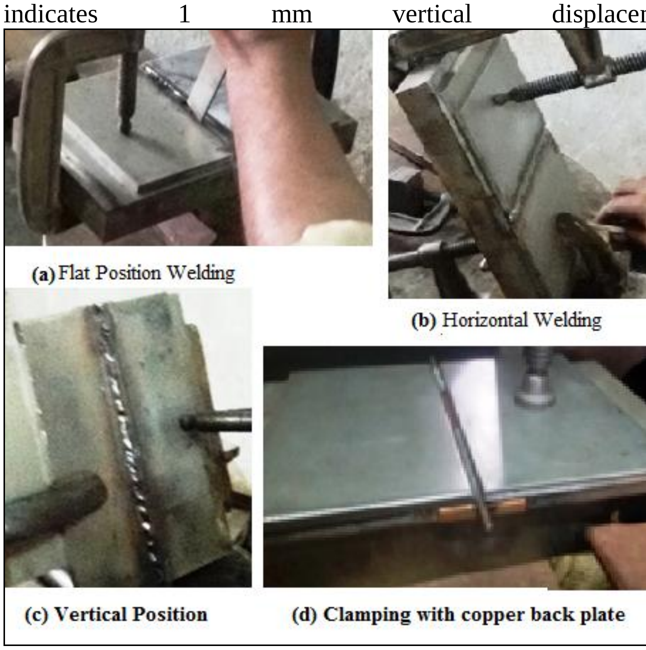


Figure 2: Welding positions: (A) Flat, (B) Horizontal (C) Vertical-up

The vertical displacement caused by welding and the angular distortion value 'U' can be determined by [vii].

U = [(A+B) – (C+D)]/2, where A, B,C and D represent the mean vertical displacement values of each points as shown in the below figure 3, A= $(A_1+A_2+A_3+\ldots\ldots+A_8) / 8$, B= $(B_1+B_2+B_3+\ldots. + B_8) /8$, C=$(C_1+C_2+C_3+\ldots\ldots+C_8) / 8$, D=$(D_1+D_2+D_3+\ldots\ldots D_8) / 8$.

Angular Distortion value U for all nine welded plates has been calculated as per the above expression and results were analyzed using MAT Lab software.

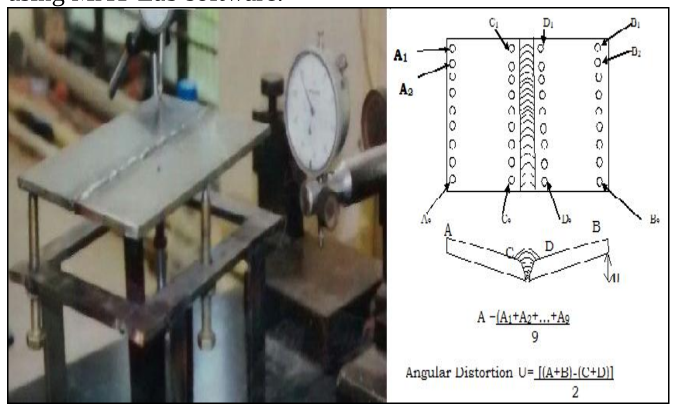


Figure 3: Fabricated stand for measuring angular distortion Test (a) & Top view and front view of welded plates (b)

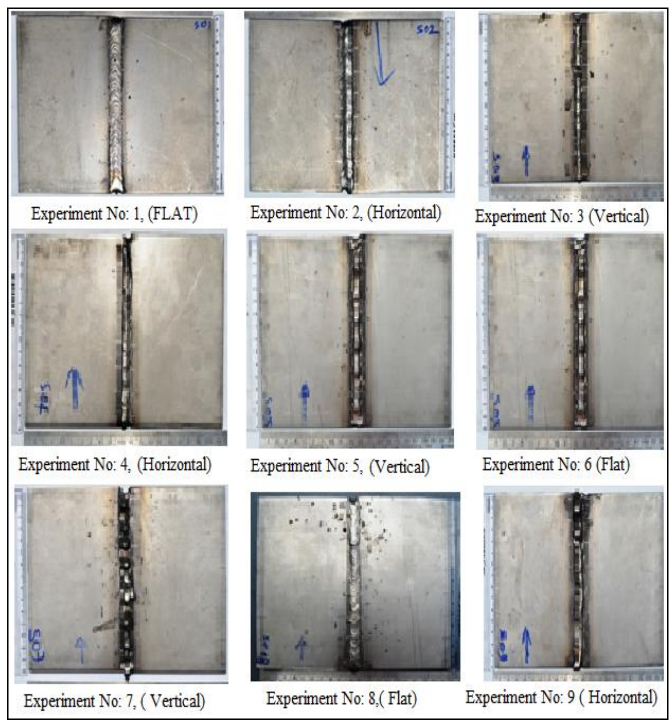
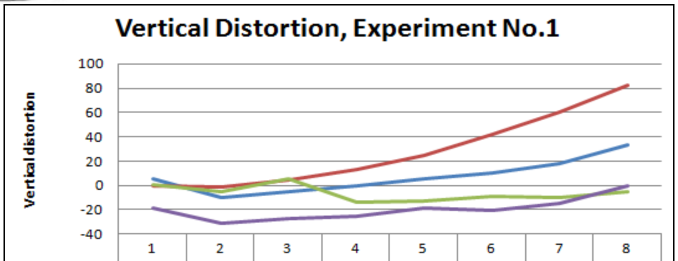


Figure 4: Welded specimens as per Taguchi L9 Orthogonal array Design of Experiment.

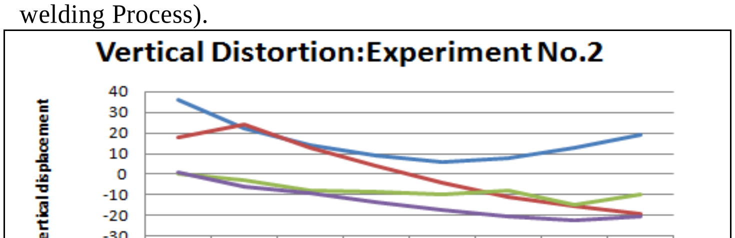
III. Results and Discussion

As per the Taguchi L_9 orthogonal experimental layout the inveatigation was done[viii].Figure 3(b) shows the points of measuring values of vertical displacement on the surface of the welded plates at 32 points were recorded, (8 points A_1 to A_8 at left corner ,8 points B_1 to B_8 at right corner,8 pints C_1 to C_8 at left HAZ and 8 points D_1 to D_8 at right HAZ of welded plates.All the dial guage reading of experiment number one and displacement graph are given in the figure 5.



	1	2	3	4	5	6	7	8
A_1 to A_8	5	-10	-5	0	5	10	18	33
B_1 to B_8	0	-1	5	13	25	42	60	82
C_1 to C_8	0	-5	5	-14	-13	-9	-10	-5
D_1 to D_8	-18	-31	-27	-25	-18	-20	-15	0

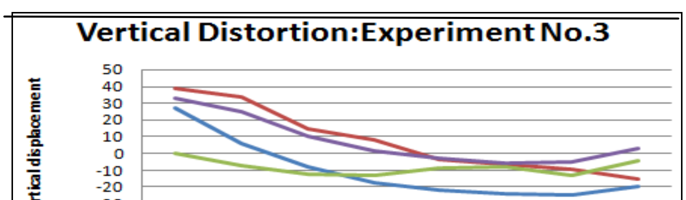
Figure 5: Vertical Distortion graph of Experiment No.1,(Flat welding Process).



	1	2	3	4	5	6	7	8
$A_1$to A_8	36	22	14	9	6	8	13	19
B_1 to B_8	18	24	13	4	-4	-11	-15	-19
C_1 to C_8	0	-3	-8	-9	-10	-8	-15	-10
D_1 to D_8	1	-6	-9	-13	-17	-20	-22	-20

Figure 6: Vertical Distortion graph of Experiment No.1, (Horizontal welding Process).

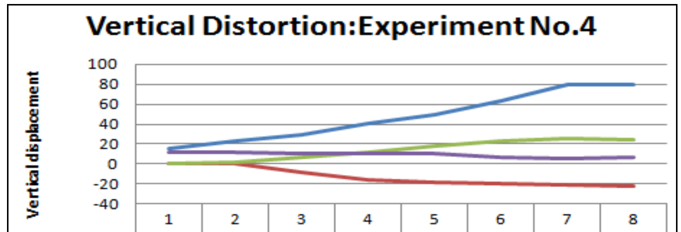
Figure 5 shows that the maximum vertical displacement range was 113 µm is in flat welding position. From the figure 6 for experiment number 2, it was found that 580 µm is the maximum vertical displacement range where as from figure 7, (-25 to 39) 640 µm was the maximum range.



	1	2	3	4	5	6	7	8
A_1 to A_8	27	6	-8	-18	-22	-24	-25	-20
B_1 to B_8	39	34	15	8	-3	-6	-9	-15
C_1 to C_8	0	-7	-12	-13	-9	-8	-13	-4
D_1 to D_9	33	25	10	1	-3	-6	-5	3

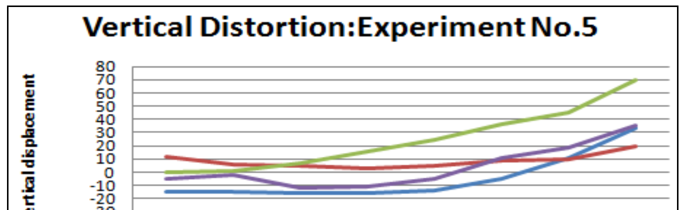
Figure 7: Vertical Distortion graph of Experiment No.3,(Vertical welding Position).

From (figure 8) the horizontal welding shielded metal Arc Welding process displacement graph values, it was found that 1020µm is the maximum range of vertical distortion.



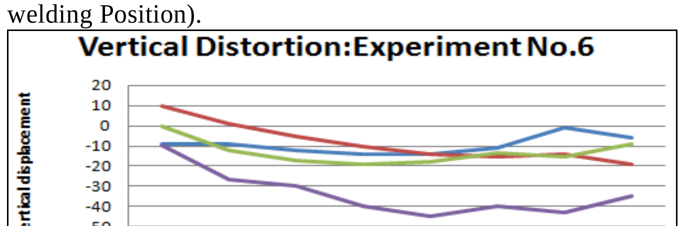
	1	2	3	4	5	6	7	8
A_1 to A_8	15	23	29	40	50	63	80	80
B_1 to B_8	1	1	-8	-16	-18	-20	-21	-22
C_1 to C_8	0	1	6	12	18	24	26	25
D_1 to D_8	12	12	11	11	10	7	5	7

Figure 8: Vertical Distortion graph of Experiment No.4,(Horizontal welding Position).



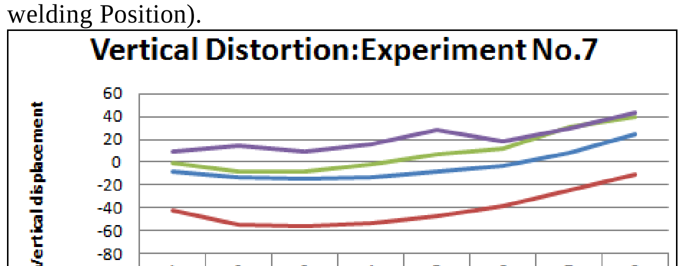
	1	2	3	4	5	6	7	8
A_1 to A_8	-15	-15	-16	-16	-14	-5	10	33
B_1 to B_8	12	6	5	3	5	9	10	20
C_1 to C_8	0	1	7	16	25	36	45	70
D_1 to D_8	-5	-2	-12	-11	-5	11	18	35

Figure 9: Vertical Distortion graph of Experiment No.5,(Vertical welding Position).



	1	2	3	4	5	6	7	8
A_1 to A_8	-9	-9	-12	-14	-14	-11	-1	-6
B_1 to B_8	10	1	-5	-10	-14	-15	-14	-19
C_1 to C_8	0	-12	-17	-19	-18	-13	-15	-9
D_1 to D_8	-10	-27	-30	-40	-45	-40	-43	-35

Figure 10: Vertical Distortion graph of Experiment No.6,(Flat welding Position).



	1	2	3	4	5	6	7	8
A_1 to A_8	-9	-14	-15	-14	-9	-3	8	25
B_1 to B_8	-42	-55	-56	-54	-47	-38	-25	-11
C_1 to C_8	0	-8	-8	-2	7	12	30	39
D_1 to D_8	10	15	10	16	28	18	30	43

Figure 11: Vertical Distortion graph of Experiment No.7,(Vertical welding Position).

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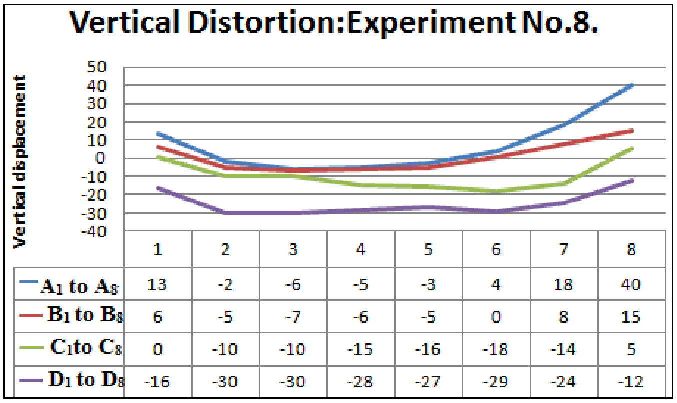

Figure 12: Vertical Distortion graph of Experiment No.8,(Flat welding Position).

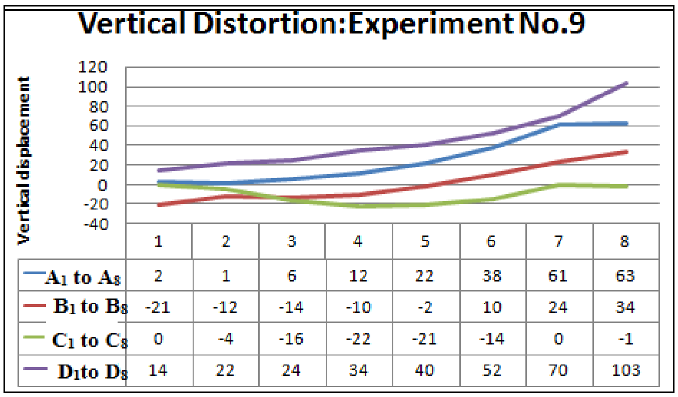

Figure 13: Vertical Distortion graph of Experiment No.9,(Horizontal welding Position).

Similarly from figure 9, (-16 to 70) 860 µm, figure 10, (-45 to 10) 550 µm, figure 11, (-56 to 43) 990 µm, figure 12, (-30 to 40) 700 µm are the vertical displacement ranges. From the figure 13, it was observed that (-22 to 103) 1250 µm which is the highest vertical displacement range. The angular distortion values of all nine experiments are given in the table 4.It is resulted that the vertical position welded samples found the negative value i.e. the distortion is in opposite direction. The minimum angular distortion found is 56.25µm in the experiment number 4,where welding current is 85 Amps, electrode material is 310ER, welding time is 1 mint 45 sec for 150 mm weld length and welding position is horizontal. The maximum negative angular distortion found was in the experiment number 7, where welding current is very high 95 amps, electrode material is 308ER, welding time is minimum and welding position is vertical.

Table 4: Angular Distortion (U) Values of SMA Welding as per L9 Orthogonal array DOE.

Experiment No	Welding current (Amps)	Welding Time (mints)	Weld Position	Filler Wire Material	Angular Distortion U= [(A+B) - (C+D)] /2 in (µm) micron meter
1	75	1.45	Flat	316 ER	304.3
2	75	2.1	Horizontal	308 ER	191.25
3	75	2.35	Vertical	310 ER	-8.125
4	85	1.45	Horizontal	310 ER	56.25
5	85	2.1	Vertical	316 ER	-123.1
6	85	2.35	Flat	308 ER	-144.3
7	95	1.45	Vertical	308 ER	-374.3
8	95	2.1	Flat	310 ER	211.8
9	95	2.35	Horizontal	316 ER	-41.875

IV. Conclusion

In this investigation, it was found that the influence of electrode material on the welding angular distortion is negligible. From the result it was observed that the minimum angular distortion 56.25µm occurs in horizontal welding where current is medium 85 Amps and welding time is less 1.45 mints. It was found that the maximum distortion resulted is -374.3µm at high current 95 Amps and in vertical welding position.The influence of the current on angular distortion is first highest next is welding position and next is welding time. The maximum vertical displacement range was found is 1250 µm at high current 75 Amps and more welding time in Horizontal welding position.

References

i. *Balaram Naik, A., Reddy, A.C, Balakrishna, B. Characteristics Optimization of Different Welding Processes on Duplex Stainless Steels Using Statistical Approach and Taguchi Technique-A Review Guide. Int. J. Eng. Inventions, 2013, 02:26-34.*

ii. *Welding Research Institute –Welding Engineering Hand Book, Bharat Heavy Electrical Limited Tiruchirapalli, Tamilnadu, 2013,pp 109-113.*

iii. *S.A.Tavara, M.D.Chapetti, J.L.Otegui, C.Manfredi Influence of nickel on the susceptibility to corrosion fatigue of duplex stainless steel welds, International Journal of Fatigue 23 (2001) 619-626.ELSEVIER.*

iv. *Cleiton C.Silva,Jesualdo P.Farias,Helio C.Miranda , Microstructural characterization of the HAZ in AISI 444 ferritic stainless steel welds. MATERIALS CHARACTERIZATION 59 (2008) 528-533.ELSEVIER.*

v. *K.Y.Benyounis, A.G.Olabi, Optimization of different welding processes using statistical and numerical approaches-A reference guide. Advance in Engineering Software 39 (2008) 483-496.ELSEVIER.*

vi. *A.Balaram Naik, A.Chennakesava Reddy, "Study of Welding Economy and Improve Productivity of 2205 Duplex Stainless Steel Material."International Conference on Advanced Materials and Manufacturing Technologies. " (AMMT) Dec-18th -20th , 2014, pp:19-32.*

vii. *Tsann-Shyi Chern,Kuang-Hung Tseng,Hsien-Lung Tsai.,"Study of the characteristics of duplex stainless steel activated tungsten inert gas welds" Elsevier, Materials and Design 32(2011),pp 255-263.*

viii. *A.BalaramNaik, A.Chennakesava Reddy, Optimizations of TIG Welding Process Parameters on Angular Distortion of Stainless Steel 301 Alloy Weldments,Journal of Material Science and Mechanical Engineering (JMSME),p-ISSN:2393-9095,e-ISSN:2393-9109,Vol 2,Issue 13, Dec-(2015),pp 32-40.*

ix. *J.Nowacki,Ferritic-austenitic steel and its weldability in large size constructions,Journal of Acheievements in Materials and Manufacturing Engineeering,AMME,Vol 32,Issue 2,Feb-2009,pp:115-141.*

x. *R.Easwaran,A..Raja,G.Ravichandran and G.Buvanashekaran,Welding Research in India: Present Status and Future Direction,Indian Welding Journal,Welding,Volume 47,No.2,April-2014,pp:59-77.*

Table 1: Chemical composition of Electrode and Base materials (wt %)

Filler/base Material	C	Cr	Si	Mn	P	S	Mo	Ni	Fe	Cu
316 ER	0.03	17.5	0.43	1.72	0.03	0.03	2.9	11.8	Rem	0.75
308 ER	0.03	21.8	0.49	1.78	0.03	0.03	0.78	9.7	Rem	0.75
310 ER	0.08	25.5	0.49	1.75	0.03	0.03	0.75	20.5	Rem	0.75
2304 DSS (base)	0.021	24.022	0.485	1.48	0.017	0.012	0.167	5.06	Rem	0.73