

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO.
1.1	Elevated temperature region of a Pseudo binary phase diagram for duplex stainless steel compositions. Shaded region represents the range for commercial alloys.	2
2.1	Typical microstructures of duplex stainless steel	8
2.2	Typical transverse section microstructure of a duplex stainless steel, showing continuous ferritic matrix, etched dark, and austenite bands running parallel to the rolling direction of the plate.	8
2.3	(a) Section through the Fe-Cr-Ni ternary phase diagram at 68% Iron figure 2.3 (b) Elevated temperature region of a pseudo binary phase balance diagram for duplex stainless steel. Shaded region represents the range for commercial alloys.	14-15
2.4	CCT diagram for a cast DSS containing 0.02%C, 23.0%vCr and 7.6%Ni with superimposed cooling curves	16
2.5	Schematic summary of the effects of alloying elements on the anodic polarisation curve	17
2.6	Schematic summary of the effects of alloying elements on the formation of various precipitates reference	22
2.7	Effect of alloying elements on the solubility of Nitrogen in liquid Fe-18%Cr-8%Ni alloys at 1600°C at 1 atm N ₂	22
2.8	Diagrammatic sketch of the shielded metal arc welding process (SMAW) using a consumable flux coated covered electrode	31

2.9	Constant Current Power Sources (Drooping Characteristics)	32
2.10	Schematic constant iron section at 65% iron of the Fe-Cr-Ni ternary diagram	35
2.11	Pseudo-binary Fe-Cr-Ni phase at 70% Fe section illustrating areas of detrimental phase formation	38
2.12	Nitrogen solubility in ferrite and in austenite. (Constructed by J.C.Lippold, based on several literature sources.)	39
2.13	Isothermal precipitation diagram for 2205 duplex stainless steel, annealed at 1050 °C (duplex grades 2307 and 2507 are shown for comparison)	41
2.14	Secondary austenite in a simulated HAZ n alloy 2205. Secondary austenite is fine light etched phase in the centre of a prior ferrite grain. (From Ramirez)	43
2.15	Secondary austenite (gamma 2) resulting from growth off of primary austenite (gamma1) in Alloy 2205	44
2.16	Cooperative growth mechanism for formation of secondary austenite	44
2.17	Schaeffler Diagram	46
2.18	New 1992 WRC diagram including solidification mode boundaries.	48
2.19	Variation weld solidification cracking susceptibility with respect to C_{req} / Ni_{eq}	49
2.20	Isocorrosion curves, 0.1 mm/year, in sulphuric acid containing 2000 ppm chloride ions	52
2.21	Iso-corrosion curves 0.1 mm/year, in hydrochloric acid	52
2.22	Iso corrosion curves, 0.1 mm/year, in sulphuric acid	53

2.23	Typical critical pitting corrosion temperatures (CPT) in 1M NaCl measured according to ASTM G 150 using the Avesta Cell. Test surfaces wet ground to P320 mesh. CPT varies with product form and surface finish	56
2.24	Typical critical crevice corrosion temperature (CCT) according to ASTM G 48 Method F. Test surfaces dry ground to 120 mesh. CCT varies with product form and surface finish	56
2.25	Stress corrosion cracking resistance of mill annealed austenitic and duplex stainless steels in the drop evaporation test with sodium chloride solutions at 120°C (248°F) (stress that caused cracking shown as a percentage of yield strength)	60
3.1	Schematic of All weld metal test coupon preparation set up	65
3.2	Weld Test Coupon prepared for welding	66
3.4	Backing Strip Weld	66
3.5	C-Clap Restraint (Front view)	66
3.6	(Side View)	67
3.7	Wire Brush finished Test Piece	67
3.8	Fill Pass completed	67
3.9	Root pass completed	67
3.10	SMAW Electrode GRINOX 2209 E 2209-16 Size 3.15 X 350 mm	67
3.11	Application of digital thermometer to control less than 150 °C inter pass temperature.	68
3.12	Application of templistic to control less than 150 °C inter pass temperature.	68
3.13	Weld test Coupon ID 10 Ni 22 Cr	68
3.14	Weld test Coupon ID 11 Ni 22 Cr	68

3.15	Weld test Coupon ID 12 Ni 22 Cr	68
3.16	Standard Dimension for preparation of all weld test specimen	78
3.17	Prepared specimen for All weld Test Longitudinal sample as per ASME SEC IX : Ø12.5 X 60	79
3.18	Initial gauge length measurement ~ 50 mm	79
3.19	Specimen under Tensile load of UTM Machine with 40 Ton capacity	79
3.20	Fracture within Gauge length at 91740 N	79
3.21	Final Diameter 7.32 mm measurement.	80
3.22	Final Length Measurement : 64.87 mm	80
3.23	a). Source Standard Methods for Mechanical Testing of Welds AWS B4.0:2007ANSI, May 2, 2007,7th Edition, Supersedes ANSI/AWS B4.0-98 Pg No. 13	81
3.23	(b) Preparation of Test Specimen for Transverse Tensile Testing as per AWS B4.0 [78]	81
3.24	Transverse Tensile Specimen before fracture	82
3.25	Specimen under Tensile load Press capacity 60 Ton Capacity	82
3.26	Transverse Tensile Specimen After fracture Dimension	82
3.27	Fractured specimen shows fracture from the P.M.	82
3.27	(a) Specimen for Hardness measurement	82
3.28	Microhardness at 12 locations away from W.C.L	84
3.29	Specimen being measured for microhardness at different 12 locations away from W.C.L with 500 gmf applied AS PER E-384, EN ISO 9015-1:2011	84
3.30	Macro examination of Weld Specimens	85
3.31	Standard dimension for the CVN Specimen	87

3.32	One Set (3 specimens) for V Notch Charpy Impact Test as per ASTM A 370-14	87
3.33	Test samples set (3 specimens)	88
3.34	Test temp -150 °C maintained by Liquid N2, Temperatures monitored by thermocouple	88
3.35	Impact Test Machine Capacity 350 Joule	88
3.36	Measurement of Lateral Expansion by dial gauge.	88
3.37	Instrument utilized was Fischer Ferritscope Germany Make: Fischer 2531	89
3.38	Calibrated Fischer Ferritscope Germany Make: Fischer 2531	89
3.39	Considering dilution from BM 15% & 70% from FM	92
3.40	WRC -1992 DIAGRAM PREDICTING FN 22	92
3.41	Calculation of Ferrite Number from WRC 1992 diagram Enlarged view indicating approx. FN 22	93
3.42	Set of 03 specimens for SMAW E 2209-16 (10 Ni 22 Cr) press bend 180° "U" bent samples (for producing stress) fastened at ree ends with anti-corrosive materials bolts, Nuts and Teflon washers.	98
3.43	Set of 03 Specimens for SMAW E 2209-16 (11 Ni 22 Cr) press bend 180 ° "U" Bent samples (for producing stress) fastened at free ends with anti-corrosive materials bolts, Nuts and Teflon washers.	99
3.44	Set of 03 Specimens for SMAW E 2209-16 (12 Ni 22 Cr) press bend 180 ° "U" Bent samples (for producing stress) fastened at free ends with anti-corrosive materials bolts, Nuts and Teflon washers.	100
3.45	Set of Specimen (03 Nos. Per Heat) immersed in boiling 25 % NaCl Solution (120-150 °C) in each flask on Hot Plate equipped with Condenser arrangement. Cycle time 1000 Hrs. (ASTM G123)	101

4.1	Fracture within Gauge length for all Weld Test Coupons	103
4.2	Ductile fracture within Gauge length for all weld test Coupons	103
4.3	Stress-Strain Curve for Weld test coupon E 2209-16 (09 Ni 22 Cr)	104
4.4	Stress-Strain Curve for Weld test coupon Coupon Id 12 Ni 22 Cr	104
4.5	Stress-Strain Curve for Weld test coupon Id 10 Ni 22 Cr	105
4.6	Stress-Strain Curve for Weld test Coupon Id 11 Ni 22 Cr	105
4.7	Transverse Tensile Specimen before fracture Dimension:	106
4.8	Specimen under Tensile load Press capacity 60 Ton Capacity	106
4.9	Transverse Tensile Specimen After fracture Dimension	106
4.10	Fractured specimen shows fracture from the P.M.	106
4.11	Shows the location of Welded coupon hardness profile	107
4.12	Micro Hardness Profile Survey	109
4.13	Macro structure examination of weld coupon id (a) 10 Ni 22 Cr (b) 11 Ni 22 Cr and (c) 12 Ni 22 Cr.	110
4.14	Brittle Fracture Pattern in Broken CVN Samples.	111
4.15	Fractured CVN Samples at -40° C	111
4.16	FN 42.7 Prediction from WRC 1992 diagram for weld sample prepared by E 2209 Sample. (Considering 30% Dilution from BM)	113
4.17	FN 48 Prediction from WRC 1992 diagram for weld sample prepared by E 2209 Sample. (Considering 40 % Dilution from BM)	114

4.18	FN 39 Prediction from WRC 1992 diagram for weld sample 9 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)	115
4.19	FN 45.5 Prediction from WRC 1992 diagram for weld sample 9 Ni 22 Cr Sample. (Considering 40 % Dilution from BM)	116
4.20	FN 46 Prediction from WRC 1992 diagram for weld sample 10 Ni 22 Cr Sample. (Considering 40 % Dilution from BM)	117
4.21	FN 39 Prediction from WRC 1992 diagram for weld sample 10 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)	118
4.22	FN 38 Prediction from WRC 1992 diagram for weld sample 11 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)	119
4.23	FN 44 Prediction from WRC 1992 diagram for weld sample 11 Ni 22 Cr Sample. (Considering 40 % Dilution from BM)	120
4.24	FN 22 Prediction from WRC 1992 diagram for weld sample 12 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)	121
4.25	FN 26 Prediction from WRC-1992 diagram for weld sample 12 Ni 22 Cr Considering 40% Dilution from Weld metal	122
4.26	Vol. fraction measurement of E2209(10Ni22Cr) Sample	123
4.27	Vol. fraction measurement of E2209(10Ni22Cr) Sample	123
4.28	Ferrite Measurement by Image Analysis Ferrite % = 12.15. *	124
4.29	No Crack appears in 10 Ni 22 Cr Weld Sample	126
4.30	Crack appears in 11 Ni 22 Cr Weld Sample	127

4.31	Crack appears in 11 Ni 22 Cr Weld Sample	127
4.32	Crack appears in 11 Ni 22 Cr Weld Sample	127
4.33	Crack appears in 11 Ni 22 Cr Weld Sample	127
4.34	No Crack appears in 12 Ni 22 Cr Weld Sample	128
5.1	Micro Hardness profile survey measured on 12 locations.	129
5.2	Tensile and Yield strength as a function of % Ferrite for 2205	131
5.3	Ductility as a function of % Ferrite for 2205	131
5.4	Charpy energy absorbed (Joule) at -40 °C as a function of Ferrite Content for 2205.	132
5.5	FZ / HAZ Interface at 100 X magnification sample 12Ni 22 Cr with 10% NaOH Etched. Ferrite is revealed as dark Phase & Austenite as Light Phase	133
5.6	FZ / HAZ Interface at 400 X magnification sample 12Ni 22 Cr with 10% NaOH Etched. Ferrite is revealed as dark Phase & Austenite as Light Phase	133
5.7	FZ Micro at 400 X magnification sample 12Ni 22 Cr with 10% NaOH Etched. Ferrite is revealed as dark Phase & Austenite as Light Phase	134
5.8	FZ Micro at 1000 X magnification sample 12Ni 22 Cr with 10% NaOH Etched. Ferrite is revealed as dark Phase & Austenite as Light Phase	134
5.9	Micro HAZ / FZ Interface at 400 X Magnification revealing coarse grain Heat affected zone (CGHAZ) Sample id 12 Ni 22 Cr	135
5.10	Micro of weld at 400 X Mag sample revealing Widmanstatten austenite as light phase and ferrite as dark phase. Sample id 12 Ni 22 Cr	135
5.11	FZ / HAZ Interface at 400 X magnification sample 11Ni 22 Cr with 10% NaOH Etched. Ferrite is revealed as dark Phase & Austenite as Light Phase	136

5.12	FZ / HAZ Interface at 1000 X magnification sample 11Ni 22 Cr with 10% NaOH Etched. Ferrite is revealed as dark Phase & Austenite as Light Phase.	136
5.13	FZ Micro at 200 x Magnification reveals light phase Widmanstatten Austenite (WA) and Ferrite (Dark Phase) Coupon Id 11Ni 22 Cr	137
5.14	FZ Micro at 1000 x Magnification clearly reveals light phase Widmanstatten Austenite (WA) and Ferrite (Dark Phase) Coupon Id 11Ni 22 Cr	137
5.15	Sample id 10 Ni 22 Cr Micro at 200 x Magnification, NaOH etched light phase austenite (WA) and ferrite (dark phase)	138
5.16	Sample id 10 Ni 22 Cr across fusion boundary showing fine grain austenite in fusion zone Weld Micro at 200 X Mag. NaOH etched	138
5.17	Comparative data of Ferrite measurement by Volume fraction measurement, point count method and Ferritscope instrument.	139
5.18	Fine grain weld metal zone microstructure of 11 Ni 22 Cr weld coupon. Dark phase is ferrite and light phase is austenite.	140
5.19	Photomicrograph of 9 Ni 22 Cr Weld coupon 10 % NaOH etched at 400 X magnification reveals dark phase as ferrite and light phase as austenite.	140
5.20	Comparisons of ferrite measurement results between top surface of weld deposits and cross section of weld for different weld compositions considered under study.	141
5.21	Scatter plot of FN measurement on weld top surface centre line and on weld cross section for E2209-16 weld sample.	142

5.22	Scatter plot of FN measurement on weld top surface centre line and on weld cross section for 9 Ni 22 Cr weld sample.	142
5.23	Scatter plot of FN measurement on weld top surface centre line and on weld cross section for 10 Ni 22 Cr weld sample.	143
5.24	Scatter plot of FN measurement on weld top surface centre line and on weld cross section for 11 Ni 22 Cr weld sample.	143
5.25	Scatter Plot of FN measurement results comparing WRC-1992 (predicted value) and Feritscope instrument (measured value) for all weld compositions (E2209-16, 9 Ni 22 Cr, 10 Ni 22 Cr and 11 Ni 22 Cr).	144
5.26	a) 11 Ni 22Cr Coupon A Crack after 2 weeks	148
5.26	(b) Crack cross section photomicrograph at etched with 10 % Ammonium Persulfate (Electrolyte) view at 100 X magnification revealed typical SCC Crack.	148
5.27	(a) 11Ni22Cr Coupon B Crack after 2 weeks	148
	(b) Crack cross section photomicrograph at etched with 10 % Ammonium Persulfate (Electrolyte) view at 400 X magnification revealed trans granular typical SCC Crack	148
5.28	(c) & (d) Perspective Views of Cross sectioned SCC specimen	148