CHAPTER - 4

RESULTS

4.1 All weld Tensile Test method as per AWS B4.0

Table 4.1 All weld Tensile Test method as per AWS B4.0

	E 2209-16 (9 Ni 22Cr) Commercial		Coupon 10 Ni 22 Cr (Low Ni)		Coupon 11 Ni 22 Cr (Medium Ni)		Coupon 12 Ni 22 Cr (High Ni)	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Gauge Dia (mm)	12.52	12.44	12.69	12.46	12.42	12.52	12.40	12.31
Area (mm2)	125.5	122.1	126.47	121.93	121.15	123.11	120.76	119.01
Gauge Length (mm)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Final Length (mm)	62.64	62.86	62.84	62.66	62.96	62.03	64.87	63.70
Final Dia. (mm)	9.25	8.98	9.28	8.96	8.71	8.97	7.55	7.32
0.2 % Proof Load (N)	85844	83359	86843	83359	82099	84043	70971	76610
Ultimate Load (N)	104830	104920	107820	104920	103959	104919	91740	92619
0.2% Proof Stress (N/mm2)	670	684	687	684	678	683	588	644
U.T.S (N/mm2)	852	860	853	860	858	852	760	778
% Reduction in area	46.52	48.28	46.52	48.28	50.81	48.66	62.92	64.64
% Elongation	26.66	25.32	25.68	25.32	26.0	24.06	29.74	27.4
Fracture	W.G.L	W.G.L	W.G.L	W.G.L	W.G.L	W.G.L	W.G.L	W.G.L

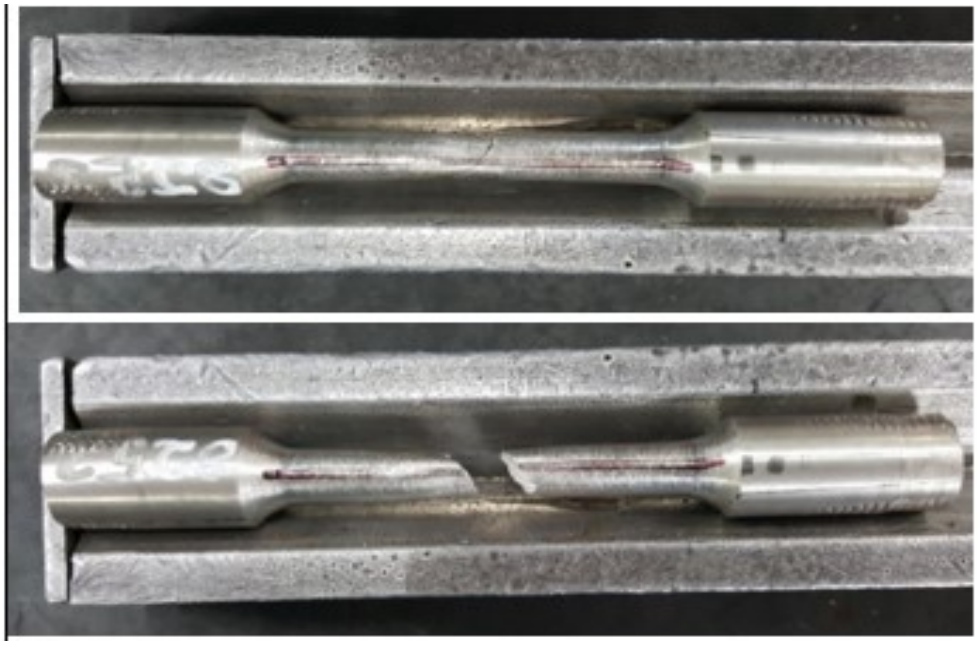


Fig.4.1 Fracture within Gauge length for all Weld Test Coupons

Fig.4.2 Ductile fracture within Gauge length for all weld test Coupons

4.1.1 Stress –Strain Curve Ductile Behaviour of All Weld Test Samples

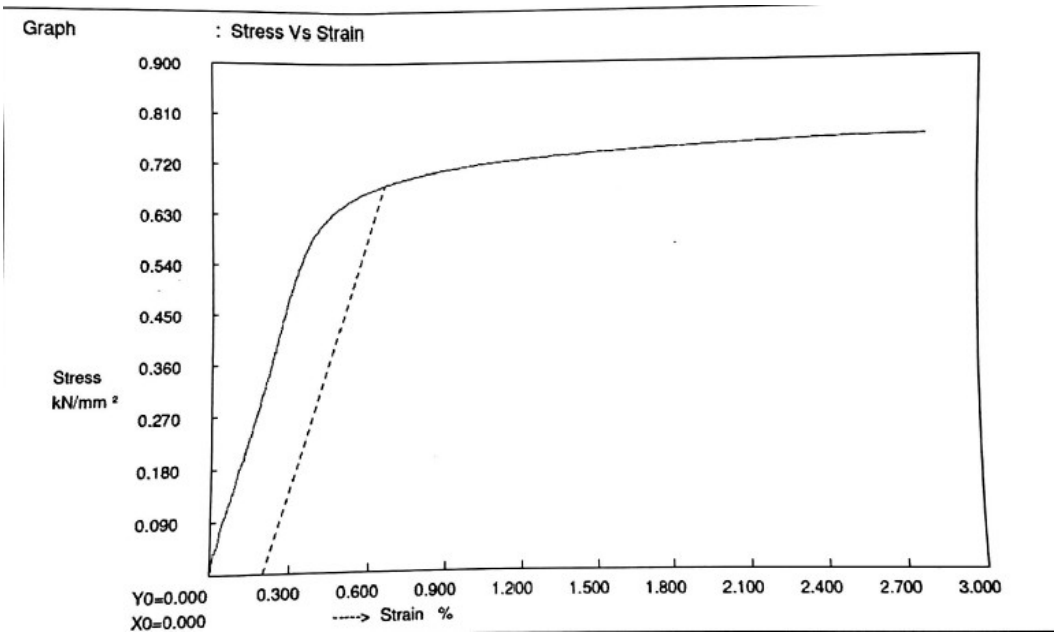


Fig.4.3 Stress-Strain Curve for Weld test coupon E 2209-16 (09 Ni 22 Cr)

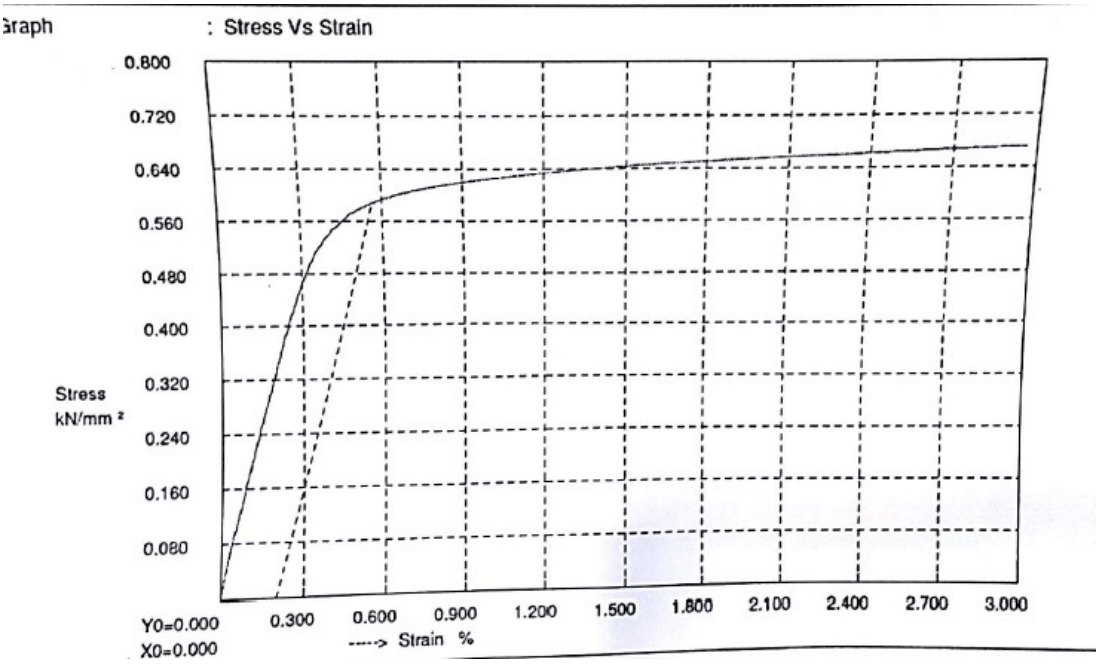


Fig.4.4 Stress-Strain Curve for Weld test coupon Coupon Id 12 Ni 22 Cr

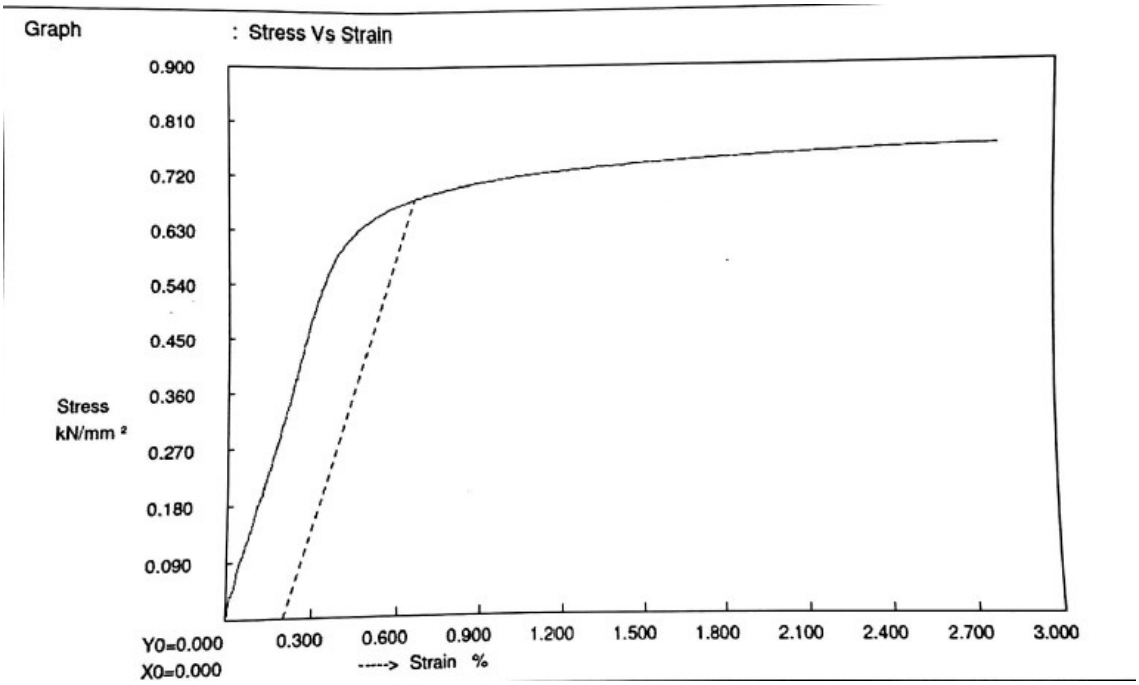


Fig.4.5 Stress-Strain Curve for Weld test coupon Id 10 Ni 22 Cr

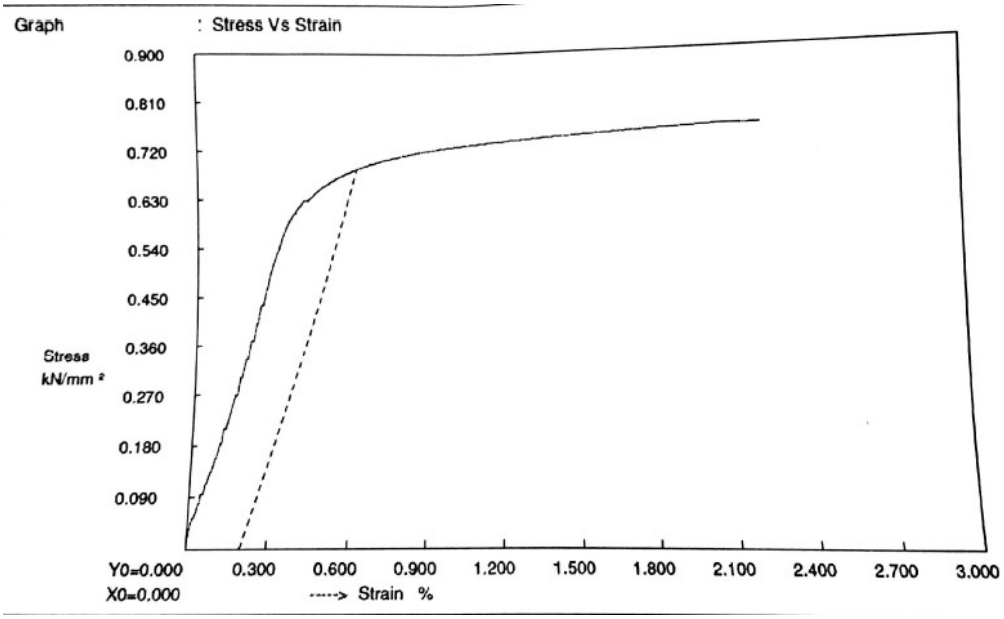


Fig.4.6 Stress-Strain Curve for Weld test Coupon Id 11 Ni 22 Cr

4.2 Transverse Rectangular Tension Test as per AWS B4.0

Table 4.2 Transverse Rectangular Tension Test Specimen (Plate)

Sample Mark **12 Ni 22 Cr**	**Sample 1**	**Sample 2**
Thickness (mm)	25.15	22.90
Width (mm)	19.29	19.13
Area (mm2)	485.14	438.08
Ultimate Load (N)	370590	340620
UTS (N/mm2)	764	778
Fracture	AT P.M.	AT P.M.
Fracture Type	Ductile	Ductile

Fig. 4.7 Transverse Tensile Specimen before fracture Dimension:

Fig. 4.8 Specimen under Tensile load Press capacity 60 Ton Capacity

Fig. 4.9 Transverse Tensile Specimen After fracture Dimension

Fig. 4.10 Fractured specimen shows fracture from the P.M.

The test was conducted for 12 Ni 22 Cr Weld test Coupon only because transverse tensile test was found meaningless for evaluating property of the all weld metal.

4.3 welded coupon microhardness Profile as per E-384, EN ISO 9015-1:2011

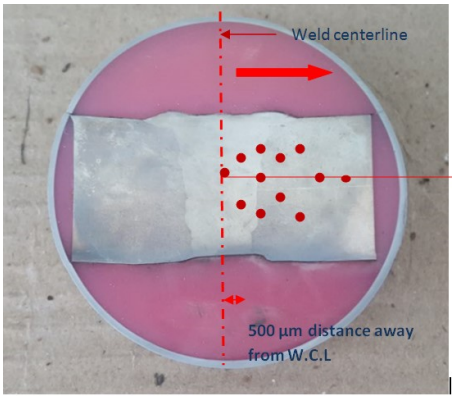


Fig. 4.11 Shows the location of welded coupon micro hardness hardness at 12 loctions away from the weld center lne.

Table 4.3 microhardness Profile as per E-384, EN ISO 9015-1:2011

Zone	DIST FROM WELD CENTER LINE(mm)	Coupon Id 10 Ni 22 Cr (Low Ni)	Coupon Id 11 Ni 22 Cr (Medium Ni)	Coupon Id 12 Ni 22 Cr (High Ni)
WM	0	291	283	288
WM	500	283	280	276
WM	1000	297	291	279
WM	1500	297	289	280
WM	2000	293	295	295
HAZ	2500	293	290	299
PM	3000	278	280	295
PM	3500	283	296	295
PM	4000	276	286	292
PM	4500	280	283	290
PM	5000	279	274	284
PM	5500	276	279	285

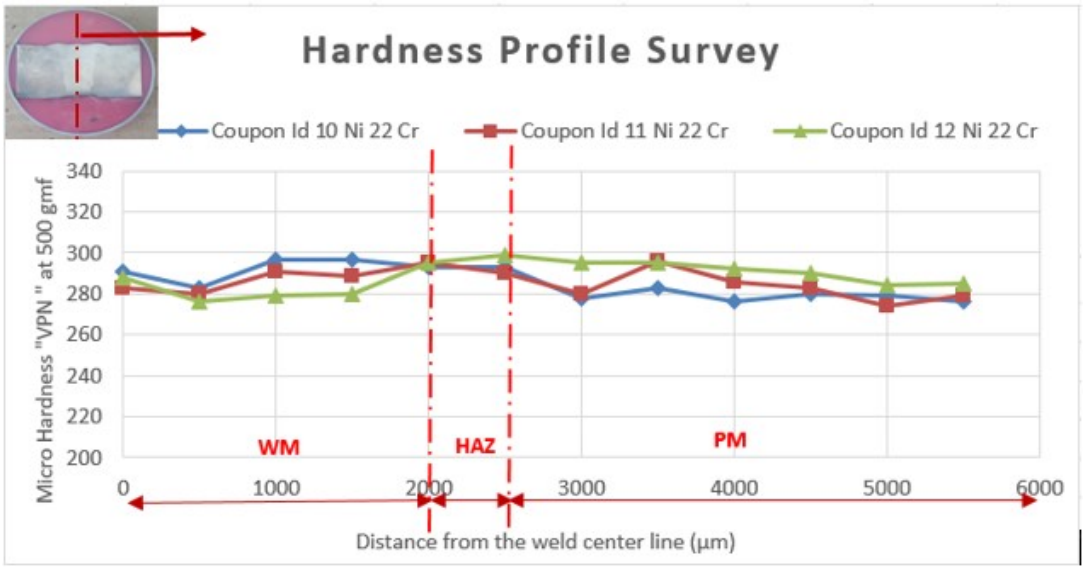


Fig. 4.13 microhardness Profile Survey

4.4 Macro examinations as per ASTM-E-381-01

4.4 Macro examinations

It is a qualitative visual examination to evaluate a weld fusion, penetration and probable defects.

Macrostructure Examination

Instrument utilized: Digital Camera/Stereo Microscope

TEST METHOD: ASTM-E-381-01

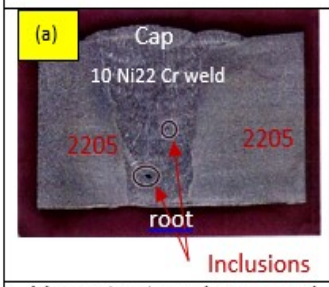
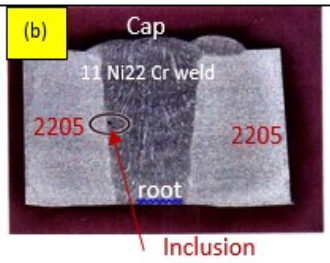
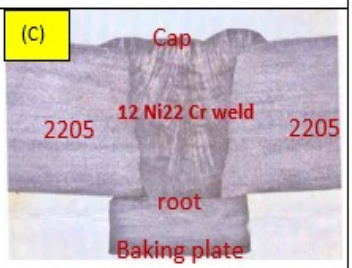
Weld Coupon prepared by 10NiCr22	Weld Coupon prepared by 11NiCr22	Weld Coupon prepared by 12NiCr22
		
Macrostructure shows good fusion however inclusion is observed.	Macrostructure shows good fusion however inclusion is observed	Weld joint sample etched with 50% HCL Macrostructure shows good fusion without any significant defect

Fig. 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.

4.5 Charpy V Notch (CVN) Impact Test as per ASTM A 370-14

Sample Size (mm) 10 X 10 X 55 mm Test Temperature (°C) -46° C

Table 4.4 CVN Results at Test Temperature (°C) -46° C

Sample Id	Weld Metal Ferrite %	Sample 1	Sample 2	Sample 3
		Energy Absorbed in Joule		
09 Ni 22 Cr*	38.5	46	48	49
10Ni22Cr	40.94	34	36	34
11Ni 22Cr	38.45	44	44	46
12Ni22Cr	12.15	28	30	28

*09 Ni 22 Cr coupon as per report provided by GEE Electrode Ltd. (Attached Annexure 6)

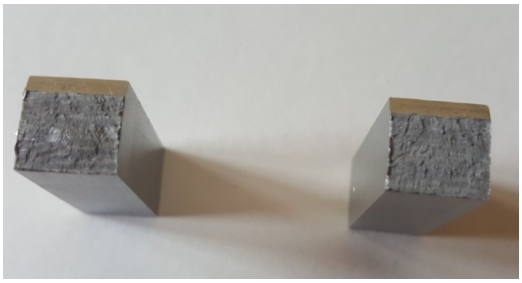


Fig.4.14 Brittle Fracture Pattern in Broken CVN Samples.

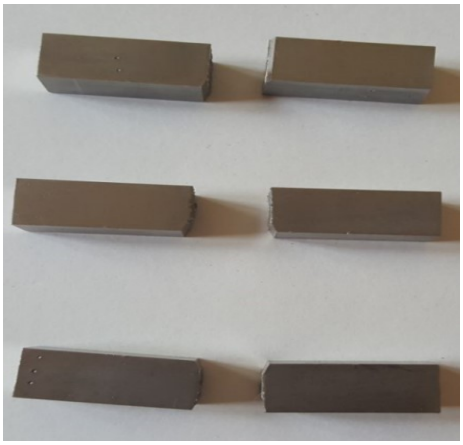


Fig.4.15 Fractured CVN Samples at -46° C

4.6 Ferrite content measurement

WRC 1992 diagram (predictive Method)

Ferrite Measurement by "Volume fraction measurement by Systematic manual point count method -ASTM E562 Method (experimental method)

Fischer Feritscope® instrument (experimental method)

4.6.1 Prediction of Ferrite Number from WRC 1992 diagram (predictive Method)

4.6.1.1 Prediction of Ferrite Number from the given composition of Base metal and filler metal using WRC-1992 Diagram.

Table No. 4.5 Chemical Composition of UNS S32205 as per PMI Spectroscopy

C	Si	Mn	P	S	Cr	Ni	Mo	Nb	Cu	Co	N
0.023	0.37	1.50	0.018	0.001	22.37	5.72	3.21	0.11	0.14	0.08	0.177

4.6.1.2 Chemical analysis of SMAW electrode

ELECTRODE COMPOSITION GRINOX 2209 size: 3.15 X 350 MM as per ASME SEC IIC, Weld Pad Method

Table No. 4.6 Chemical compositions of the undiluted weld metals carried out on weld pad as per ASME SEC II C.

SMAW Electrode with Nickel content	C	Mn	Si,	S	P	Cr	Ni	Mo	Cu	N
Standard 2209 Electrode E2209	0.031	1.08	0.59	0.007	0.025	22.38	9.15	3.35	0.096	0.18
Low Ni	0.019	0.99	0.61	0.005	0.027	22.29	9.80	3.19	0.068	0.17
Medium Ni	0.021	0.99	0.58	0.007	0.028	22.35	10.20	3.16	0.075	0.16
High Ni	0.017	1.11	0.62	0.008	0.028	22.33	12.55	3.20	0.069	0.18

Standard 2209 Electrode				30:70 Dilution	
E2209		FN=42.7			
					Synthetic
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Base Metal
C, %	0.023	0.023	0.031	0.029	0.023
Mn, %	1.50	1.50	1.08	1.206	1.500
Cr, %	22.37	22.37	22.38	22.377	22.370
Ni, %	5.72	5.72	9.15	8.121	5.720
Mo, %	3.21	3.21	3.35	3.308	3.210
Nb, %	0.11	0.11	0	0.033	0.110
Cu, %	0.14	0.14	0.096	0.109	0.140
N, %	0.177	0.177	0.18	0.179	0.177
% of Joint	15	15	70	100	
Creq	25.657	25.657	25.73	25.7081	25.657
Nieq	10.1	10.1	13.859	12.7313	10.1
FN	86.4	86.4	29.5	42.7	

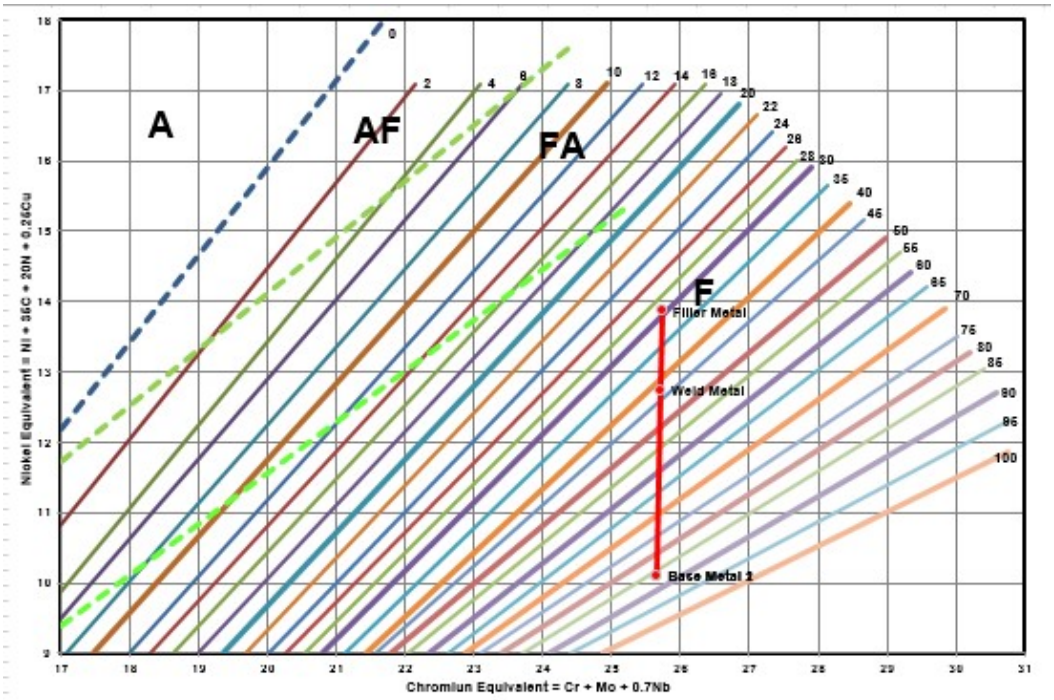


Fig. 4.16 FN 42.7 Prediction from WRC 1992 diagram for weld sample prepared by E 2209 Sample. (Considering 30% Dilution from BM)

Standard 2209 Electrode					
E2209		FN=48		40:60 Dilution	
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Synthetic Base Metal
C, %	0.023	0.023	0.031	0.028	0.023
Mn, %	1.50	1.50	1.08	1.248	1.500
Cr, %	22.37	22.37	22.38	22.376	22.370
Ni, %	5.72	5.72	9.15	7.778	5.720
Mo, %	3.21	3.21	3.35	3.294	3.210
Nb, %	0.11	0.11	0	0.044	0.110
Cu, %	0.14	0.14	0.096	0.114	0.140
N, %	0.177	0.177	0.18	0.179	0.177
% of Joint	20	20	60	100	
Creq	25.657	25.657	25.73	25.7008	25.657
Nieq	10.1	10.1	13.859	12.3554	10.1
FN	86.4	86.4	29.5	48.0	

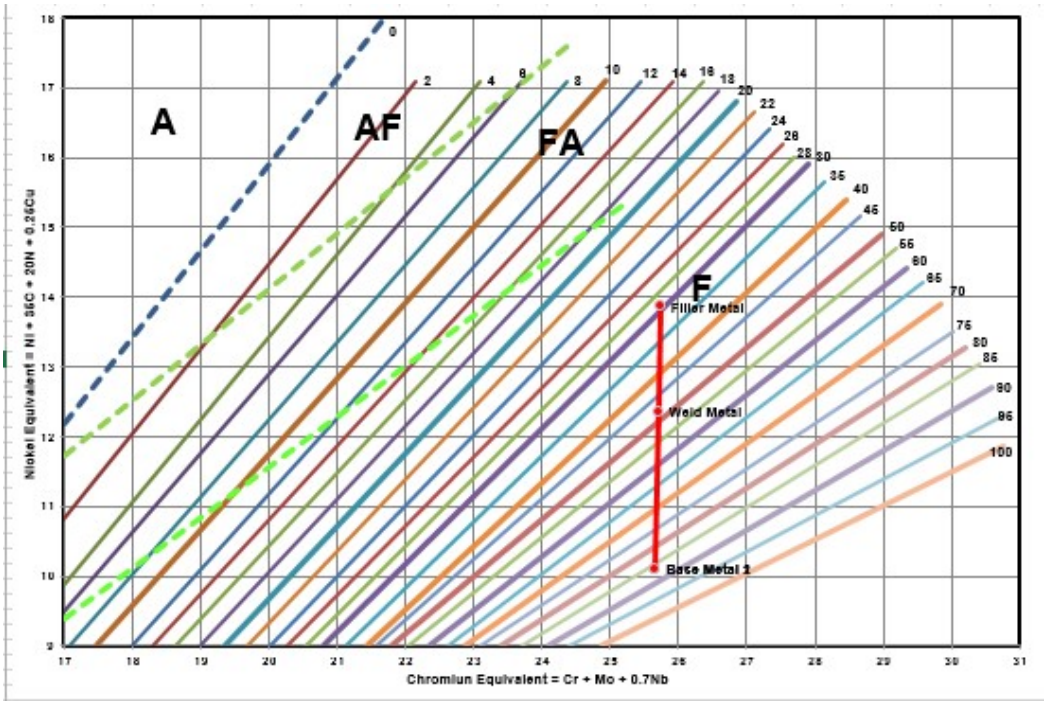


Fig. 4.17 FN 48 Prediction from WRC 1992 diagram for weld sample prepared by E 2209 Sample. (Considering 40 % Dilution from BM)

9.0 -9.5 % wt	30:70				
	FN=39.2				
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Synthetic Base Metal
C, %	0.023	0.023	0.031	0.029	0.023
Mn, %	1.50	1.50	0.98	1.136	1.500
Cr, %	22.37	22.37	22.32	22.335	22.370
Ni, %	5.72	5.72	9.2	8.156	5.720
Mo, %	3.21	3.21	3.32	3.287	3.210
Nb, %	0.11	0.11	0	0.033	0.110
Cu, %	0.14	0.14	0.089	0.104	0.140
N, %	0.177	0.177	0.19	0.186	0.177
% of Joint	15	15	70	100	
Creq	25.657	25.657	25.64	25.6451	25.657
Nieq	10.1	10.1	14.1073	12.905075	10.1
FN	86.4	86.4	27.3	39.2	

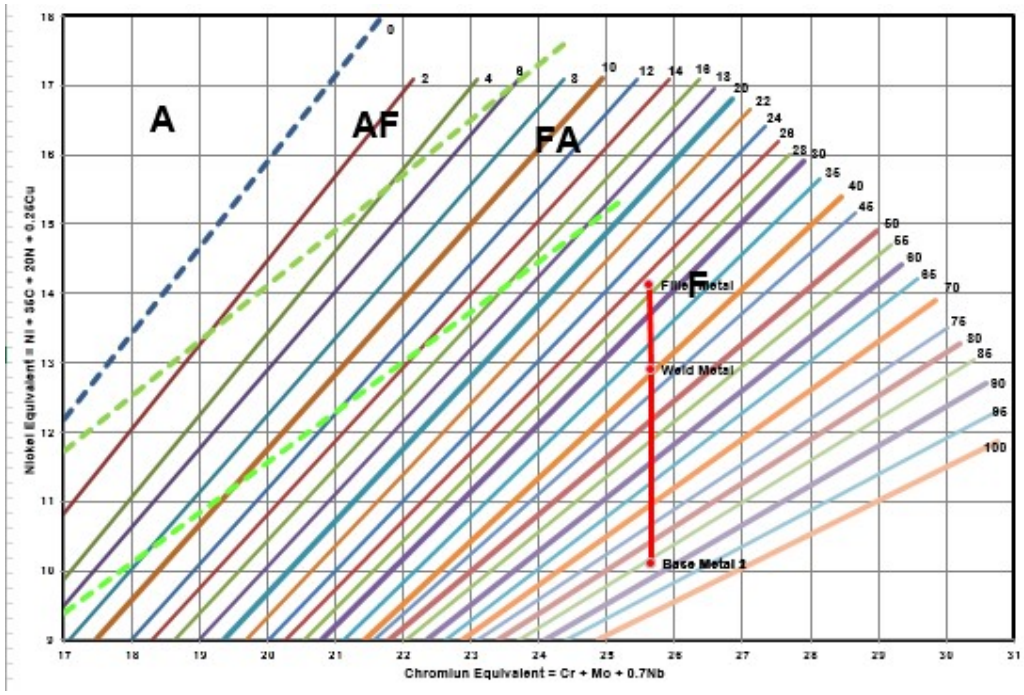


Fig. 4.18 FN 39 Prediction from WRC 1992 diagram for weld sample 9 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)

9.0 -9.5 % wt		40:60	FN=45.5		
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Synthetic Base Metal
C, %	0.023	0.023	0.031	0.028	0.023
Mn, %	1.50	1.50	0.98	1.188	1.500
Cr, %	22.37	22.37	22.32	22.340	22.370
Ni, %	5.72	5.72	9.2	7.808	5.720
Mo, %	3.21	3.21	3.32	3.276	3.210
Nb, %	0.11	0.11	0	0.044	0.110
Cu, %	0.14	0.14	0.089	0.109	0.140
N, %	0.177	0.177	0.19	0.185	0.177
% of Joint	20	20	60	100	
Creq	25.657	25.657	25.64	25.6468	25.657
Nieq	10.1	10.1	14.1073	12.50435	10.1
FN	86.4	86.4	27.3	45.5	

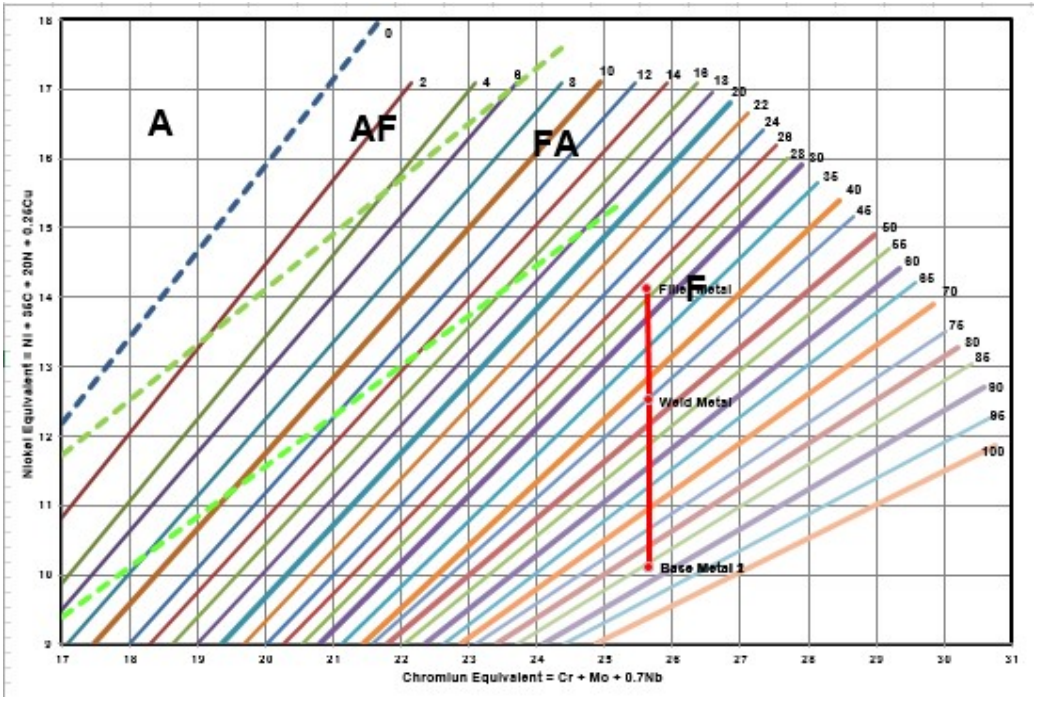


Fig. 4.19 FN 45.5 Prediction from WRC 1992 diagram for weld sample 9 Ni 22 Cr Sample. (Considering 40 % Dilution from BM)

9.5-10.5 % wt.	40:60	FN=46.1		

	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Synthetic Base Metal
C, %	0.023	0.023	0.019	0.021	0.023
Mn, %	1.50	1.50	0.99	1.194	1.500
Cr, %	22.37	22.37	22.29	22.322	22.370
Ni, %	5.72	5.72	9.8	8.168	5.720
Mo, %	3.21	3.21	3.19	3.198	3.210
Nb, %	0.11	0.11	0	0.044	0.110
Cu, %	0.14	0.14	0.068	0.097	0.140
N, %	0.177	0.177	0.17	0.173	0.177
% of Joint	20	20	60	100	
Creq	25.657	25.657	25.48	25.5508	25.657
Nieq	10.1	10.1	13.882	12.3692	10.1
FN	86.4	86.4	27.7	46.1	

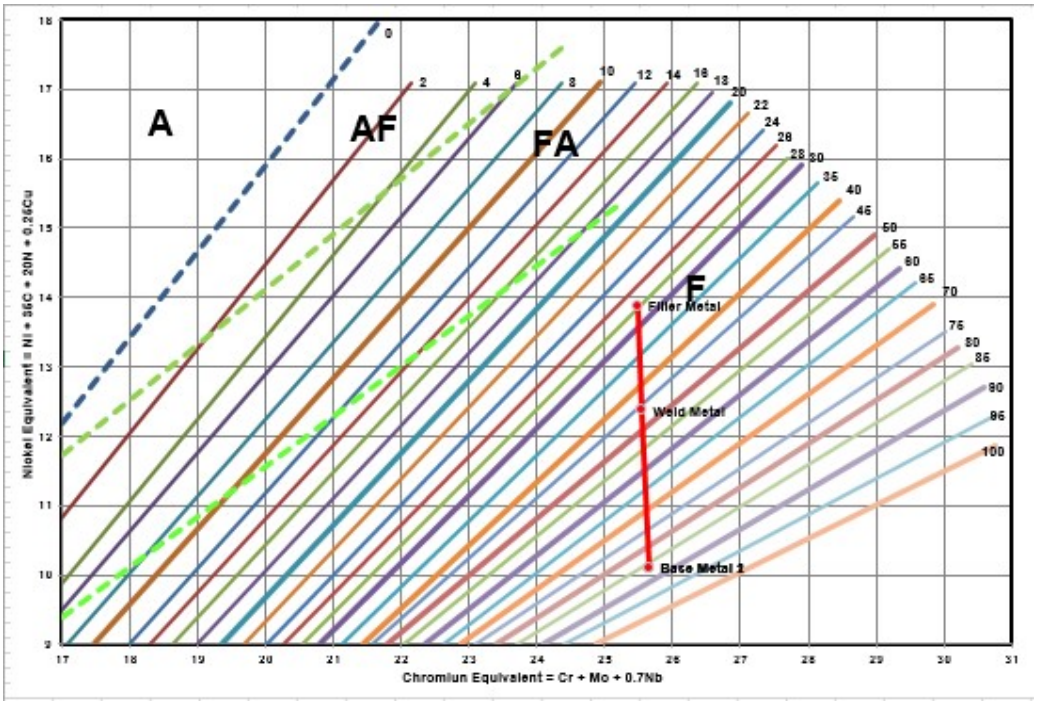


Fig. 4.20 FN 46 Prediction from WRC 1992 diagram for weld sample 10 Ni 22 Cr Sample. (Considering 40 % Dilution from BM)

9.5-10.5 % wt.		30:70	FN=39.8		
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Synthetic Base Metal
C, %	0.023	0.023	0.019	0.020	0.023
Mn, %	1.50	1.50	0.99	1.143	1.500
Cr, %	22.37	22.37	22.29	22.314	22.370
Ni, %	5.72	5.72	9.8	8.576	5.720
Mo, %	3.21	3.21	3.19	3.196	3.210
Nb, %	0.11	0.11	0	0.033	0.110
Cu, %	0.14	0.14	0.068	0.090	0.140
N, %	0.177	0.177	0.17	0.172	0.177
% of Joint	15	15	70	100	
Creq	25.657	25.657	25.48	25.5331	25.657
Nieq	10.1	10.1	13.882	12.7474	10.1
FN	86.4	86.4	27.7	39.8	

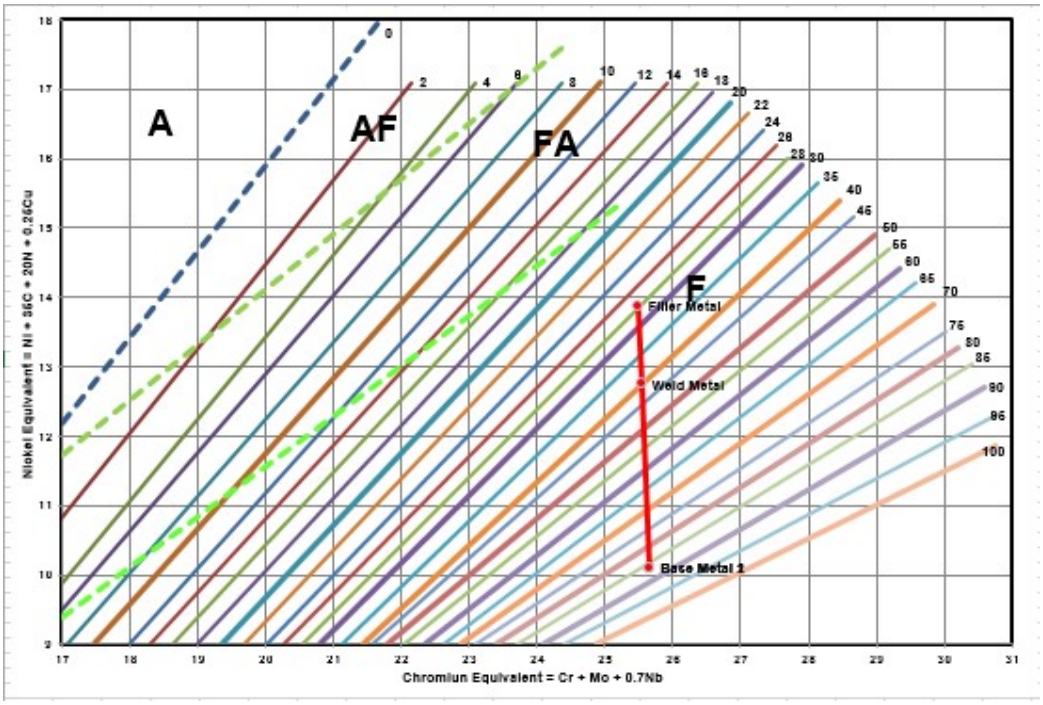


Fig. 4.21 FN 39 Prediction from WRC 1992 diagram for weld sample 10 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)

10.5-11.5 %wt.	FN=37.9		30:70		
					Synthetic
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Base Metal
C, %	0.023	0.023	0.021	0.022	0.023
Mn, %	1.50	1.50	0.99	1.143	1.500
Cr, %	22.37	22.37	22.35	22.356	22.370
Ni, %	5.72	5.72	10.2	8.856	5.720
Mo, %	3.21	3.21	3.16	3.175	3.210
Nb, %	0.11	0.11	0	0.033	0.110
Cu, %	0.14	0.14	0.075	0.095	0.140
N, %	0.177	0.177	0.16	0.165	0.177
% of Joint	15	15	70	100	
Creq	25.657	25.657	25.51	25.5541	25.657
Nieq	10.1	10.1	14.1538	12.937625	10.1
FN	86.4	86.4	26.2	37.9	

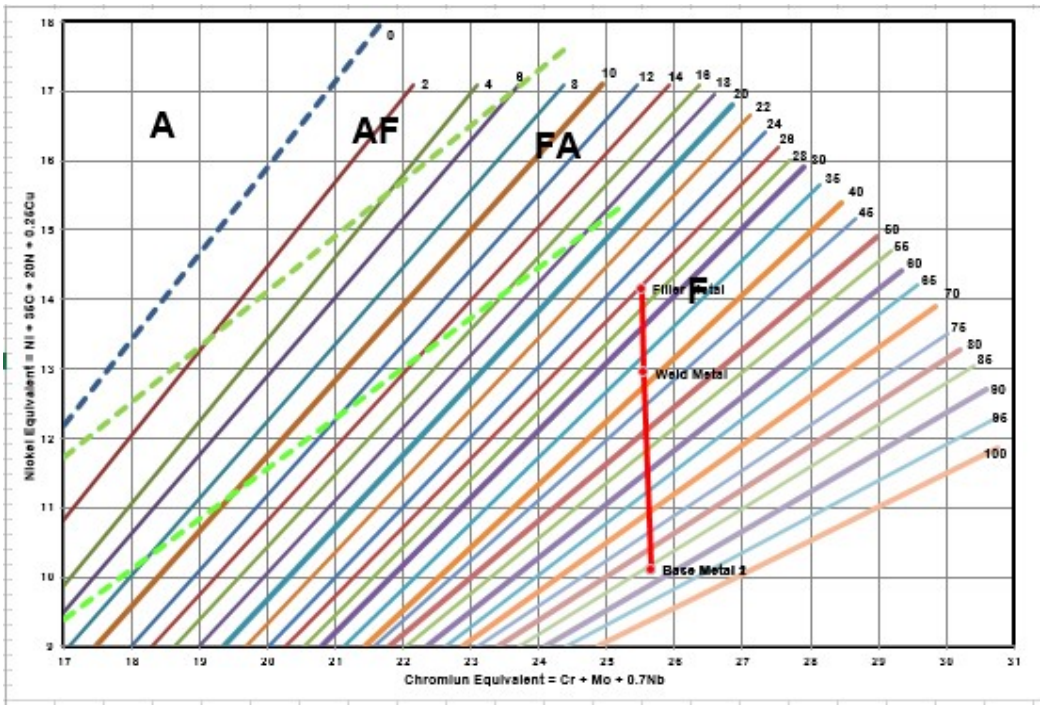


Fig. 4.22 FN 38 Prediction from WRC 1992 diagram for weld sample 11 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)

10.5-11.5 %wt.	FN=44		40:60		
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Synthetic Base Metal
C, %	0.023	0.023	0.021	0.022	0.023
Mn, %	1.50	1.50	0.99	1.194	1.500
Cr, %	22.37	22.37	22.35	22.358	22.370
Ni, %	5.72	5.72	10.2	8.408	5.720
Mo, %	3.21	3.21	3.16	3.180	3.210
Nb, %	0.11	0.11	0	0.044	0.110
Cu, %	0.14	0.14	0.075	0.101	0.140
N, %	0.177	0.177	0.16	0.167	0.177
% of Joint	20	20	60	100	
Creq	25.657	25.657	25.51	25.5688	25.657
Nieq	10.1	10.1	14.1538	12.53225	10.1
FN	86.4	86.4	26.2	44.0	

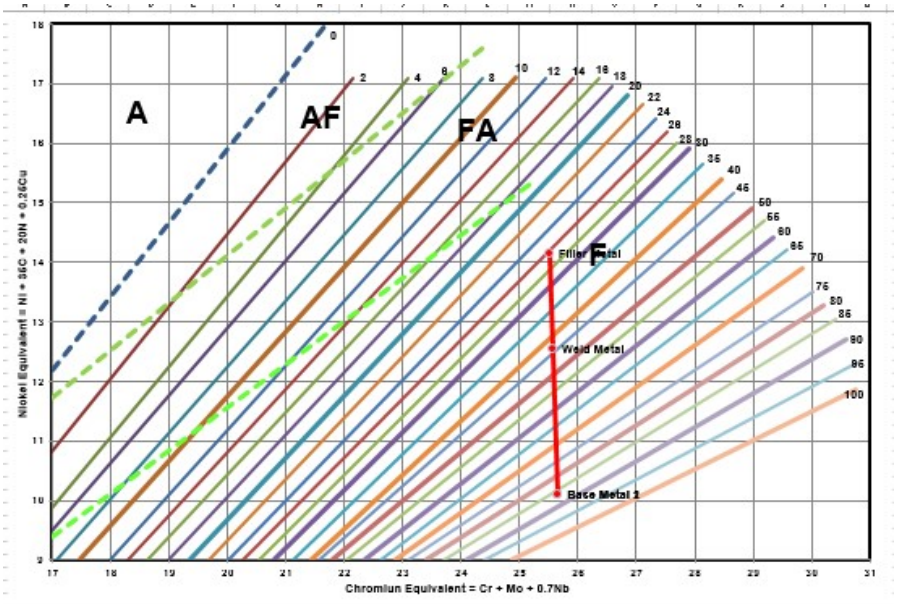


Fig. 4.23 FN 44 Prediction from WRC 1992 diagram for weld sample 11 Ni 22 Cr Sample. (Considering 40 % Dilution from BM)

11.5-12.5 %wt.	30:70	FN=22.7			
					Synthetic
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Base Metal
C, %	0.023	0.023	0.017	0.019	0.023
Mn, %	1.50	1.50	1.11	1.227	1.500
Cr, %	22.37	22.37	22.33	22.342	22.370
Ni, %	5.72	5.72	12.75	10.641	5.720
Mo, %	3.21	3.21	3.2	3.203	3.210
Nb, %	0.11	0.11	0	0.033	0.110
Cu, %	0.14	0.14	0.069	0.090	0.140
N, %	0.177	0.177	0.18	0.179	0.177
% of Joint	15	15	70	100	
Creq	25.657	25.657	25.53	25.5681	25.657
Nieq	10.1	10.1	16.9623	14.903575	10.1
FN	86.4	86.4	12.9	22.7	

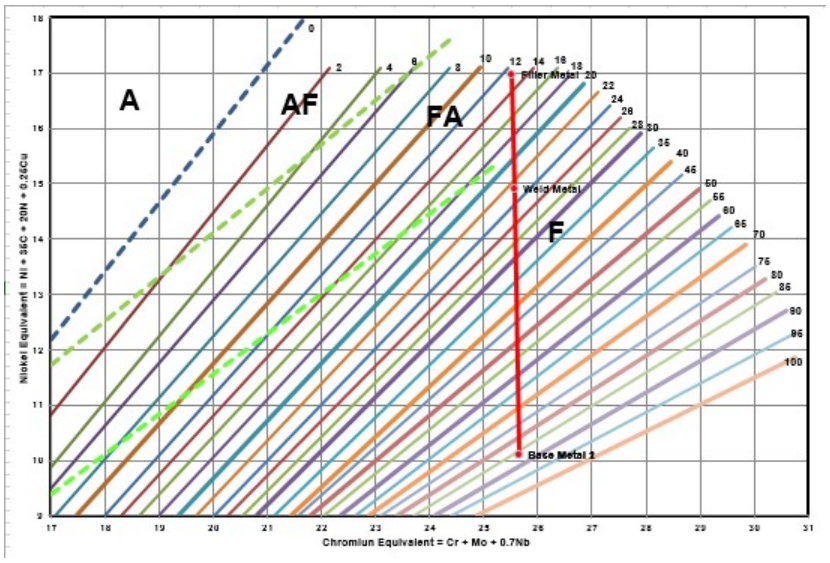


Fig. 4.24 FN 22 Prediction from WRC 1992 diagram for weld sample 12 Ni 22 Cr Sample. (Considering 30 % Dilution from BM)

11.5-12.5 %wt.	40:60		FN=26.3		
					Synthetic
	Base Metal 2	Base Metal 1	Filler Metal	Weld Metal	Base Metal
C, %	0.023	0.023	0.017	0.019	0.023
Mn, %	1.50	1.50	1.11	1.266	1.500
Cr, %	22.37	22.37	22.33	22.346	22.370
Ni, %	5.72	5.72	12.75	9.938	5.720
Mo, %	3.21	3.21	3.2	3.204	3.210
Nb, %	0.11	0.11	0	0.044	0.110
Cu, %	0.14	0.14	0.069	0.097	0.140
N, %	0.177	0.177	0.18	0.179	0.177
% of Joint	20	20	60	100	
Creq	25.657	25.657	25.53	25.5808	25.657
Nieq	10.1	10.1	16.9623	14.21735	10.1
FN	86.4	86.4	12.9	26.3	

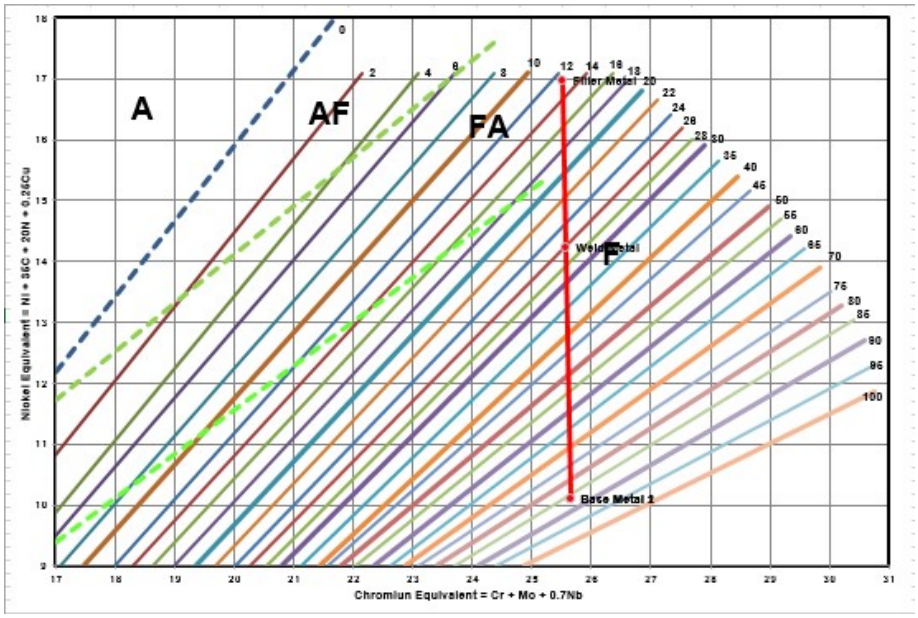
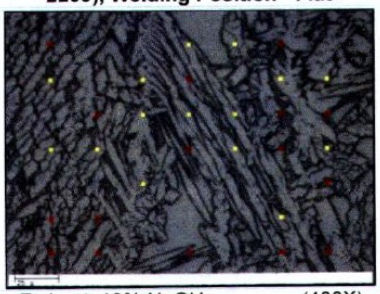


Fig.4.25 FN 26 Prediction from WRC-1992 diagram for weld sample 12 Ni 22 Cr Considering 40% Dilution from Weld metal

4.6.2 Prediction of Ferrite Number by "Volume fraction measurement by systematic manual point count method: ASTM E 562 (Experimental method)

*SAMPLE ID: Coupon ID - E2209(10Ni22Cr), Welding Process - SMAW, Filler Wire - E2209-16 (GRINOX-2209), Welding Position - Flat



Etchant: 10% NaOH (400X)

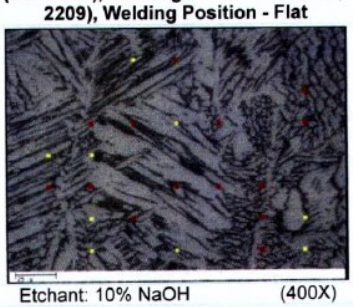
Frames	% Ferrite	Frames	% Ferrite	Frames	% Ferrite
1	45.9	11	37.8	21	40.8
2	40.8	12	43.9	22	34.7
3	35.7	13	43.9	23	39.8
4	40.8	14	38.8	24	42.9
5	39.8	15	40.8	25	44.9
6	42.9	16	38.8	26	40.8
7	42.9	17	39.8	27	41.8
8	44.9	18	45.9	28	26.0
9	48.0	19	42.9	29	40.8
10	45.9	20	37.8	30	37.8

Average of 30 Frames: 40.94 % Requirement:

Fig. 4.26 Vol. frac measurement of E2209(10Ni22Cr) Sample

WM Ferrite % = 40.94% Volume fraction measurement by systematic point count method ASTM E 562

*SAMPLE ID: Coupon ID - E2209(11Ni22Cr), Welding Process - SMAW, Filler Wire - E2209-16 (GRINOX-2209), Welding Position - Flat



Etchant: 10% NaOH (400X)

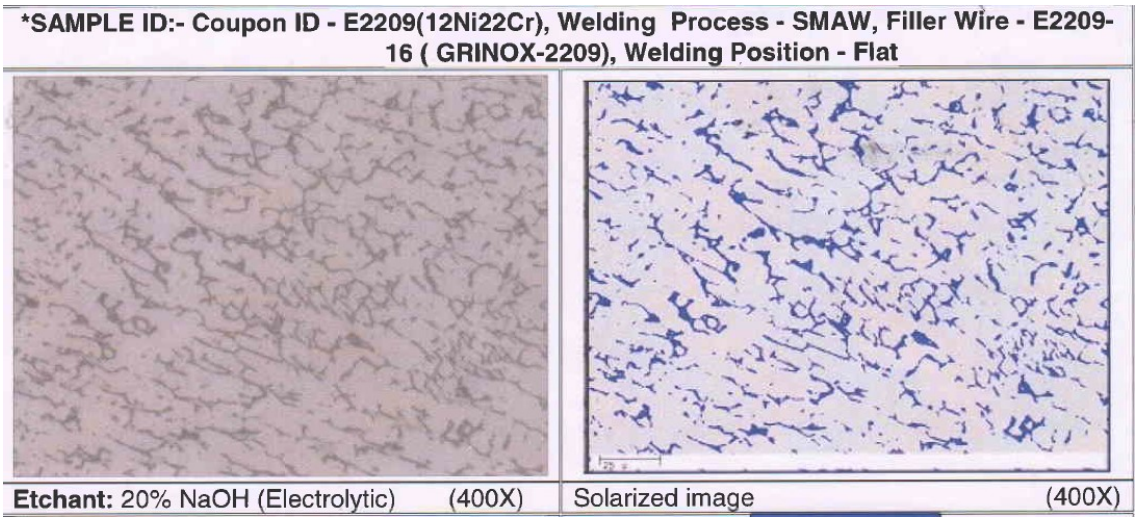
Frames	% Ferrite	Frames	% Ferrite	Frames	% Ferrite
1	45.9	11	38.8	21	40.8
2	40.8	12	43.9	22	39.8
3	35.7	13	40.8	23	39.8
4	40.8	14	39.8	24	40.8
5	38.8	15	42.9	25	36.7
6	38.8	16	40.8	26	38.8
7	40.8	17	38.8	27	34.7
8	35.7	18	33.7	28	35.7
9	26.0	19	40.8	29	35.7
10	33.7	20	35.7	30	37.8

Average of 30 Frames: 38.45 % Requirement:

Fig. 4.27 Vol. frac measurement of E2209(10Ni22Cr) Sample

WM Ferrite % = 38.45 % Volume fraction measurement by systematic point count method ASTM E 562

4.6.2.1 Phase Quantification Ferrite Measurement by MAGE ANALYSIS (MiC V. 2.0)



Frames	% Ferrite	% Austenite
1.	08.33	91.67
2.	12.04	87.96
3.	16.61	83.39
4.	10.92	89.08
5.	12.86	87.14
Average of 5 Frames	**12.15**	**87.85**

Fig. 4.28 Ferrite Measurement by Image Analysis Ferrite % = 12.15. *

*Phase Quantification Ferrite Measurement by MAGE ANALYSIS. It is noteworthy that due to skeletal ferrite grain structure produced due to FA Mode solidification in a weld metal zone, placement of points on respective austenitic and ferrite grains for quantification. So Ferrite measurement was conducted by Image Analysis (Mic V 2.0) under estimated Ferrite content measurement.

4.6.3 Measurement of Ferrite Number by Fischer Make Feritscope® Instrument (Experimental method)

Table 4.7 WM FN 31.54 (Low Ni = 9.5 – 10.5 %) Fischer Make Feritscope @

Sr. No	Location	Ferrite Number	Average	Ferrite Percentage (%)	Average
1	Welded Plate sample (On weld)	31.8,33.1,30.9	31.66	31.34,32.16,31.12	31.54

Table 4.8 WM FN 27.6 (Medium Ni = 10.5-11.5%) Fischer Make Feritscope®

Sr. No	Location	Ferrite Number	Average	Ferrite Percentage (%)	Average
1	Welded Plate sample (On weld)	27.6,28.7,28.2	28.16	27.70,27.66, 27.44	27.6

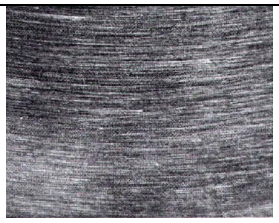
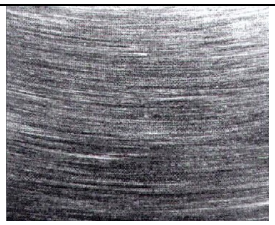
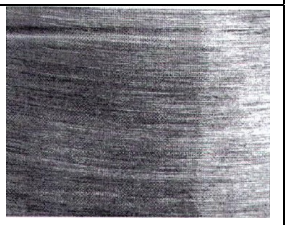
Table 4.9 WM FN 14.4 (High Ni = 11.5-12.5%) Fischer Make Feritscope @

Sr. No	Location	Ferrite Number	Average	Ferrite Percentage (%)	Average
1	Welded Plate sample (On weld)	10.8, 16.8, 13.5, 16.1, 12.1	13.68	11.85, 16.52,14.50,14.96,13.49,12.96	14.04

@ Instrument utilized was Fischer Ferritscope Germany Make: Fischer 2531

4.7 Pitting corrosion results as per ASTM G48 Method A

Table 4.10 Pitting corrosion results as per ASTM G48 Method A

Coupon Id	**10 Ni 22 Cr** **Low Ni**	**11 Ni 22 Cr** **Medium Ni**	**12 Ni 22 Cr** **High Ni**
Sample Photo at 20 X magnification	 20 X Magnification	 20 X Magnification	 20 X Magnification
Weight Loss in gms	0.0003	0.0007	0.0007
Corrosion rate in gm/m^2	0.15	0.36	0.32

4.8 Chloride Stress corrosion Cracking susceptibility test results (ASTM G123 Method)

4.8.1 Observation of Stress Corrosion samples after two weeks' time period.

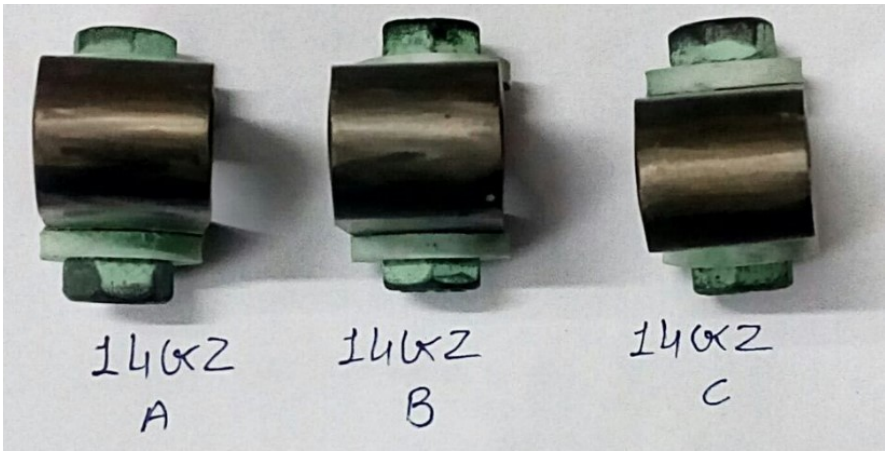


Fig. 4.29 No Crack appears in 10 Ni 22 Cr Weld Sample

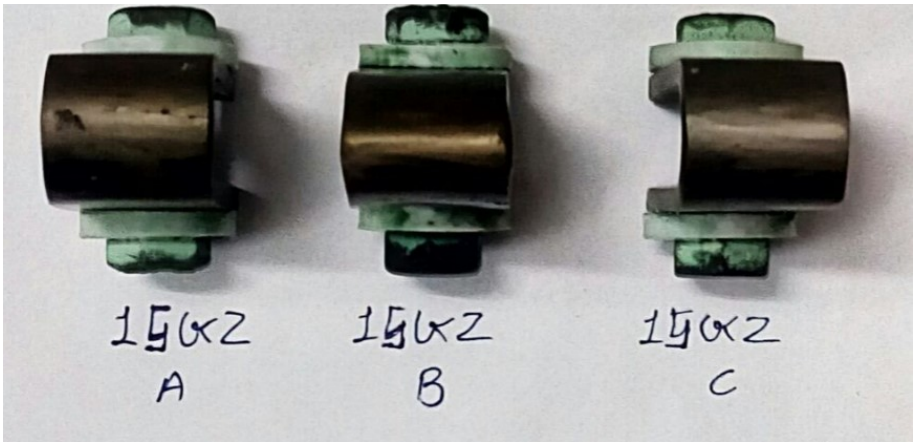


Fig.4.30 Crack appears in 11 Ni 22 Cr Weld Sample

Fig. 4.31 Crack appears in 11 Ni 22 Cr Weld Sample

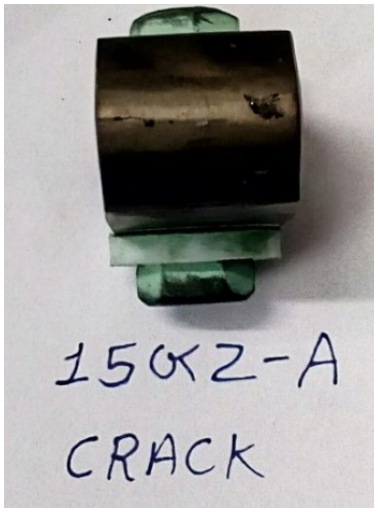


Fig. 4.32 Crack appears in 11 Ni 22 Cr Weld Sample

Fig. 4.33 Crack appears in 11 Ni 22 Cr Weld Sample

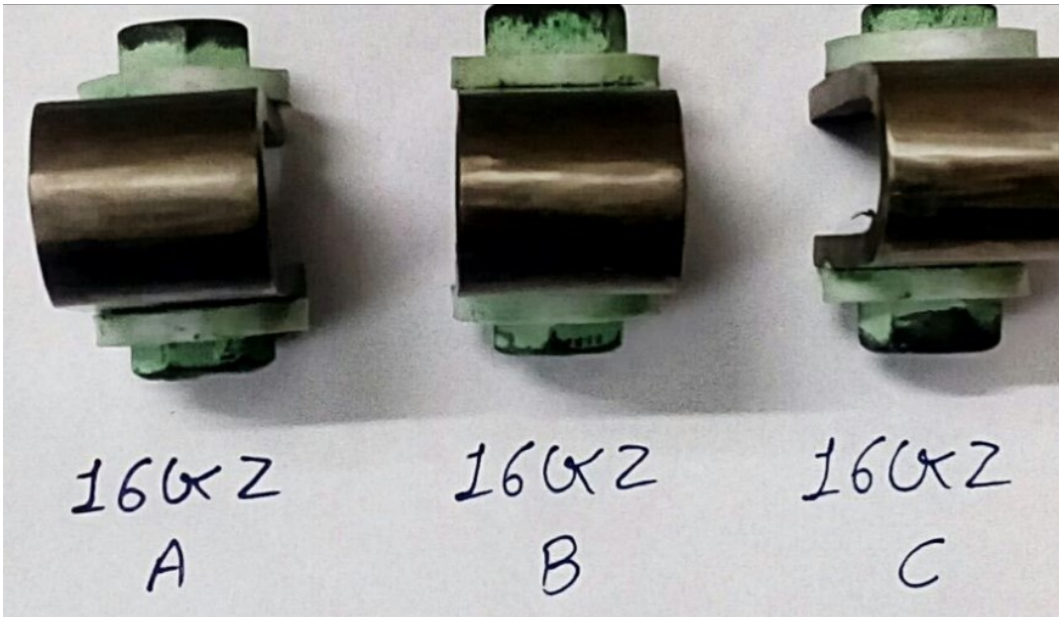


Fig. 4.34 No Crack appears in 12 Ni 22 Cr Weld Sample