Challenges Involved in Qualifying Butt Weld of Dissimilar Materials and Dissimilar Thicknesses for Subsea Connectors System

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ABSTRACT

This paper describes the challenges encountered during qualification of butt welds of dissimilar materials and dissimilar thicknesses for diverless subsea Tie-in-connection systems. These connections are designed for flowlines, umbilical and jumper spools for a temperature range of: -22° to +135°C, and for a pressure range of 138 bar to 371 bar, and operating at a depth of 240m.

To achieve the minimum required strength of the welded joint configuration, tapered weld joint with a taper angle of 14°7' was selected. The specimen could have failed in conventional tensile testing. The problem was overcome by using the as welded geometry for tensile testing.

Establishment of technique for performing UT of dissimilar thickness & material weld joint was a challenge. Technique for UT was established by preparing a new reference block of same material and dimensions. For this complex welded joint, special probes were used to perform UT.

Keywords : Welding, Dissimilar Welding, Under Water Application, Testing

1.0 INTRODUCTION

This paper describes the complexity of welding qualification in Subsea Oil and Gas production systems.

Subsea technology in offshore oil and gas production is a highly specialized field of application with stringent demands on engineering, manufacturing, safety and quality. Aker Solutions has over half a century of experience in the subsea industry, with a key focus on providing top tier global subsea production system and products.

One of the key challenges was achieving welding qualification for Subsea Tie-in connectors for dissimilar Materials and Thicknesses meeting DNVOS-F101:2010 requirements. This connection system is designed for sour environment.

The welding involved cladded forging (ASTM A694 F65 clad nickel alloy 625) and seamless pipe (Duplex SS 22%Cr) as base materials.

The forging was quenched and tempered carbon steel which was cladded with austenitic grade to be used for sour service environment. This cladded forging was welded with solution annealed duplex stainless steel pipe. Austenitic grade of welding consumable ERNiCrMo-13 was selected as filler material, which is suitable for welding different grades of material to achieve metallurgical and mechanical properties from the weldment.

The wall thickness variation between two parent materials was 17.7 mm which resulted in a tapered weld joint as shown in **Fig. 1**. The standard sample preparation for tensile strength testing as per the qualification code could not serve the result intended when it came to tensile testing. Challenges were also faced while referring the standard method for impact test sample location as per the code. The critical section of the welded joint was located at, or close to, the transition between piping and the hub.

In this paper, authors also focus on NDT, of this complex welded joint, for meeting requirement of DNV-OS-F101:2010.

2.0 BACKGROUND HISTORY

These Tie-in-Connections are designed for subsea applications for flow lines, umbilicals and jumper spools.

System Design Pressure	:	371 bar (max)
Design Temperature	:	-22° to +135°C
Ambient Sea Water Temperature	:	90C
Depth of mudline	:	240m (approx.)

DSS-materials are susceptible to hydrogen induced stress cracking (HISC) in subsea environment.

In general, HISC-capacities of connection systems are limited by large utilization at the welds, due to the stress/strain raisers imposed by the geometrical change at the forging – pipe transitions. To eliminate the HISC risk in the forging – pipe weld transition, forging was selected with carbon steel material, cladded internally with Ni alloy 625. This introduced dissimilar metal joint and to meet the structural integrity on both sides of the joint, dissimilar thickness of joint had to be dealt with.

Code of Construction	:	DNV-OS-F101:2010
Material of Construction	:	ASTM A 694 F65- Forging internally Cladded with Ni Alloy 625ASTM A 790- 22Cr Pipe
Welding Process	:	GTAW
Joint Configuration	:	Single Bevel
Included Angle	:	72°
Taper Angle (slope)	:	14°7'
Forging thickness	:	50.9mm (3mm of clad thickness included)
Pipe thickness	:	33.9mm

See **Fig. 1** for weld joint configuration.

One of the major challenges faced during the qualification was Mechanical Testing (Tensile & Impact) as per DNV-OS-F101:2010.

As there were three different material grades and different thicknesses of the parent materials involved, performing volumetric NDT, using UT method, was a challenge. Conventional RT or UT alone was not suitable to scan and evaluate the weld volume, fusion zones and HAZ on both sides of the weld.

3.0 EXPERIMENTAL WORK AND RESULTS.

This welding was performed for Subsea Tie-in connection joint using semi-automatic GTAW. To ensure required results in mechanical testing and metallurgical composition of the weldment, special consideration was given for filler material selection, weld parameters and interpass temperature. The yield strength of the material of construction are as given below:

- ASTM A694 F65 – Forging : 430 MPa,
- ASTM 790 Duplex Stainless Steel Pipe : 530MPa
- Welding Consumable ErNiCrMo-13 (UNS006625) : 550 MPa

Welding Parameters are given in **Table 1**.

Acceptance criteria for the WPQ are listed in **Table 1.1**

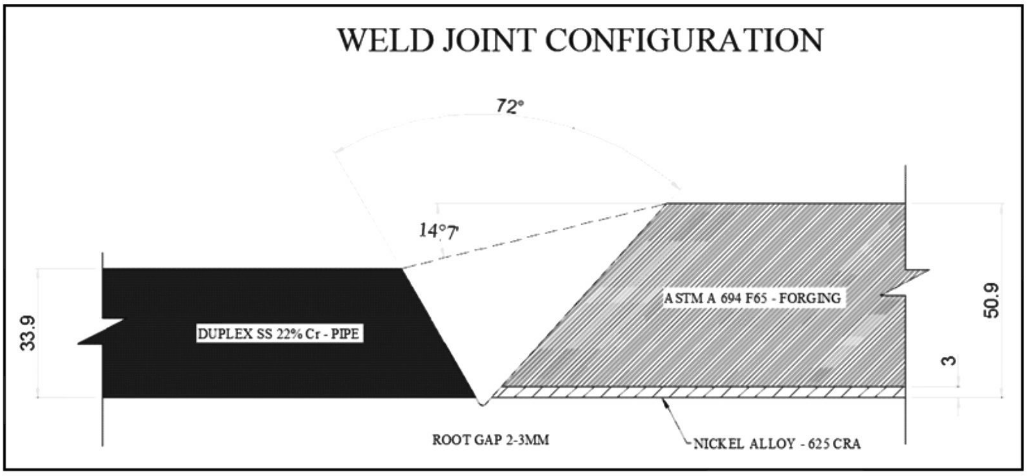

Fig.1 : Weld Joint Configuration

Table 1 : Welding Parameters

Pass	Dia (mm)	Weld process	Current (A)	Volt (V)	Current Polarit	Welding speed (mm/min)	Interpass Temp °C (Max)	Shielding Gas (l/min)	Heat input (KJ/mm)
Root	2,40	GTAW	90 -130	10-11	DC-	40-60	136	10-14	1,0-2,1
Fill-up	2,40	GTAW	140-175	11-12	DC-	80-120	137	10-14	0,8-1,4
Cap	2,40	GTAW	150 -215	11-13	DC-	60-160	140	10-14	0,8-2,3

Shielding Gas : Argon (I1)
Purging Gas : Nitrogen (N1)

Table 1.1 : Acceptance Criteria for Welding Procedure Qualification

Tensile Strength Rm (MPa)	Yield Strength Rm (MPa)	Vickers Hardness					Charpy V-notch energy (J) (at -30°C)		Side Bend Test	Marco Test	Micro-structure Exam**
Transverse Tensile	All Weld tensile	BM (22%Cr)	HAZ (22%Cr)	WM	HAZ (F65-CLAD)	BM (F65-CLAD)					
min		max					avg	min	Satis-factory	Satis-factory	Satis-factory
620	530	350	350	350	325	325	45	35			
** For duplex steel the ferrite content of the weld metal and HAZ shall be within the range 35-65%											

3.1 Tensile Testing

The sample preparation suggested in DNV OS F101:2010, Appendix B is a standard Rectangular Tensile Sample, see **Fig. 2.1**. This sample preparation suggested in DNV code is for joint configuration of similar base metal thicknesses.

In this case, the authors had dissimilar material with dissimilar strengths.

A technical query was prepared which was highlighting the differences in yield strength of the two materials and was presented to DNV-GL. In this technical query, the gage section of the test sample was kept 'as welded'. The weld beads were ground flush and local imperfections were removed to avoid any stress raisers. However the shoulders of the specimen were modified for gripping on tensile testing machine.

For the 'All weld tensile sample', standard method as per DNV OS F101:2010, was adopted. Two 'All Weld Test' samples and two 'Cross weld tensile test' samples were taken.

Both the cross weld tensile test samples fractured in pipe side (22Cr Duplex side). The results are tabulated in **Table 2**.

The test sample preparation is shown in **Fig. 2.2**.

3.2 Impact Testing

Code of testing : DNV OS F101: 2010

Impact test locations : 2mm below Top Surface at -

- WM
- FL
- FL+2mm
- FL+5mm

Size : 10 x 10 x 55 mm

The dissimilarity in parent metal thicknesses (17.7mm) could not allow the standard method to be adopted. i.e. at 2mm below the top surface of welded test coupon. A deviation had to be sought.

A technical query was prepared and presented to DNV-GL to justify this deviation.

For duplex pipe the sample location was taken as per **Fig. 3.**

Testing was done as per DNV OS F101-2010. Results from the testing are tabulated in **Table 3**.

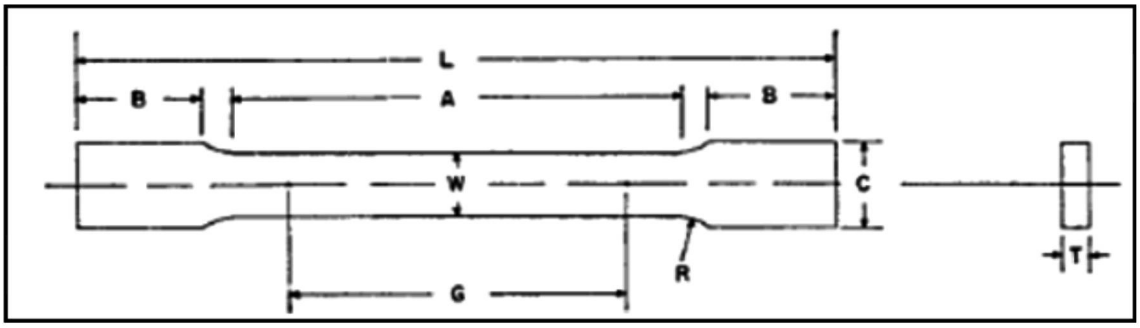

Fig. 2.1 : Rectangular Tensile test specimen as per DNV-OS-F101: 2010, Appendix B, A-400

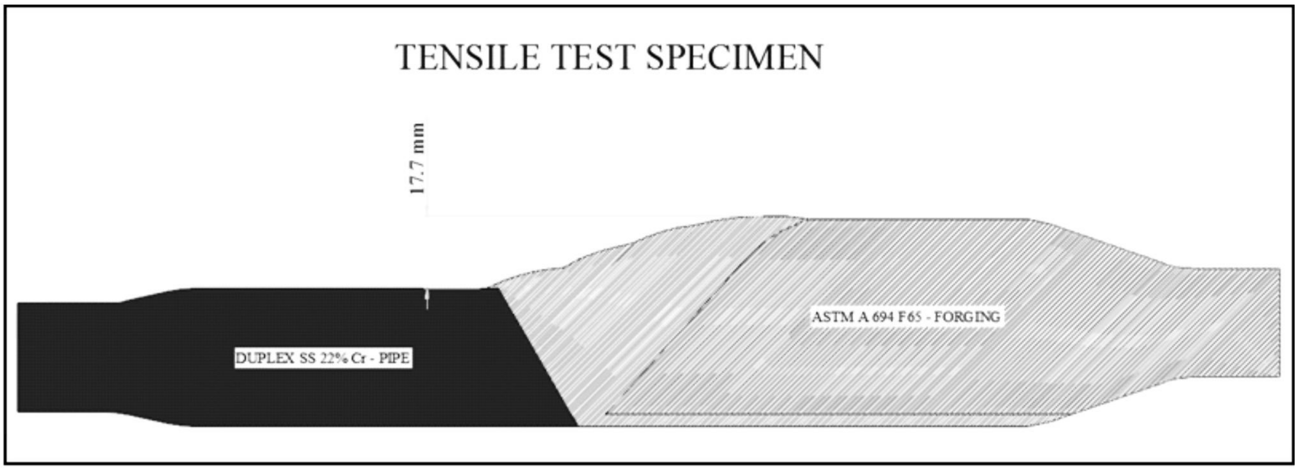

Fig.2.2 : As welded Tensile Test Specimen

Table 2 : Tensile test results.

Tensile test (According to EN ISO 6892-1, Cross Weld/Acc to ISO 4136, All Weld EN ISO 5178)									
SPECIMEN DATE						TEST RESULT			
Test No.	Specimen Type	Area (mm^2)	Dim. BxT or Dia (mm)	Gauge Length L0 (mm)	Yield Point Rp0,2 (N/mm2)	Tensile Strength, Rm (N/mm2)	Elongation A5 (%)	Red. of Z (%)	Location of Fracture
MT-011789-1	All Weld	112,85	ϕ 11,99	60	531	776	37,2	41	
MT-011789-2	All Weld	113,23	ϕ 12,01	60	547	774	31,8	41	
MT-011789-3	Cross Weld	665,36	24,92 *26,70			718			DSS Pipe
MT-011789-4	Cross Weld	611,27	24,95 *24,50			721			DSS Pipe

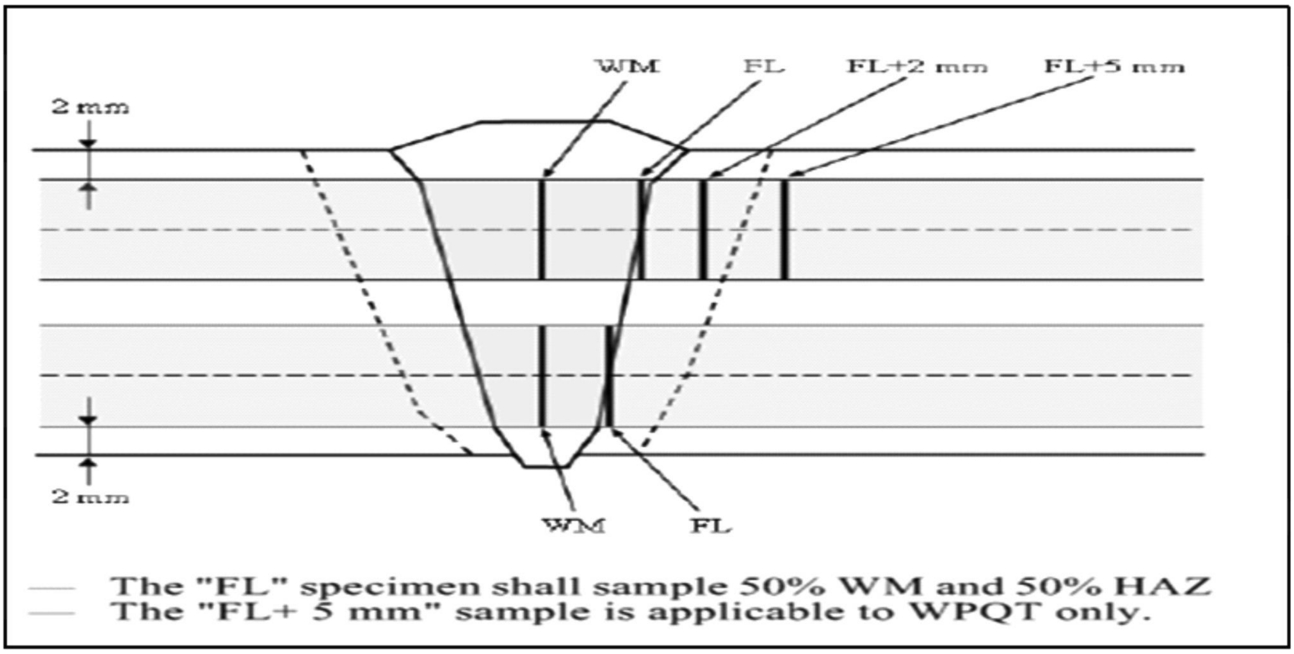

Fig. 3 : Charpy V-notch impact test specimen positions for single sided welds with t > 25 mm as per DNV-OS-F101: 2010, Appendix B, A-500

Table 3 : Charpy-V test results.

Charpy- V (according to ISO 148-1. Similar to ASTM 370 / E23								
	SPECIMEN DATA			TEST RESULT				
Test No.	Specimen Dim. (mm)	Test temp (°C)	Notch Location	Impact Energy (Joule)			Aver. (Joule)	Lowest Value (Joule)
MT-011790-1	10*10	-30	WM Cap	119	135	120	125	119
MT-011790-2	10*10	-30	FL Cap F65	180	168	171	173	168
MT-011790-3	10*10	-30	FL +2 Cap F65	212	212	210	211	210
MT-011790-4	10*10	-30	FL +5 Cap F65	240	235	244	240	235
MT-011790-5	10*10	-30	FL Cap 22CrD	123	120	103	115	103
MT-011790-6	10*10	-30	FL +2 Cap 22 CrD	146	121	128	132	121
MT-011790-7	10*10	-30	FL +5 Cap 22CrD	205	167	160	177	160
MT-011790-8	10*10	-30	WM Root	83	77	78	79	77
MT-011790-9	10*10	-30	FL Root F65	179	189	189	186	179
MT-011790-10	10*10	-30	FL Root 22 CrD	119	124	124	122	119

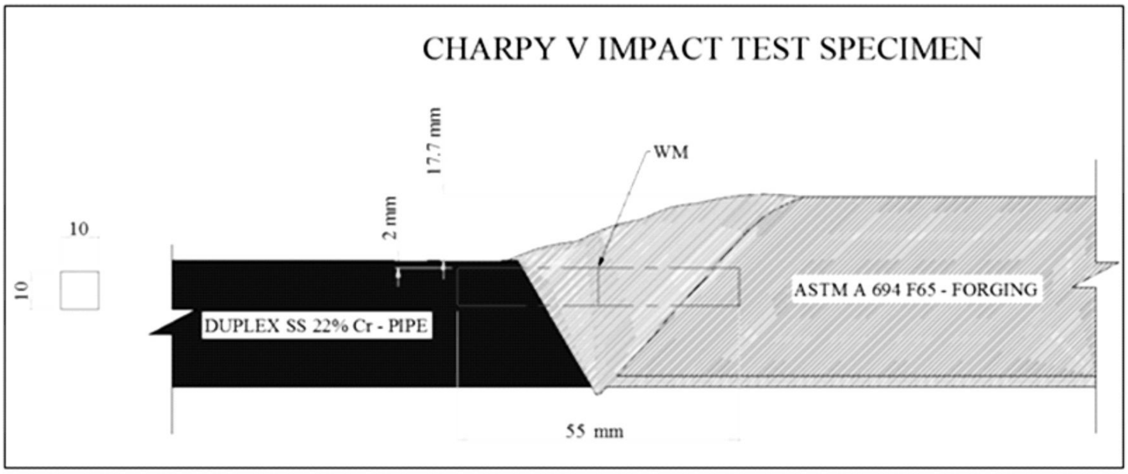

Fig 3.1 : Charpy-V Specimen at WM.

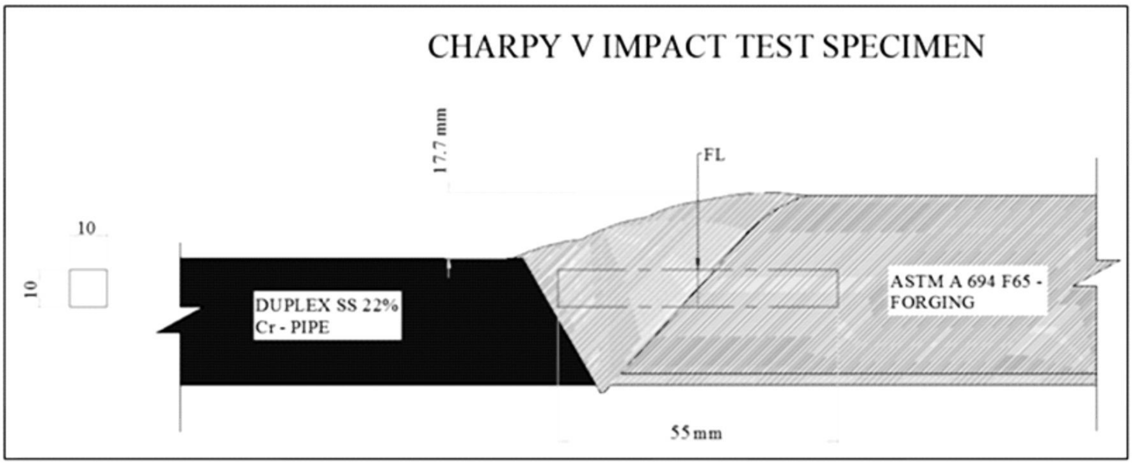

Fig 3.2 : Charpy-V Specimen at forging side fusion line

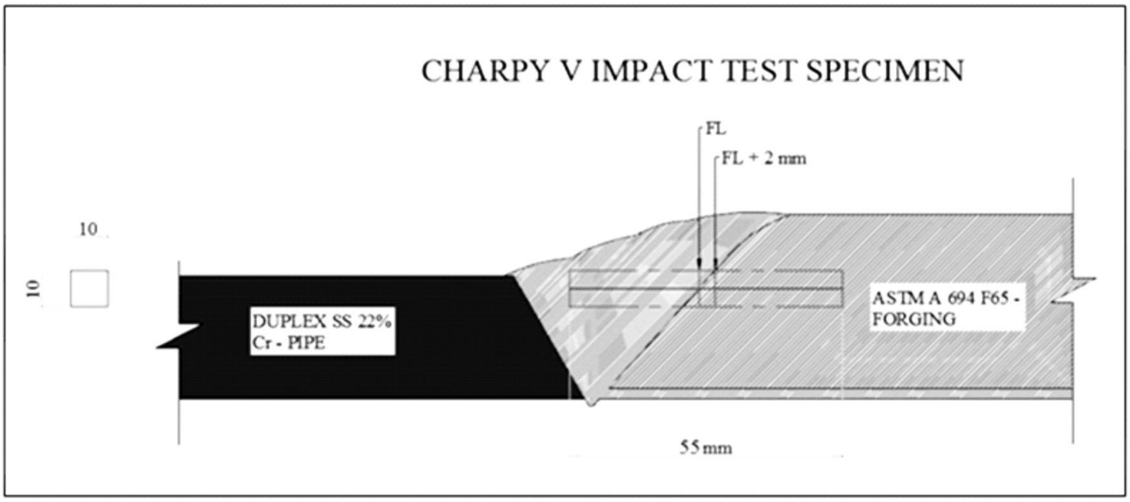

Fig 3.3 : Charpy-V Specimen at forging side fusion line +2mm

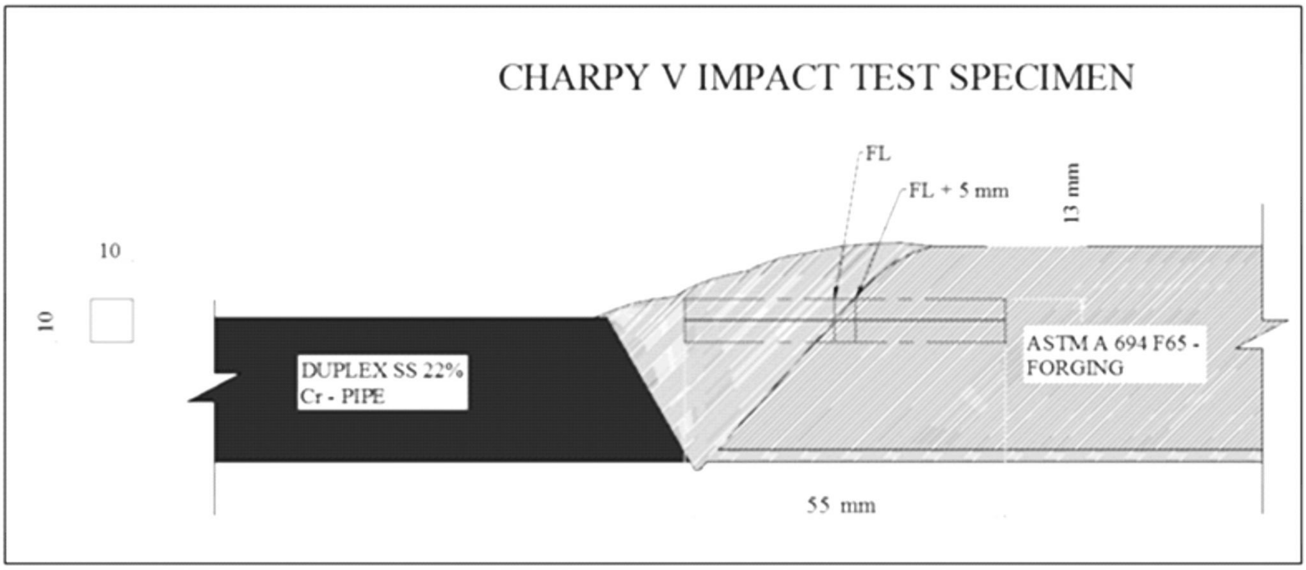

Fig 3.4 : Charpy-V Specimen at forging side fusion line +5mm

3.3 Non Destructive Testing.

Different NDT methods were selected as per DNV-OS-F101:2010 at different stages as follows:

- Visual weld inspection before, during and after welding
- MT or PT of weld grove before welding
- 100% PT after root pass
- 100% PT after welding
- 100% RT and UT after welding

The major challenge was to perform UT on a weld having a complexity regarding materials as well as thicknesses. The discontinuity evaluation and acceptance requirements were as per DNV-OS-F-101:2010 Appendix D, Section B900, Table D6. ISO 17640 and DNV-OS-F-101:2010 Appendix D, Section B300 and B400 was the reference document for basic requirements for setting sensitivity levels and performing ultrasonic testing.

Because of anisotropic grain structure of 22% Cr Duplex (UNS 32505) material, there was huge loss of sound energy and hence extensive care was required while performing UT on this material. The conventional scanning in full 'V' path (second leg) was not possible as confirmed by using the mock-up piece (see **Fig. 4**) with known defects/reference reflectors.

After taking different trials, the other basic reference blocks as per DNV-OS-F101 Appendix D, Section B300 and B400 were prepared for different materials involved and used for gain setting for the fusion zones and HAZ as well as weld volume (see) & refer **Table 4.**

The weld was scanned from inside & outside by using creep wave probe and advanced digital UT equipment with A-scan display.

Table 4: Reference block details in line with table D1 & D 3 of DNV-OS-F-101:2010 Appendix D, Section B300 & B400

Component Thicknesses		Block thickness (based on HUB side thickness) 'T' mm	Diameter of side drilled hole mm	Position of side drilled hole for F65	Position of side drilled hole for duplex
Modified HUB (F65+Inconel 625) mm	Pipe (duplex) mm				
50.85	31.75	38	3.0 ± 0.2	T/2	T/4, T2 & 3T/4

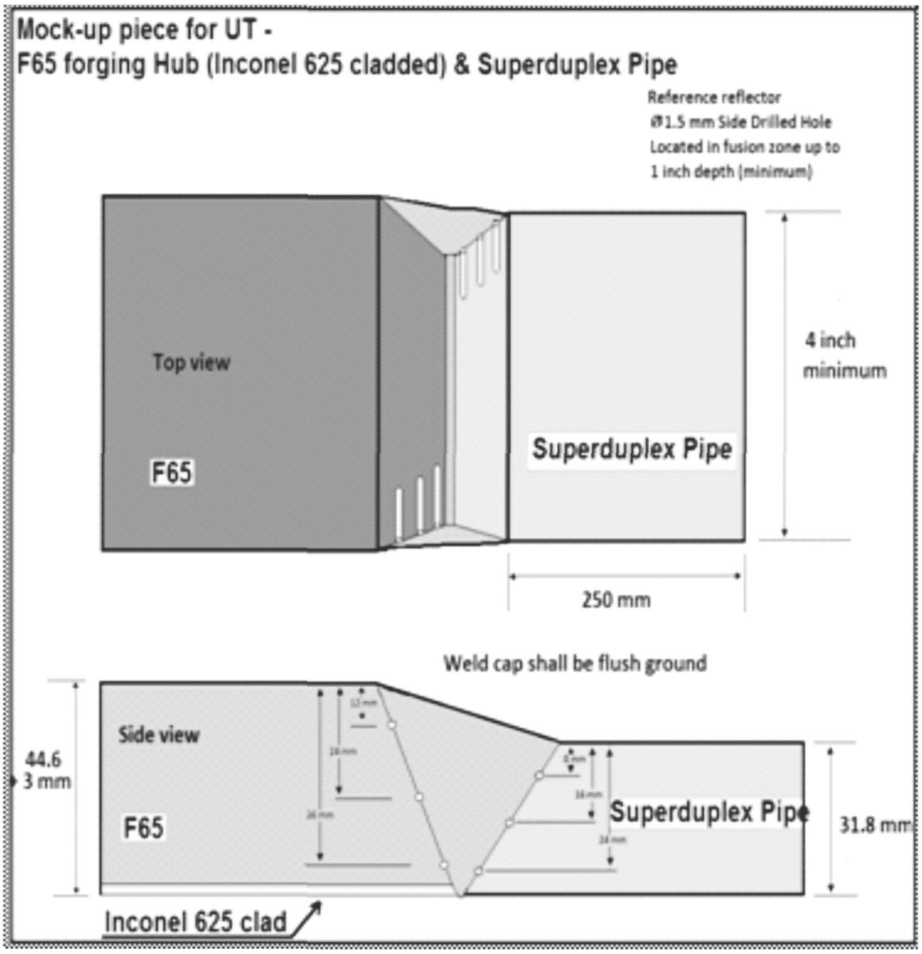

Fig. 4 : Mock-Up Test sample for UT

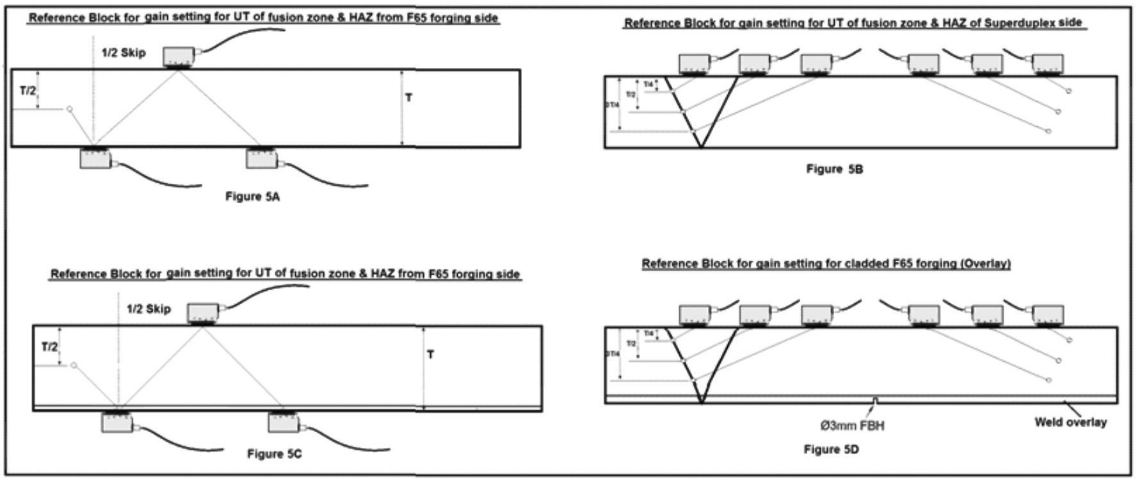

Fig.5: Reference blocks as per DNV-OS-F101 Appendix D, Section B300 & B400

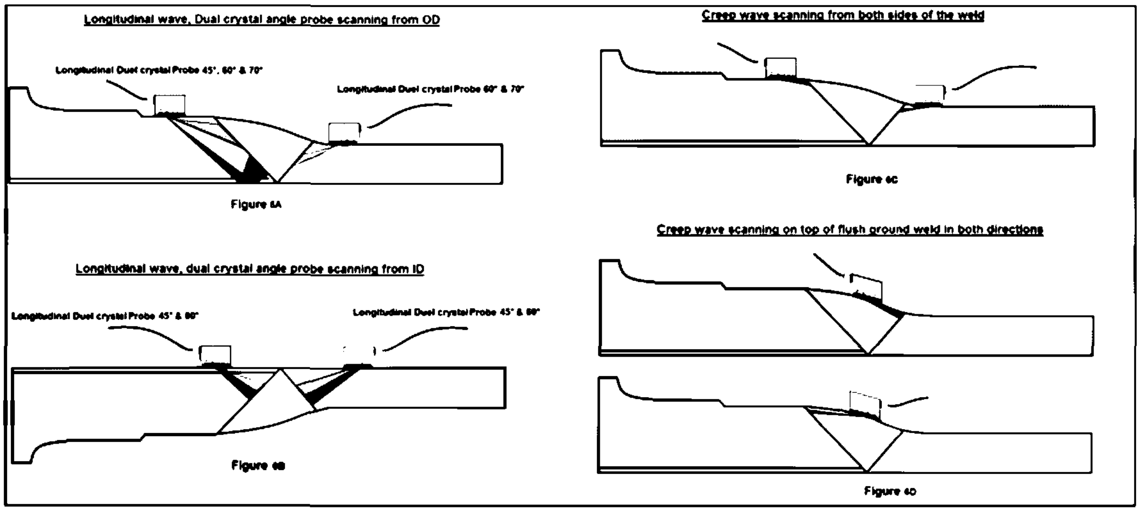

Fig. 6 : Final Scan plan established by using the mock-up & reference blocks (Figure 5& 2A to 2D)

4.0 CONCLUSION

100% UT was performed successfully as per the established technique & the results/indications were verified by comparing the echoes from the reference reflectors in the mock-up piece.

Ultrasonic testing can be an effective tool to verify the soundness of the entire weld volume, fusion zones and HAZ of a weld where dissimilar material and dissimilar thicknesses of the parent materials involved, if the UT technique is established by using the mock-up piece, selecting appropriate probes and setting the scan plan. The cross verification of the indications by comparing with the indications from the known reflectors in mock-up piece established a good practice to conclude the results.

With such an experimental method through approved and acceptable results from qualitative and quantitative testing verified by third party agency/ expertise, authors can qualify a sound weld joint configuration of dissimilar materials and dissimilar thicknesses successfully.

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