

INDEX

CHAPTER NO	TITLE	PAGE NO.
1.	INTRODUCTION	1-6
2.	LITERATURE REVIEW	7-61
2.1	History of duplex stainless steel	7
2.2	Introduction of duplex stainless steel	7
2.3	Mechanical Properties	13
2.4	Physical Metallurgy	14
2.5	Alloy Design and Alloying additions of Duplex Stainless Steels	17
2.6	Welding of duplex stainless steel (General Welding Guidelines)	23
2.6.1.	Cleaning before welding	23
2.6.2.	Preheating	24
2.6.3.	Heat Input	24
2.6.4.	Inter pass temperature	26
2.6.5.	Desired phase balance	26
2.6.6.	Post weld Heat treatment (PWHT)	26
2.6.7.	Dissimilar metal weld	27
2.6.8.	Welding Process Selection	28
2.6.9.	Shielded Metal Arc welding	30
2.7.	Welding metallurgy of duplex stainless steel	34
2.7.1.	Role of Nitrogen in Solidification Mechanism	37
2.7.2.	Intermetallic and secondary phases	40
2.7.2.1.	Alpha prime (α')	41
2.7.2.2.	Sigma phase (σ)	42

2.7.2.3.	Carbides M23C6 and M7C3	42
2.7.2.4.	Secondary Austenite	43
2.8	Ferrite measurement	45
2.8.1.	Introduction to Schaeffler, WRC De-Long & WRC 1992 Diagram	46
2.8.1.1.	Schaeffler diagram	46
2.8.1.2.	WRC-1992 diagram	47
2.9.	Weldability of duplex Stainless Steels	48
2.9.1.	Weld solidification cracking	48
2.9.2.	Hydrogen induce cracking	50
2.10.	Corrosion behaviour of Duplex stainless steel	50
2.10.1.	Uniform corrosion	51
2.10.2.	Corrosion behaviour in Sulphuric acid	51
2.10.3.	Corrosion behaviour in Hydrochloric acid	51
2.10.4.	Corrosion behaviour in Nitric acid	51
2.10.5.	Pitting and crevice corrosion	53
2.11	Stress corrosion cracking	57
2.11.1.	Chloride and Sulphide induced stress corrosion cracking	58
3.	EXPERIMENTAL WORK	62-100
3.1	Procurement of Candidate Materials	61
3.2	Procurement of sample SMAW Electrodes	63
3.2.1.	Specification of Electrodes E 2209-16 (GRINOX-2209-16)	63
3.3	Preparation of Weld Test coupon	64
3.4.	Welding Procedure	64
3.4.1.	SMAW process	68
3.4.2.	Welding Machine specifications:	69

3.4.3.	Setting up process parameters	69
3.4.4.	Calculations of H.I	69
3.4.5.	Weld process data recording sheet.	70
3.5	Test Plan for Weld Coupon	74
3.6	Mechanical Tastings	78
3.6.1.	All Weld Tensile Test	78
3.6.2.	Transverse Rectangular Tension Test Specimen (Plate)	80
3.7.	Hardness test	82
3.8.	Macro examinations	84
3.9.	Metallography	85
3.10.	Chemical Analysis	86
3.11.	Impact Test	86
3.12.	Ferrite measurement	88
3.12.1.	Volume Fraction by Systematic Manual Point Count (ASTM 562 practice E)	89
3.12.2.	Magnetic permeability (e.g.: Feritscope)	89
3.12.3.	Ferrite Measurement by WRC 1992 diagram	90
3.13.	Corrosion Testing	93
3.13.1.	Pitting corrosion (ASTM G 48 Practice A)	93
3.13.2	Chloride induced Stress Corrosion Test (Ch-CSSt)	94
3.14.1	Typical: U-Bend" Test Specimens	95
3.14.2.	Test solution: CSCC	96
3.14.3.	Test Procedure : CSCC	96
4.	RESULTS	101-126
4.1	All weld Tensile Test method as per AWS B4.0	102
4.1.1.	Stress –Strain Curve Ductile Behaviour of All Weld Test Samples	104

4.2	Transverse Rectangular Tension Test as per AWS B4.0	106
4.3	Welded Coupon micro hardness Test as PER E-384, EN ISO 9015-1:2011	107
4.4	Macro examinations as per ASTM-E-381-01	108
4.5	V Notch Charpy Impact Test as per ASTM A 370-14	108
4.6	Ferrite content measurement	109
4.6.1.	Prediction of Ferrite Number from WRC 1992 diagram (predictive Method)	110
4.6.2.	Prediction of Ferrite Number by “Volume fraction measurement by systematic manual point count method: ASTM E 562 (Experimental method)	111
4.6.2.1.	Phase Quantification Ferrite Measurement by MAGE ANALYSIS (MiC V. 2.0)	122
4.6.3.	Measurement of Ferrite Number by Fischer Make Feritscope® Instrument (Experimental method)	123
4.7.	Pitting corrosion results as per ASTM G48 Method A	124
4.8.	Chloride Stress corrosion Cracking susceptibility test results (ASTM G123 Method)	124
5.	RESULTS & DISCUSSIONS	127
5.1	Effect of Ferrite content on the Hardness profile	127
5.2	Effect of ferrite content on strength	130
5.3	Microstructure examinations	129
5.4	Comparisons of Ferrite Measurement results between ASTM E 562-11: Volume Fraction measurement by systematic Point Count method and Feritscope ® Instrument	137
5.5	Comparisons of Ferrite Measurement results between Top surface of Weld deposits and Cross	139

	Section of Weld.	
5.6	Comparisons of Ferrite Measurement results between WRC-1992 diagram (Predictive method) and Feritscope Instrument (Actual Measurement method)	142
5.7	Effect of ferrite content on pitting behaviour	143
5.8	Effect of ferrite content on Stress Corrosion Cracking susceptibility	146
6.	CONCLUSIONS	150-151
7.	SCOPE OF FUTURE WORK	153
8.	REFERENCES	154-163
9.	BIBLIOGRAPHY	164-165
10.	PUBLICATIONS AND RECOGNITIONS	166
	ANNEXURES	167-230
	01 Research Publication in IIW-IWJ	167-176
	02 IIW Conf. Paper Selected	177
	03 GUJCOST – DST Research Grant	178
	04 IIW : Annual Assembly Meet Italy -Genova	179
	05 IIW : Paper Accepted In Annual Assembly & recommended for Pub.	180
	06 Test Certificate and UNS S 32205 Base metal composition and mechanical property validation test reports	180-187
	07 All Weld Metal Test reports	187-205
	08 Microhardness Test reports	206-208
	09 ASTM A 923 Test reports	209-211
	10 ASTM E-562 Test reports	212-213
	11 CVN TEST AT -46 °C TEST RESULTS	214-216
	12 ASTM G 48 A Pitting Corrosion Test	217-219

	reports	
	13 SCC Test Micrograph and FN Test reports	222
	14 ASME BPVC 2015 SMAW Welding Variable	223
	15 Research Paper Publication recommends WitW.	224-225
	16 Submitted Synopsis Copy	226-256