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Macro-Section and Micro Structure Evaluation of TIG on Duplex Stainless Steel (2304) with Weld Bead Geometry at Different Position

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Abstract

Duplex Stainless Steel (2304) steel plates of 6 mm thickness have been fabricated by one-side butt welding procedure employing Tungsten Inert Gas welding process at three different positions (i.e. Flat, Horizontal and Vertical).The effort of welding position on Macro-section and Microstructure of TIG welded specimen was observed. The welding current, filler material and speed was optimizing by carefully evaluating weld geometry and microstructure of different welding positions. Design of experiment was carried out using Taguchi technique to optimize the process parameters of welding. The input variable process parameters are welding current, speed, filler material and welding position, whereas output parameters are weld width, reinforcement, penetration and wetting angle. The experimental results illustrate that the joint of horizontal weld has more reinforcement and microstructure and macro-section includes three zones: weld zone, heat affected zone, thermal affected zone showed that unsymmetrical weld interface and thermo mechanically affected zone boundary was found in horizontal and vertical position joints. The formation of fine grains with less fusion area and less reinforcement were found in flat welding positions. Form all the samples it was found that the heat affected zone area, fusion angle and wetting angle is more for vertical position welding specimens. By analyzing macro-section and microstructure of joints it was observed the fusion area at root gap for vertical weld is three times more compared to flat welding position and root penetration is more at high welding current. It was found that the migrated grain boundaries are formed on the weld zones for all the weldments.

Keywords: Duplex Stainless Steel; Macro-Section, Microstructure; Tungsten Inert Gas welding; Weld Geometry; Taguchi experimental design
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1. INTRODUCTION

Duplex stainless steel (DSS) is usually used in chemical, Thermal sector, and foodstuff processing large-scale companies due to their good hot cracking résistance. Metallurgy is the science and technology of metals which has evolved into three separate groups: extractive, mechanical and physical. Aigbodion, V.S et al [1] (2015, 495) has reported that the weld bead joint strength and fracture depends on the orientation of grains and particle size of the grain. The main two structures studied in physical metallurgy are the crystal structure and microstructure. Aravind, Vadiraj and Shashank, Tiwari. (2015, 491), [2] reported that the micro phase images and properties of medium carbon CI be vary by alloying add-ons. Si robustly influences graphitization, fluidity and chilled zone in C.I. Mn

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improves strength and hardness ranges. All engineering products utilize metallic material with specific characteristics such that the materials can be processed into final products satisfactorily and economically and the products will serve appropriately in service. The first important phase of designing a weldment is the selection of the best type of edge preparation for welding specimen [3].The Behaviour of materials is determined by composition, microstructure, service conditions and interactions among them. The outcome of isothermal heat treatments is extra at 300 °C on micro-structure evolution after welding by Tungsten Inert Gas (TIG) welding practice. The macrostructure and microstructure of weld bead is mainly depending on the skill of the welder [4, 5].The cracks most typical of 24% Chromium duplex stainless steel are associated with the heat-affected zone (HAZ) and not with the weld origin. The micro structure of the parent metal has uniform grain orientation where as HAZ grains size is not uniform and it orientated is mainly depends upon current of welding. The hardness of HAZ increased after welding is due to dendrite Chromium in the fusion area [6, 7].The micro structural transform robustly influences the toughness of micro alloyed steel. The mechanical properties like tensile stress, yield stress and ductility of the micro alloyed steels with ordinary cooling circumstances meet the requirements of earth moving vehicle front axle application. The grain size equivalent to the weldment was changed in radial path due to diverse extent of deformed region [8, 9]. Acicular and crude serrated type of ‘α’ in enormous prior ‘β’ grains micro-structure form near fusion zone of TIG weldments.The grain size of weld area seen to uniform with small border lines on TIG elements than EB welds. The hardness range of welding zone decreased and the value is higher at thermally affected zone and coarse grained structure in HAZ region. The failure started via crack in near Thermal affected zone and fracture carried out in heat affected zone [10, 11].The Present work deals with an evaluation of macro-section and microstructure of Tungsten Inert gas weld welded joints on DSS (2304) at different welding positions. The weldability of Duplex stainless steel is generally good. Tungsten inert Gas (TIG) welding process is one of the major welding techniques currently used in power sector industries. TIG welding produces high quality of welds besides providing precise control of current with accurate weld design. So, in this work, an attempt is made for macro-section and microstructure evaluation of Tungsten Inert Gas welding on Duplex Stainless Steel (2205) with weld geometry at flat, horizontal and vertical welding Position has been widely investigated and analyzed the combination of variations. The reinforcement, weld width, penetration and wetting angle of flat welded butt-sample were measured and compared with other two different welding positions.

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2. MATERIAL AND WELD DESIGN

The percentage contribution of chemical composition of Base Material (wt %) 2304 (Duplex Stainless Steel) SA 240 Gr: TP 220 of 6 mm plates which are used here in this work are given in Table 1

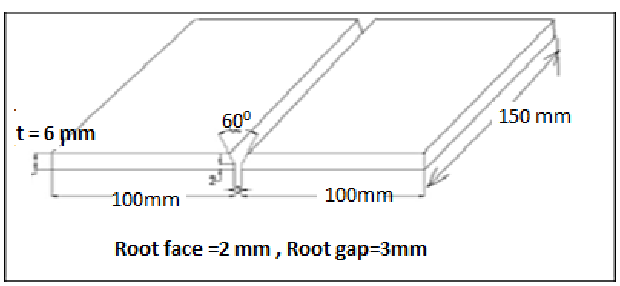

Figure 1 (a) Weld Joint Design

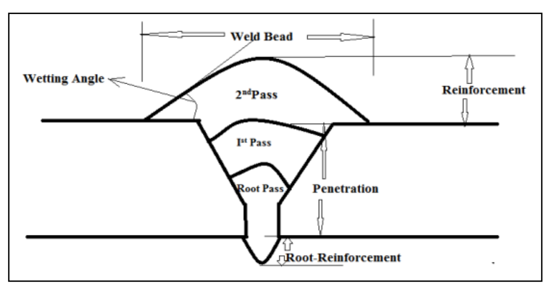

Figure 1 (b) **Wled bead geometry and three passes**

The plates have been cut to (150 x 100 x 6 mm) dimension and edge preparation was machined on milling machine to fit the dimension as per the design of welding in the Figure 1(a).In the present investigation, the impact of four selected variable welding parameters each at three levels have been studied using L_9 (3^4) orthogonal design with three pass welding as shown in Figure 1(b).The four control parameters i.e. welding current, weld speed, welding position and filler material are used in this study and assignments of their corresponding levels are described in Table 3.

Table 1: Chemical composition of Base Material (wt %) 2304 (Duplex Stainless Steel) SA 240 Gr: TP 220

Base Material	C	Cr	Si	Mn	P	S	Mo	Ni	Fe	cu
(2304) DSS	0.021	24.022	0.485	1.48	0.017	0.012	0.167	5.06	Rem	0.413

3. TUNGSTEN INERT GAS POWER SOURCES AND EXPERIMENT PROCEDURE

The TIG welding technique is an inert gas shielded arc welding process in which the heat is generated near the DSS (2304) plates between non consumable Thoriated tungsten electrode. This welding is widely used as a production tool in many industries because of high quality welds achieved by this process. The variable TIG process parameters and its three levels are given in Table 2. An either drooping or nearly true constant-current static output characteristics type power source was used. In this present work direct current electrode negative (Straight polarity) type was selected for welding. With DCEN and a thermionic electrode such as tungsten, approximately 70 percent of heat is generated at the anode and 30 percent at the cathode. DCEN will provide deeper weld penetration and the most common configuration used in TIG welding with argon as the shielding gas, to protect the back of the weld when filler metal depositing the root run. The constant non-consumable tungsten electron of 3mm diameter has been selected by taking Argon as a shielding gas with 7 litres/mint gas flow rate for conducting welding as per experiment designs. In a conventional experimental design (full factorial), it would require $3^4 = 81$ TIG performance have to study the influence of four variable parameters each at three levels, whereas, Taguchi's factorial experiment approach reduces it to 9 trails only, contributing a great improvement in terms of trial time and welding expenditure. The Chemical composition of various type of Filler wire given in Table 3.The complete experimental design of TIG-three pass welding on two Duplex Stainless Steel (2304) plates of 100 mm X 150 mm X 6 mm dimension are given in Table 4.

Table 2: Variable TIG welding Parameters and its 3-Levels.

	TIGW Parameters	Level -One	Level-Two	Level-Three
A	Weld Current(Amps)	125	145	165
S	Weld Speed,	17	22	27
Z	Weld Position	Flat	Horizontal	Vertical
F	Filler Material	316 L	308 L	310 L

Table 3: Percentage contribution of Chemical composition of Filler wires (wt %)

Filler Material	C	Cr	Si	Mn	P	S	Mo	Ni	Fe	Cu
ER 316 L	0.03	18.5	0.45	1.75	0.03	0.03	2.8	11.5	Rem	0.75
ER 308 L	0.03	21.5	0.47	1.75	0.03	0.03	0.75	9.5	Rem	0.75
ER 310	0.08	25.5	0.49	1.75	0.03	0.03	0.75	20.5	Rem	0.75

Table 4: Design of Experiment of TIG Welding L9 Orthogonal array

Expt.No	Welding Current (Amps)	Welding Speed mm/mint	Weld Position	Filler Wire Material
1	125	17	Flat |(1G)	316 L
2	125	22	Horizontal(2G)	308 L
3	125	27	Vertical (3G)	310 L
4	145	17	Horizontal(2G)	310 L
5	145	22	Vertical (3G)	316 L
6	145	27	Flat (1G)	308 L
7	165	17	Vertical (3G)	308 L
8	165	22	Flat (1G)	310 L
9	165	27	Horizontal(2G)	316 L

Experiment Number:01, Flat Position (1G), Current: 125 Amp, Filler Material: 316 L. Weld Interphase Micro Test Report :Calib:Obj-10x,Unit:µm, X=1.0785,Y=1.0785 (pixels/µm)
Field measured=1,
Analyzed Area=5005 Sq.mm,
Standard Used: ASTM E112
ASTM Grain Size=5.5
Intercepts =139.
Mean Int length (µm)= 50.9,
Experiment Number:02, Horizontal Position (2 G),Current:125 Amp, Filler Material: 308 L. Weld Interphase Report :Calib:Obj-10x,Unit:µm, X=1.0785,Y=1.0785 (pixels/µm)
Field measured=1,
Analyzed Area=5005 Sq.mm,
Standard Used: ASTM E112
ASTM Grain Size=5
Intercepts =125.
Mean Int length (µm)= 56.6
Experiment Number: 03, Vertical Position (3G),Current :125 Amps, Filler Material: 310 L. Weld Interphase Micro Test Report :Calib:Obj-10x,Unit:µm, X=1.0785,Y=1.0785 (pixels/µm)
Field measured=1,
Analyzed Area=5005 Sq.mm,
Standard Used: ASTM E112
ASTM Grain Size=5,Intercepts =133Mean Int length (µm)= 53.2

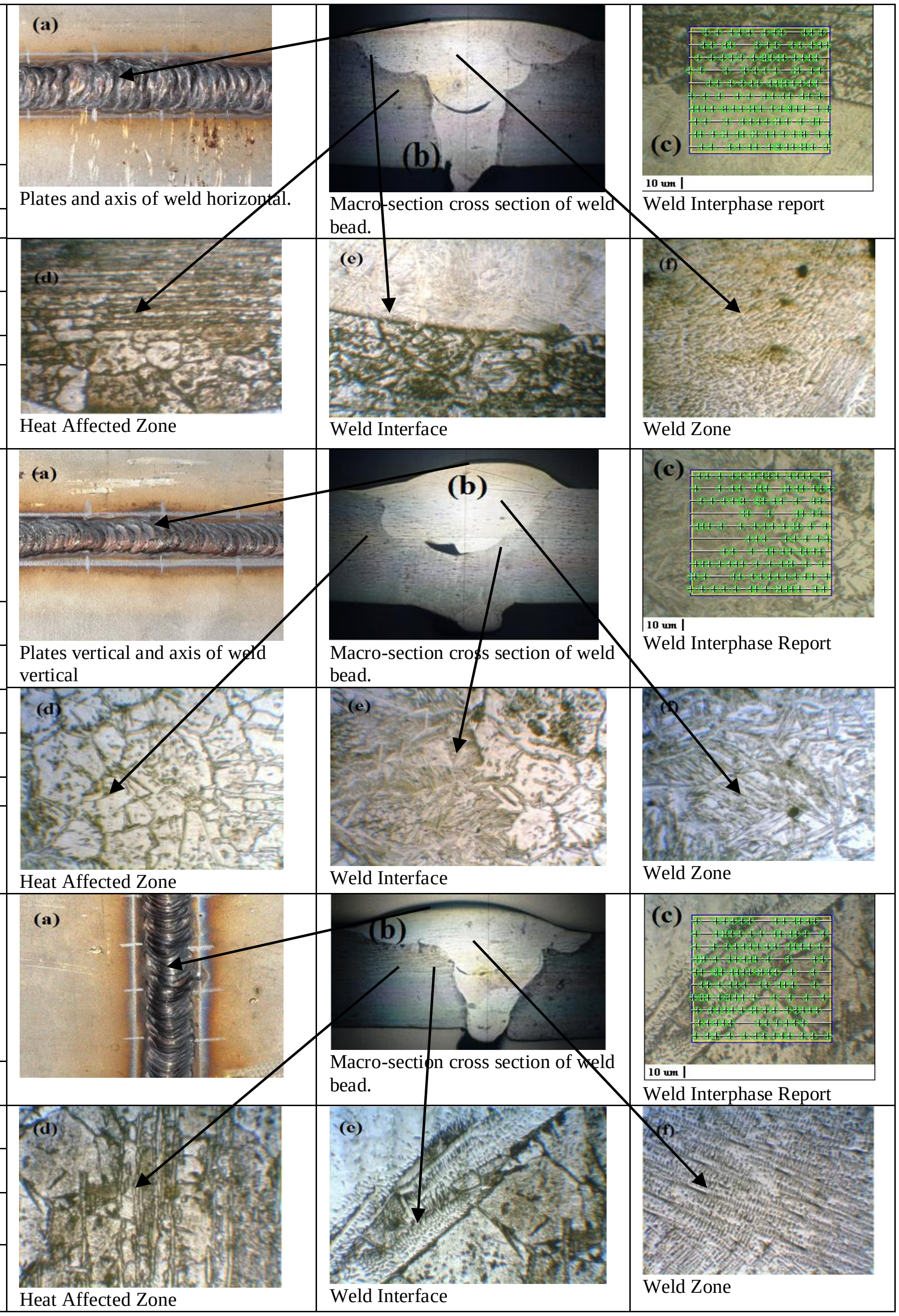

Figure 2: Compares (a) Weld bead surface,(b) Macro section Cross section,(c)Weld interface Phase analysis,(d) HAZ, (e) Weld interface & TMAZ,(f) Weld zone of Experiment No:01(flat position),Exp.No:02(horizontal position) and Exp.No:03(vertical position)

4. RESULTS AND DISCUSSION

The research shows that at low current (125Amps) macro section of weld bead is symmetric shape for flat position and the micro structure variations are different for different zones (weld, HAZ, weld interface zones, base metal). During solidification of weld pool the amount of grain borderlines of austenite-γ increased. It is clearly observed that unsymmetrical interface line was found for horizontal and vertical position weldments. The major chemical composition in all three filler metal is chromium.

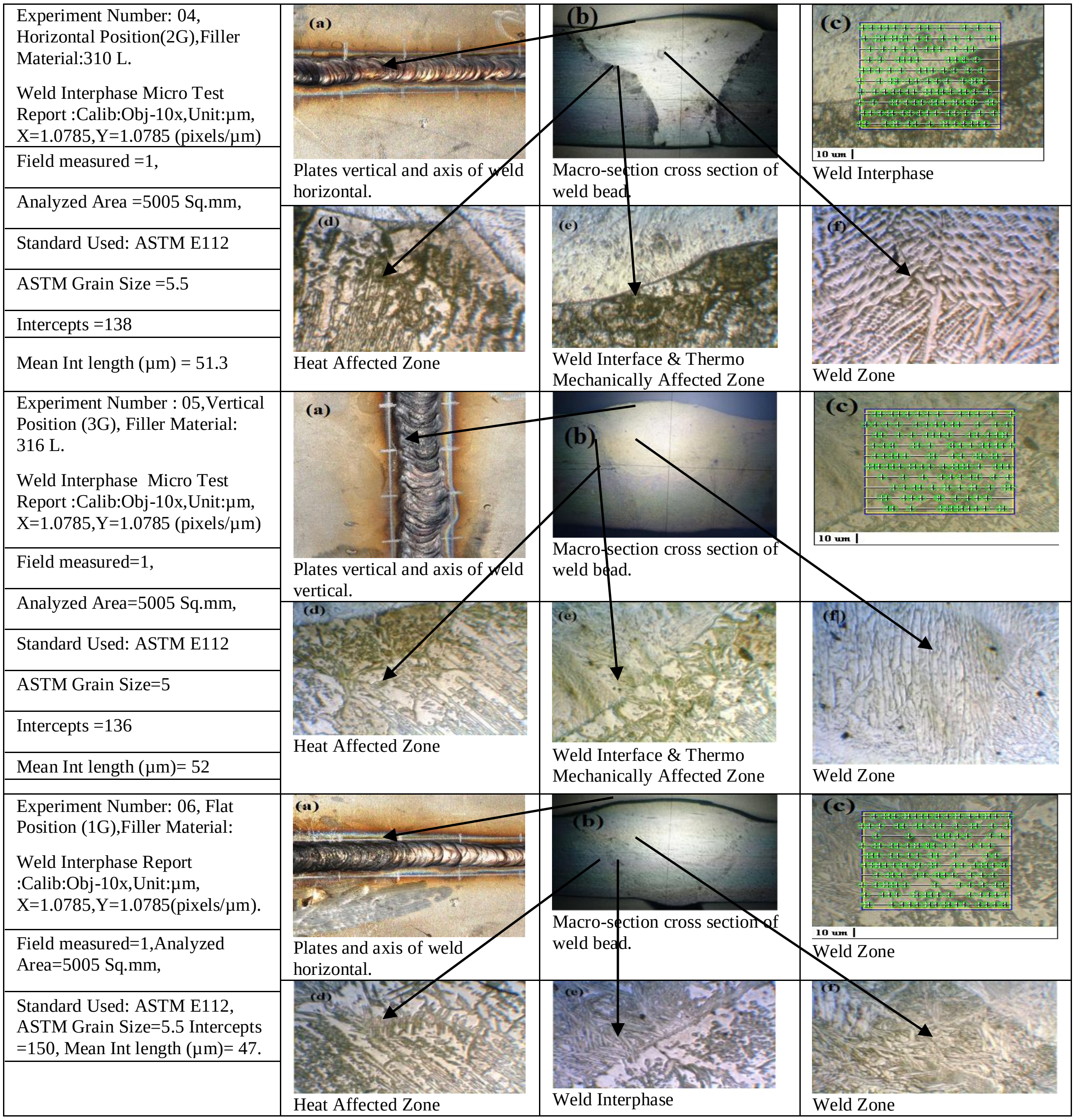

Figure 3: Compares (a) Weld bead surface, (b) Macro section Cross section,(c)Weld interface Phase analysis,(d) HAZ, (e) Weld interface & TMAZ, (f) Weld zone of Experiment No:04 (Horizontal position), Exp.No:05 (Vertical position) and Exp.No:06 (Flat position).

After examine the phase or volume fraction analysis, the volume % estimate of ferrite grains and austenite-γ matrix of weld area all experiments by calibrating object-10x, unit: µm, X: 1.0785, Y: 1.0785 (pixels /µm), standard used ASTME 562, Analysed Area: 1.1269 Sq.mm of weld area, it was clearly observed that maximum austenite-γ matrix is 65.84%and minimum ferrite grain is 31.63% of vertical weldment which current is 145 Amps, speed 22 mm/mint, filler wire is 316L. The maximum ferrite grains is 52.4% and minimum austenite-γ matrix is 45.62% found on flat weld sample which current is 125 amps, speed 17 mm/mints and current (165 Amps) at 22 mm/mint speed and filler metal is 310 L. The ferrite-α gain volume fracture is a significant factor to control the intragranular austenite-γ arrangement in Microstructure of all experiments for HAZ, WZ, and Inter phase Zone (shown in fig.2, fig.3 & fig.4).

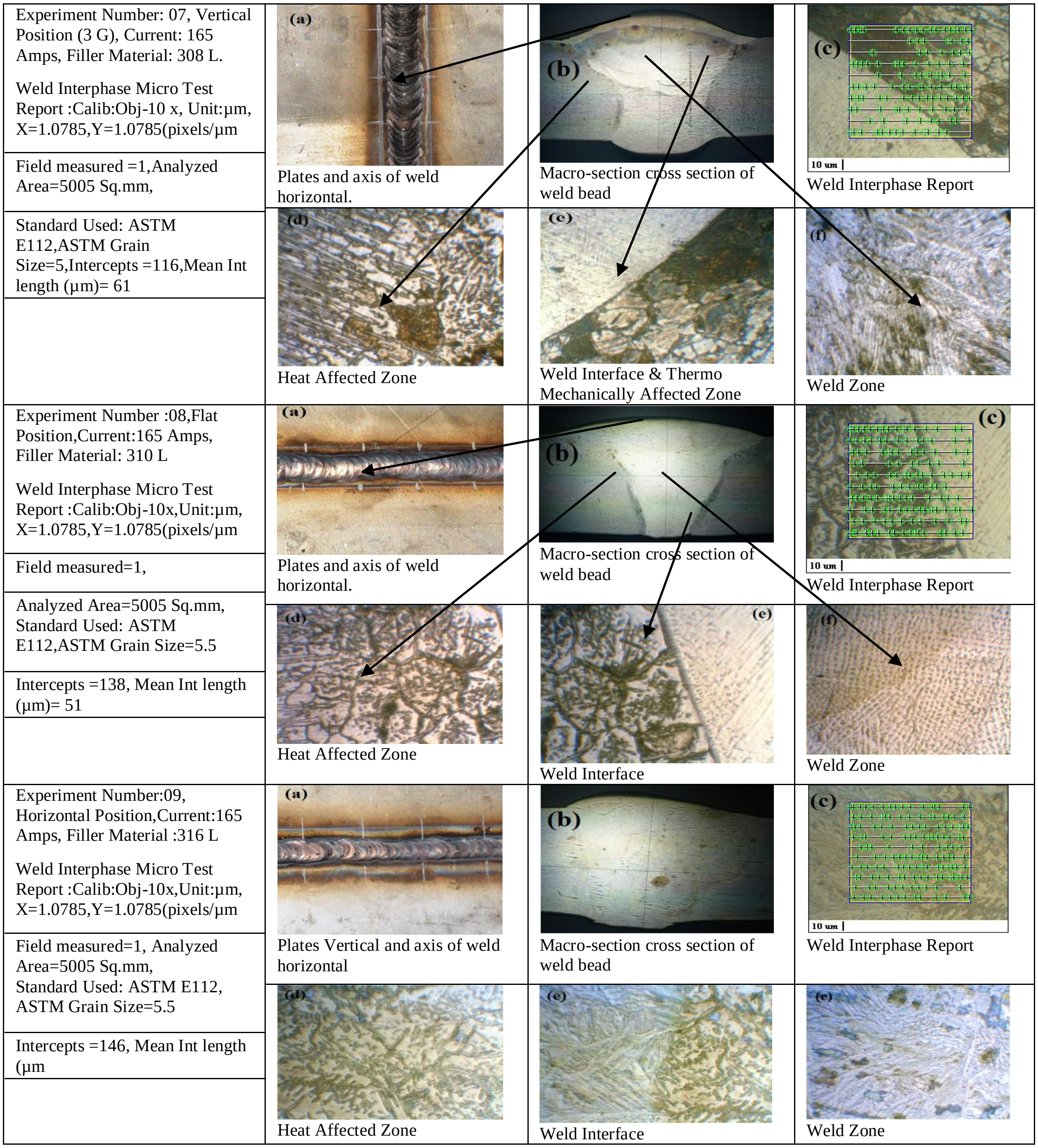

Fig. 4. (a) Bead Surface (b) Macro-Section (c) weld interface report (d) Heat Affected Zone (e) Thermo Mechanically Effected Zone (f) Weld Zone of Experiment No: 07 (Vertical Position), Exp.No:08 (Flat position) and Exp.No:09 (Horizontal Position).

The migrated grain boundaries are formed on the weld zones for all the weldments and formation of delta stringers in the austenitic coarse grains was observed at mechanically affected zone and at HAZ of DSS. It was observed that lamellar and layered ferrite grains are found on specimen number 05. From microstructure image of all welded specimen, it is found that sigma phase is formed at ferrite-α and austenite-γ interface, but the process is deferred during elevated coherent low energy ferrite-α and austenite-γ interfaces arrange while welding. The formation of sigma phase result in increase in brittleness and minimize in corrosion resistance.

Table No 5: L9 Orthogonal array weld bead geometry results:

Exp. No	Welding current (Amps)	Welding Speed mm / mint	Weld Position	Filler Wire Material	Reinforcement mm	Bead Width (mm)	Penetration +Root Reinforcement.	Wetting Angle (Degree)
1	125	17	Flat |(1G)	316 L	1.05	14.3	7.94	16
2	125	22	Horizontal(2G)	308 L	1.58	9.87	7.69	24
3	125	27	Vertical (3G)	310 L	1.57	13.59	6.49	15
4	145	17	Horizontal(2G)	310 L	1.12	9.76	5.89	18
5	145	22	Vertical (3G)	316 L	1.35	9.71	6.23	11
6	145	27	Flat (1G)	308 L	1.14	11.21	5.61	21
7	165	17	Vertical (3G)	308 L	1.7	8.83	7.2	19
8	165	22	Flat (1G)	310 L	1.09	12.5	5.58	17
9	165	27	Horizontal(2G)	316 L	1.37	9	6.59	17.5

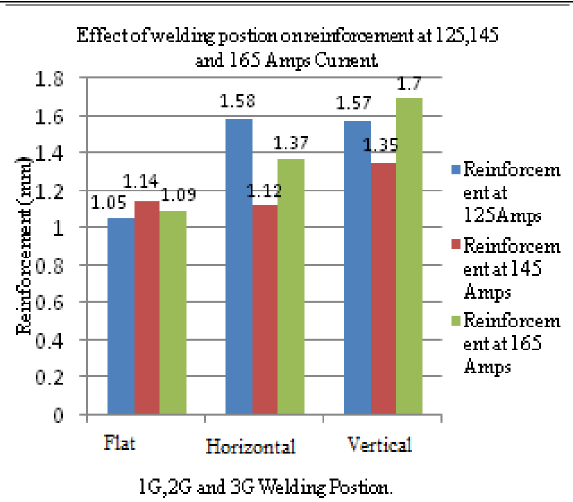

Figure 5. Variation of Reinforcement with welding position in single V-groove butt joints three pass welding.

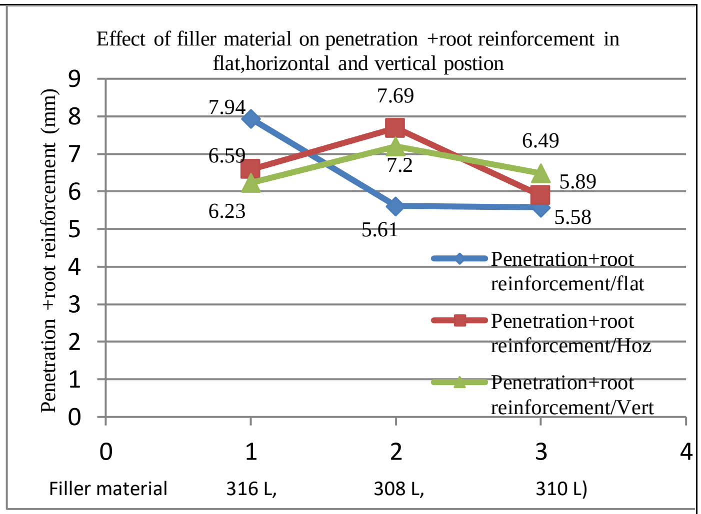

Figure 6. Variation of Penetration + Root reinforcement with welding position of different filler material.

It is observed that with 316 L filler material, it clearly shows that wetting angle is maximum for horizontal position welding with 308 L filler material as per results from Table 5.Strength of weld metal is greatly influence more by filler material.The technical reasons for the above results is clearly observed that due to the gravity of heated filler material will deposited in to weld gap and the influence of welding postion is more for the formation of weld bead,weld reinforcement and wetting angle.The reinforcement range is 1.35 mm to 1.7 mm observed maximum on vertical welding postions due to affect of gravitation force acting on heated filler metal during welding process in Figure 5. **It is** observed from the experimental value that maximum penetration +root reinforcement is 6.23 mm to 7.94 mm with 316 L as a filler metal on flat welding process as shown in Figure 6.

5. CONCLUSIONS

The results obtained by experimental investigations will be greatly use to the designers to account for the evaluation of macro-section and microstructure of TIG on Duplex Stainless Steel (2304) with weld bead geometry at different welding position. The investigational research for the influence of welding current(Amps), speed (mm/mints),welding position and filler material on bead geometry and microstructure of TIG weld joints using L9 orthogonal array design of experiments leads to the following conclusions..

(1) It observed that specimen number 08 corresponding to current 165 Amps, speed 33 mm/mint, flat position, filler material 310 L, gives maximum percentage of (dark region) ferrite grains (47.28 %) and minimum percentage of (bright grains) austenite marix (50.7%) in weld zone.

(2) By microstructure examination it was found that the migrated grain boundaries are formed on the weld zones for all the weldments and formation of delta stringers of austenitic coarse grains was observed at mechanically affected zone and at HAZ of DSS..

(3) Based on experiential that depending on the welding position and thermal effected mechanical conditions a variety of microstructure has been attained. In all specimens weld zone, ferrite-α type is largely present at grain border line with austenite as the medium. Coarse grain was found in horizontal welding specimen, corresponding current 125 Amps and volume fraction of austenite marix is 54.22%.The dark carbides were observed in specimen number 09 weld zone, corresponding current is 165 Amps, horizontal welding, 27 mm/mints, filler material is 316 L. Ledeburite coarse grain boundary was observed in HAZ region.

(4) The reinforcement is (1.05 mm) less, penetration plus root reinforcement is (7.94 mm) more, fusion area and Wetting angle (16^0) is less in flat welding position as compared with horizontal and vertical positions.

(5) It is concluded that the optimal process parameter for flat position are current (125 Amps), speed (17 mm/mint), filler wire 316L.For horizontal current (145 Amps), speed (17 mm/mint), filler wire 310 L.

(6) The optimal process parameter for vertical welding position are current (165 Amps), speed 17 mm/mint, filler wire 308 L.

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