Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE **R&D** DÉFENSE

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls

Final Report

Doug Swanek and Chris Timms
C-FER Technologies

Rick Link
Martec Limited

Prepared by:
C-FER Technologies (1999) Inc.
200 Karl Clark Road
Edmonton, AB T6N 1H2

The scientific or technical validity of this Contract Report is entirely the responsibility of the contractor and the contents do not necessarily have the approval or endorsement of Defence R&D Canada.

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2011-334
February 2012

Canada

This page intentionally left blank.

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls

Final Report

Doug Swanek
C-FER Technologies

Chris Timms
C-FER Technologies

Rick Link
Martec Limited

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2011-334
February 2012

Principal Author

Original signed by Doug S. Swanek

Doug S. Swanek

Research Engineer, Design and Construction, Pipelines and Structures

Approved by

Original signed by Neil G. Pegg

Neil G. Pegg

Head, Warship Performance

Approved for release by

Original signed by Leon Cheng

Leon Cheng

Chair, Document Review Panel

Abstract

C-FER Technologies (1999) Inc. (C-FER) was awarded Contract Number W7707-098210/001/HAL with Public Works and Government Services Canada (PWGSC) to design, fabricate and test large-scale ring-stiffened cylinders. The objective of this project was to assess the impact on the collapse pressure of submarine pressure hulls of metal loss due to corrosion, with and without subsequent weld buttering repair. C-FER and Martec Limited ("Martec") contributed to the preparation of this report and the work. Martec was responsible for the final cylinder design and finite element (FE) analysis, while C-FER was responsible for providing technical support on the end cap design, collapse testing facilities, testing expertise and overall project coordination. The three specimens, designated as Specimen A – Baseline, Specimen B – Damaged and Specimen C – Repaired, were fabricated and tested, and the resulting collapse pressures were 7.75, 7.31 and 7.66 MPa, respectively. The simulated corrosion damage (i.e. metal loss) reduced the collapse capacity by 5.9%, whereas repair of simulated corrosion damage by metal replacement through weld buttering recovered 4.8% of that capacity. The findings indicate that weld buttering can be an effective corrosion repair technique.

Résumé

C-FER Technologies (1999) Inc. s'est vue attribuer le contrat W7707-098210/001/HAL par Travaux publics et Services gouvernementaux Canada (TPSGC) pour la conception, la fabrication et l'essai de cylindres à grande échelle renforcés à l'aide d'anneaux. L'objectif de ce projet était d'évaluer l'impact, sur la pression d'effondrement de coques épaisses de sous-marins, de la perte de métal par corrosion, avec et sans beurrage subséquent. C-FER et Martec Limited ont contribué à la préparation du présent rapport et aux travaux. Martec était responsable de la conception finale des cylindres et de l'analyse par éléments finis, alors que C-FER était chargée de fournir du soutien technique portant sur la conception du bouchon d'extrémité, ainsi que les installations d'essai d'effondrement, l'expertise d'essai, et de faire la coordination du projet. Les trois spécimens, désignés de la façon suivante : spécimen A – point de comparaison, spécimen B – endommagé, et spécimen C – réparé, ont été fabriqués et testés, et les pressions d'effondrement résultantes étaient de 7,75, 7,31 et 7,66 MPa respectivement. Les dommages par corrosion simulés (c.-à-d. les pertes de métal) ont réduit la capacité d'effondrement de 5,9 %, alors que la réparation des dommages par corrosion simulés par remplacement de métal par beurrage a permis de récupérer 4,8 % de cette capacité. Les conclusions indiquent que le beurrage peut être une technique de réparation de la corrosion efficace.

This page intentionally left blank.

Executive summary

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls: Final Report

Doug Swanek; Chris Timms; Rick Link; DRDC Atlantic CR 2011-334; Defence R&D Canada – Atlantic; February 2012.

Introduction: Wastage of a submarine pressure hull by corrosion can significantly reduce its collapse strength, to an extent that may require the submarine's diving depth to be restricted. The thickness of corroded hull plating is often restored by weld buttering, whereby weld material is applied to the affected area and ground flush with the surrounding intact plating. Weld buttering (also known as weld overlay, build-up or cladding) is a convenient and cost effective choice, especially compared to more drastic repair options like the complete replacement of the corroded hull plating. Nonetheless, there are concerns with weld repairs, especially the impact of weld distortions and residual stresses on hull collapse. The work described in this report was designed to study the effectiveness of weld buttering through pressure hull collapse tests.

Results: Three ring-stiffened cylinders were fabricated from HY80 steel using conventional methods for submarine construction, i.e. cold rolling and welding. The test specimens were approximately one-sixth scale, with reference to conventional diesel-electric submarines hulls. Artificial corrosion was applied to two of the specimens by milling away approximately 20% of the plating thickness in a square patch covering one frame bay. The corrosion damage on one of those specimens was repaired by weld buttering. The collapse pressure of the cylinder with unrepaired corrosion damage was found to be 5.7% less than a similar intact cylinder with no damage. The loss of strength was mainly due to early yielding at the plate thinning. Premature yielding was less pronounced in the weld buttered cylinder, which was only 1.2% weaker than the intact specimen. It is possible that the small difference in the strengths of the intact and repaired cylinders is due to the large distortions and stresses that arose due to buttering. On the other hand, the discrepancy may be explained by random scatter that affects all test results.

Significance: The experiments showed that weld buttering can reclaim 80% of the collapse strength that is lost due to corrosion damage. In most cases, that margin would be sufficient to negate the need for corrosion related diving restrictions for in-service submarines. The experiments also alleviate concerns related to distortions and stresses that are introduced during weld buttering, since those secondary effects were not found to significantly affect collapse strength despite being of large magnitude. Furthermore, it is expected that the relative magnitude of weld distortions and stresses would be smaller in real hulls due to scaling effects with the test cylinders. Therefore, weld buttering may be able to reclaim an even greater percentage of the collapse pressure for a full-scale hull.

Future plans: The test results will be used to validate the SubSAS submarine structural modelling software, as well as other computer programs that are used to simulate hull collapse and weld procedures. In fact, some of that modelling work is presented in the current report. The validated modelling methodology will then be used to study a greater range of corrosion and weld buttering cases than was practical in the experimental program. Those analyses will be used to make recommendations regarding the limitations of weld buttering.

Sommaire

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls: Final Report

Doug Swanek; Chris Timms; Rick Link; DRDC Atlantic CR 2011-334; R & D pour la défense Canada – Atlantique; février 2012.

Introduction ou contexte: La détérioration d'une coque épaisse de sous-marin par corrosion peut diminuer de façon importante sa résistance à l'effondrement au point que l'on pourrait devoir restreindre la profondeur de plongée du sous-marin. L'épaisseur du bordé de carène corrodé est souvent restaurée par beurrage, méthode où du matériau de soudage est appliqué à la surface touchée et meulé jusqu'au niveau du bordé de carène intact environnant. Le beurrage (aussi connu sous le nom de recouvrement de soudure, accumulation ou surfaçage) est un choix pratique et rentable, en particulier en comparaison à des options de réparation plus radicales comme le remplacement complet du bordé de carène corrodé. Néanmoins, il pourrait y avoir certains problèmes avec les réparations par soudure, en particulier les conséquences des distorsions et des contraintes résiduelles sur l'effondrement de la coque. Les travaux décrits dans le présent rapport ont été conçus pour étudier l'efficacité du beurrage par le biais d'essais d'effondrement de coque épaisse.

Résultats: Trois cylindres renforcés à l'aide d'anneaux ont été fabriqués à partir d'acier HY80 grâce à des méthodes classiques pour la construction de sous-marins, c.-à-d. le soudage et le laminage à froid. L'échelle des spécimens d'essai était d'environ un sixième, avec référence aux coques de sous-marin diesel-électrique classique. De la corrosion artificielle a été appliquée sur deux des spécimens en enlevant par fraisage environ 20 % de l'épaisseur du bordé de carène dans un morceau rapiécé de forme carrée couvrant l'espace entre deux couples. Les dommages par corrosion sur l'un de ces spécimens ont été réparés par beurrage. La pression d'effondrement du cylindre comportant des dommages de corrosion non réparés s'est avérée être 5,7 % plus petite que celle d'un cylindre intact semblable non endommagé. La perte de résistance était principalement due au fléchissement précoce à l'amincissement du bordé de carène. Le fléchissement prématuré était moins prononcé dans le cylindre beurré, qui était seulement 1,2 % plus faible que le spécimen intact. Il est possible que la petite différence entre la résistance du cylindre intact et celle du cylindre réparé soit due aux grandes distorsions et contraintes qui ont découlé du beurrage. D'autre part, la différence peut être expliquée par la dispersion aléatoire qui influe sur tous les résultats d'essai.

Portée: Les expériences ont montré que le beurrage peut permettre de regagner 80 % de la résistance à l'effondrement perdue à cause des dommages par corrosion. Dans la plupart des cas, cette marge serait suffisante pour qu'il ne soit pas nécessaire d'imposer, aux sous-marins en service, des restrictions à la plongée liées à la corrosion. Les expériences, aussi, diminuent les inquiétudes liées aux distorsions et aux contraintes qui sont introduites pendant le beurrage, car ces effets secondaires ne semblent pas avoir une incidence importante sur la résistance à l'effondrement, même s'ils sont importants. De plus, on s'attend à ce que la magnitude relative des contraintes et des distorsions soit plus petite dans le cas de coques réelles à cause des effets d'écaillage avec les cylindres d'essai. Donc, le beurrage pourrait permettre de regagner un pourcentage encore plus grand de la pression d'effondrement d'une coque grandeur nature.

Recherches futures: Les résultats d'essai seront utilisés pour valider le logiciel de modélisation de structure de sous-marin SubSAS, ainsi que d'autres logiciels utilisés pour simuler l'effondrement d'une coque et les procédures de soudage. En fait, une partie de ces travaux de modélisation est présentée dans le présent rapport. La méthodologie de modélisation validée sera ensuite utilisée pour étudier une plage plus importante de cas de beurrage et de corrosion qu'il n'a été possible de le faire dans le programme expérimental. Ces analyses seront utilisées pour faire des recommandations sur les limites du beurrage.

This page intentionally left blank.

Table of contents

List of figures

List of tables

1 Introduction

1.1 Terms of Reference

C-FER Technologies (1999) Inc. (C-FER) was awarded Contract Number W7707-098210/001/HAL with Public Works and Government Services Canada (PWGSC) to design, fabricate and test three large-scale ring-stiffened steel cylinders. The objective of this project was to assess the impact on the collapse pressure of submarine pressure hulls of metal loss due to corrosion, with and without subsequent weld buttering repair.

1.2 Project Scope of Work

The project involved the design, fabrication and collapse testing of three initially identical large-scale ring-stiffened cylinders. The work scope included the following: testing of a "baseline" specimen as initially fabricated; the testing of a "damaged" specimen that contained an area of reduced shell wall thickness that was intended to simulate corrosion; and the testing of a "repaired" specimen that also contained an area of reduced wall thickness that was subject to metal replacement by weld buttering (also referred to as weld overlay, build-up or cladding). This report addresses the following aspects of the project:

- Final cylinder design:
  - Predicted collapse pressure; and
  - Design methodology and fabrication drawings.
- Cylinder fabrication:
  - Shell, T-frame and end cap fabrication; and
  - Weld procedures.
- Geometric surveys:
  - Out-of-circularity (OOC) measurements; and
  - Wall thickness measurements.
- Predictive FE analysis:
  - Modelling cylinder Specimen A – Baseline; and
  - Predicting the collapse pressure and failure mode.
- Coupon Testing:
  - Results for material properties; and
  - Stress-strain curves.
- Collapse Testing:
  - Results for each cylinder model; and
  - Pressure-strain curves.

2 Specimen Design

2.1 Overview

The initial design of the ring-stiffened cylinder specimens was based on the following criteria and constraints:

1. The interframe buckling load should be between 4.2 and 4.5 MPa.

2. The overall buckling load should not exceed the interframe buckling load by more than 5%.

3. The T-frame stiffeners should be sufficiently stocky to ensure that stiffener tripping does not occur.

4. The specimen diameter should be 1.0 m or less to readily fit within the available pressure test chamber.

Preliminary specimen sizing was determined based on the SSP 74 [1] design code. The preliminary design had to be revised due to the lack of availability of the plate material chosen for the preliminary design (i.e. 0.1875-inch HY80 plate). The material finally selected was 0.25-inch HY80 plate. To offset the use of thicker plate material, the specimen diameter was increased to 1.15 m, which is the maximum size that the testing apparatus can accommodate. A higher design collapse pressure of approximately 7 MPa had to be accepted as a result of these changes, which was approved by the project authority at DRDC.

Figure 2.1 identifies the key elements of the final specimen design:

1. The sizing of structural elements, including outer cylinder, stiffener webs and flanges, and the spacing of the stiffeners;

2. The detailing of the welds connecting the outer cylinder, web and flanges;

3. The sizing of the solid specimen end cap;

4. The sizing of the removable specimen end cap;

5. The sizing of the bolts for the removable end cap; and

6. The detailing of the cylinder to end cap connection.
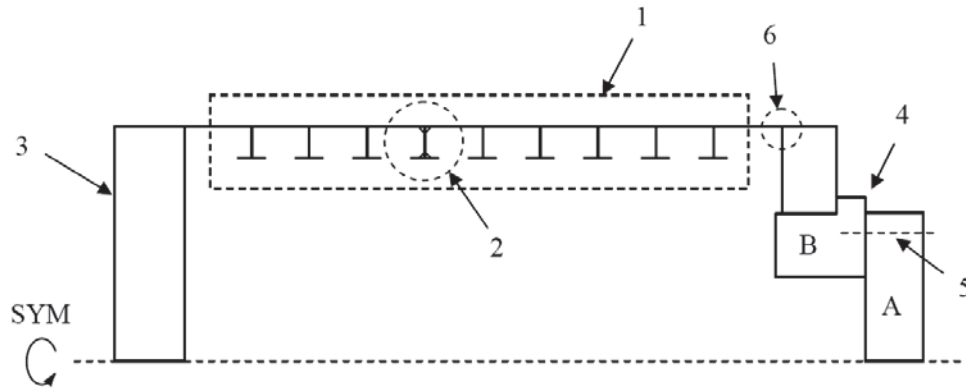
Figure 2.1: Cylinder specimen and design elements.

A copy of Martec's design notes detailing the final design calculations is included in Annex A.

2.2   Specimen Element Sizing

A spreadsheet incorporating the SSP 74 [1] design code, as developed by DRDC Atlantic, was checked for errors and used to obtain the final framing member sizes. Figure 2.2 shows the final size selection.

The overall buckling capacity was checked using a more accurate modelling technique that considered the effect of residual stresses and OOC. This method is outlined in Annex 6D of SSP 74 [1]. K79, a program written to implement this analysis technique, was obtained from DRDC Atlantic for this purpose.

To properly address residual stress effects, it is important to understand how the specimen was fabricated. Initially, it was decided that the cylinder would be constructed in four stages:

1. The external shell would be rolled to the correct diameter.

2. The web and flange elements would be welded together to form straight T-frames.

3. The T-frames would be rolled to the correct curvature.

4. The T-frames would be welded to the external shell.

The K79 analysis assumed that the T-frames and shell were rolled separately. Table 2.1 shows the computed buckling loads. The tabulated results indicate that the K79 buckling pressure was within 1% of the buckling pressure obtained from the SSP 74 spreadsheet.

Strength of Ring-Stiffened Cylinders and Unstiffened Dome Ends Under External Pressure

Design Variables

Material Properties (Metric):

E	207000	MPa
σ_{yp}	646.0	MPa
σ_{yf}	646.0	MPa
μ	0.3	
ρ	7850.0	kg/m^3

Geometric Properties (Metric):

h	6.350	mm
h_w	6.350	mm
d	33.000	mm
h_f	6.350	mm
f	30.000	mm
a	571.825	mm
L_f	160.000	mm
L_B	1840.000	mm
OOC	0.500	%
R_{sf}	1.000	
Int. Frames	yes	

Relative Proportions:
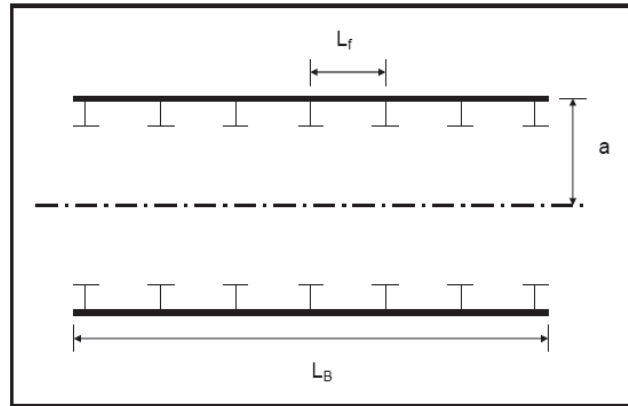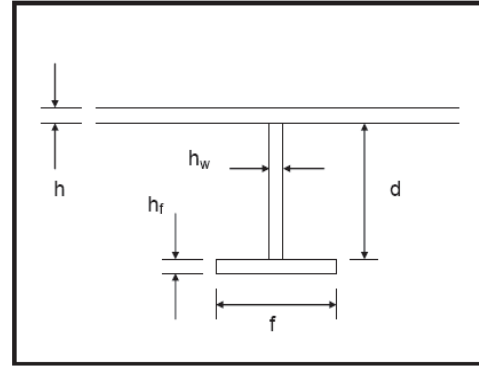
Figure 2.2: Specimen sizing.

Table 2.1: Buckling pressures for interframe and overall modes.

Buckling Mode	SSP 74 Spreadsheet	K79 Method
Interframe	6.798 MPa	–
Overall	7.028 MPa	7.078 MPa

It was determined that because the plate thickness was increased to 0.25 inches, the T-frames could not be rolled as one piece. It was therefore decided that it would be preferable to first fabricate the web elements in three 120° arc lengths, and then weld them together to obtain a circular web element. The flange plate element could then be rolled and welded to the web section. It is noted that the lack of web residual stresses resulting from this alternate fabrication sequence would be expected to result in an overall buckling pressure slightly higher than the values given in Table 2.1.

An additional finite element (FE) analysis was subsequently conducted by Martec using SubSAS and VAST following specimen fabrication. This analysis, which incorporated the as-fabricated geometry and material properties of the initial "baseline" test specimen, is discussed in Section 4.

2.3   Welds Connecting Specimen Elements

The welds joining the outer cylinder, web elements and flange elements were designed to transfer the full web shear capacity, assuming an effective width equal to the span between stiffeners. Fillet welds were used to weld the T-frame flange to the web and the web to the shell. Full penetration welds were used to join the web sections and were also used for the longitudinal shell seam weld. The CSA steel code CAN3-S16.1-01 [2] was used to establish appropriate base and weld metal strengths. A copy of the cylinder and end cap fabrication drawings is provided in Annex B. Additionally, the weld procedures used for joining HY80 to HY80 are included in Annex C.

2.4   End Cap Sizing

The end caps were designed to withstand a minimum pressure equal to two times the specimen collapse pressure. One solid end cap and one removable end cap were fabricated from 152.4-mm thick 350W mild steel. Those end caps were used for all three cylinder tests. The solid end cap consisted of a flat, circular plate, while the removable end cap had a large circular opening to allow access to the inside of the cylinder after end cap welding. The removable end cap also incorporated a cover plate with a face-seal arrangement to seal the circular opening for collapse testing. The end cap fabrication drawings are provided in Annex B.

To arrive at the required thickness of the solid end cap, it was idealized as a circular plate with pinned edges subject to external pressure loading. The maximum bending stress, which controls the thickness requirement, was computed using elastic thin-plate plate theory [3].

To reduce fabrication and material costs, the removable end cap was designed to include a thick insert piece fitted to the inner diameter of the circular opening, so that the material removed for the circular opening could be utilized as a cover plate. The insert was cut with a lip designed to rest against the outer face of the circular opening. The shear, bending and bearing capacities of the lip were checked using CSA S16.1-02 [4].

The potential for excessive prying forces acting on the bolts connecting the removable end cap components was checked using a simple FE model, wherein the removable end cap (labelled "A" in Figure 2.1) was assumed to be fixed at its exterior edge to the base end cap (labelled "B" in Figure 2.1). The gap was then determined, and the bolt strain was computed by dividing the gap size by the minimum bolt length.

2.5   Specimen to End Cap Connection

Preliminary FE analysis of the specimen end cap region revealed that high bending stresses would result if the cylinder was to be welded directly to the end cap. This is because the weld would restrain the cylinder wall from moving inward, causing large bending stresses to develop in the

cylindrical plate. This issue was compounded due to the difference in yield strength between the end cap and shell materials. Multiple options to reduce the tensile stresses were investigated, including the following:

1. overlapping the plates;

2. recessing the end cap to allow the cylinder to fit over top of the end cap; and

3. using a thicker QT100 shell insert with transition to cylinder.

While Option 2 was preferred for stress relief, the anticipated expense of cutting a cap recess, combined with potential fitting problems, made this choice unfeasible. Option 3 was selected over Option 1 due to ease of fabrication and because the insert material (QT100) has a higher yield strength than HY80. Several FE analyses were performed to optimize the tensile stress distribution at the cylinder-cap junction.

The specimen-to-end cap detail is included in the fabrication drawings in Annex B.

2.6 Design Review

International Submarine Engineering Research Ltd. ("ISER") reviewed Martec's design notes and conducted an independent check of the proposed specimen design using ABS rules [5]. ISER found no issues with the design approach or calculations as set out in the design notes. The collapse pressure predicted by ISER was within 5.9% of that predicted by Martec using SSP 74.

2.7 Fabrication Drawings

Fabrication drawings were prepared by Martec based on the final design parameters detailed above. The drawings specify the following:

- dimensions for the shell, T-frame stiffeners and end caps;
- sizing and type of welded joints;
- sizing and orientation of bolt holes and strain gauge connector ports; and
- face-seal arrangement for the removable end cap.

A copy of the cylinder and end cap fabrication drawings is provided in Annex B.

3 Specimen Fabrication

3.1 Overview

Petersen's Welding, located in Edmonton, Alberta, was contracted by C-FER to undertake the fabrication portion of the project. The company was responsible for fabricating the three test specimens and the associated specimen end caps. They also performed the machining required to simulate corrosion damage as well as the weld buttering repair.

3.2 Plate Material and Piece Layout

Three HY80 plates with nominal dimensions of 240 inches × 96 inches × 0.25 inches were purchased for the project. Each plate was obtained from the same heat, and mill certificates for each plate were provided by the vendor (see Annex D). For each test specimen, the shell plate, flanges, webs, coupon panel and spare material panel were taken from the same "parent" plate. The parent plate used to fabricate each specimen, by plate heat/lot-slab, is listed in Table 3.1.

Table 3.1: Parent plate used for specimen fabrication.

Specimen	Plate Heat – Slab
Specimen A	R2452-01AC
Specimen B	R2452-01AB
Specimen C	R2452-01AD

Each parent plate was cut into two pieces prior to shipping. One piece served as the source material for the shell and flange elements, while the other piece served as the source material for the web elements, coupon panel and spare material panel.

The shell, flanges, webs, coupon panel and spare plate for each specimen were waterjet cut from their parent plate pieces. Waterjet cutting was utilized to minimize the heat input and distortions resulting from the cutting process.

The shell and T-frame flange elements were laid out such that the hoop direction of both components matched after rolling.

Copies of the vendor cut and plate layout drawings are included in Annex E.

3.3 Specimen Fabrication

A cylinder fabrication procedure developed by Petersen's Welding was submitted and approved by DRDC Atlantic. The major elements of the fabrication procedure are listed below:

- The shell, flanges and QT100 stiffeners were cold rolled following waterjet cutting.

- For the T-frame stiffeners,
  - three 120° arc segments were tack welded together to form a complete circular web;
  - flanges and webs were then tack welded together;
  - groove welds between web pieces were completed; and
  - a fillet weld of the flange-web connection was completed.
- The first three completed T-frames underwent non-destructive examination (NDE).
- Once the NDE requirements were satisfied, the remaining T-frames were welded.
- The longitudinal seam of the outer shell was tack welded.
- The T-frames were welded into place inside the shell plate.
- The seam weld was completed as T-frames were welded in place.
- Grid markings were drawn on the outer surface of the cylinders (see Figure 3.1).
- The end caps were welded to the specimen ends.

The complete procedure for specimen fabrication is included in Annex F.

Figure 3.1: Specimen A – Baseline showing outer surface grid markings.

3.4   Additional Fabrication to Simulate Corrosion Damage

A 160-mm × 160-mm patch of material was removed from the outer shell surface to simulate wall loss due to corrosion. The targeted mean wall loss was 20% of the shell wall thickness. This wall thickness reduction was introduced in Specimen B – Damaged and Specimen C – Repaired.

The simulated corrosion patch was machined into the shell at a location equidistant between Stiffener Frames 5 and 6 with the patch centre oriented 180° from the seam weld.

The simulated corrosion patch was machined by mounting the cylinder on a lathe and using a spring-mounted cutter to remove the material. The cylinder was indexed about its longitudinal

axis, and the cutting tool was moved radially until the desired wall thickness reduction was achieved.

To achieve the desired longitudinal and circumferential dimensions of the area of reduced wall thickness, the tool was first incremented in the longitudinal direction until the desired length of the patch was reached. It was then returned to its original starting position, and the cylinder was rotated about its longitudinal axis by a fixed angular displacement. The tool was then incremented once again in the longitudinal direction. This process was continued until the desired metal loss extent was achieved. Leftover slivers of material between the longitudinal cuts were smoothed out using a buffing wheel.

After the area of reduced wall thickness was machined, a fine grid pattern was marked across the area to provide a reference for subsequent geometry surveys (see Figure 3.2).

Figure 3.2: Simulated corrosion patch on Specimen B – Damaged.

3.5   Additional Fabrication to Repair Damaged Region

The simulated corrosion patch machined into the outer shell surface of Specimen C was "repaired" using weld buttering.

Weld buttering was carried out using a PGMAW welding process. Multiple side-to-side passes (28 in total) were applied across the area of reduced wall thickness until the built-up thickness was greater than the original thickness of the shell. The local plate temperature was monitored, and sufficient time between welding passes was taken to allow the material to air cool to within the maximum specified interpass temperature. The majority of weld passes took between 30 and 40 seconds to complete (with the longest being 51 seconds), and the voltage and amperage ranged from approximately 20.1 to 20.9 V and 100 to 115 A, respectively.

The weld passes were then manually blended into the surrounding shell material using a grinder/sander, and a fine grid pattern was marked onto the area to provide a reference for subsequent geometry surveys.

Figures 3.3 and 3.4 show the progression of the weld buttering process.

(a) Repair area following initial weld passes
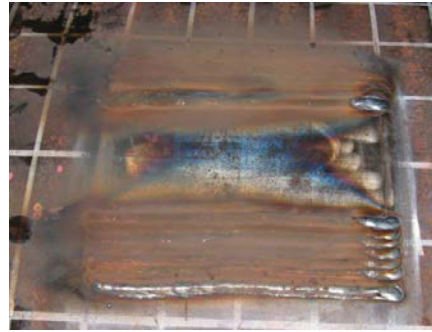
(b) Repair area after additional weld passes

(c) Repair area before final blending

(d) Repair area after final blending

Figure 3.3: Progression of weld buttering.

Figure 3.4: Repaired region on Specimen C – Repaired.

It should be noted that there was visible "dishing" in the weld repaired area. This distortion was attributed to the heat input during the repair process. The extent of this distortion was captured in the geometry surveys detailed in Section 3.9.

3.6 NDE Program

Petersen's Welding supervised the execution of an NDE program that was developed, in consultation with DRDC Atlantic, to ensure that the approved weld procedures produce quality welds.

The required NDE program used surface inspection techniques (i.e. MPI or dye penetrant) to examine the fillet welds used to join the web sections and web-flange joint. NDE was carried out on the first three fabricated T-frames, prior to welding them to the shell plate, in accordance with ASME BPVC, Section IX [6].

The welds successfully passed the NDE inspection. A copy of the inspection report is included in Annex G.

3.7 Component Element Dimensional Tolerances

Dimensional tolerances were specified for various components of the test specimens.

The quality assurance/quality control (QA/QC) program was developed to verify that dimensional tolerances were met. For each cylinder, the QA/QC program consisted of the following:

- Each T-frame was measured at two locations: 90° and 270° (with respect to the seam weld). The following measurements were taken at each location: flange width, flange thickness, web thickness, web width, flange-web centring, and the angle between flange and web.

- After the T-frames were welded to the inside the shell plate, the interframe spacing, end bay spacing, and the angle between the shell and web (for each T-frame) were measured at two locations: 90° and 270° (with respect to the seam weld).

A summary of the dimensional tolerance measurements for each test specimen is provided in Table 3.2.

Table 3.2: Summary of dimensional tolerance measurements.

Specimen Component Dimension		Target Value	Measured Values		
			Specimen A	Specimen B	Specimen C
Frame Web Depth	Mean (mm)	33 ± 4	33.2	33.2	33.0
	Std. Dev. (mm)		0.6	0.5	0.6
	COV (%)		1.77	1.65	1.78
Frame Web Thickness[1]	Mean (mm)	(A) 6.71 ± 0.40 (B) 6.73 ± 0.40 (C) 6.80 ± 0.41	6.82	6.84	6.81
	Std. Dev. (mm)		0.1	0.1	0.1
	COV (%)		1.03	1.01	1.22
Frame Flange Width	Mean (mm)	30 ± 4	29.8	30.0	29.9
	Std. Dev. (mm)		0.6	0.6	0.6
	COV (%)		1.90	1.88	1.95
Frame Flange Thickness[1]	Mean (mm)	(A) 6.71 ± 0.40 (B) 6.73 ± 0.40 (C) 6.80 ± 0.41	6.79	6.82	6.83
	Std. Dev. (mm)		0.06	0.07	0.08
	COV (%)		0.95	0.95	1.13
Frame Web/Flange Centre	Mean (mm)	15 ± 2	15.0	15.3	15.4
	Std. Dev. (mm)		0.7	0.6	0.5
	COV (%)		4.87	4.23	3.54
Web/Flange Angle	Mean (deg.)	90 ± 5°	88.6	88.3	88.4
	Std. Dev. (deg.)		0.8	1.0	0.8
	COV (%)		0.95	1.11	0.96
Interframe Spacing	Mean (mm)	160 ± 4	160.2	159.6	159.9
	Std. Dev. (mm)		0.8	0.8	0.9
	COV (%)		0.0	0.0	0.0
Shell/Web Angle	Mean (deg.)	90 ± 5°	88.3	88.4	88.3
	Std. Dev. (deg.)		0.9	0.9	0.7
	COV (%)		0.97	1.06	0.76

[1] Mean plate thickness with specified tolerance (±6%) expressed in mm. Mean plate thickness determined from material certificate for corresponding specimen.

The measurements comply with the specified dimensional tolerances and were quite uniform, as indicated by the low COV (less that 2%), for all parameters.

The detailed dimensional tolerance check results are included in Annex H.

3.8 Fabricated Specimen Geometry and Residual Stress Surveys

Each test specimen was surveyed during various stages of fabrication to determine geometric and residual stress characteristics. Table 3.3 details the survey intervals.

Table 3.3: Geometric and residual stress survey schedules.

Fabrication Stage	Geometric Surveys			Residual Stress Surveys		
	Specimen A	Specimen B	Specimen C	Specimen A	Specimen B	Specimen C
After welding of the cold rolled plates and frames to form the ring-stiffened cylinder	X	X	X	X		
After application of simulated corrosion thinning		X	X			X	
After weld buttering			X			X

3.8.1 Geometric Surveys

The geometric surveys consisted of measuring the cylinder radius (to determine OOC) and shell plate thickness. Radius was measured using a Faro Laser Tracker™, which has an accuracy of ±0.0254 mm (0.001 inches). The OOC was characterized by measuring specimen radius at 36 circumferential locations, spaced at 10° radial arc intervals, along the cylinder length at each T-frame and mid-bay. Positive angles were referenced as clockwise with respect to End A on the specimen. A refined survey grid was used to better characterize the wall thickness and OOC in the vicinity of the corrosion damage/repair for Specimens B and C, respectively. The middle of the corrosion patch was aligned with 0° (180° from the seam weld) and centred between T-frames 5 and 6. The measurement grid is illustrated in Figure 3.5.
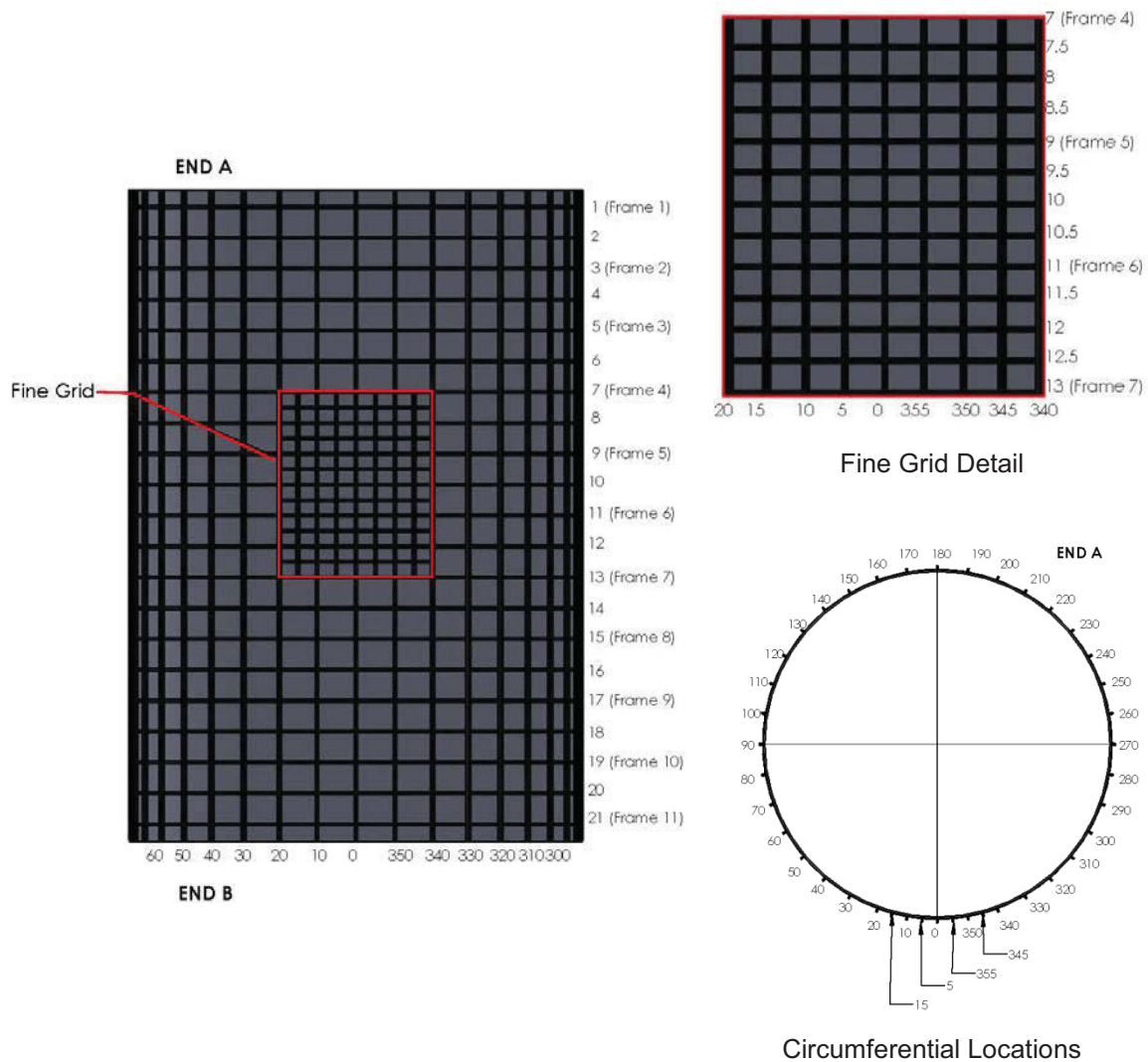
Figure 3.5: Geometric survey grid.

To determine OOC, the individual radius measurements were subtracted from those associated with a specimen-specific reference cylinder. The reference cylinder was determined by the Laser Tracker software, which effectively interpolated between best-fit circles as obtained from the survey measurement taken at each end of the specimen.

The OOC measurements for each cylinder, at each stage of fabrication, are listed in Tables 3.4 to 3.8. The tabulated maximum OOC was the largest absolute OOC value measured around the circumference at the specified longitudinal position.

Table 3.4: Geometric survey of Specimen A – Baseline, measurements taken after fabrication.

Measurement Position		Specimen A After Cylinder Formed			
		Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos. (deg)
Frame 1	Position 1	575.36	1.71	0.65%	180
Mid-bay	Position 2	575.42	1.75	0.67%	180
Frame 2	Position 3	575.46	1.73	0.62%	180
Mid-bay	Position 4	575.37	1.81	0.68%	180
Frame 3	Position 5	575.80	1.78	0.69%	260
Mid-bay	Position 6	575.49	1.82	0.68%	250
Frame 4	Position 7	575.61	1.75	0.73%	250
Fine Grid	Position 7.5	574.13	0.31	0.20%	340
Mid-bay	Position 8	575.46	1.69	0.70%	250
Fine Grid	Position 8.5	574.22	0.28	0.20%	340
Frame 5	Position 9*	575.75	1.76	0.77%	250
Fine Grid	Position 9.5*	574.11	0.26	0.21%	340
Mid-bay	Position 10*	575.46	1.75	0.69%	250
Fine Grid	Position 10.5*	574.24	0.23	0.16%	0
Frame 6	Position 11*	575.74	1.81	0.71%	250
Fine Grid	Position 11.5	574.23	0.22	0.16%	340
Mid-bay	Position 12	575.52	1.89	0.69%	250
Fine Grid	Position 12.5	574.19	0.20	0.17%	340
Frame 7	Position 13	575.66	1.95	0.72%	250
Mid-bay	Position 14	575.68	2.01	0.70%	250
Frame 8	Position 15	575.73	2.08	0.73%	250
Mid-bay	Position 16	575.63	2.18	0.79%	180
Frame 9	Position 17	575.65	2.21	0.80%	180
Mid-bay	Position 18	575.61	2.27	0.91%	180
Frame 10	Position 19	575.70	2.27	0.85%	180
Mid-bay	Position 20	575.71	2.27	0.88%	180
Frame 11	Position 21	575.81	2.12	0.80%	180

* Simulated corrosion patch area (not machined on this specimen but marked).

Table 3.5: Geometric survey of Specimen B – Damaged, measurements taken after simulated corrosion machining.

Measurement Position		Specimen B After Simulated Corrosion			
		Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos. (deg)
Frame 1	Position 1	575.64	1.80	0.82%	180
Mid-bay	Position 2	575.61	1.76	0.78%	180
Frame 2	Position 3	575.83	1.61	0.61%	120
Mid-bay	Position 4	575.63	1.53	0.59%	180
Frame 3	Position 5	575.87	1.51	0.59%	120
Mid-bay	Position 6	575.67	1.41	0.56%	190
Frame 4	Position 7	575.87	1.38	0.53%	120
Fine Grid	Position 7.5	574.71	0.38	0.10%	15
Mid-bay	Position 8	575.62	1.30	0.55%	180
Fine Grid	Position 8.5	574.84	0.26	0.08%	5
Frame 5	Position 9*	575.92	1.29	0.51%	250
Fine Grid	Position 9.5*	574.52	0.81	0.27%	5
Mid-bay	Position 10*	575.52	1.36	0.56%	180
Fine Grid	Position 10.5*	574.48	0.78	0.28%	355
Frame 6	Position 11*	575.82	1.27	0.56%	240
Fine Grid	Position 11.5	575.08	0.24	0.09%	20
Mid-bay	Position 12	575.71	1.06	0.47%	240
Fine Grid	Position 12.5	575.15	0.27	0.12%	20
Frame 7	Position 13	576.04	1.05	0.55%	240
Mid-bay	Position 14	575.91	1.06	0.48%	240
Frame 8	Position 15	576.00	1.12	0.51%	240
Mid-bay	Position 16	575.90	1.17	0.49%	230
Frame 9	Position 17	576.07	1.32	0.57%	240
Mid-bay	Position 18	575.81	1.37	0.53%	240
Frame 10	Position 19	575.96	1.47	0.56%	230
Mid-bay	Position 20	575.86	1.56	0.60%	230
Frame 11	Position 21	576.03	1.59	0.65%	230

* Simulated corrosion patch area.

Table 3.6: Geometric survey of Specimen C – Repaired, measurements taken after fabrication.

Measurement Position		Specimen C After Cylinder Formed			
		Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos. (deg)
Frame 1	Position 1	575.88	2.30	1.01%	240
Mid-bay	Position 2	575.85	2.27	0.96%	240
Frame 2	Position 3	575.98	2.20	0.95%	240
Mid-bay	Position 4	575.87	2.19	0.89%	240
Frame 3	Position 5	575.92	2.03	0.83%	240
Mid-bay	Position 6	575.93	2.10	0.85%	240
Frame 4	Position 7	575.98	2.06	0.88%	240
Mid-bay	Position 8	575.88	2.10	0.85%	240
Frame 5	Position 9	576.13	2.02	0.90%	240
Mid-bay	Position 10	575.80	2.05	0.82%	240
Frame 6	Position 11	576.00	2.04	0.85%	240
Mid-bay	Position 12	575.83	2.12	0.81%	240
Frame 7	Position 13	575.90	1.98	0.76%	250
Mid-bay	Position 14	575.69	2.12	0.77%	180
Frame 8	Position 15	575.91	2.09	0.95%	180
Mid-bay	Position 16	575.56	2.17	0.88%	180
Frame 9	Position 17	575.69	2.04	0.71%	250
Mid-bay	Position 18	575.54	2.06	0.86%	180
Frame 10	Position 19	575.77	2.01	0.75%	180
Mid-bay	Position 20	575.61	2.10	0.95%	180
Frame 11	Position 21	575.67	1.97	0.83%	180

Table 3.7: Geometric survey of Specimen C – Repaired, measurements taken after simulated corrosion machining (fine grid only).

Measurement Position		Specimen C After Simulated Corrosion			
		Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos. (deg)
Frame 4	Position 7	575.86	1.97	0.88%	240
Fine Grid	Position 7.5	574.46	0.15	0.13%	340
Mid-bay	Position 8	575.78	2.02	0.86%	240
Fine Grid	Position 8.5	574.56	0.12	0.12%	340
Frame 5	Position 9*	575.89	2.05	0.90%	240
Fine Grid	Position 9.5*	574.09	0.60	0.30%	355
Mid-bay	Position 10*	575.61	2.06	0.82%	240
Fine Grid	Position 10.5*	574.03	0.65	0.33%	355
Frame 6	Position 11*	575.81	2.01	0.85%	240
Fine Grid	Position 11.5	574.43	0.10	0.13%	340
Mid-bay	Position 12	575.73	2.03	0.80%	240
Fine Grid	Position 12.5	574.43	0.08	0.12%	0
Frame 7	Position 13	575.79	1.92	0.77%	250

* Simulated corrosion patch area.

Table 3.8: Geometric survey of Specimen C – Repaired, measurements taken after weld buttering repair (fine grid only).

Measurement Position	Specimen C After Weld Buttering			
	Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos.(deg)
Frame 4 Position 7	575.80	2.14	0.88%	240
Fine Grid Position 7.5	574.05	0.14	0.19%	340
Mid-bay Position 8	575.72	2.18	0.86%	240
Fine Grid Position 8.5	573.80	0.16	0.23%	0
Frame 5 Position 9[*]	575.72	2.40	0.90%	240
Fine Grid Position 9.5[*]	572.36	0.64	0.56%	5
Mid-bay Position 10[*]	575.17	2.69	0.82%	240
Fine Grid Position 10.5[*]	572.21	0.74	0.64%	5
Frame 6 Position 11[*]	575.63	2.36	0.85%	240
Fine Grid Position 11.5	573.75	0.12	0.25%	0
Mid-bay Position 12	575.68	2.20	0.81%	240
Fine Grid Position 12.5	574.04	0.07	0.18%	0
Frame 7 Position 13	575.74	2.08	0.79%	250

[*] Simulated corrosion patch area.

The effect of simulated corrosion machining and weld buttering on the geometry of Specimen C are shown in Figures 3.6 to 3.10. The figures show the variation in shell plate radius for a portion of the fine grid area through the complete manufacturing process. The fine grid spanned Positions 7 through 13, with the simulated corrosion patch spanning Positions 9 to 11. The fine grid extended over a circumferential arc length of 40° (from 20° to 340°), with the simulated corrosion patch extending from 7.5° to 352.5° (covering a 15° arc length).

Similar radial dimensions, before and after the introduction of simulated corrosion, were measured during the fabrication of Specimen B; however, due to software issues, the data after fabrication, but before simulated corrosion machining, was not retained. While the data for Specimen B is not available, note that it would be expected to be similar to that obtained from Specimens A or C.
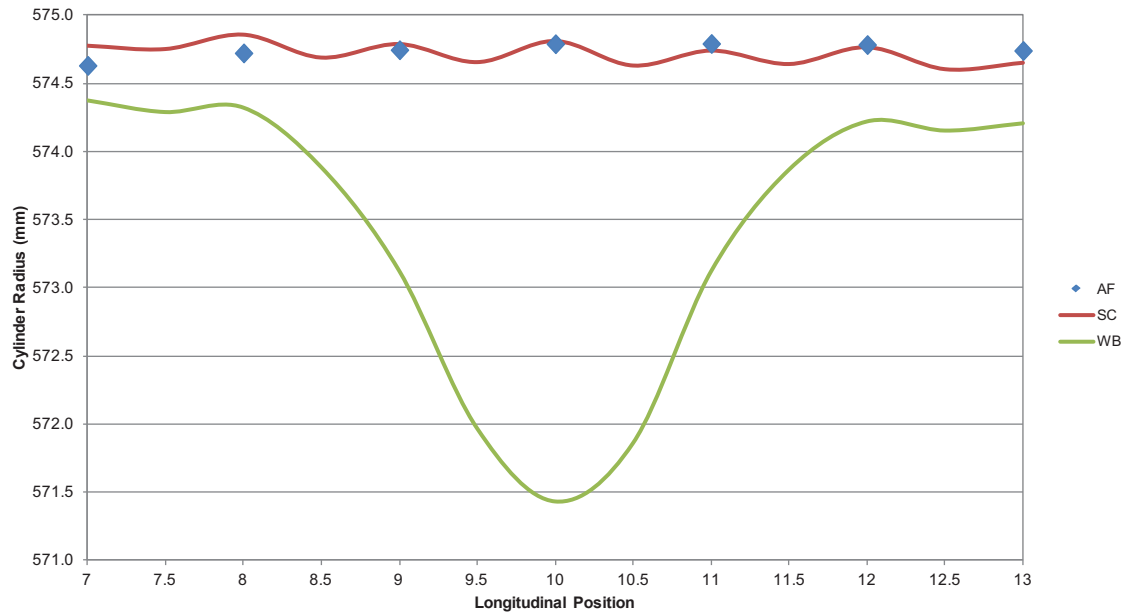
Figure 3.6: Specimen C – Repaired radius at the 10° position in the fine grid (AF: after fabrication, SC: simulated corrosion, WB: weld buttering).
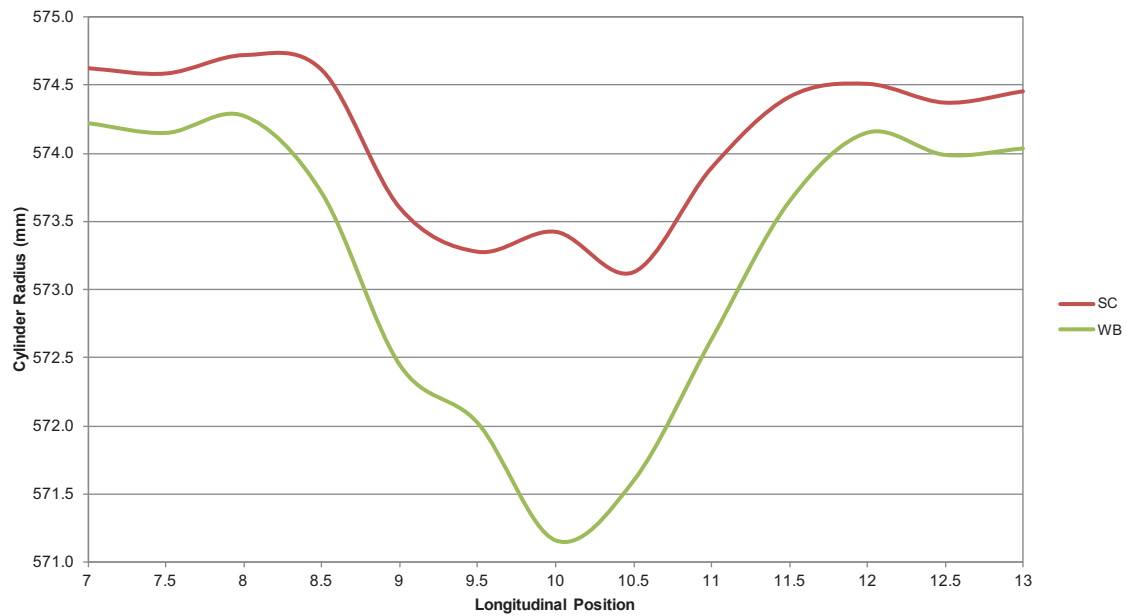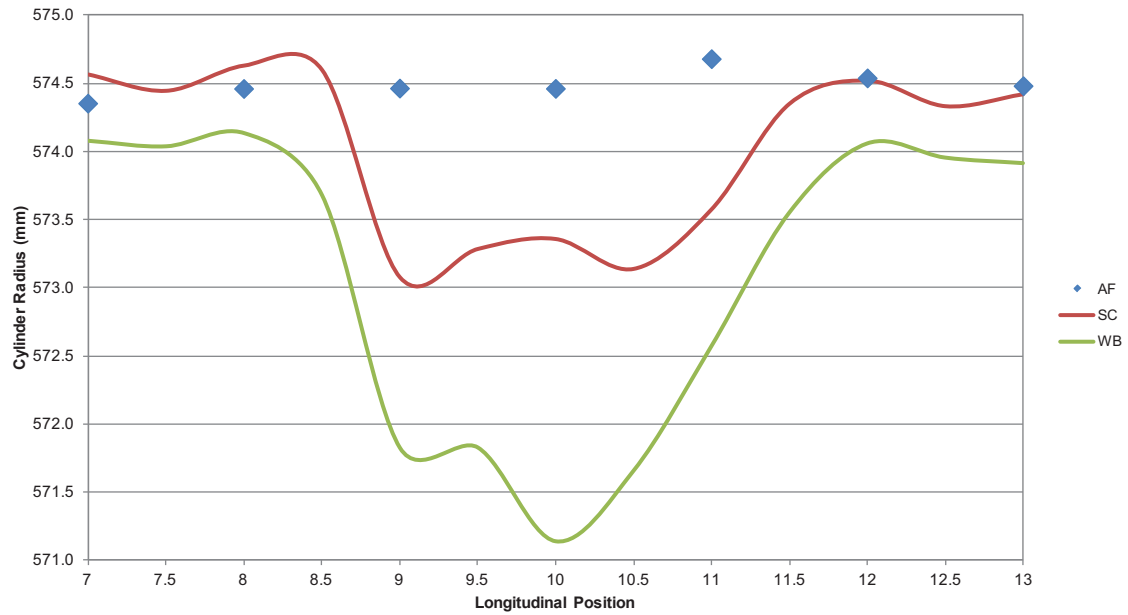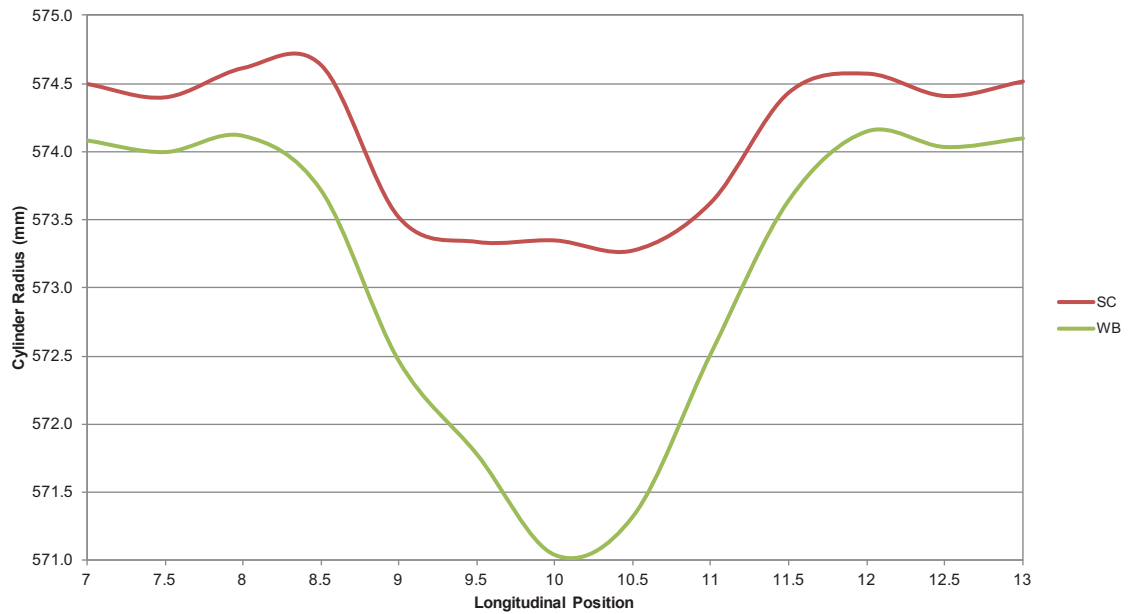

Figure 3.7: Specimen C – Repaired radius at the 5° position in the fine grid (SC: simulated corrosion, WB: weld buttering).
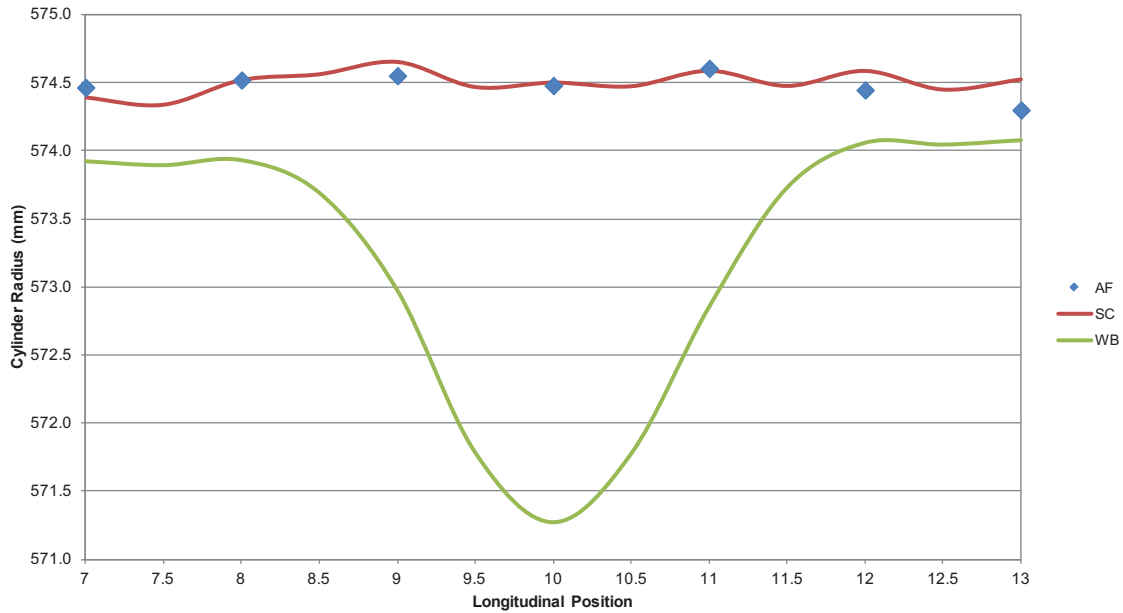
Figure 3.8: Specimen C – Repaired radius at the 0° position in the fine grid (AF: after fabrication, SC: simulated corrosion, WB: weld buttering).

Figure 3.9: Specimen C – Repaired radius at the 355° position in the fine grid (SC: simulated corrosion, WB: weld buttering).

*Figure 3.10: Specimen C – Repaired radius at the 350° position in the fine grid
(AF: after fabrication, SC: simulated corrosion, WB: weld buttering).*

The wall thickness reduction and corrosion patch contour are reflected in the radius profiles on the plots of the 5°, 0° and 355° positions (Figures 3.7, 3.8 and 3.9, respectively). The machining process that introduced the simulated corrosion did not significantly affect the radial dimensions of the shell plate beyond the extent of the corrosion patch area. However, the weld buttering did affect the shell plate radius beyond the corrosion patch as is evident in Figures 3.6 and 3.10. These locations were outside of the repair area; however, the radius deviated approximately 2.5 mm over the length of the fine grid, with the largest deviation observed between Frames 5 and 6. The relatively thin plating combined with the large amount of heat input, associated with weld buttering, likely caused the heat-affected zone to extend outside the buttered region, which led, in turn, to weld distortions outside the repaired area.

Wall thickness was measured using an ultrasonic probe with an accuracy of ±0.0254 mm (0.001 inches). The wall thickness profile was established by taking measurements from the same circumferential locations as the radius measurements but only from the mid-bay positions along the cylinder length. A summary of the wall thickness measurements is presented in Table 3.9, with the detailed measurements available in Annex I.

Table 3.9: Summary of geometric survey wall thickness measurements.

Cylinder	Plate Thickness[1]	Shell Thickness After Fabrication[2]			Shell Thickness in Damaged Region			Shell Thickness in Weld Buttering Region		
	Mean (mm)	Mean (mm)	Std. Dev. (mm)	COV (%)	Mean (mm)	Std. Dev. (mm)	COV (%)	Mean (mm)	Std. Dev. (mm)	COV (%)
Specimen A	6.71	6.79	0.11	1.59	-	-	-	-	-	-
Specimen B	6.73	6.76	0.05	0.69	5.50	0.10	1.78	-	-	-
Specimen C	6.80	6.58	0.16	2.39	5.52	0.05	0.94	8.09	0.36	4.42

[1] Mean value determined from material certificates.

[2] Does not include seam weld.

All of the wall thickness measurements, with the exception of the weld buttering region, were relatively uniform as indicated by the COV. The average shell thickness was within 3% of the mean plate thickness values. Wall loss from simulated corrosion machining was determined as the difference between the post-fabrication and damaged region values. The mean wall loss values in the simulated corrosion areas were 18.6% and 16.1% for Specimens B and C, respectively, which are just below the 20% target. Conversely, the mean wall thickness in repaired region was approximately 22.9% greater than the mean post-fabrication value.

3.8.2 Residual Stress Surveys

Residual stress surveys were conducted by DRDC Atlantic staff using a portable miniature X-ray diffractometer (mXRD).

4 Finite Element Predictive Collapse Load for Specimen A

4.1 Overview

Two FE analyses were performed by Martec Limited using VAST and LS-DYNA FE codes. The models are identical in all aspects except for the element types and solution strategies. The models were generated using Martec's submarine structural modelling software, SubSAS, and were converted to VAST and LS-DYNA formats.

4.2 FE Model Geometry

The finite element model consisted of 32,580 four-node shell elements as shown in Figure 4.1. Eighty-one elements were used in the circumferential direction, with eight elements between frames. The frames were modelled using four-node shell elements, with four elements through the web and four elements across the flange.

Two types of measured imperfections [8] were mapped onto an initially perfect geometric model using SubSAS: thickness variations and OOC variations.

The shell plate thicknesses were mapped onto the FE model using the Voronoi thickness map option in SubSAS [9]. Frame element thickness measurements were not obtained, so the frame elements were assigned a constant thickness of 6.78 mm. Figure 4.1a shows the variation in element thickness for the entire specimen. Note that the shell ends have thicker plating to preclude bending overstress in that area. Figure 4.1b shows the thickness variation with the thick end plates removed. The figure indicates that there are thicker areas along the weld seam; this occurs because of the weld metal accumulation along the seam.

(a) Complete FE model   (b) FE model with thick end elements removed
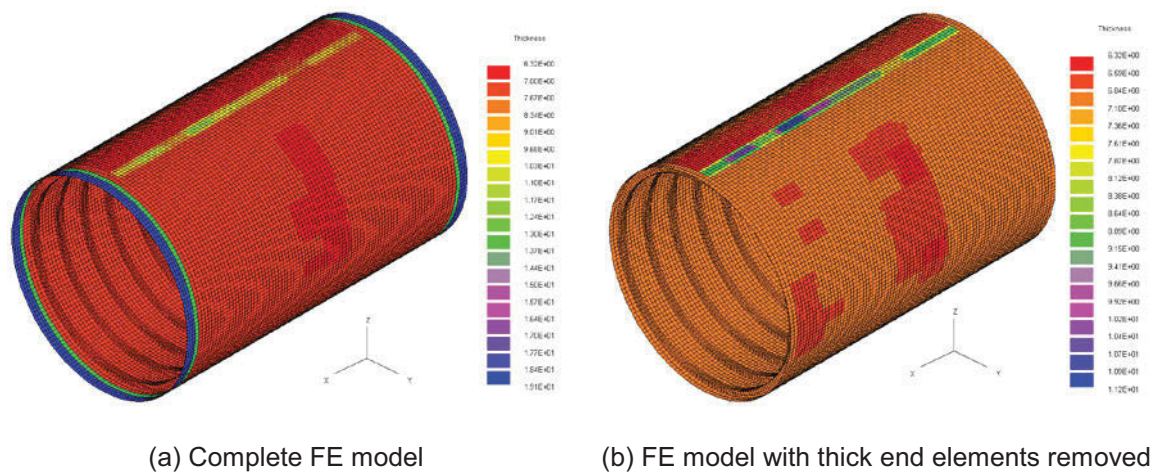
Figure 4.1: Element thickness contours.

Figure 4.2 shows the OOC variations, which were mapped onto the FE model using the overall OOC mapping option in SubSAS [9]. The plate OOC variations were mapped to the frame elements directly since there were no measurements for these. It can be seen that there is a radial depression in the seam area. This is attributed to welding-induced distortion. The maximum measured OOC was on the order of 0.9%, which is higher than the 0.5% assumed in the original design calculations.

(a) Pristine model   (b) OOC model – OOC magnification 25×
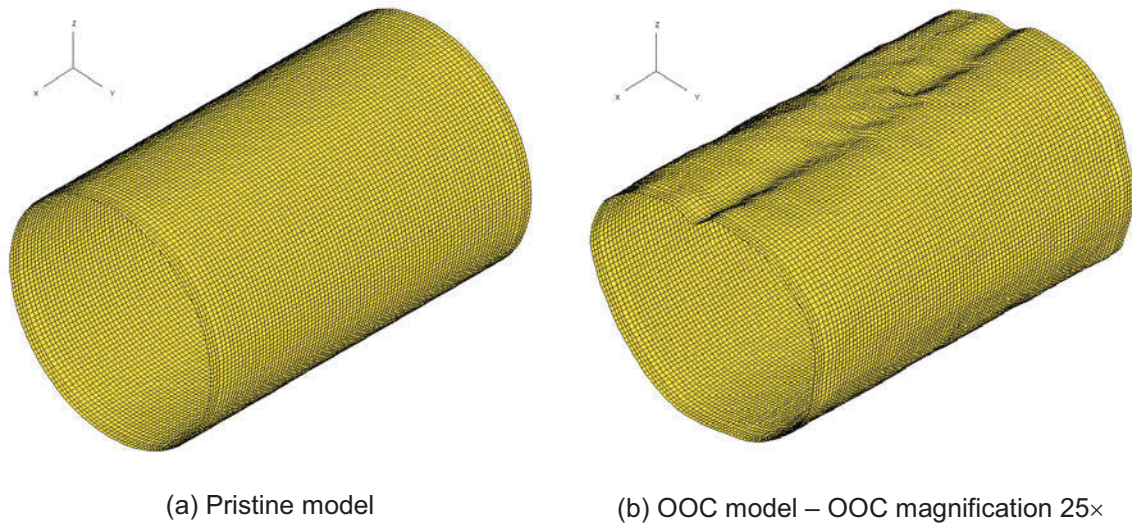
Figure 4.2: Element OOC plot.

4.3   Boundary Conditions and Loads

Figure 4.3 shows the loading and boundary conditions used in the model. To model the effects of the stiff 150-mm thick end plates, both ends were fully restrained against radial movement. To model the application of end cap pressure, one end was restrained to prevent x-axis displacement and the other end was allowed to translate in the x-direction. Radial pressures were applied over the outer shell plate and line loads corresponding to the applied end cap pressure were applied along the translating cylinder end.
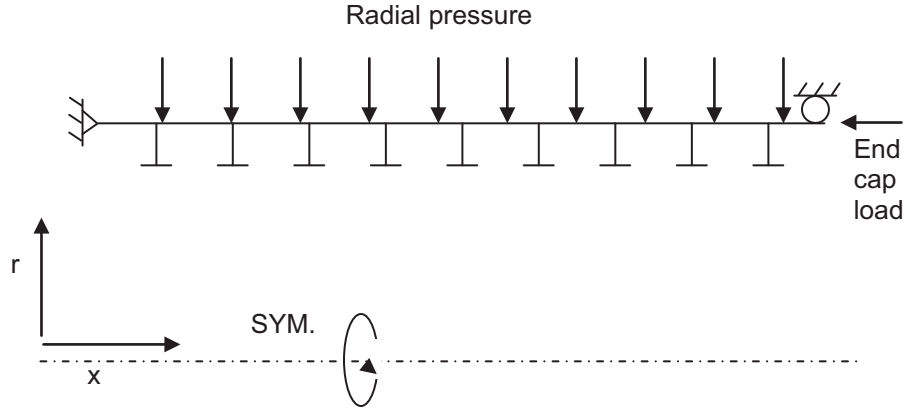
Figure 4.3: Boundary conditions and loads.

4.4   Material Properties

All elements were assigned nonlinear material properties using piece-wise linear stress-strain curves. The stress-strain curves for the cylinder plating and frame flanges are the so-called effective stress-strain curves, which include the effects of cold-bending residual stresses.

Cold-bending residual stresses were estimated using a simplified analytical model assuming an elastic-perfectly plastic material behaviour and an entirely elastic springback [10]. The over-bend radius was approximated using the following expression:

$$R_{ob} = \left[\frac{1}{R_{final}} + \frac{3\sigma_Y \left(1-v^2\right)}{tE} \right]^{-1} \tag{4.1}$$

where

R_{ob} = over-bend radius,

R_{final} = final radius after springback,

σ_Y = yield stress,

t = plate thickness,

E = elastic modulus, and

v = Poisson's ratio.

Assuming a linear distribution of strain through the thickness of the element, the maximum strain at the cross-section after over-bending and just before the onset of springback is given by the following:

$$\varepsilon_{max} = \kappa \frac{t}{2} = \frac{1}{R_{ob}} \frac{t}{2} \qquad (4.2)$$

where

ε_{max} = maximum strain in the over-bend cross-section, and

κ = plate curvature.

The resulting stress distribution is estimated using an elastic-perfectly plastic idealization of the material behaviour as given by

$$\sigma = \begin{cases} \varepsilon E & if \ |\varepsilon| < \varepsilon_y \\ \sigma_Y & if \ |\varepsilon| > \varepsilon_y \end{cases} \qquad (4.3)$$

where

ε_Y = yield strain.

The stress distribution above is used to determine the bending moment in the cross-section, which is also equal to the bending moment released during springback, M_{sb}. Assuming an entirely elastic springback, the equivalent elastic stress distribution is determined by classical beam theory, with the maximum springback stress given by

$$\sigma_{sb} = \frac{6M_{sb}}{t^2} \qquad (4.4)$$

where

σ_{sb} = maximum springback stress, and

M_{sb} = springback bending moment.

Figure 4.4 shows the residual stress distributions in the shell plating and frame flanges after springback. Good agreement was observed between the analytical results and the results obtained from DRDC Atlantic's residual stress calculator, K79 [11].

Through Thickness Residual Stresses (Flanges)

K79 — Analytical

Through Thickness Residual Stresses (Plating)

K79 — Analytical

Stress (MPa)

Stress (MPa)
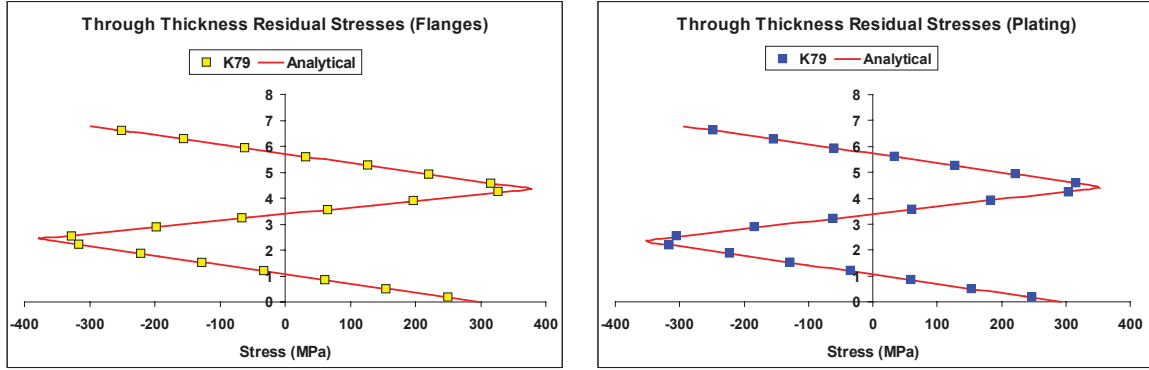
(a) Cylinder plating   (b) Frame flanges

Figure 4.4: Cold-bending residual stress distribution.

The effective stress-strain curves were computed by applying increments of compressive strain to the cross-section, and then calculating the resulting stress on the cross-section using the following equation:

$$\sigma_{eff} = \frac{\sum_{i=1}^{N} \sigma_i A_i}{\sum_{i=1}^{N} A_i} \tag{4.5}$$

where

σ_{eff} = effective stress,

σ_i = compressive stress in i^{th} incremental area but not less than $-\sigma_y$, and

A_i = area of the ith increment.

Figure 4.5 shows the stress-strain curves for the different specimen components. Unlike the shell plating and frame flanges, the frame webs were not cold-bent. Therefore, the frame web elements were assigned elastic-perfectly plastic material properties. The original design yield stress of 646 MPa was adjusted to 635 MPa [12], which was obtained from the tensile testing of the parent plate (see circumferential properties in Section 5.1.1)

The perfectly plastic portion of the stress-strain curve was maintained to a strain level of 2%. At this strain level, a hardening modulus was selected to achieve strain hardening to 1.5 times the yield stress at approximately 15% strain.

Stress Strain Curves
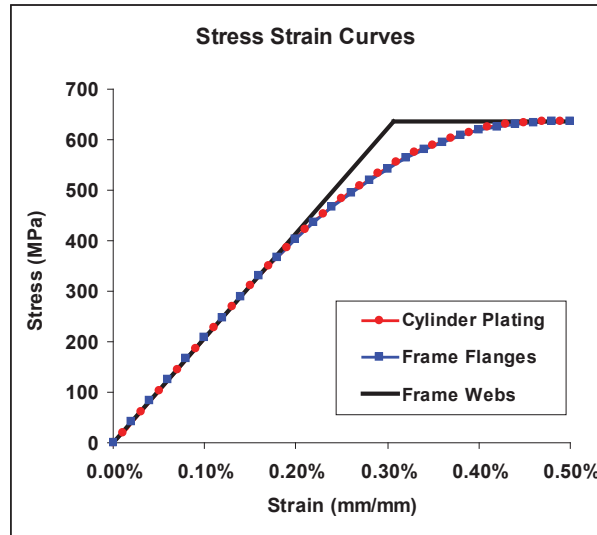
Figure 4.5: Material stress-strain curves.

4.5   Solution Techniques

The finite element analysis in VAST was performed using the nonlinear geometry and material option [13]. Because the load decreases with increasing deformation for post-peak analysis, the solution was obtained using the orthogonal trajectory (arc length) method. The solution consisted of 80 load increments, with an initial load increment of 0.4 MPa. VAST adjusted the size of the load increment as required to ensure convergence.

The BFGS method with arc-length [14] was used for the LS-DYNA analysis. Automatic time stepping was used to ensure convergence.

4.6   FE Results

Figure 4.6 shows contours of resultant displacement on the outer shell for the VAST analysis. At 3.94 MPa (Figure 4.6a), the largest displacements occur in the vicinity of the weld seam. At the failure load of 8.02 MPa (Figure 4.6b), localized deformation patterns begin to form near the ends, with the largest displacements occurring between the first and third frames from the fixed end, and the first and second frames from the loaded end. The plot at the post-peak load (Figure 4.6c) shows that failure occurs between the first and third frames from the fixed end. Figure 4.6d shows significant stiffener deformations at 6.17 MPa, indicating that the deformation mode is not interframe, but rather of the overall buckling type. An interframe buckling mode would be characterized by alternating bulges in the plates between frames.

(a) 3.94 MPa

(b) 8.02 MPa – Failure

(c) 6.17 MPa – post-peak

(d) Post-peak stiffener plot
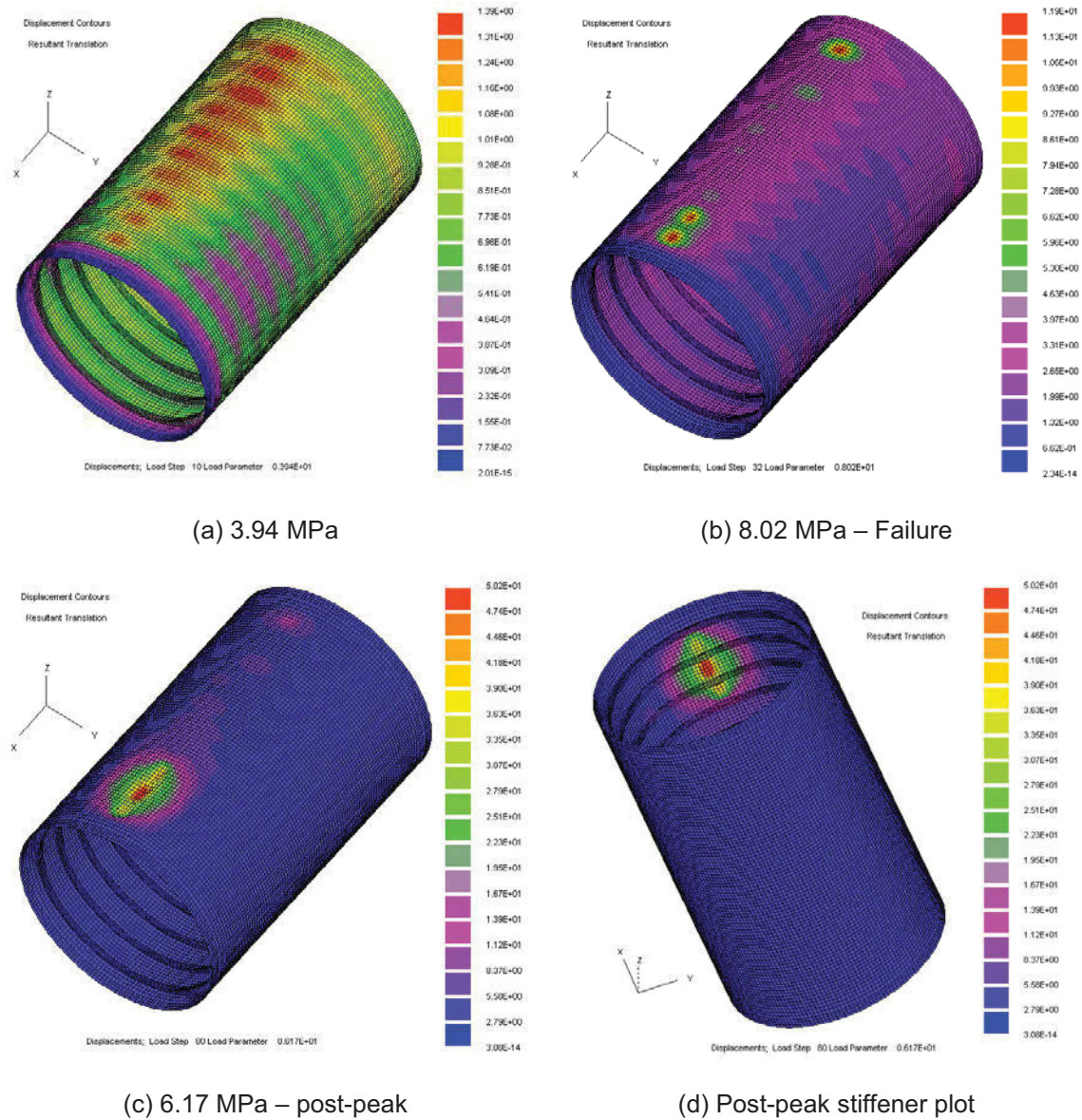
Figure 4.6: Resultant displacement contour plots – VAST analysis.

Figures 4.7 to 4.10 are LS-DYNA resultant displacement plots. From the examination of Figures 4.8 and 4.9, it is evident that the failure location is different from that of the VAST analysis. The failure is shown to occur between the third and fifth frame from the loaded end near the weld seam. The displacements in Figure 4.9 indicate that the failure mode includes a significant interframe buckling component as evidenced by alternating plate bulges. Figure 4.9 shows the stiffener deflections in the failure region. It is clear that there is significant stiffener deformation, indicating that the failure mode includes overall buckling characteristics. The failure mode thus appears to be of a mixed mode.

Time = 0.37378
Contours of Resultant Displacement
min=0, at node# 12310
max=1.32244, at node# 10316
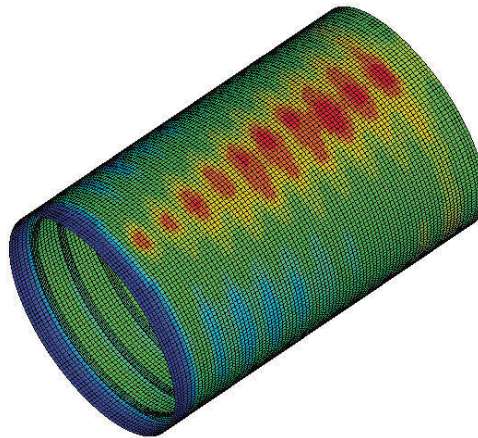
Fringe Levels
1.322e+00
1.190e+00
1.058e+00
9.257e-01
7.935e-01
6.612e-01
5.290e-01
3.967e-01
2.645e-01
1.322e-01
0.000e+00

Figure 4.7: LS-DYNA displacement plot – 3.73 MPa.

Time = 0.7864
Contours of Resultant Displacement
min=0, at node# 12310
max=11.2501, at node# 10406
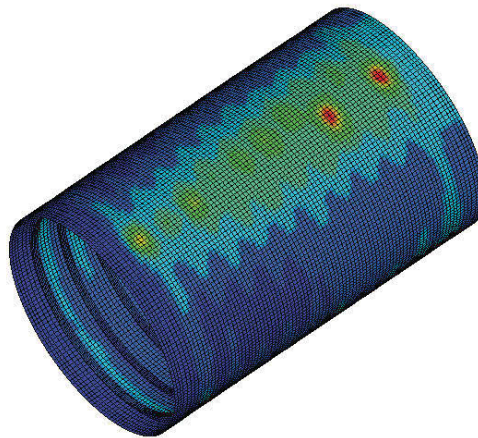
Fringe Levels
1.125e+01
1.013e+01
9.000e+00
7.875e+00
6.750e+00
5.625e+00
4.500e+00
3.375e+00
2.250e+00
1.125e+00
0.000e+00

Figure 4.8: LS-DYNA displacement plot – 7.86 MPa (failure).

Time = 0.54449
Contours of Resultant Displacement
min=0, at node# 12310
max=49.6987, at node# 9994
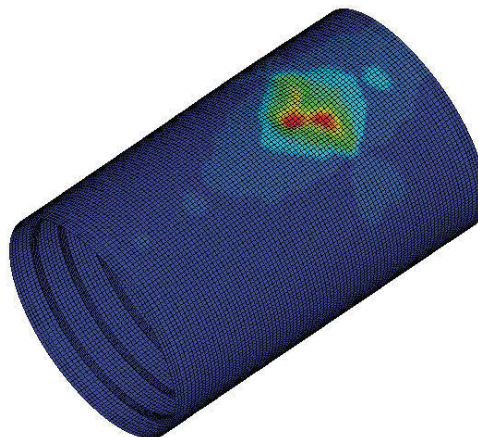
Fringe Levels
4.970e+01
4.473e+01
3.976e+01
3.479e+01
2.982e+01
2.485e+01
1.988e+01
1.491e+01
9.940e+00
4.970e+00
0.000e+00

Figure 4.9: LS-DYNA displacement plot – 5.44 MPa (post-peak).
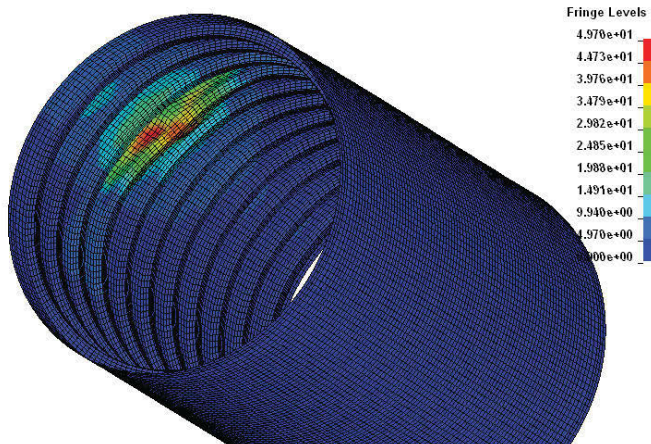
Figure 4.10: LS-DYNA displacement plot – post-peak stiffener.

Figures 4.11a and 4.11b show the load versus shortening curves for nodes 10591 and 1440, located at the cylinder end at 0° and 180° from the seam weld, respectively. The structural response obtained from both models is nearly identical up to a load of 4.1 MPa. At higher loads, the LS-DYNA analysis appears to exhibit a more flexible response than the VAST analysis. Since the failure locations are different for the two analyses, the load versus shortening response would not be expected to be identical.
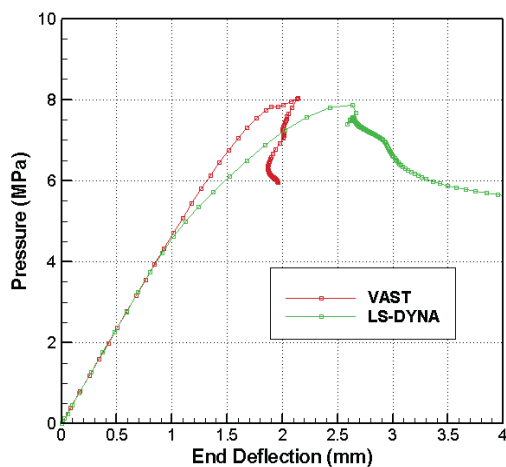
(a) 0°from seam
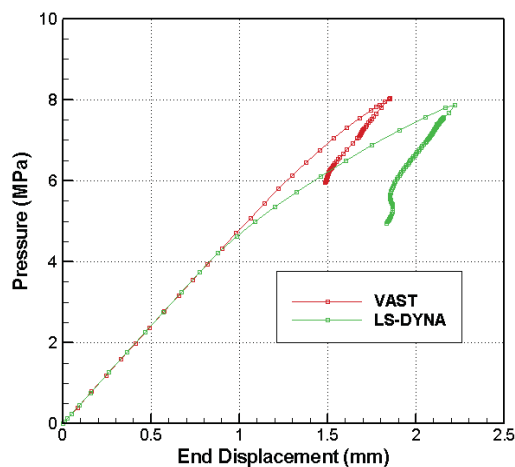
(b) 180° from seam

Figure 4.11: Load shortening curves for FE analyses.

There are a number of model differences between the VAST and LS-DYNA analyses (such as the shell element formulation, and the convergence criteria and determination) that could account for

the differences in results. Regardless, the failure loads are within 2%, and the failure prediction is along the weld seam for both FE codes.

An additional analysis consideration involves initial imperfections. The imperfections incorporated in the analyses above were obtained before the specimen end caps were welded into place. End cap welding could alter the imperfection pattern and thereby potentially the failure load and mode. These effects were not reflected in the analyses.

5   Test Results

5.1   Coupon Testing

5.1.1   Overview

Coupon testing was conducted to determine the yield strength, tensile strength, Young's modulus and Poisson's ratio of the HY80 parent plate material. Coupons were taken from the plates in the directions corresponding to the longitudinal and hoop directions on the fabricated specimens. Three coupons from each orientation were tested from the plate used to fabricate Specimen A. One coupon from each direction was tested from the plate material used to fabricate Specimens B and C.

A 50.8-mm (2-inch) gauge length extensometer was attached to each coupon to determine Young's modulus, yield strength and tensile strength. A displacement rate of 0.23 mm/min (0.009 in/min) was used until the load started to drop, at which point the test was paused, the extensometer was removed and the test was resumed at an increased rate of 2.3 mm/min (0.09 in/min). Nominal coupons dimensions are detailed in Figure 5.1 below.
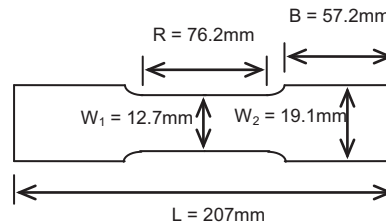
Figure 5.1: Nominal tension coupon dimensions.

Young's modulus for each coupon was determined by averaging the results from three load cycles wherein the coupon was loaded to 26.7 kN (6,000 lb), within the proportional limit, and then unloaded to near zero load. Young's modulus from each load cycle was determined using the method of least squares as specified in ASTM E111 [15].

Yield strength was determined using the 0.2% offset method as outlined in ASTM E8 [16], and tensile strength corresponded to the highest stress value achieved during testing.

Poisson's ratio was calculated as outlined in ASTM E132 [17]. In addition to the extensometer, biaxial strain gauges were affixed onto both sides of the coupon to determine the negative ratio of transverse to longitudinal strain in the elastic region.

The complete coupon test procedure and drawings are included in Annex J.

5.1.2 Coupon Test Results

A summary of the test results are provided in Tables 5.1 to 5.3 and Figures 5.2 and 5.3. Detailed coupon test results are included in Annex K.

Table 5.1: Longitudinal direction coupon test results.

Specimen/Coupon ID	Yield Strength, 0.2% Offset (MPa)	Tensile Strength (MPa)	Young's Modulus (GPa)
Specimen A			
- P1L1	644	719	209
- P1L2	645	717	197
- P1L3	644	717	195
- Mean	644	718	200
Specimen B			
- P2L1	638	718	204
Specimen C			
- P3L1	635	720	205

Table 5.2: Circumferential direction coupon test results.

Specimen/Coupon ID	Yield Strength, 0.2% Offset (MPa)	Tensile Strength (MPa)	Young's Modulus (GPa)
Specimen A			
- P1C2	634	720	194
- P1C3	637	722	204
- P1C4	635	721	198
- Mean	635	721	199
Specimen B			
- P2C2	632	717	199
Specimen C			
- P3C2	634	720	203

Table 5.3: Coupon test results for Poisson's Ratio.

Specimen/Coupon ID	Poisson's Ratio
Specimen A - P1C1	0.279
Specimen B - P2C1	0.279
Specimen C - P3C1	0.276
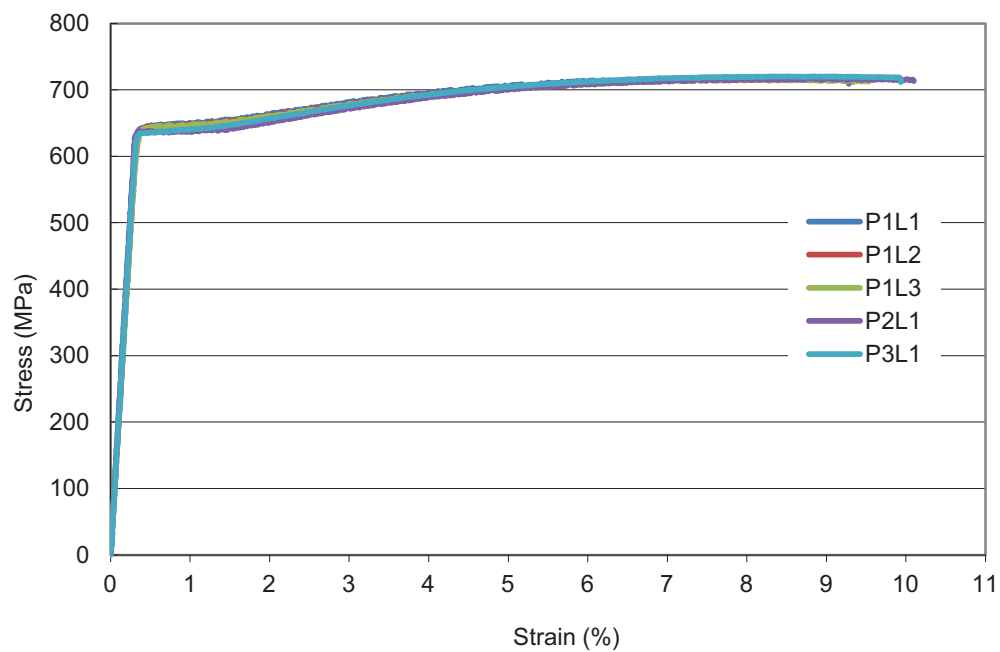
Figure 5.2: Stress vs. strain curves for axial direction coupon test results.
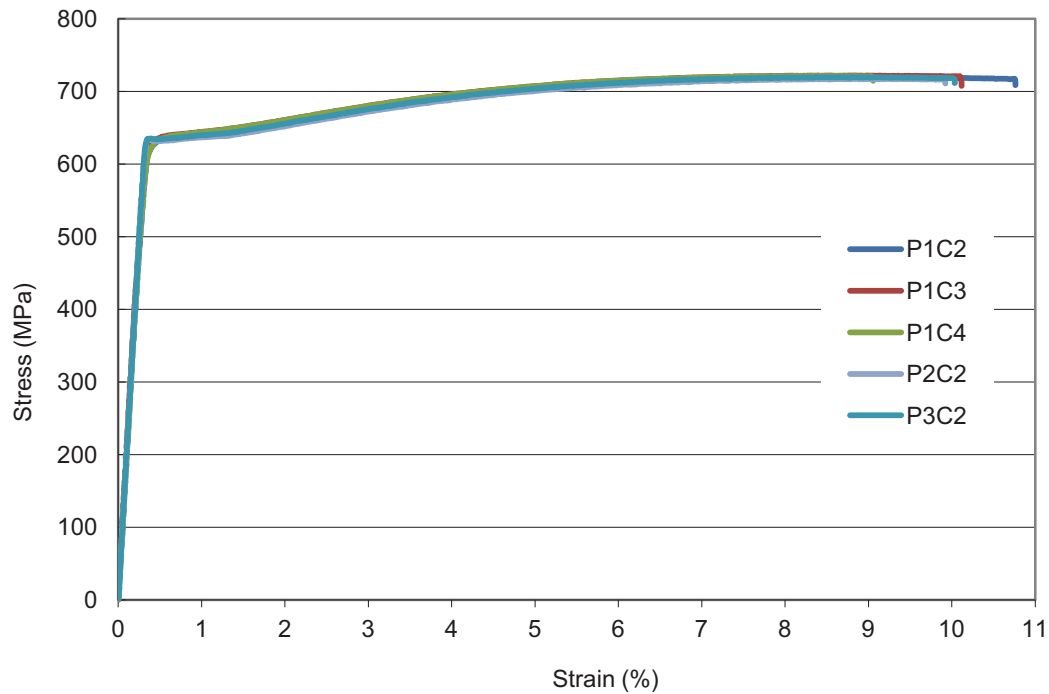
Figure 5.3: Stress vs. strain curves for hoop direction coupon test results.

The results show good agreement between the material properties obtained from each parent plate. Additionally, there is good agreement between the strength properties obtained in each direction (i.e. longitudinal and circumferential), indicating that the isotropic nature of the material was retained following plate forming.

5.2 Collapse Testing

5.2.1 Deepwater Experimental Chamber

C-FER's Deepwater Experimental Chamber (DEC; see Figures 5.4 and 5.5) was used for the collapse testing. The chamber has a tested pressure capacity of 62 MPa, with an inside diameter of 1.22 m and an overall inside length of 10.3 m. The DEC was used in conjunction with state-of-the-art computer hardware, software and signal conditioning equipment to control and monitor each test.
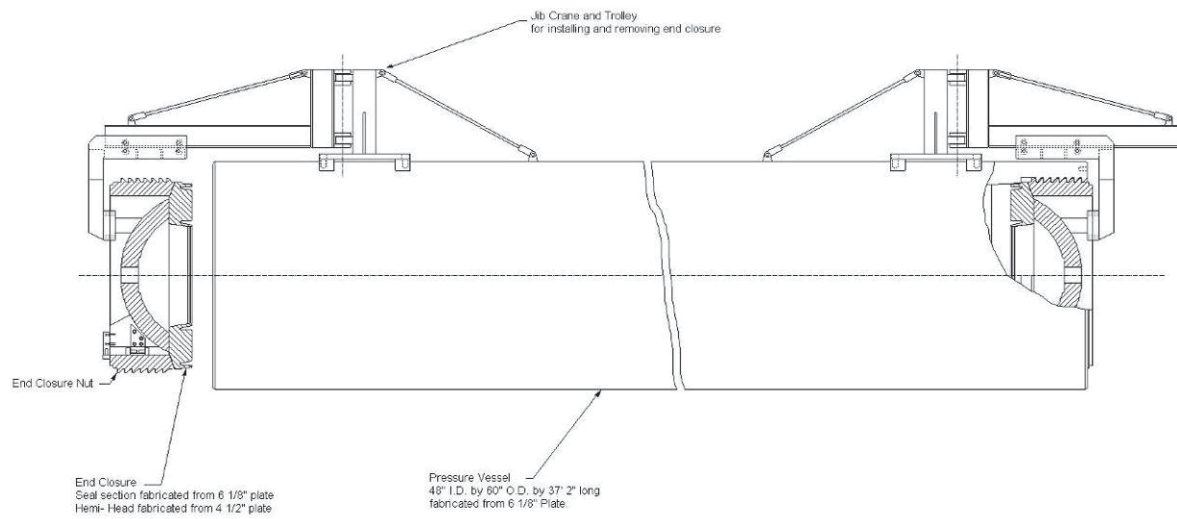
Figure 5.4: Schematic of C-FER's deepwater experimental chamber.

Figure 5.5: Photograph of C-FER's deepwater experimental chamber.

5.2.2   Instrumentation and Test Procedure

DRDC Atlantic provided C-FER with an instrumentation plan for each specimen, which clearly defined the type, location and naming convention for all of the applied strain gauges.   This instrumentation plan is included in Annex L.

For Specimen A, 12 internally located uniaxial gauges, oriented in the circumferential direction, were placed on the flange of T-frame 6 and spaced at 30° arc length intervals.   Additional circumferentially oriented uniaxial gauges were placed on each of the other T-frame flanges at 0°. External biaxial strain gauges were affixed to the shell mid-bay between T-frames 1 and 2 and T-frames 10 and 11, spaced at 60° arc length intervals and aligned in the longitudinal and circumferential directions.   An additional 24 biaxial gauges were placed mid-bay between T-frames 5 and 6, spaced 15° apart and aligned with the longitudinal and circumferential directions.

For Specimens B and C, 12 internally located uniaxial gauges, oriented in the circumferential direction, were placed on the flange of T-frame 6 at 30°, 15° and 345° arc length intervals. Circumferentially oriented uniaxial gauges were also placed on each of the other T-frame flanges at 0°. Seven rosette gauges and two internally located biaxial gauges were placed mid-bay between T-frames 5 and 6, which were also mirrored on the external shell surface. Additionally, a single biaxial gauge was placed between T-frames 4 and 5 and oriented at 0°. Eleven externally located biaxial gauges were oriented in 30° arc length increments between 30° and 330°, mid-bay between T-frames 5 and 6.   Two additional gauges were located on the outside shell surface, mid-bay between T-frames 5 and 6 and oriented at 15° and 345°, respectively.

Two pressure transducers (with ±0.05% accuracy) were used to monitor the collapse tests: one to monitor the externally applied (DEC) pressure and a second to monitor the internal specimen pressure.   Figure 5.6 shows the arrangement in the DEC.   For the test on Specimen A, 2,000-psi transducers were used to monitor both the DEC pressure and internal specimen pressure.   For the tests on Specimens B and C, a 5,000-psi transducer was used to monitor the DEC pressure and a 2,000-psi transducer was used to monitor the internal specimen pressure.

All strain gauge and pressure data was recorded at a read rate of 100 Hz.
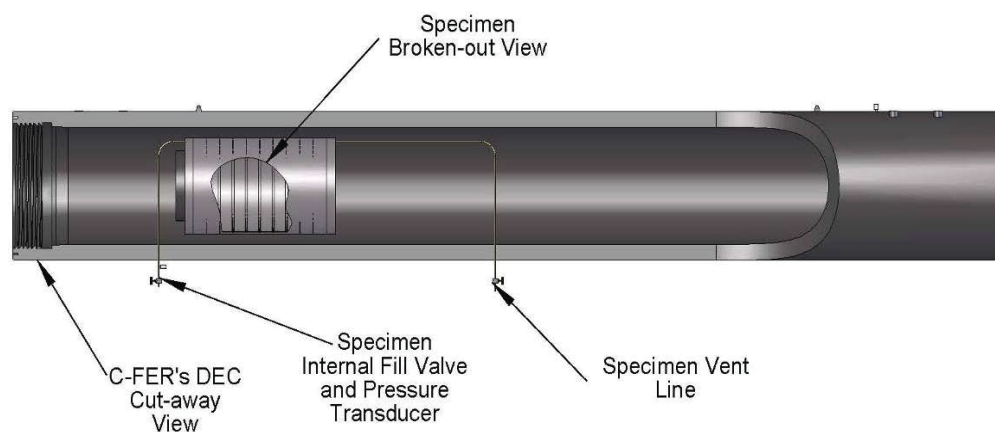
Figure 5.6: Collapse testing schematic.

Inside the DEC, the specimen rested on the bottom of the vessel, supported by a pair of "tabs" that were welded onto each end cap, so the cylinder wall was not in contact with the vessel wall.

The general test procedure involved simultaneously elevating the specimen internal and external pressure, and then loading the specimen, with net external pressure, by slowly releasing the specimen internal pressure. With the specimen vent valve closed, the DEC and specimen were pressurized simultaneously while keeping the differential pressure to a minimum. Once the DEC pressure reached 6.89 MPa (1,000 psi), the pump was stopped and the vessel was visually inspected for leaks. After this leak inspection, testing was resumed, and the DEC and specimen were pressurized until they reached a pressure greater than the predicted collapse pressure but not greater than 2,000 psi. The pump was then stopped, and the DEC and specimen were isolated. The specimen internal pressure vent valve was opened and water was allowed to bleed out at a controlled rate until specimen collapse occurred.

A detailed test procedure was prepared for DRDC Atlantic's review prior to testing and is available in Annex M.

5.2.3   Collapse Test Results

5.2.3.1   Specimen A – Baseline

Specimen A collapsed at a net differential pressure of 7.75 MPa. Following testing, the specimen displayed multiple permanent buckles, primarily located between T-frames 5, 6 and 7 and extending between approximately 75° and 225° (i.e. 75° CW and 135° CCW with respect to 0° from End A of the cylinder).

The post-collapse photos (Figure 5.7) and strain gauge data (Figures 5.8 to 5.15) indicate that the failure mode was interframe collapse. It should be noted that failed strain gauges are not included in the figures.

The onset of yielding of the shell plating and T-frames, which occurred well before specimen collapse, was determined using the procedure developed by MacKay [18]. Using this approach, yielding is assumed to occur if the calculated equivalent von Mises stress reaches the yield strength as determined from tensile coupon tests on the parent material. In determining the equivalent von Mises stress, it was assumed that membrane shear stresses are negligible and thus the longitudinal and circumferential stresses, as determined from the corresponding strain measurements, are effectively principal stresses.

Based on the above procedure, initial yielding in the outer shell plate was estimated to have occurred mid-bay between T-frames 10 and 11 at 0° at approximately 69% of the collapse pressure. However, subsequent shell plate yielding was concentrated mid-bay between T-frames 5 and 6 at 15° and 270°, which exceeded the yield strength almost simultaneously at approximately 74% of collapse pressure. By the onset of collapse, the majority of the stresses calculated from the shell mid-bay strain gauges exceeded the yield strength.

Pre-collapse T-frame yielding was evident at approximately 93% of the collapse load on T-frame 6 at 240°. Subsequent T-frame yielding was exclusively post-collapse.
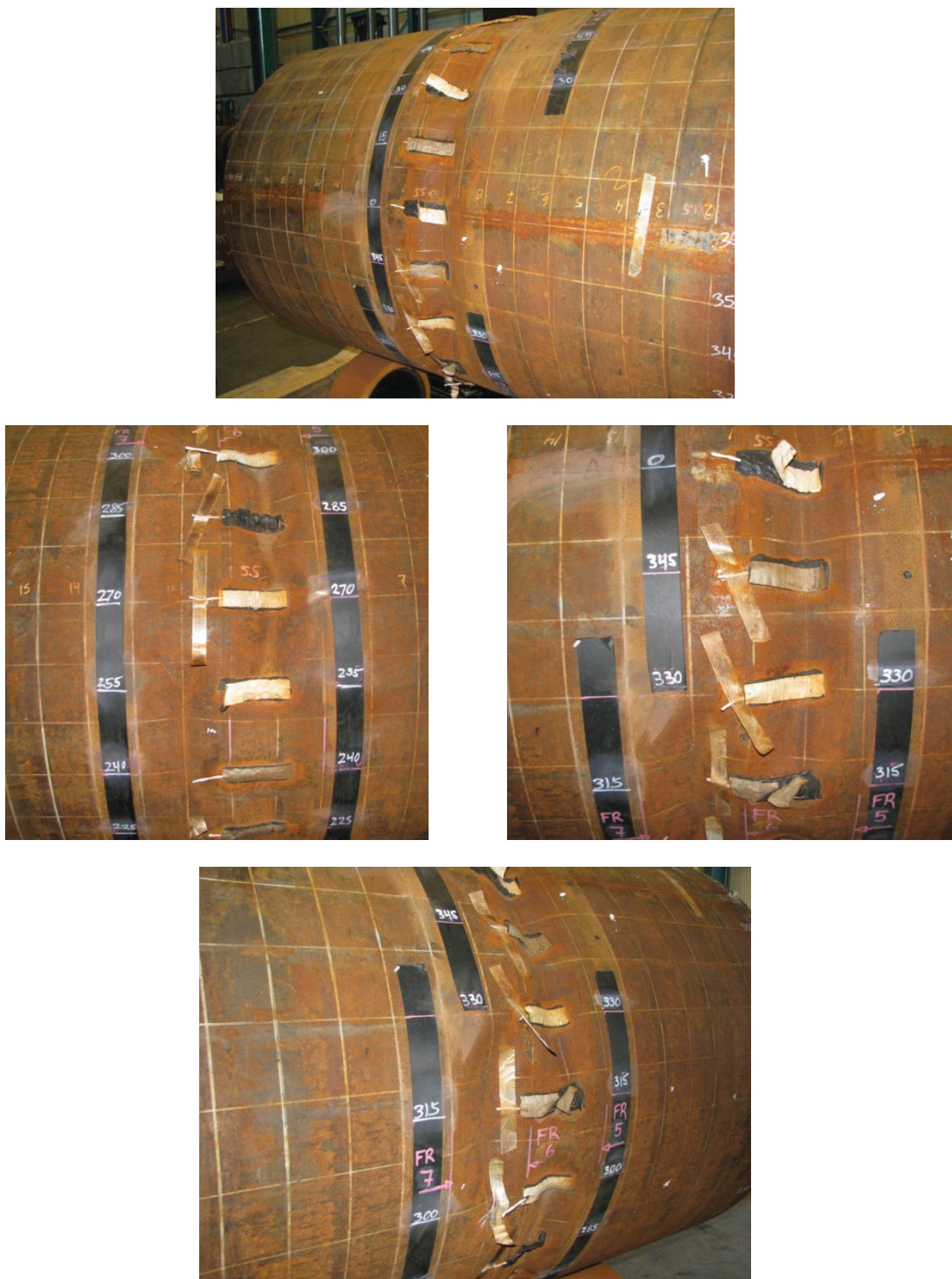
Figure 5.7: Post-collapse buckled configuration of Specimen A – Baseline.
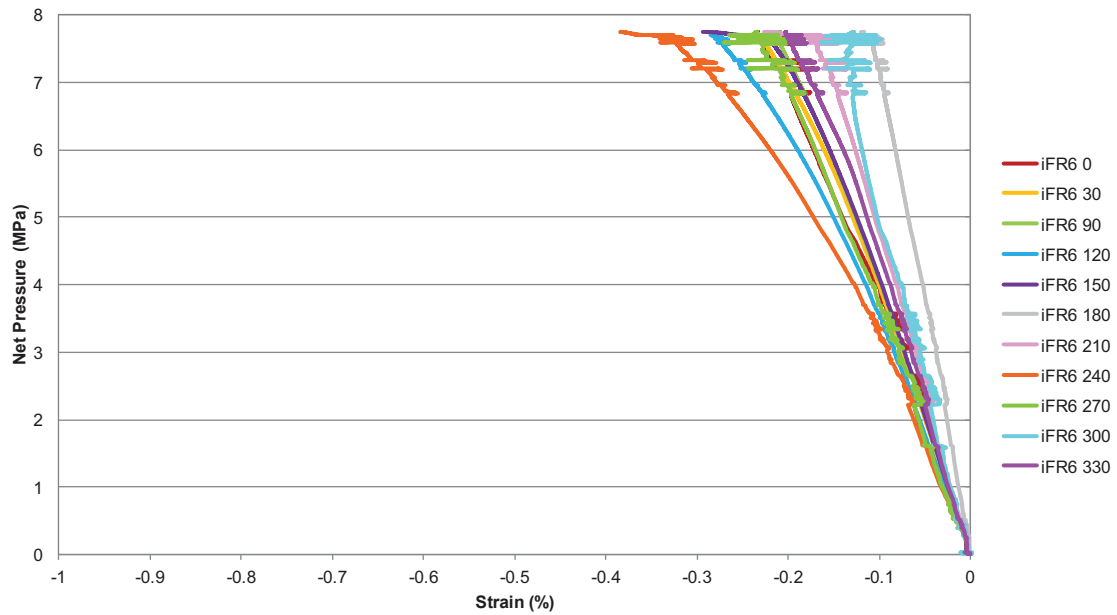
*Figure 5.8: Circumferential strains on the flange of
T-frame 6 of Specimen A – Baseline.*
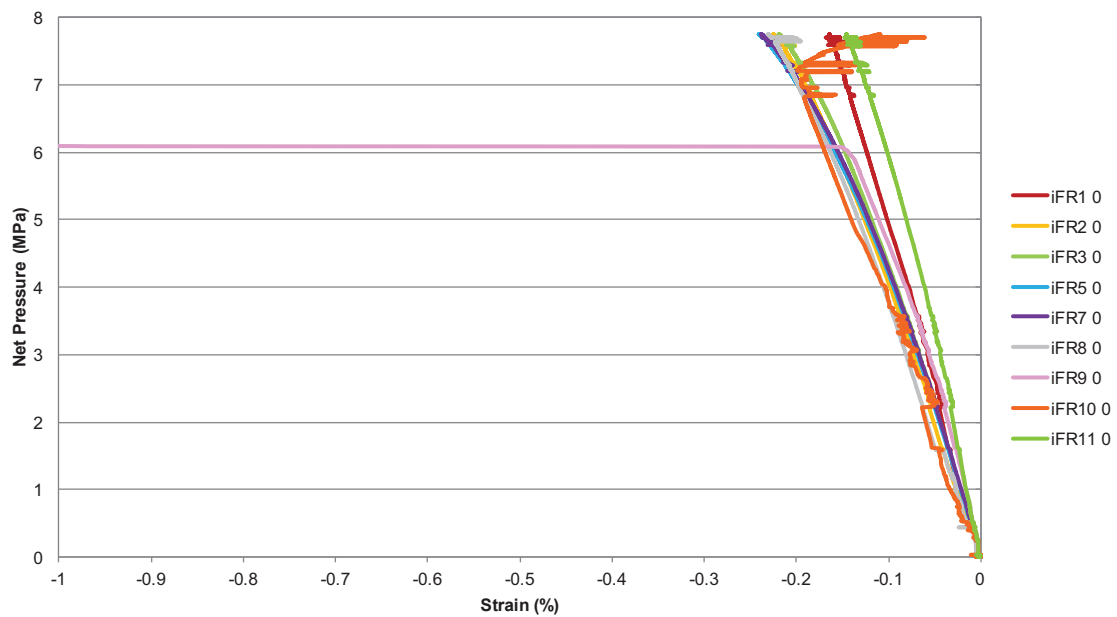
*Figure 5.9: Circumferential strains on the flanges of
T-frames 1-5 and 7-11 of Specimen A – Baseline.*
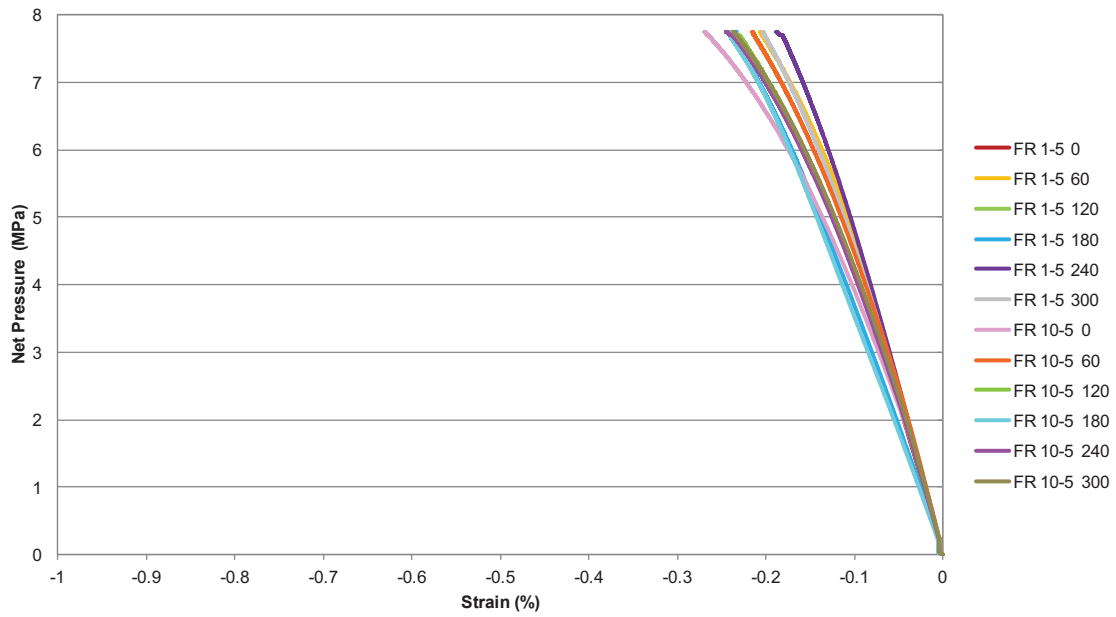
Figure 5.10: Longitudinal strains mid-bay between
T-frames1-2 and 10-11 for Specimen A – Baseline.
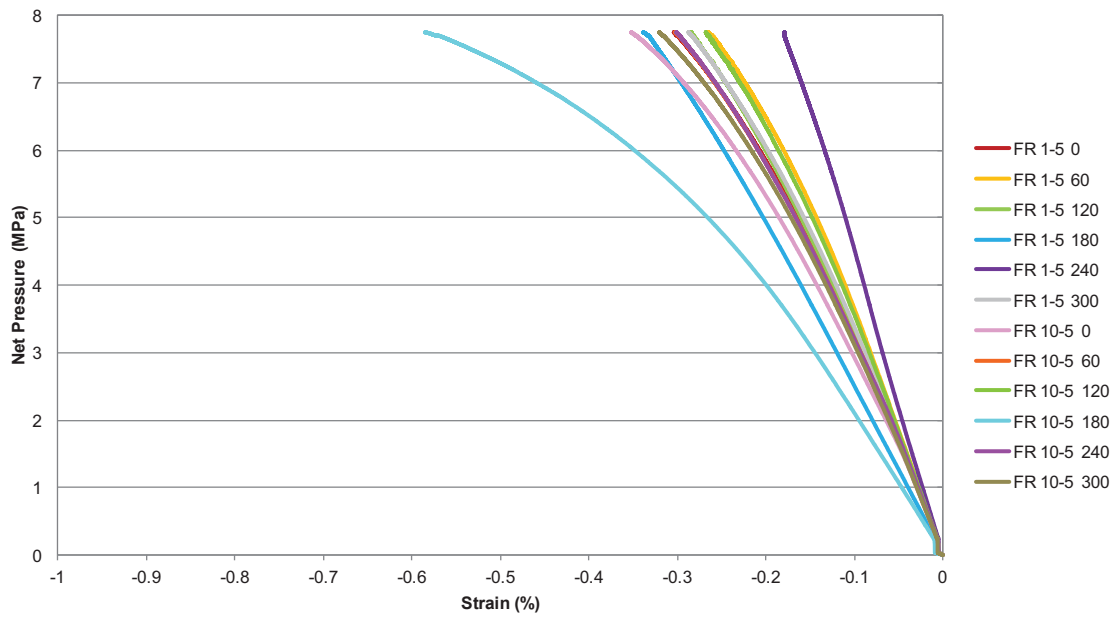
Figure 5.11: Circumferential strains mid-bay between
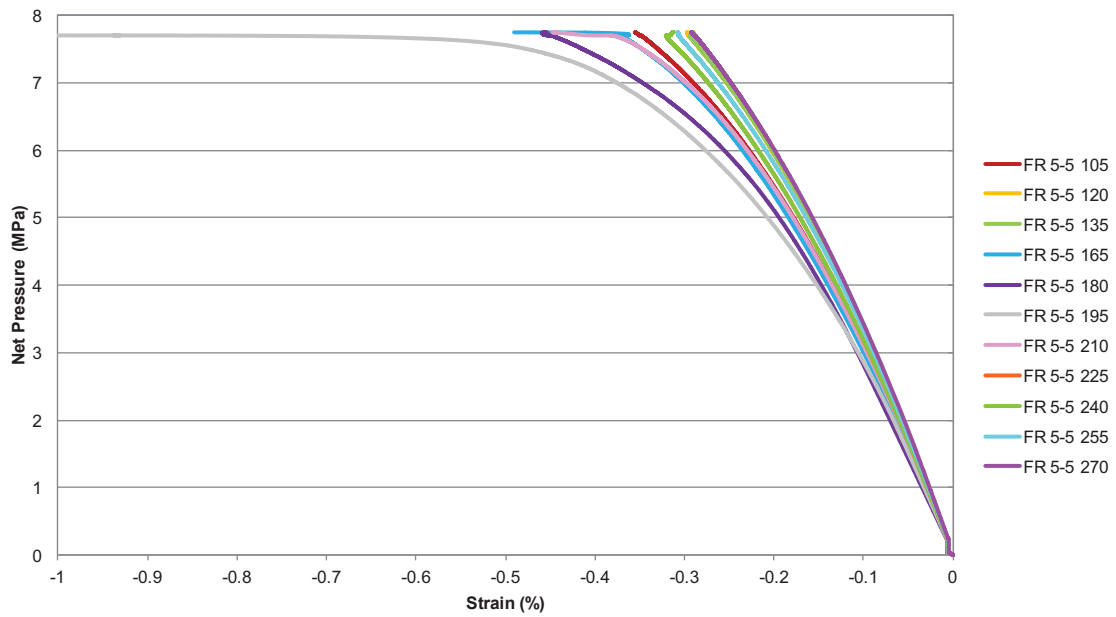*T-frames 1-2 and 10-11 for Specimen A – Baseline.*
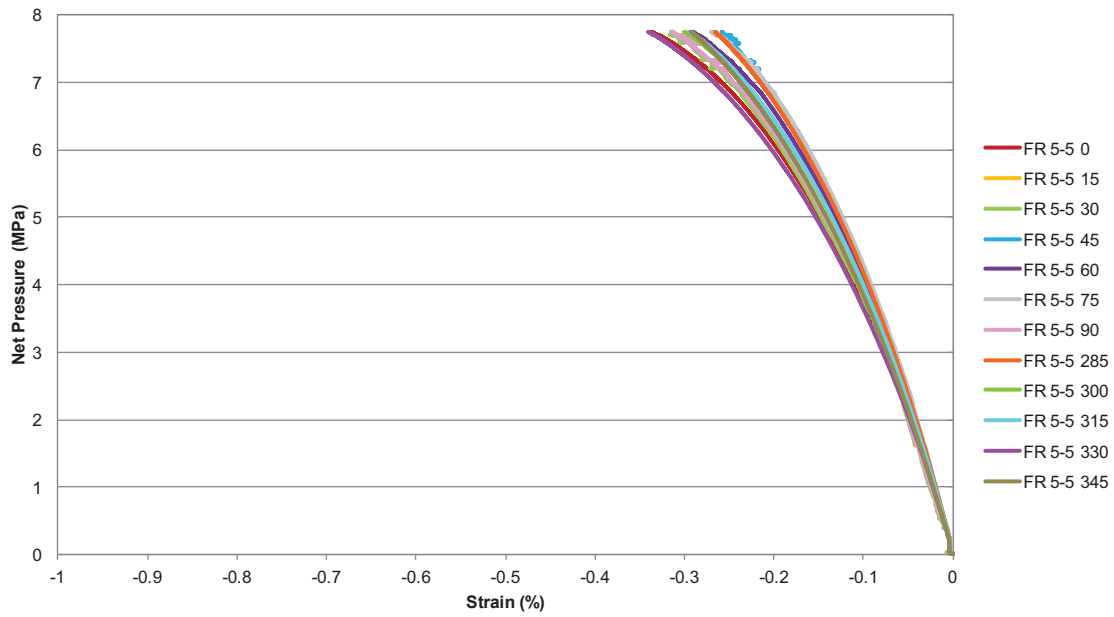
*Figure 5.12: Longitudinal strains mid-bay between
T-frames 5-6 and 0°±90° for Specimen A – Baseline.*
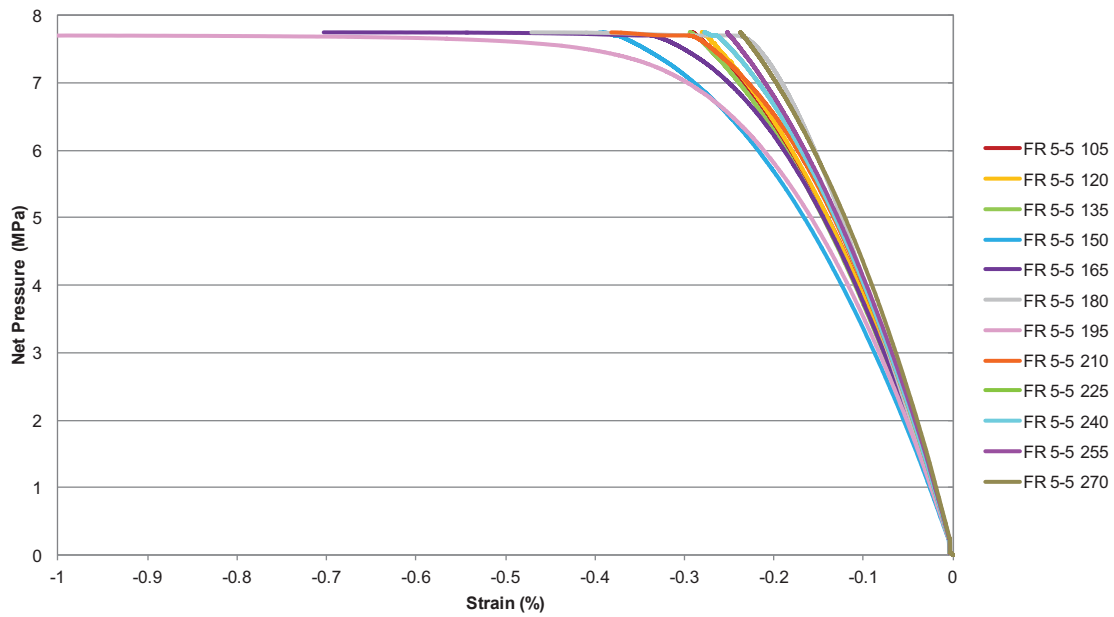
*Figure 5.13: Longitudinal strains mid-bay between
T-frames 5-6 and 180°±90° for Specimen A – Baseline.*
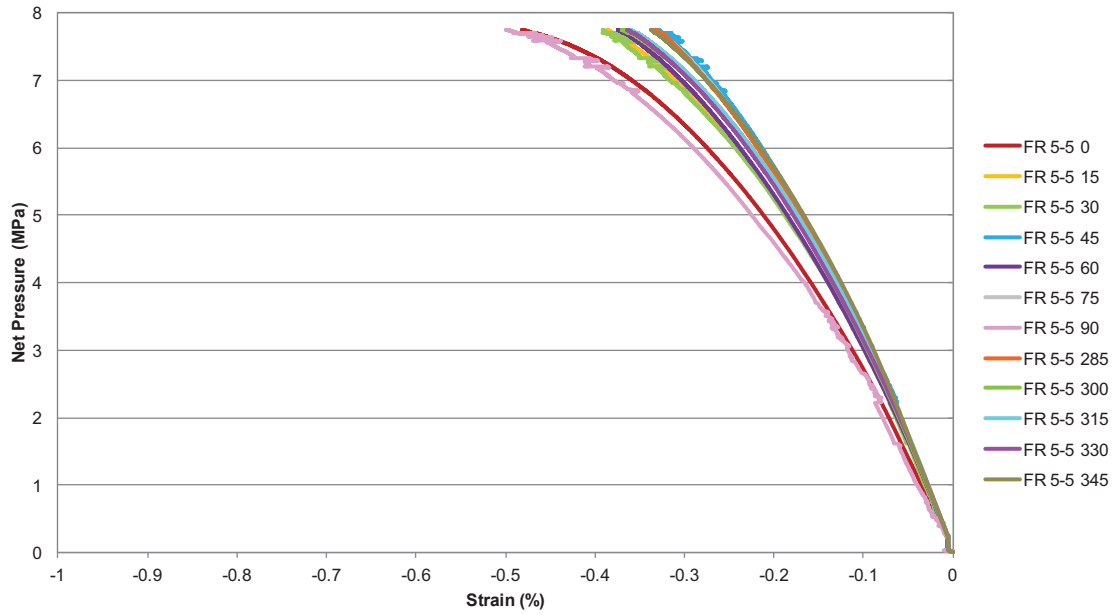
Figure 5.14: Circumferential strains mid-bay between
T-frames 5-6 and 0°±90° for Specimen A – Baseline.

Figure 5.15: Circumferential strains mid-bay between
T-frames 5-6 and 180°±90° for Specimen A – Baseline.

5.2.3.2   Specimen B – Damaged

Specimen B sustained a net differential pressure of 7.31 MPa. The specimen experienced interframe collapse with the initial buckle occurring in the region of simulated corrosion. Post-test photos are provided in Figure 5.16.

Based on the strain gauge data, initial shell plate yielding was estimated to have occurred 30 mm from the centre of the corrosion area, mid-bay between T-frames 5 and 6 at approximately 53% of the collapse pressure. The majority of pre-collapse shell plate yielding was in or adjacent to the simulated corrosion area. T-frame yielding did not occur until approximately 92% of the collapse load on T-frame 6 at 330°. The majority of T-frame yielding occurred post-collapse.

The pressure-strain plots for Specimen B are provided in Figures 5.17 to 5.24. It should be noted that failed strain gauges are not included in the figures.
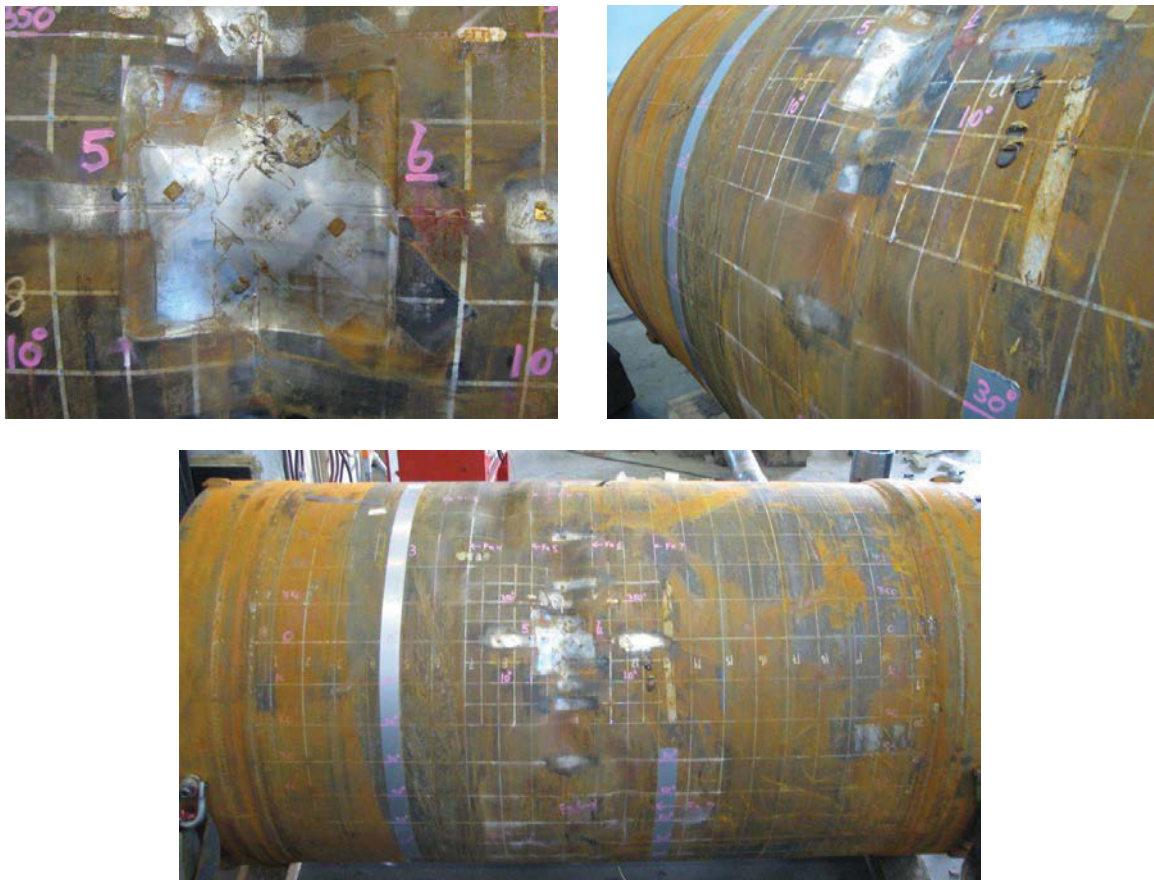
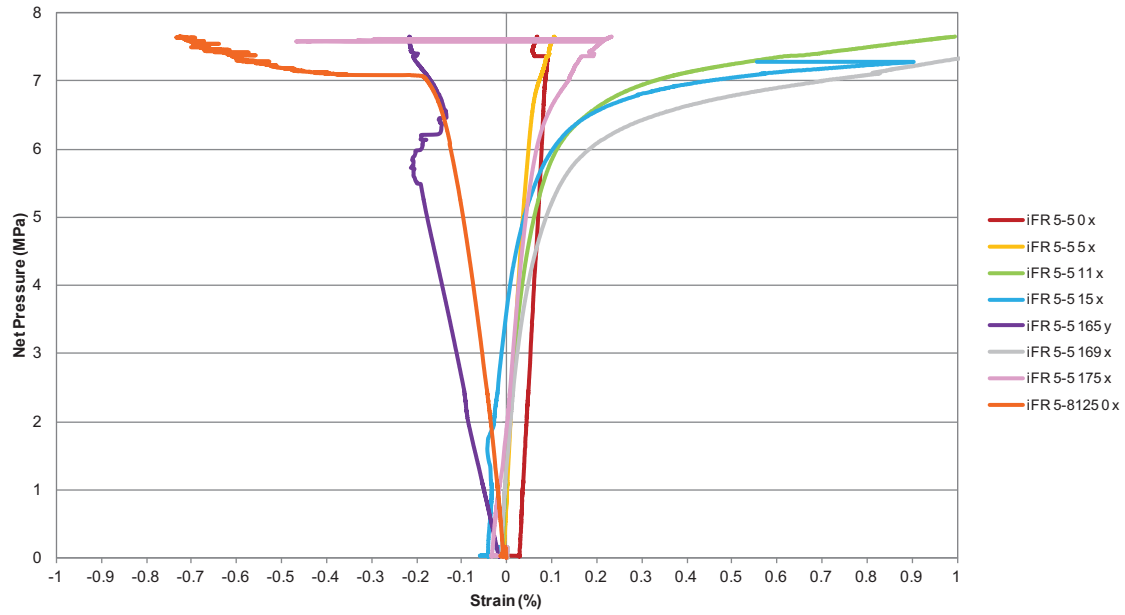*Figure 5.16: Post-collapse photos of cylinder Specimen B – Damaged.*
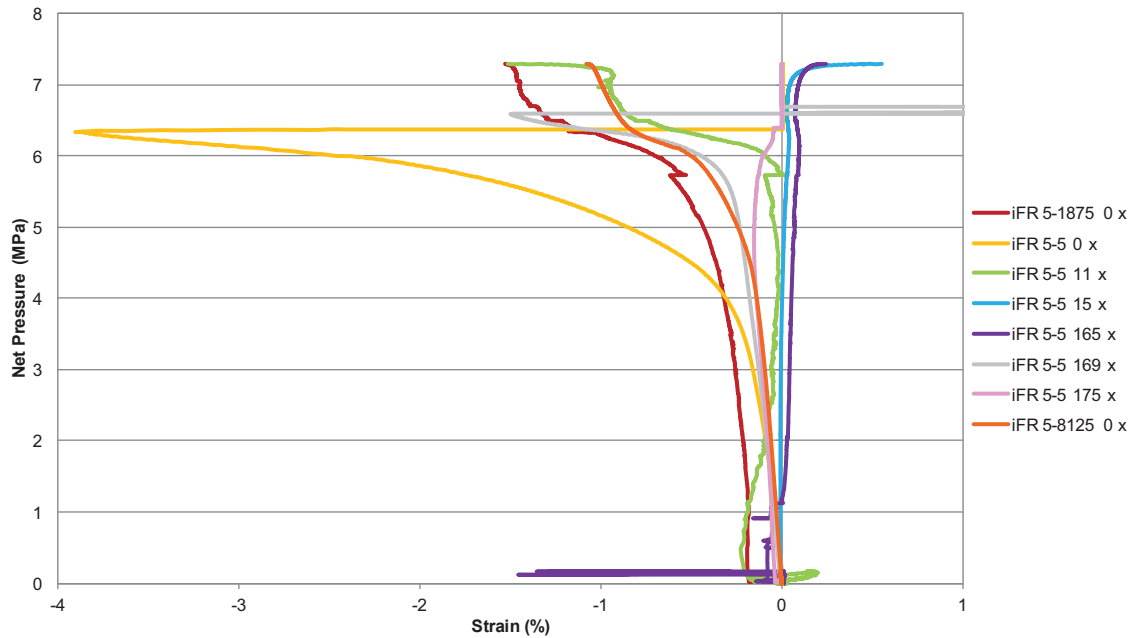
*Figure 5.17: Longitudinal internal shell strains between
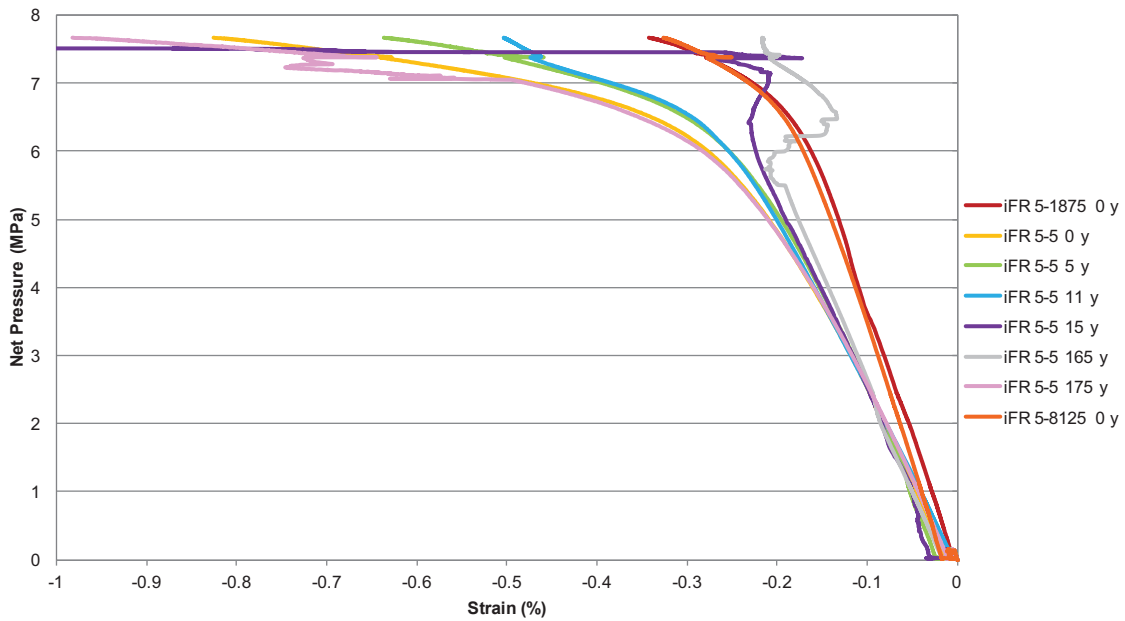T-frames 5 and 6 for Specimen B – Damaged.*
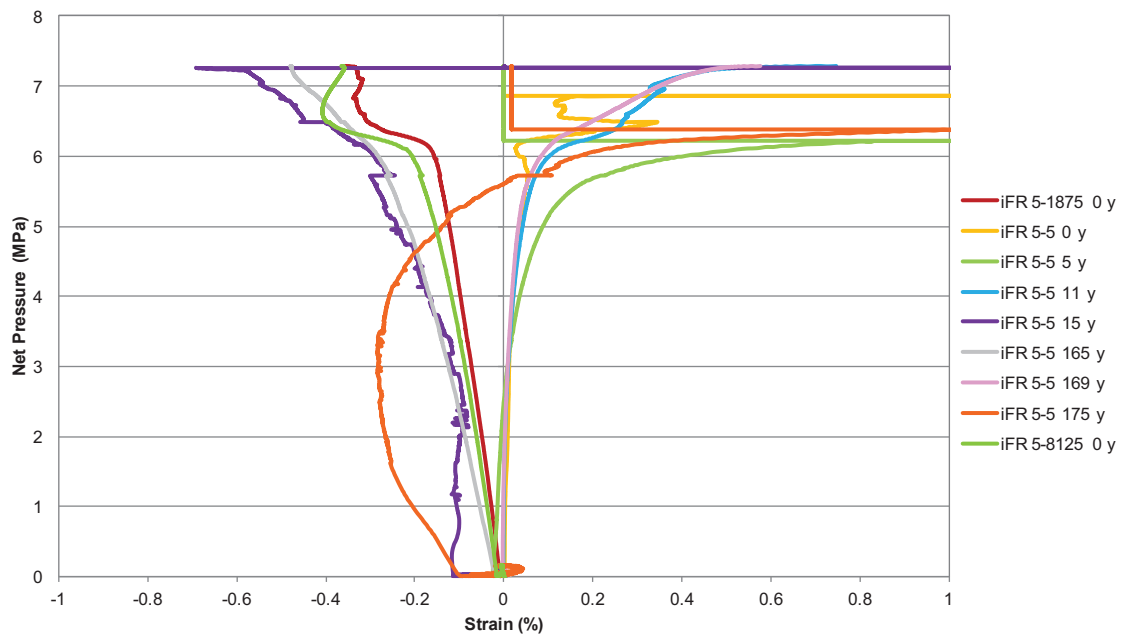
*Figure 5.18: Circumferential internal strains between
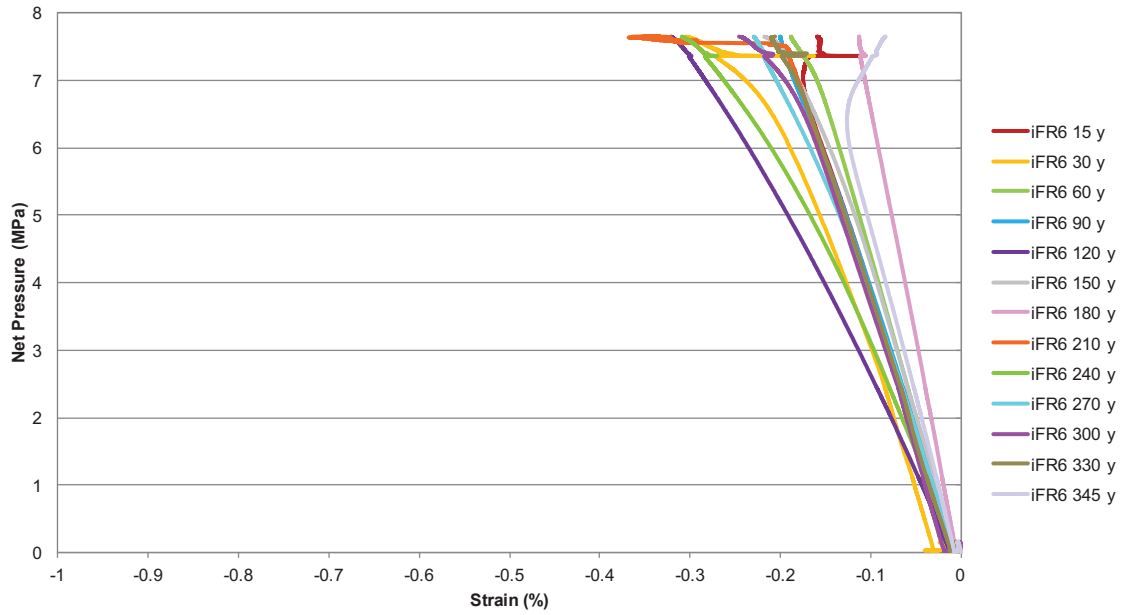T-frames 5 and 6 for Specimen B – Damaged.*
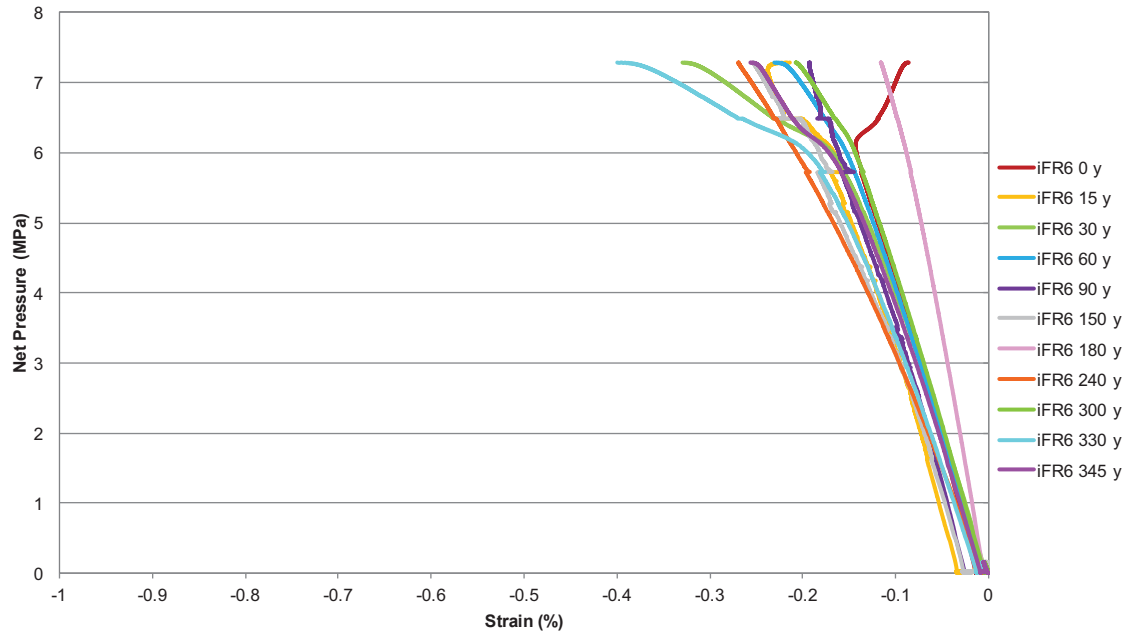
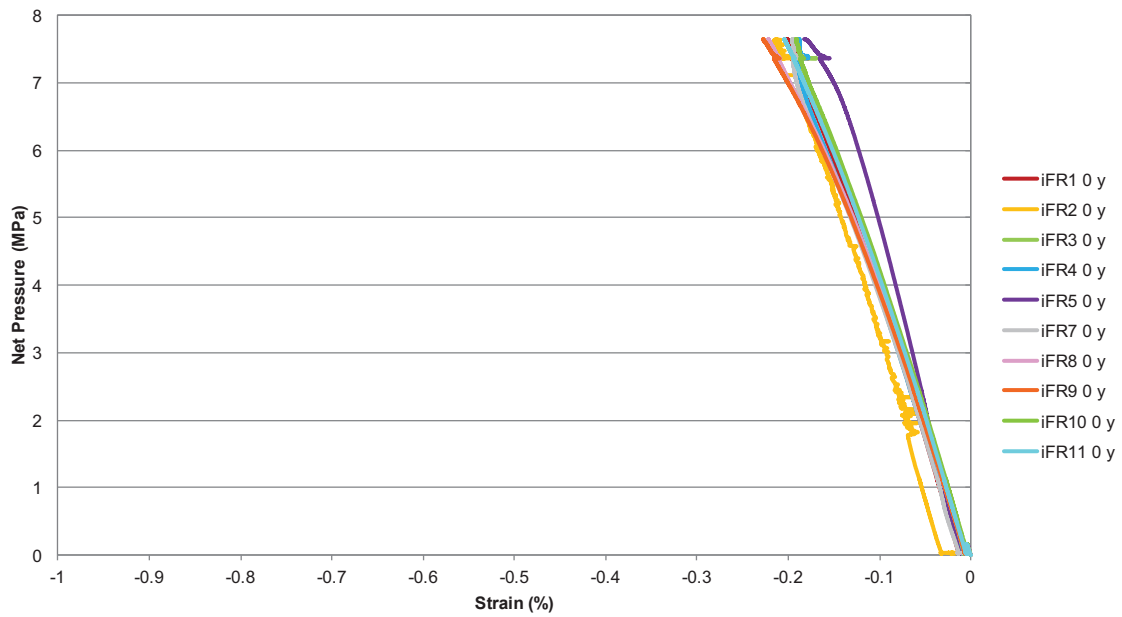*Figure 5.19: Circumferential internal strains around the flange of T-frame 6 for Specimen B – Damaged.*
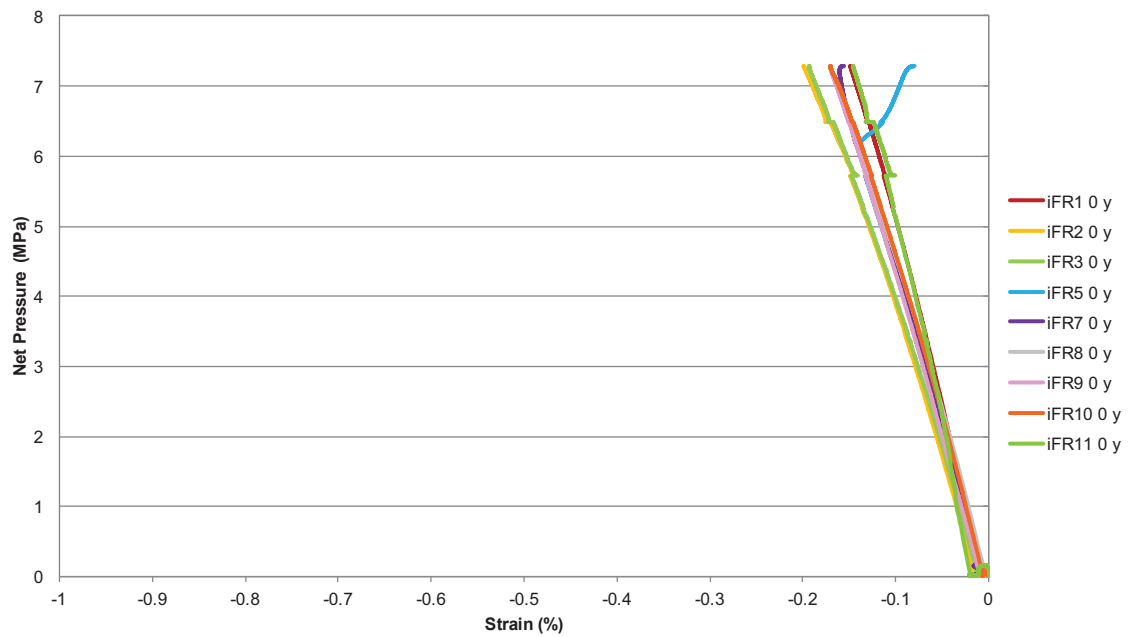
Figure 5.20: Circumferential internal strains on the flange of T-frames 1-5 and 7-11 at 0° for Specimen B – Damaged.
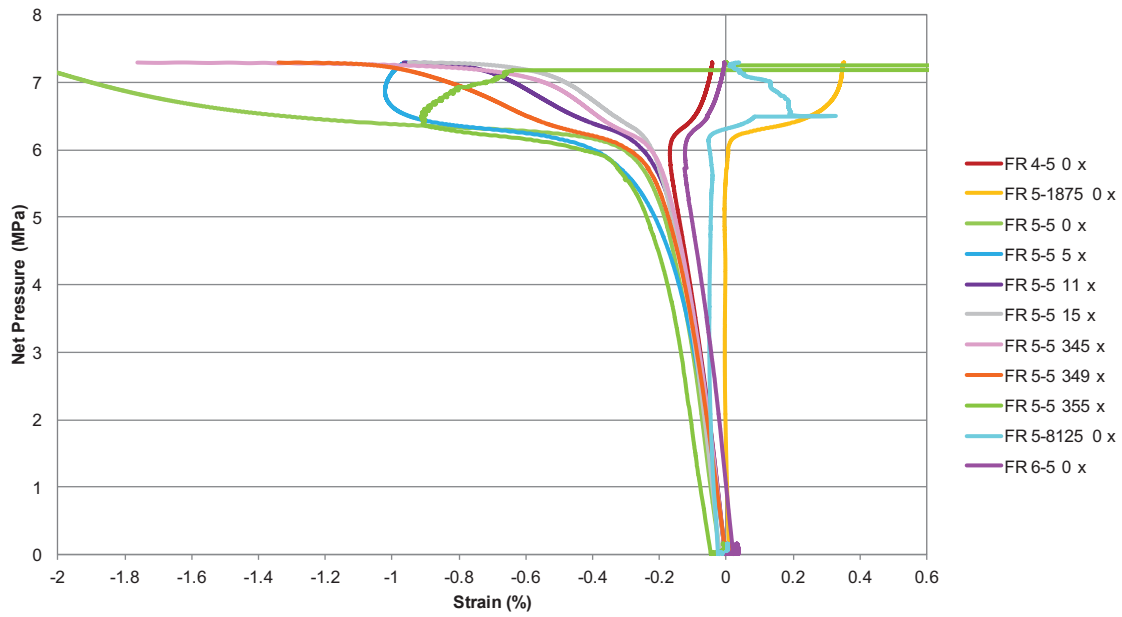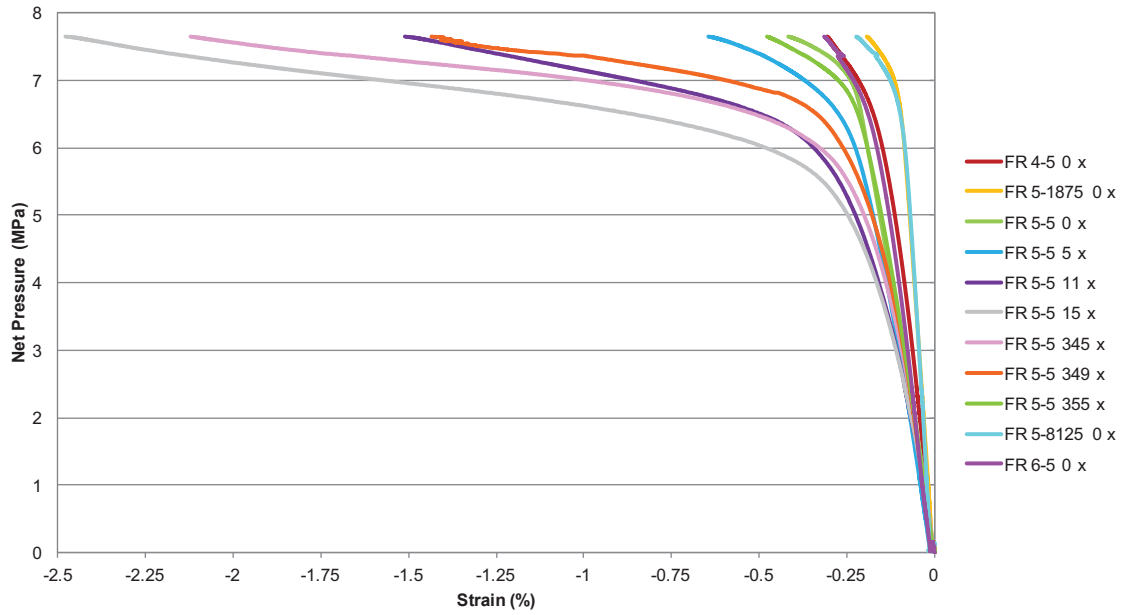
Figure 5.21: Longitudinal external shell strains inside the fine grid area for Specimen B – Damaged.
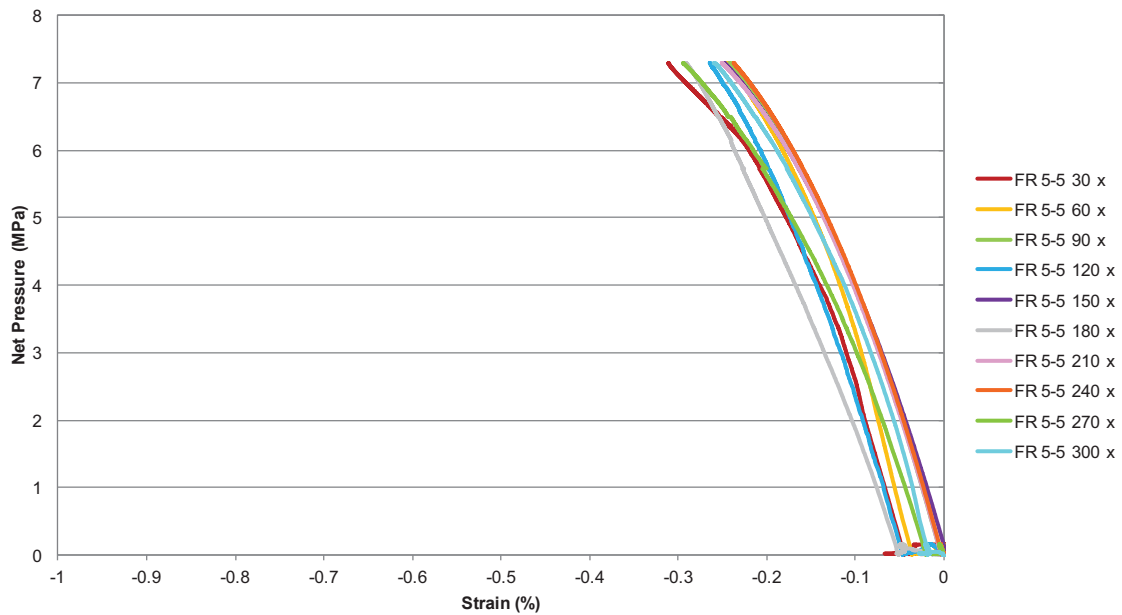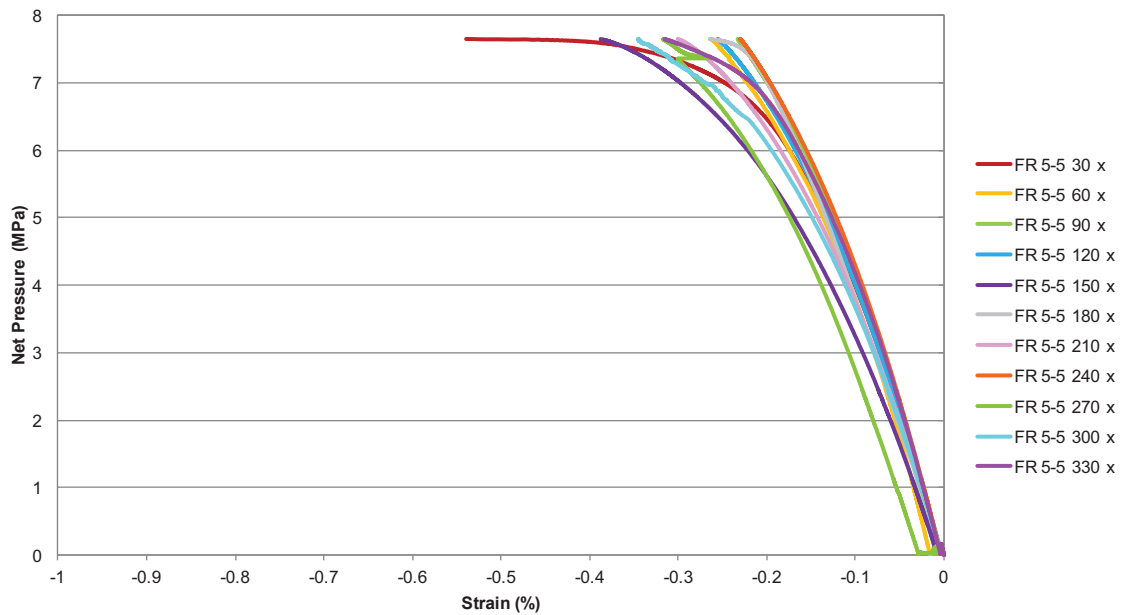

Figure 5.22: Longitudinal external shell strains outside the fine grid area for Specimen B – Damaged.
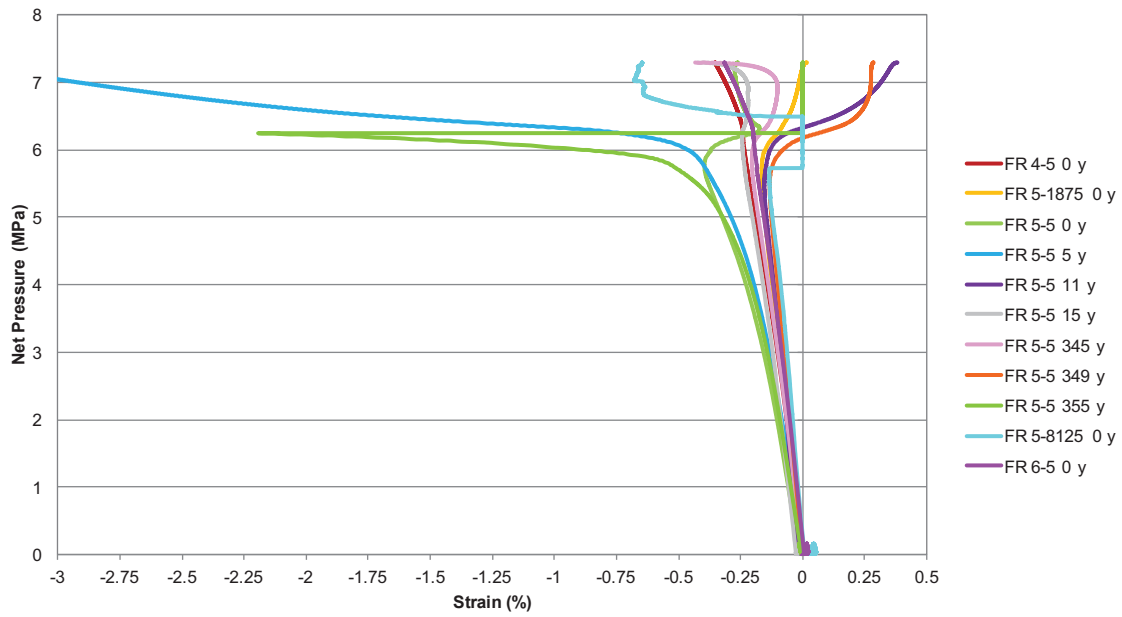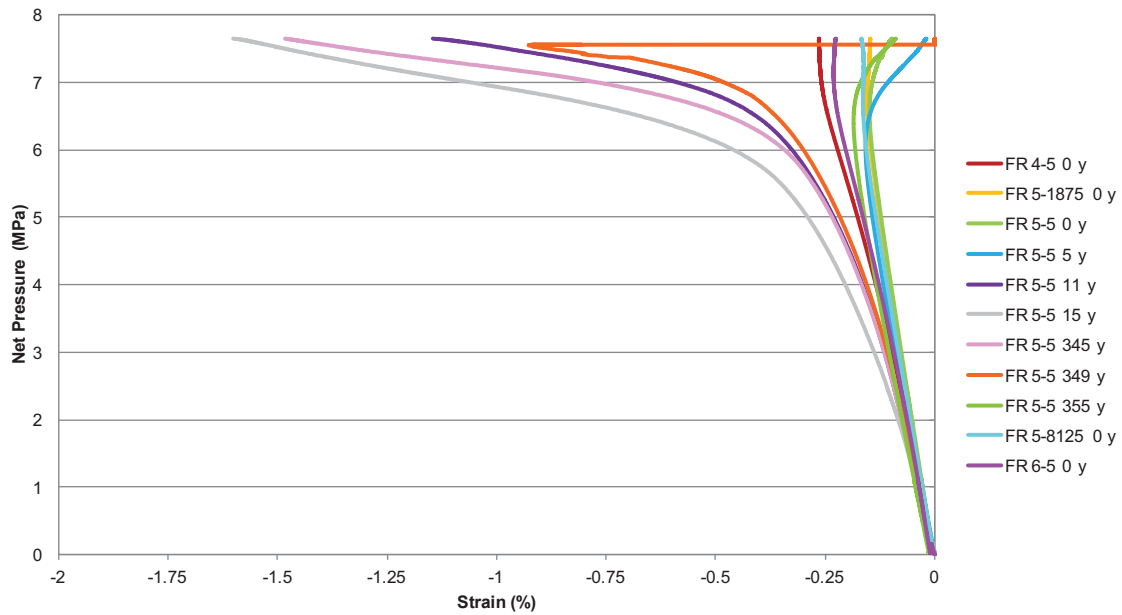
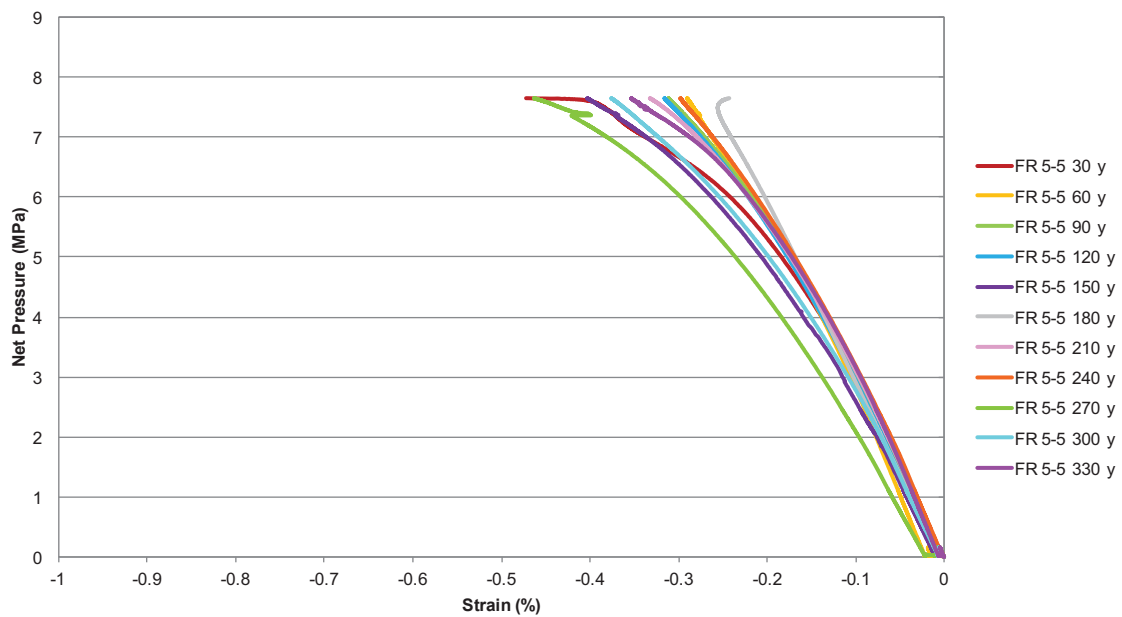*Figure 5.23: Circumferential external shell strains inside the fine grid area for Specimen B – Damaged.*
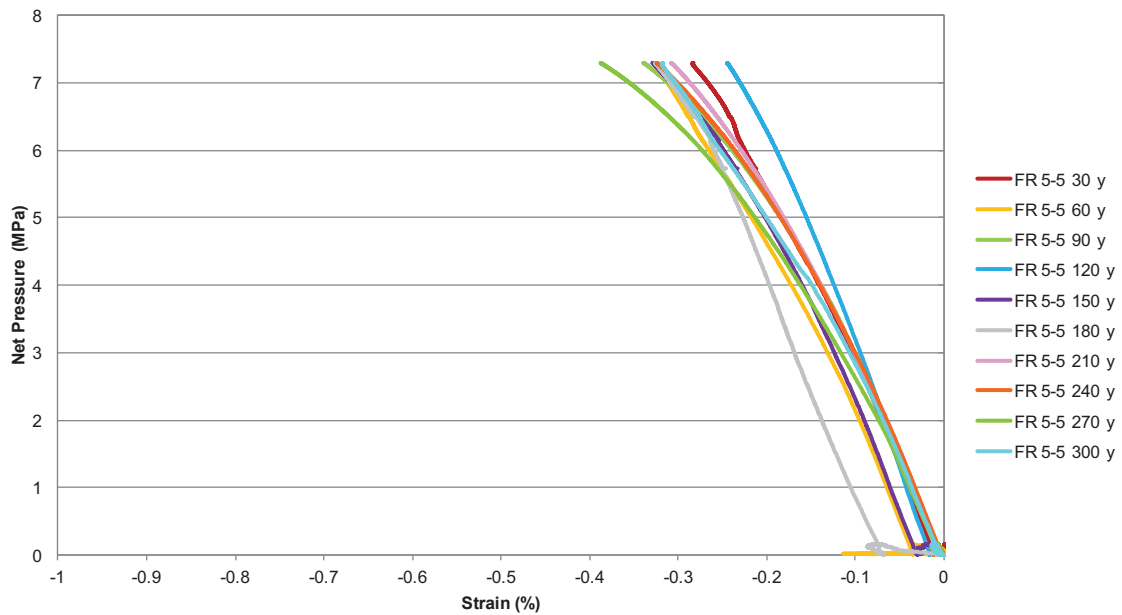
Figure 5.24: Circumferential external shell strains outside the fine grid area for Specimen B – Damaged.

5.2.3.3   Specimen C – Repaired

Specimen C sustained a peak differential pressure of 7.66 MPa.   The specimen failed by interframe collapse with the initial buckle occurring in the region of weld repair. Post-test photos are provided in Figure 5.25.

Based on the strain gauge data, initial shell yielding was estimated to have occurred 15° from the centre of the repaired area, mid-bay between T-frames 5 and 6 at approximately 59% of the collapse pressure. The majority of pre-collapse shell yielding was in or adjacent to the repaired area. T-frame yielding did not occur until approximately 94% of the collapse load on T-frame 6 at 15°.

The pressure-strain plots for Specimen C are below in Figures 5.26 to 5.33. It should be noted that failed strain gauges are not included in the figures.
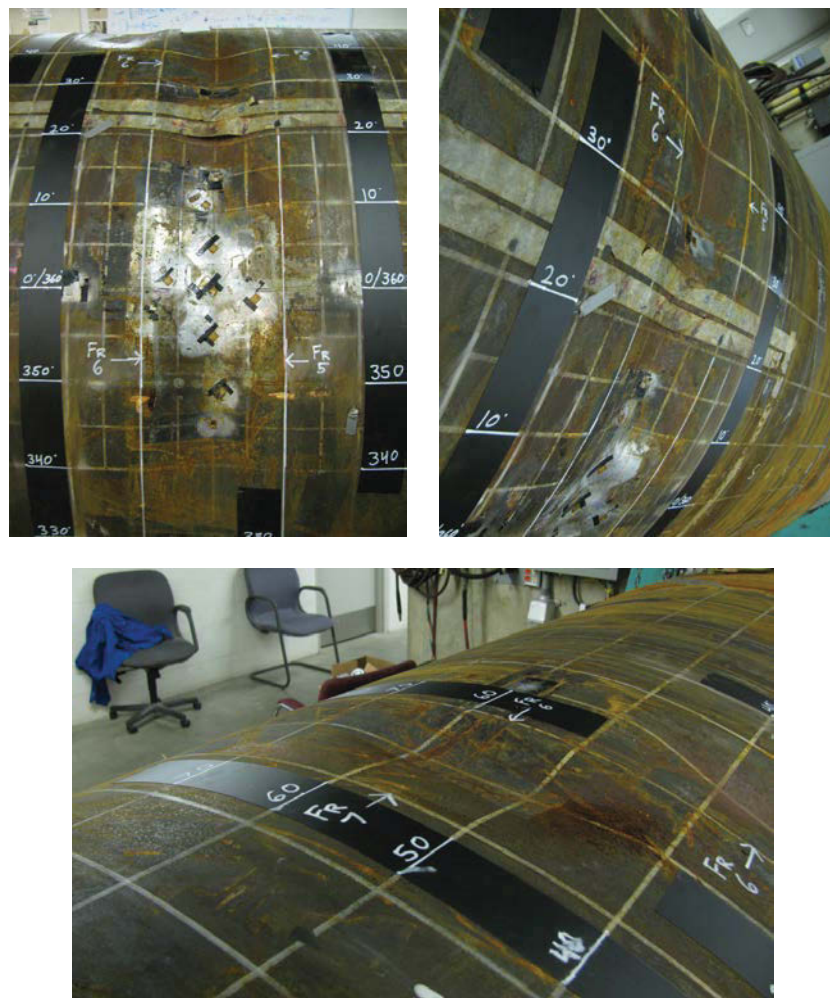
Figure 5.25: Post-collapse photos of cylinder Specimen C – Repaired.

*Figure 5.26: Longitudinal internal shell strains between
T frames 5 and 6 for Specimen C – Damaged.*

*Figure 5.27: Circumferential internal strains between
T-frames 5 and 6 for Specimen C – Damaged.*

Figure 5.28: Circumferential internal strains around the flange of T-frame 6 for Specimen C – Damaged.

Figure 5.29: Circumferential internal strains on the flange of T-frames 1-5 and 7-11 at 0° for Specimen C – Damaged.

Figure 5.30: Longitudinal external shell strains inside the fine grid area for Specimen C – Damaged.

Figure 5.31: Longitudinal external shell strains outside the fine grid area for Specimen C – Damaged.

Figure 5.32: Circumferential external shell strains inside the fine grid area for Specimen C – Damaged.

Figure 5.33: Circumferential external shell strains outside the fine grid area for Specimen C – Damaged.

5.2.3.4 Collapse Test Summary

A summary of the collapse pressure, failure mode and post-yield mode shape for each specimen is provided in Table 5.4.

Table 5.4: Summary of collapse test results for each specimen.

Cylinder	First Yielding of the Shell Plate		First Yielding of the T-frame		Collapse Pressure (MPa)	Failure Mode
	Location	P_y (MPa)	Location	P_y (MPa)		
Specimen A	Mid-bay between T-frames 10 and 11	5.31	T-frame 6 at 120°	7.21	7.75	Interframe
Specimen B	50-mm from Frame 5 between T-frames 5 and 6	3.89	T-frame 6 at 330°	6.69	7.31	Interframe
Specimen C	15° from centre of repair are mid-bay between T-frames 5 and 6	4.50	T-frame 6 at 15°	7.22	7.66	Interframe

6 Discussion and Conclusions

6.1 Experimental versus Predicted Collapse Capacity

A direct comparison between the experimental results obtained for Specimen A (baseline specimen without damage) and the two FE analyses described in Section 4 is provided in Table 6.1.

Table 6.1: Summary of collapse test and FE results for Specimen A – Baseline.

	Collapse Pressure (MPa)	Failure Mode	Failure Location
Collapse Test	7.75	Interframe	Mid-bay between T-frames 5 and 6 in the range of 165° to 195°
LS-DYNA Analysis	7.86	Mixed mode	Between T-frames 3 and 5 near seam weld
VAST Analysis	8.02	Overall buckling	Between T-frames 1 and 3 near seam weld

The tabulated results indicate close agreement between the numerical and experimental results with respect to collapse pressure, with the LS-DYNA and VAST analyses overestimating the collapse pressure by only 1.4% and 3.5%, respectively. Both FE analyses also predicted the circumferential location of failure to be in the vicinity of the seam weld, which is consistent with that of the test specimen that collapsed in the 165° to 195° location (with the seam weld being located at 180°). However, with respect to the axial location of failure, the FE analyses predicted that collapse would occur closer to the end caps, whereas the test specimen collapsed mid-bay between T-frames 5 and 6. In addition, the actual specimen failure mode was interframe, whereas the FE analyses predicted either mixed mode or overall buckling.

6.2 Effect of Simulated Metal Loss on Collapse Pressure

A reduction in wall thickness over an isolated area, intended to simulate corrosion damage, resulted in a collapse pressure for Specimen B that was 5.7% lower than that of the undamaged baseline Specimen A. The point of collapse was centred on the area of reduced wall thickness. The simulated corrosion did not change the failure mode as the initially "undamaged" and "damaged" specimens both experienced interframe failure.

6.3 Effect of Weld Repair on Collapse Pressure

Repair of an isolated region of wall loss by weld buttering resulted in a collapse pressure for Specimen C that was only 1.2% lower than that of the undamaged baseline Specimen A. This constitutes a 4.8% increase in collapse pressure compared to the damaged and unrepaired

Specimen B. Effectively, the capacity lost due to metal loss was almost fully recovered by the adopted weld repair procedure. The slight capacity reduction, compared to the undamaged reference specimen, may simply reflect the inherent variability in collapse capacity. However, it may also be attributable, at least in part, to the increased OOC resulting from the shell plate distortion caused by the heat input during weld repair. In general, because collapse is strongly influenced by geometric imperfections, minimizing the conditions that increase OOC should benefit collapse capacity recovery.

References

[1]   Defence Procurement Agency. 2001. Design of Submarine Structures. Sea Systems Publication (SSP) No. 74, Sea Technology Group.

[2]   Canadian Standards Association. 2001. Limit States Design of Steel Structures. CAN/CSA-S16.1-01.

[3]   Timoshenko, S. 1959. Theory of Plates and Shells. McGraw-Hill College.

[4]   Canadian Standards Association. 2002. Limit States Design of Steel Structures. CAN/CSA-S16.1-01.

[5]   American Bureau of Shipping. 2002. Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities. Publication #0007.

[6]   American Society of Mechanical Engineers. 2010. Boiler and Pressure Vessel Code. Section IX: Welding and Brazing Qualifications.

[7]   Swanek, D. 2011. Private Communication (e-mail; June 30, 2011).

[8]   Martec Limited. 2009. SubSAS: An Integrated Suite of Submarine Structural Analysis Codes User's Manual. Martec Limited, Halifax, NS, Canada.

[10]   Hosford, W. and Caddell, R. 2007. Metal Forming: Mechanics and Metallurgy. 3rd Edition, Cambridge University Press.

[11]   Smith, M.J. 2004. K79 User's Manual – Version 2. DRDC Atlantic.

[12]   MacKay, J. 2011. Private Communication.

[13]   Martec Limited. 2010. Vibration and Strength Analysis Program (VAST) User's Manual. Version 9.0, Martec Limited, Halifax, NS, Canada.

[14]   Livermore Software Technology Corporation. 2007. LS-DYNA Keyword User's Manual – Version 971. Livermore Software Technology Corporation, Livermore, CA, USA.

[15]   American Society for Testing and Materials. 2004. Standard Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus. ASTM E111-04.

[16]   American Society for Testing and Materials. 2004. Standard Test Methods for Tension Testing of Metallic Materials. ASTM E8-04.

[17]   American Society of Testing and Materials. 2004. Standard Test Method for Poisson's Ratio at Room Temperature. ASTM E132-04.

[18] MacKay, J.R. Experimental Investigation of the Strength of Damaged Pressure Hulls –
      Phase 3. DRDC Atlantic TM 2008-093, Defence R&D Canada – Atlantic.

List of symbols/abbreviations/acronyms/initialisms

List of Symbols

%	Percent
°	Degree
μ	Poisson's ratio
ρ	Density
σ_{yf}	Yield stress of flange
σ_{yp}	Yield stress of plate
a	Mean radius of cylindrical shell
B	Coupon tab length
d	Frame web depth
f	Frame flange depth
E	Young's modulus
h	Shell thickness of cylindrical specimen
h_f	Frame flange thickness
h_w	Frame web thickness of T-frame
kg/m^3	Kilogram per cubic metre
L_B	Overall length of cylindrical specimen
L_f	Frame spacing
MPa	Megapascals
R	Reduced section length
R_{sf}	Safety factor
W_1	Reduced section width
W_2	Coupon tab width

List of Abbreviations/Acronyms/Initialisms

ABS	American Bureau of Shipping
AF	After Fabrication
ASME	American Society of Mechanical Engineers
BPVC	Boiler and Pressure Vessel Code
C-FER	C-FER Technologies
DRDC Atlantic	Defence Research & Development Canada – Atlantic
DEC	Deepwater Experimental Chamber
FE	Finite Element
ISER	International Submarine Engineering Research Ltd.
MPI	Magnetic Particle Inspection
mXRD	Miniature X-Ray Diffractometer
NDE	Non Destructive Examination
OD	Outer Diameter
OOC	Out-of-Circularity
PWGSC	Public Works and Government Services Canada
RFP	Request for Proposal
SC	Simulated Corrosion
SSP	Sea Systems Publications
SubSAS	Submarine Structural Analysis Suite
QA/QC	Quality Assurance / Quality Control
VAST	Vibration and Strength
WB	Weld Buttering

Annex A   Final Design Notes

This page intentionally left blank.

Design Calculations

1) Preliminary and Final Sizing.

2) Stiffener Web to Flange and Shell Welds

3) Solid End Cap

4) End Cap With Hatch

5) Shell Insert at End Cap - Shell Junction

6) Modified End Cap for End Cap Plate #3.

1) Preliminary and Final Sizing

Preliminary:
SSP 74 Design Code used for determining interframe and overall collapse load Results on "SSP 74 Spread sheet - Final Configuration"

Final:
Elastic - plastic collapse analysis described in SSP 74 used to determine overall buckling collapse load - effect of residual stresses included - Program K79 (Malcolm Smith) does this

Method of Construction

1) Shell is rolled to desired radius and the longitudinal seam is butt welded

2) Stiffener webs are cut in circular segments and welded together (3-4 pieces)

3) Stiffener flanges are rolled to desired radius and welded to stiffener webs.

4) Stiffener web-flange pieces are welded to shell)

This means that rolling stresses are considered for shell and flange, but not for web.

Results

Buckling Load (MPa)	Spreadsheet	K79
Interframe	6.798	—
Overall	7.028	7.078[1]

$$\frac{\text{Interframe}}{\text{Overall}} = \frac{6.798}{7.028} = 0.967 > 0.95 \text{ ok}$$

Interframe collapse load within 5% of overall collapse load.

Results Files

1) Spreadsheet

   SSP74 Spreadsheet – Final Configuration 2.xls

2) K79

   Input : Overall Collapse K79. dat

   Output : Overall Collapse K79. out

Notes:

(1) K79 analysis performed with slightly different dimensions

$a = 575$ mm $\Big)$ — These make very

$L_B = 1760$ mm $\Big)$ little difference

in SSP74 Spreadsheet

67

Strength of Ring-Stiffened Cylinders and Unstiffened Dome Ends Under External Pressure

Design Variables

Material Properties (Metric):

E	207000	MPa
σ_{yp}	646.0	MPa
σ_{yf}	646.0	MPa
μ	0.3	
ρ	7850.0	kg/m^3

Geometric Properties (Metric):

h	6.350	mm
h_{dome}	0.000	mm
h_w	6.350	mm
d	33.000	mm
h_f	6.350	mm
f	30.000	mm
a	571.825	mm
L_f	160.000	mm
L_B	1840.000	mm
OOC	0.500	%
R_{sf}	1.000	
Int. Frames	yes	

Relative Proportions:

DEFENCE R&D DÉFENSE

Material Properties:

E	207000	MPa
σ_{yp}	646	MPa
σ_{yf}	646	MPa
μ	0.3	

Geometric Properties:

Internal Frames

h	6.350	mm
h_{dome}	0.000	mm
h_w	6.350	mm
d	33.000	mm
h_f	6.350	mm
f	30.000	mm
a	571.825	mm
L_f	160.000	mm
L_B	1840	mm
OOC	0.500	%
R_{sf}	1.000	

Calculated Properties:

N_f	11	
$V_{material}$	0.0570	m³
Mass	447.3	kg
$V_{displaced}$	1.9112	m³
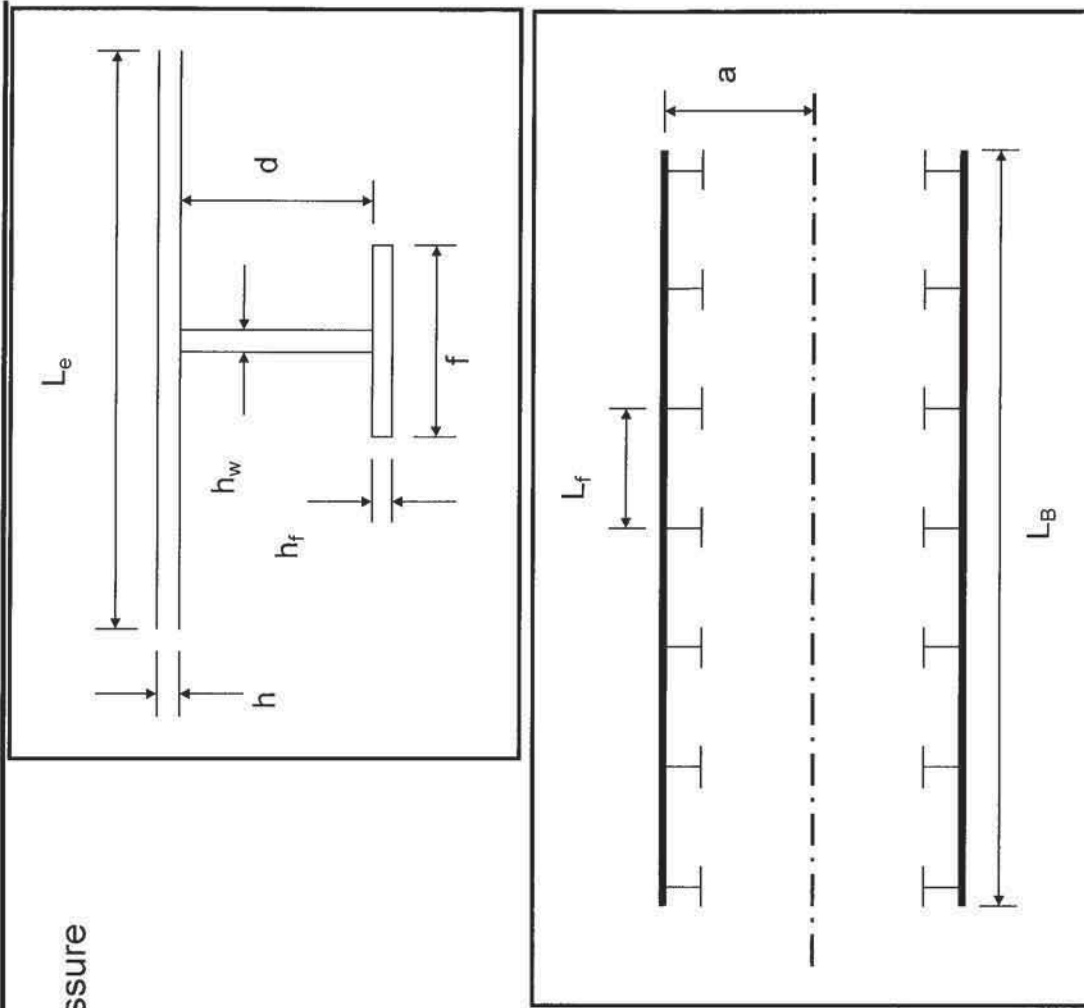
COLLAPSE MODE	EXTERNAL PRESSURE (MPa)	MODE NUMBER (n)
Shell Yielding		
P_{c3}	7.539	N/A
P_{c5}	8.218	N/A
P_{c6}	9.455	N/A
P_{c7}	6.419	N/A
Frame Yielding		
P_{fy}	12.849	N/A
Interframe Collapse		
P_m	12.251	N/A
P_{m1}	12.142	13
Lower Bound P_c	5.437	N/A
Mean P_c	6.798	N/A
Overall Collapse		
P_B	5.848	2
P_N	17.933	3
$P_{y(n)}$	7.028	3
P_P	7.140	3

Frame tripping parameters are satisfied

Interframe/overall   0.967

Notes

```
SECTION
160.0     // b    (plate width)
6.35      // plateThick
33.0      // webHeight
6.35      // webWidth
6.35      // flangeThick
30.0      // flangeWidth
1         // interior stiffeners flag

CYLINDER
575.0   // a    ← Actual - 571.825.
1760.0     // overallLength  ← Actual - 1840.
160.0     // L  (frame spacing)
3         // mode
2.850     // delta
0.0       // phase

MATERIAL
207000   // E
0.3      // pr
646.0    // yieldShell
646.0    // yieldFrame

OPTIONS
2         // residual stresses
1         // stress correction
1  100.0  // effective width option
1   13.52        // finite length correction
0         // interframe interaction correction

MODEL
HALFSHAPE
1500     // number of finite difference steps
15       // plate fibres
15       // web fibres
15       // flange fibres
```

70

```
-----------------------------------------------
-------              K79              -------
-------     A Program for Overall     -------
-------     Elasto-Plastic Collapse    -------
-------   of Ring-Stiffened Cylinders  -------
-----------------------------------------------
        Input File Name  : kendrick4.dat
        Output File Name : kendrick4.out
```

Record of data input:

SECTION
160   // b   (plate width)
6.35   // plateThick
33   // webHeight
6.35   // webWidth
6.35   // flangeThick
30   // flangeWidth
1   // interior stiffeners flag

CYLINDER
575 // a
1760   // overallLength
160   // L (frame spacing)
3   // mode
2.85   // delta
0   // phase

MATERIAL
207000 // E
0.3   // pr
646   // yieldShell
646   // yieldFrame

OPTIONS
2   // residual stresses
1   // stress correction
1 100.0   // effective width option
1   13.52   // finite length correction
0   // interframe interaction correction

MODEL
HALFSHAPE
1500   // number of finite difference steps
15   // plate fibres
15   // web fibres
15   // flange fibres

Ring Section Dimensions

Breadth of plating   160
Shell thickness   6.35
Web height   33
Web thickness   6.35
Flange width   30
Flange thickness   6.35
Internally stiffened
Frame area   400.05
Plate area   1016
Ratio of frame area to total   0.282511

Material Properties
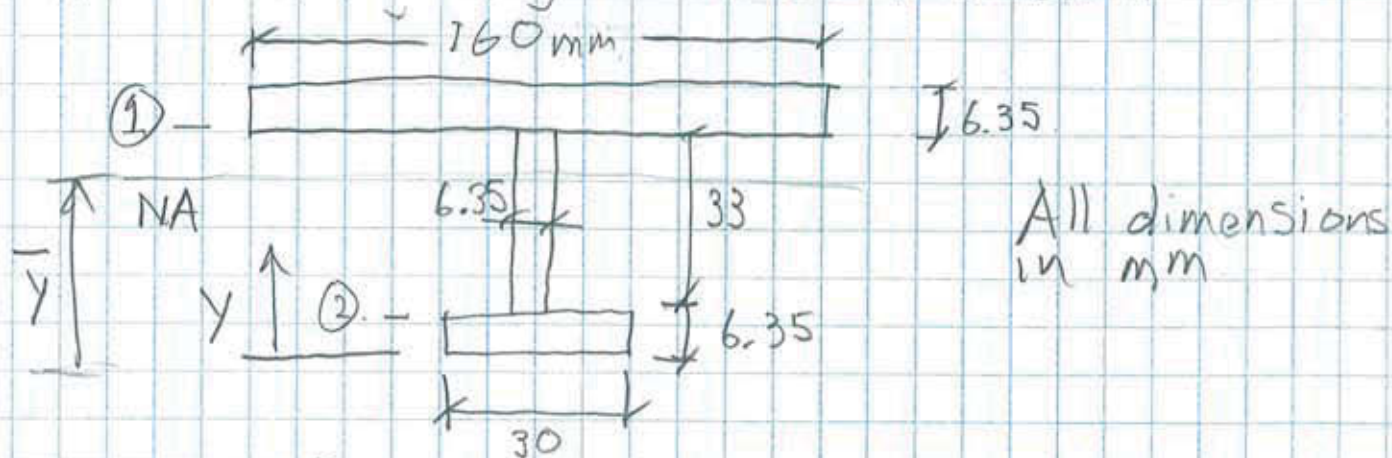
                        1
```

| | | |
|---|---|---|
| 4 | 16.25 | 0 |
| 5 | 18.45 | 0 |
| 6 | 20.65 | 0 |
| 7 | 22.85 | 0 |
| 8 | 25.05 | 0 |
| 9 | 27.25 | 0 |
| 10 | 29.45 | 0 |
| 11 | 31.65 | 0 |
| 12 | 33.85 | 0 |
| 13 | 36.05 | 0 |
| 14 | 38.25 | 0 |

Shell plating

| | | |
|---|---|---|
| 0 | 39.56 | 230.9 |
| 1 | 39.98 | 105.6 |
| 2 | 40.41 | -19.63 |
| 3 | 40.83 | -144.9 |
| 4 | 41.25 | -270.2 |
| 5 | 41.68 | -304.8 |
| 6 | 42.1 | -152.4 |
| 7 | 42.52 | 0.0001926 |
| 8 | 42.95 | 152.4 |
| 9 | 43.37 | 304.8 |
| 10 | 43.79 | 270.2 |
| 11 | 44.22 | 144.9 |
| 12 | 44.64 | 19.63 |
| 13 | 45.06 | -105.6 |
| 14 | 45.49 | -230.9 |

Elasto-plastic calculation
--------------------------

| | |
|---|---|
| Collapse pressure | 7.078 |
| Maximum frame deflection | 5.233 |
| Last pressure step size | 3.526e-005 |

Fibre Stresses in Cross-Section
-------------------------------

Frame flange

| | | |
|---|---|---|
| 0 | 0.2117 | -646 |
| 1 | 0.635 | -646 |
| 2 | 1.058 | -646 |
| 3 | 1.482 | -646 |
| 4 | 1.905 | -646 |
| 5 | 2.328 | -646 |
| 6 | 2.752 | -646 |
| 7 | 3.175 | -646 |
| 8 | 3.598 | -646 |
| 9 | 4.022 | -646 |
| 10 | 4.445 | -646 |
| 11 | 4.868 | -646 |
| 12 | 5.292 | -646 |
| 13 | 5.715 | -646 |
| 14 | 6.138 | -646 |

Frame web

| | | |
|---|---|---|
| 0 | 7.45 | -646 |
| 1 | 9.65 | -646 |
| 2 | 11.85 | -646 |
| 3 | 14.05 | -646 |
| 4 | 16.25 | -646 |
| 5 | 18.45 | -646 |
| 6 | 20.65 | -646 |
| 7 | 22.85 | -646 |
| 8 | 25.05 | -646 |

3

72

2) Stiffener Web to Flange and Shell Welds.



All dimensions in mm

Centroid: $\bar{y} = \dfrac{\Sigma A \bar{y}}{\Sigma A}$

$$\bar{y} = \dfrac{\overset{(604.84)}{30 \times 6.35 \times 6.35/2} + \overset{(4788.22)}{33 \times 6.35 \times \left(\frac{33}{2} + 6.35\right)} + \overset{(43205.4)}{160 \times 6.35 \times \left(6.35 + 33 + 6.35/2\right)}}{\underset{(1416.05)}{30 \times 6.35 + 33 \times 6.35 + 160 \times 6.35}}$$

$\bar{y} = 34.32$ mm ✓

Moment of Inertia

$I = \Sigma I_0 + Ad^2$

$$\Sigma I_0 = \dfrac{\overset{(640.12)}{30 \times 6.35^3}}{12} + \dfrac{\overset{(19016.67)}{6.35 \times 33^3}}{12} + \dfrac{\overset{(2709.84)}{127 \times 6.35^3}}{12} = 22366.6 \text{ mm}^4$$

$$\Sigma Ad^2 = \overset{(184787.10)}{30 \times 6.35 \times \left(34.32 - 6.35/2\right)^2} + \overset{(27560.59)}{33 \times 6.35 \times \left(34.32 - 22.85\right)^2}$$
$$+ \underset{(68399.18)}{160 \times 6.35 \times \left(34.32 - 42.525\right)^2} = 280746.87 \text{ mm}^4$$

$I = 22366.6 + 280746.87 = 303113.47 \text{ mm}^4$  3.030 ✓

Shear Capacity: CAN3-S16.1-M78  13.4.1

Unstiffened Web: $K_v = 5.34$

$\dfrac{h}{w} = \dfrac{33}{6.35} = 5.197$   $439\sqrt{\dfrac{K_v}{F_y}} = 439\sqrt{\dfrac{5.34}{646}} = 39.91$

73

$(S16.1$
$13.4.1)$ $F_s = 0.66 F_y = 0.66 \times 646 = 426.36$ MPa

$V_r = \phi A_w F_s$

$= 0.9 \times 6.35 \times 33 \times 426.36 = 80409.36$ N/mm ✓

___

## Web to Shell Junction

$q = \dfrac{VQ}{I}$

$Q = (\Sigma A \bar{y})_{①}$

$= (160 \times 6.35) \times (42.525 - 34.32) = 8336.28$ mm³

$q = \dfrac{80409.36 \times 8336.28}{303113.47} = 2211.43$ N/mm ✓

$S16.1 \quad 13.13.2.1$

① Weld metal strength $= 0.67 \phi A_w X_u$ — assume matched electrode

$X_u = 711$ MPa from mill cert

$= 0.67 \times 0.9 \times (1 \times 0.7071) \times 711 = 303.16$ N/mm

② Base metal strength $= 0.67 \phi A_m F_y$

$= 0.67 \times 0.9 \times 1 \times 646 = 389.54$ N/mm

Weld thickness required (2 legs) $= \dfrac{q}{2 \times ①} = \dfrac{2211.43}{303.16 \times 2} = 3.64$ mm

Use 4 mm weld ✓

74

## Web to Flange Junction

$$Q = (\Sigma A\bar{y})_{②} = 30 \times 6.35 \times (34.32 - 6.35/2)$$

$$= 5933.12 \ mm^3$$

$$q = \frac{80409.36 \times 5933.12}{303113.47} = 1573.93 \ N/mm$$

Weld thickness required (2 legs) $= \frac{q}{2 \times ①} = \frac{1573.93}{2 \times 303.16} = 2.59 \ mm$

3.89

Use 4 mm welds

3) Solid End Cap to Flange and Shell Welds



SYM

## End Cap Design

1) Simple

2) Removable

3) Stiff. - meant to represent bulkhead

C-FER suggested 6" (152.4 mm) 350W.
plate. Check plate for maximum bending
stress.

Model plate as pinned at cap-shell junction
Timoshenko (1959)

$$\sigma_{max} = \frac{3(3+\nu)\, q\, a^2}{8h^2}$$

$\nu = 0.3$
$q = 6.762$ MPa.
$a = 575$ mm.
$h = 152.4$ mm. ✓

$$= \frac{3(3+0.3)\, 6.762 \times 575^2}{8 \times 152.4^2} = 119.12 \text{ MPa.} < 300$$

— ok

76

# 4) End Cap With Hatch

C-FER suggested the following configuration



Drill +
tap

B

C

A

455.5

410

355.6

575

152.4  152.4

SYM

Potential problem is that bolt at C
may experience prying from bearing at
A or B. Use FEA model to compute
maximum gap



SYM

Stiff Spring

Contact
Region

Springs are placed
in contact region.

Gap at A is
evaluated.

Contact region
determined iteratively
with springs.

77

# Maximum Stresses



72.1 MPa    154.4 MPa

A   174.8 MPa

610 - Localized due to boundary condition - ignore

Check gap at A

Gap = $4.542 \times 10^{-5}$ m

Strain due to gap = $\dfrac{\Delta}{L_{bolt}} \approx \dfrac{4.542 \times 10^{-5}}{0.1524}$

$$= 2.980 \times 10^{-4}$$

Yield strain = $\dfrac{830}{200,000}$ = $4.15 \times 10^{-3}$ (A490 bolts).

$F_u = 830$ MPa

Strain is relatively small ∴ bolts are good

Data files in "End Cap With Hatch - Gap Check" folder. - binary file "d3plot" can be read with LS - Prepost or Hypermesh

78

5) Shell Insert at End Cap - Shell Junction.



Local bending @ Point A causes large
bending stresses - must reduce them



FEA analysis done with LS-DYNA
Model in
End Cap - Shell Junction - Stress Check Final
/LSDYNA/axisym4.dyn

FE model:



$F_y = 350 MPa$

B

D

A

C

E

$F_y = 100 ksi (690 MPa)$

1.0 MPa pressure
- multiply stresses
by 6.8 to get
"failure" Stresses

$F_y = 646 MPa.$

A-B-C-D
area of
Concern

Axisym.

Y

X

Model geometry, loads, boundary conditions
checked 12/15/10

Vertical loading (: $\sigma_y$) checked 12/15/10.

Results                                     (MPa).

| Location | Mises Stress | Yield Stress |
|----------|--------------|--------------|
| A | 392.2 | 690. |
| B | 252.6 | 350. |
| C | 126.4. | 696 |
| D | 121.4 | 350. |
| E | 498.3 | 646. |

80

# 6) End Cap Plate #3 - Shear Lip Check



End Cap Plate 1

25.4

R

QT 100.

38.1

End Cap Plate 3

Cover Plate

38.1

C ←— P

Design Pressure:

$$p = 6.8 \, MPa$$
$$= 6.8 \times 10^6 \, N/m^2$$

$$P = \pi r^2 p = \pi \times 0.381^2 \times 6.8 \times 10^6 = 3.101 \times 10^6 \, N$$

$$A_{shear} = 2\pi r_{avg} h = 2 \times \pi \times (0.381) \times 0.0381$$
$$= 0.0912 \, m^2$$

### S16-1: Shear

$$V_F = \phi A_w F_s$$

$$F_s = 0.66 \times F_y = 0.66 \times 689.5 = 455.1 \, MPa$$

$$V_F = 0.9 \times 0.0912 \times 455.1 \times 10^6 = 37.35 \times 10^6 \, N$$
$$> 3.101 \times 10^6 \, N \quad ok$$

### S16.1: Bending



R

$L_b/2$

$L_b$

$r_{avg}$

d

$$R = \frac{P}{A} L_b$$

$$A = 2\pi r_{avg} L_b$$

81

$$A = 2\pi \times \left(0.381 + \frac{0.0254}{2}\right) \times 0.0254 = 0.06283 \text{ m}^2$$

$$R = \frac{3.101 \times 10^6}{0.06283} \times 0.0254 = 1.254 \times 10^6 \text{ N/m}$$

Consider 1.0 m strip

$$M_r = \phi Z F_y$$

$$Z = \frac{bd^2}{4} = \frac{1.0 \times 0.0381^2}{4} = 3.629 \times 10^{-4} \text{ m}^3$$

$$M_r = 0.9 \times 3.629 \times 10^{-4} \times 689.5 \times 10^6 = 225198 \text{ Nm}$$

$$M_f = \frac{R L_b}{2} = \frac{1.254 \times 10^6 \times 0.0254}{2} = 15925.8 \text{ Nm}$$

$$M_r > M_f \qquad \text{ok}$$

S16.1 Bearing

$$B_r = 1.50 \phi F_y A \qquad\qquad F_y = 350 \times 10^6 \text{ N/m}^2$$

$$= 1.50 \times 0.9 \times 350 \times 10^6 \times 0.06283$$

$$= 29.687 \times 10^6 \text{ N} > 3.101 \times 10^6 \qquad \text{ok}$$

Conclusions:

1) All areas of concern under yield.
2) All areas on tension side (C, D) have very low tensile stresses — will not break.

This page intentionally left blank.

# Annex B    Fabrication Drawings

This page intentionally left blank.

NOTES :

1. DIMENSIONS ARE IN METRIC UNITS.
2. O-RING GROVE DIMENSIONS CORRESPOND TO PARKER O-RING 2-474 AND 2-475.
3. O-RING GROVE SURFACE MUST MATCH STRONGER MATERIAL.
4. HAV MATERIAL MUST HAVE MILL CERTIFICATION OF 50ksi.
5. SURFACE FINISH 12" OF END CAP COVER PLATE TO 32uINCHRa.
6. SURFACE FINISH OUTER 6"9 OF END CAP COVER PLATE TO 32uINCHRa.

MARTEC

400, 1888 Brunswick Street, Halifax, Nova Scotia, Canada, B3J 3J8

DRAWING TITLE

REFERENCE DRAWINGS

DRAWING NUMBER

ISSUED FOR FABRICATION

| REV | DATE | DESCRIPTION | BY | CHK | ENG | APP | CLT |
|-----|------|-------------|----|----|----|----|----|
| 0 | 03.02.11 | ISSUED FOR FABRICATION | RL | | | | |

REVISIONS

CLIENT :

PROJECT :

TITLE : CYLINDER SPECIMEN ASSEMBLY AND DETAILS

DRAWING NUMBER 2010-001

REVISION 0

DCN No.

SHT 1 OF 3    DRG. SIZE Ansi D    SCALE 1:10    PROJECT No.

CYLINDER SPECIMEN ASSEMBLY
SCALE 1:10

END CAP PLATE NUMBER 1
SEE DETAIL SHEET 2

END CAP PLATE NO. 3
SEE DETAIL SHEET 2

COVER PLATE
SEE DETAIL SHEET 2

SUPPORT RING

END CAP PLATE NO. 1

COVER PLATE

END CAP PLATE NO. 2

Ø1162.70

1150.0

2144.80

SECTION "A"-"A"
SCALE 1:10

SECTION "B"-"B"
SCALE 1:10

STIFFENER FRAMES

CYLINDER SHELL

120.0°

120.0°

CYLINDER SHELL

STIFFENER FRAMES

SUPPORT RING

END CAP PLATE NO. 1

END CAP PLATE NO. 3

FOR SEALING PURPOSES

6.35

Ø1162.70

6.35V

1150.0

1600.00

2144.80

2182.9

160.00 TYP

120.0

30.0

9.53
9.53

75.4

6.35V

6.35mm THK PLATE
STEEL HY80

19.05mm THK PLATE
STEEL QT100

6.35mm THK PLATE
STEEL HY80

6.35mm THK FLAT BAR
STEEL HY80

STEEL HY80

33.0

4
4

4
4

END CAP PLATE NO. 2

(3)

NOTES :

1: DIMENSIONS ARE IN METRIC UNITS.
2: D-RING GROVE DIMENSIONS CORRESPOND TO PARKER O-RING 2-474 AND 2-475.
3: WELD ELECTRODES MUST MATCH STRINGER MATERIAL.
4: 44W MATERIAL MUST HAVE MILL CERTIFICATION OF 50ksi.
5: SURFACE FINISH I.D'n OF END CAP COVER PLATE TO 32µINCHRa
6: SURFACE FINISH OUTER 6'9 OF END CAP COVER PLATE TO 32µINCHRa



SECTION "C" – "C"
SCALE 1:1

SEE NOTE NUMBER 2

32

5.00°
TYP

63

R0.71 (TYP)

PARKER O-RING 2-474

PARKER O-RING 2-475

8.941±0.254

5.18±0.127



25.40

203.20

38.10

ⵁ642.40±2.9

ⵁ667.80±3.0

END CAP PLATE NO. 3 DETAIL
SCALE 1:5
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED



ⵁ642.40±2.9
ⵁ667.80±3.0
ⵁ609.60
ⵁ698.50
ⵁ762.00
ⵁ812.80

DRILL AND TAP FOR
9/16-10UNC, 40mm DEEP
16 HOLES

88

NOTES :

1) DIMENSIONS ARE IN METRIC UNITS.
2) O-RING GROVE DIMENSIONS CORRESPOND TO PARKER O-RING 2-474 AND 2-475.
3) WELD ELECTRODES MUST MATCH STRONGER MATERIAL.
4) 44W MATERIAL MUST HAVE MILL CERTIFICATION OF 50ksi.
5) SURFACE FINISH 12°0 OF END CAP COVER PLATE TO 3.2μINCHRa.
6) SURFACE FINISH OUTER 6°0 OF END CAP COVER PLATE TO 3.2μINCHRa.

SUPPORT RING
SCALE 1:10
MATERIAL: STEEL QT100
TWO IN NUMBER REQUIRED

75.00
19.05
25.40
19.05
6.35
"D"
"D"

SECTION "D"-"D"
SCALE 1:2

9.53
19.05
75.00
40.08
6.35

END CAP COVER PLATE
SCALE 1:10
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED

ø698.50
ø254.00
ø717.55

DRILL AND TAP FOR
7/16-20 ↧ 0.88 (BOTH SIDES)
UNF-2A, ø25/64 X 10 HOLES
THRU.

9/16" DIA 16 HOLES

END CAP PLATE NO. 2 DETAIL
SCALE 1:10
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED

152.4
ø1162.70

END CAP PLATE NO. 1 DETAIL
SCALE 1:10
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED

152.4
ø736.60
ø1162.70

This page intentionally left blank.

# Annex C    HY80 Weld Procedures

This page intentionally left blank.

# Petersen's Welding

## WELD PROCEDURE SPECIFICATION

Company Name:    Petersen's Welding      By:

Weld Procedure Specification No:   WPS HY80     Date:   June 2, 2009     Supporting PQR No(s):

Revision No:      Date:      PQR Revision(s):

Purpose of Revision:

Welding Process(es):   GMAW      Types:   Manual

Title:      MIL-S-16215K HY80 to MIL-S-16215K HY80

---

### JOINTS (QW-402)

Details

Weld procedure will be used for fillet welds on T-frames and for cap pass on shell seam weld.

Joint Design:    All Typical ASME Joint Designs

Backing (Yes):   X     (No):   X

Backing Material (Type):   Base or weld metal where applicable

Metal   X     Nonfusing Metal

Other      Nonmetallic

---

### BASE METALS (QW-403)

P-No:   ---    Gp   ---    to P-No:   ---    Gp   ---

No:      No:

OR

Specifiction Type and  Grade:    MIL-S-16215K HY80

to Specification Type and  Grade:    MIL-S-16215K HY80

OR

Chem. Analysis and Mech. Prop.

to Chem. Analysis and Mech. Prop.

THICKNESS RANGE:

Base Metal:      Groove:    0.062 to 0.750" pipe base metal to 0.188" to 3" plate base metal

Pipe Dia. Range:      Groove:    Unlimited     Fillet:    All

Other:   Maximum thickness of any weld layer should not exceed 0.500"

---

### FILLER METAL (QW-404)

| | | |
|---|---|---|
| Process | GMAW | |
| Spec No. (SFA) | 5.28 | |
| AWS No. (Class) | ER100S-1 | |
| F-No. | | |
| A-No. | | |
| Size of Filler Metals | 0.035" | |
| Weld Metal Name | | |
| Thickness Range:   Groove: | 0.100" max. | |
| Fillet: | Unlimited | |
| Electrode - Flux (Class) | N/A | |
| Flux Trade Name | N/A | |
| Consumable Insert | N/A | |
| Other | Cold Solid Wire | |

WPS No.  WP305  Revision  1

## POSITIONS (QW-405)

| | | |
|---|---|---|
| Positions of Groove: | All position | |
| Welding Progression: | Up  X  Down  X | |
| Positon(s) of Fillet | All | |

## POSTWELD HEAT TREATMENT (QW-407

Heating Rate:
Temperature Range:
Time Range:
Cooling Rate:

## PREHEAT (QW-406)

Preheat Temp.  None < 1", over 1" is 175 $^{o}$ F, over 2" is 250$^{o}$ F

Interpass Temp.  Max:  350$^{o}$ F

Method:  Propane, oxy-acetylene, induction

Other:  Monitor using tempsticks or other suitable method

## GAS (QW-408)

Percent Composition

| | Gas(es) | (Mixture) | Flow Rate |
|---|---|---|---|
| Shielding | 90% Argon/10% CO2 | Weld Grade | 30 cfh |
| Trailing | None | | |
| Backing | None | | |
| Other | | | |

## ELECTRICAL CHARACTERISTICS (QW-409)

| | | | |
|---|---|---|---|
| Current AC or DC:  DC | | Polarity: | GMAW: Straight |
| Amps (Range):  GMAW: 180-240 | | Volts (Range): | GMAW: 23-26 |

Tungsten Electrode Size and Type:  N/A
Mode of Metal Transfer for GMAW:  Spray transfer
Electrode Wire feed speed range:  400 - 500 ipm

## TECHNIQUE (QW-410)

| | |
|---|---|
| String or Weave Bead: | String or Weave |
| Orifice or Gas Cup Size | 3/8" to 3/4" |
| Initial and Interpass Cleaning: | Brushing, grinding and/or chipping. |
| Method of Back Gouging: | Arc air, gouge, grind, etc. |
| Oscillation: | N/A |
| Contact Tube to Work Distance: | ½" |
| Multiple or Single Pass (per side): | Multiple |
| Multiple or Single Electrode: | Single |
| Peening: | None |
| Other | |

| Weld Layer(s) | Process | Filler Metal | | Current | | Volt Range | Travel Speed Range | Other Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Class | Dia. | Type Polarity | Amp. Range | | | |
| 1 | GMAW | ER100S-1 | 0.035" | DCSP | 180-240 | 23-26 | 12-24 IPM | |

94

# Petersen's Welding

## WELD PROCEDURE SPECIFICATION

Company Name:   Petersen's Welding        By:

Weld Procedure Specification No:  WPS HY80     Date:  June 2, 2009    Supporting PQR No(s):

Revision No:                        Date:                    PQR Revision(s):

Purpose of Revision:

Welding Process(es):  GMAW               Types:   Manual

Title:           MIL-S-16215K HY80 to MIL-S-16215K HY80

---

### JOINTS (QW-402)

**Details**

Weld procedure will be used to tack assemblies, splice webs on T-frames, and root pass for seam weld on shell.

Joint Design:   All Typical ASME Joint Designs

Backing (Yes):  X      (No):  X

Backing Material (Type):  Base or weld metal where applicable

Metal  X       Nonfusing Metal

Other            Nonmetallic

---

### BASE METALS (QW-403)

P-No:  ---     Gp   ---     to P-No:  ---     Gp   ---

             No:                           No:

                OR

Specifiction Type and Grade:    MIL-S-16215K HY80

to Specification Type and Grade:   MIL-S-16215K HY80

                OR

Chem. Analysis and Mech. Prop.

to Chem. Analysis and Mech. Prop.

THICKNESS RANGE:

Base Metal:              Groove:   0.062 to 0.750" pipe base metal to 0.188" to 3" plate base metal

Pipe Dia. Range:         Groove:    Unlimited    Fillet:     All

Other:  Maximum thickness of any weld layer should not exceed 0.500"

---

### FILLER METAL (QW-404)

| | | |
|---|---|---|
| Process | GMAW | |
| Spec No. (SFA) | 5.28 | |
| AWS No. (Class) | ER100S-1 | |
| F-No. | | |
| A-No. | | |
| Size of Filler Metals | 0.035" | |
| Weld Metal Name | | |
| Thickness Range:  Groove: | 0.100" max. | |
| Fillet: | Unlimited | |
| Electrode - Flux (Class) | N/A | |
| Flux Trade Name | N/A | |
| Consumable Insert | N/A | |
| Other | Cold Solid Wire | |

WPS No.   WP305   Revision   1

| POSITIONS (QW-405) | POSTWELD HEAT TREATMENT (QW-407 |
|---|---|
| Positions of Groove:   All position<br>Welding Progression:   Up  X   Down   X<br>Positon(s) of Fillet   All | Heating Rate:<br>Temperature Range:<br>Time Range:<br>Cooling Rate: |

| PREHEAT (QW-406) | GAS (QW-408) | | |
|---|---|---|---|

PREHEAT (QW-406)

Preheat Temp.   None < 1", over 1" is 175 $^{o}$ F, over 2" is 250$^{o}$ F

Interpass Temp.  Max:   350$^{o}$ F

Method:   Propane, oxy-acetylene, induction
Other:   Monitor using tempsticks or other suitable method

GAS (QW-408)

Percent Composition

| | Gas(es) | (Mixture) | Flow Rate |
|---|---|---|---|
| Shielding | 90% Argon/10% CO2 | Weld Grade | 30 cfh |
| Trailing | None | | |
| Backing | None | | |
| Other | | | |

ELECTRICAL CHARACTERISTICS (QW-409)

Current AC or DC:   DC                            Polarity:   GMAW: Straight
Amps (Range):   GMAW: 60-180              Volts (Range):   GMAW: 18-21
Tungsten Electrode Size and Type:   N/A
Mode of Metal Transfer for GMAW:   Short circuit,
Electrode Wire feed speed range:   250 - 300 ipm

TECHNIQUE (QW-410)

String or Weave Bead:                 String or Weave
Orifice or Gas Cup Size               3/8" to 3/4"
Initial and Interpass Cleaning:      Brushing, grinding and/or chipping.
Method of Back Gouging:              Arc air, gouge, grind, etc.
Oscillation:                         N/A
Contact Tube to Work Distance:       ½"
Multiple or Single Pass (per side):  Multiple
Multiple or Single Electrode:        Single
Peening:                             None
Other

| Weld Layer(s) | Process | Filler Metal | | Current | | Volt Range | Travel Speed Range | Other Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Class | Dia. | Type Polarity | Amp. Range | | | |
| 1 | GMAW | ER100S-1 | 0.035" | DCSP | 60-180 | 18-21 | 6-12 IPM | |

96

# Annex D    HY80 Plate Mill Certificates

This page intentionally left blank.

# Ronson Technical Products Division

**ENERGY & PROCESS CORP.**

2146-B Flintstone Drive
Tucker, GA 30084-5000
Phone: (770) 414-8488
FAX: (770) 621-9660
WATS: (800) 524-0698

---

## CERTIFICATE OF COMPLIANCE

THIS IS TO CERTIFY THAT THE MATERIAL SHIPPED IS IN COMPLIANCE WITH THE REFERENCED SPECIFICATIONS AND YOUR PURCHASE ORDER REQUIREMENTS.

ORIGINAL TEST REPORTS ARE MAINTAINED IN OUR FILES.

YOUR PURCHASE ORDER:   CT5807

PURCHASE ORDER DATE:   9-9-10

RONSON SALES ORDER:   RE-9887

SHIPPED TO:   C-FER TECNOLOGIES (1999) INC
200 KARL CLARK RD
EDMONTON, ALBERTA
CANADA, T6N 1H2

REPORT OF CHEMICAL
AND PHYSICAL TEST TO:   MIL-S-16216K HY80 TY.1

DESCRIPTION:   ITEM 1:   3PCS ¼" X 96" X 240" PLATE
CUT PER DRAWING CFER-F034-07
ARCELORMITTAL
1PC HT# R2452-01AB
1PC HT# R2452-01AC
1PC HT# R2452-01AD

THIS MATERIAL HAS NOT COME INTO CONTACT WITH MERCURY OR ANY OF ITS COMPOUNDS WHILE IN OUR POSSESSION.

JIM COYER
QUALITY ASSURANCE DEPT.

September 22, 2010
DATE

99

# Ronson Technical Products Division

**ENERGY & PROCESS CORP.**

2146-B Flintstone Drive
Tucker, GA 30084-5000
Phone: (770) 414-8488
FAX: (770) 621-9660
WATS: (800) 524-0698

## CERTIFICATE OF COMPLIANCE

THIS IS TO CERTIFY THAT THE MATERIAL SHIPPED IS IN COMPLIANCE WITH THE REFERENCED SPECIFICATIONS AND YOUR PURCHASE ORDER REQUIREMENTS.

ORIGINAL TEST REPORTS ARE MAINTAINED IN OUR FILES.

YOUR PURCHASE ORDER:  CT5807

PURCHASE ORDER DATE:  9-9-10

RONSON SALES ORDER:  RE-9887

SHIPPED TO:  C-FER TECNOLOGIES (1999) INC
200 KARL CLARK RD
EDMONTON, ALBERTA
CANADA, T6N 1H2

REPORT OF CHEMICAL
AND PHYSICAL TEST TO:  MIL-S-16216K HY80 TY.1

DESCRIPTION:   ITEM 1:   3PCS ¼" X 96" X 240" PLATE
CUT PER DRAWING CFER-F034-07
ARCELORMITTAL
1PC HT# R2452-01AB
1PC HT# R2452-01AC
1PC HT# R2452-01AD

THIS MATERIAL HAS NOT COME INTO CONTACT WITH MERCURY OR ANY OF ITS COMPOUNDS WHILE IN OUR POSSESSION.

JIM COYER
QUALITY ASSURANCE DEPT.

September 22, 2010
DATE

100

ARCELORMITTAL PLATE LLC

# T E S T   C E R T I F I C A T E

SHIP TO:
RONSON TECHNICAL PRODUCTS
C/O HUDSON METAL PROCESSING
1500 NATIONAL CEMETARY ROAD
FLORENCE SC  29506

PAGE NO: 01 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AD
DATE: 05/25/10

SOLD TO:
ENERGY & PROCESS CORPORATION
A FERGUSON ENTERPRISE
P.O. BOX 125
TUCKER GA  30085-0125

SEND TO:                                    01-C

## P L A T E   D I M E N S I O N S   /   D E S C R I P T I O N

| TOTAL QTY | GAUGE | WIDTH | LENGTH | DESCRIPTION | PIECE WEIGHT |
|-----------|-------|-------|--------|-------------|--------------|
| 1 | 1/4" | 96" | 240" | RECTANGLE | 1634# |

## C U S T O M E R   I N F O R M A T I O N

CUSTOMER PO: E257-451

CONTRACT NO. CD8-46079-08                PART NO. HY8014N

## S P E C I F I C A T I O N ( S )

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE
ORDER REQUIREMENTS AND SPECIFICATION(S).

NAVSE TECH-PUB-T9074 REV 0 YR 02 HY80-TY.I
MIL S-16216K(SH) 87 GRADE HY80 TYPE I
NAVSEA TECH. PUBLICATION T9074-BD-GIB-010/0300
REVISION 0 DATED 08/09/02 HY80-TYI
WITH ACN 1 OF 11 DEC. 2002.
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED
TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE
NO. 006928).

## C H E M I C A L   C O M P O S I T I O N

|  | C | MN | P | S | CU | SI | NI | CR | MO |
|---|---|----|---|---|----|----|----|----|----|
| MELT:R2452 | .13 | .31 | .005 | .002 | .14 | .20 | 2.16 | 1.11 | .24 |
| PROD ANALYSIS | .12 | .30 | .004 | .002 | .13 | .20 | 2.06 | 1.07 | .22 |

|  | V | TI | AL | CB | SB | AS | SN |
|---|---|----|----|----|----|----|----|
| MELT:R2452 | .003 | .001 | .016 | .001 | .0010 | .0030 | .007 |
| PROD ANALYSIS | .003 | .001 | .018 | .001 | .0010 | .0030 | .005 |

## M A N U F A C T U R E

ELECTRIC FURNACE QUALITY - FINELINE - VACUUM DEGASSED - FINE GRAIN
PRACTICE

Q.A. APPROVED
RONSON TECHNICAL PRODUCTS

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA  19320

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

101

411006

TEST CERTIFICATE
PAGE NO: 02 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AD
DATE: 05/25/10

# HEAT TREAT CONDITION

| MATL OR TEST | HEAT TREAT DESCRIPTION | NOM TEMP | HOLD MINS | COOL MTHD |
|---|---|---|---|---|
| PL/TEST | HARDEN | 1659F | 16 | W.QUENCH |
| PL/TEST | TEMPER | 1280F | 27 | AIR COOL |

# TENSILE PROPERTIES

| SLAB NO. | LOC | DIR | YIELD STRENGTH PSI X 100 | TENSILE STRENGTH PSI X 100 | ELONGATION GAGE LGTH | % |
|---|---|---|---|---|---|---|
| 1AD | BOT. | TRANS. | 972 | 1063 | 2.00" | 28.0 |
| 1AD | TOP | TRANS. | 949 | 1046 | 2.00" | 28.0 |

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA  19320

*Elinore Zaplitny*

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

411006

TEST CERTIFICATE

PAGE NO: 03 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AD
DATE: 05/25/10

# GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
PRODUCED IN ACCORDANCE WITH INSPECTION SYSTEM
REQUIREMENTS OF MIL-I-45208A AMEND #1.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED
FOR SULFIDE SHAPE CONTROL. FINELINE MOD FOR SULPHUR
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
THE TEST RESULTS SHOWN IN THIS REPORT ARE THE
RESULTS OF TESTING PERFORMED BY OUR ORGANIZATION.
LOW MELTING ALLOYS OR LOW MELTING COMPOUNDS ARE NOT
USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC
PRODUCTS OTHER THAN AS DEOXIDIZING AGENTS.
MERCURY OR MERCURY COMPOUNDS ARE NOT USED IN THE
MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS.

NDT, VISUAL AND DIMENSIONAL INSPECTION AS REQUIRED BY THE SPECIFICATION
WAS SATISFACTORILY PERFORMED.

MATERIAL HAS BEEN SAMPLED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE
SPECIFICATION REQUIREMENTS. THE MANUFACTURER HAS MAINTAINED MANUFACTURING
PROCEDURES AND PRACTICES WHICH PRODUCE PLATES WHICH MEET THE MINIMUM
PROPERTY REQUIREMENTS THROUGHOUT THE PLATE. THE MATERIAL MEETS ALL
SPECIFICATION REQUIREMENTS.

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED,
PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED AND HEAT TREATMENT.

KNOWINGLY AND WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS
FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT ENTRIES OR REPRESENTATIONS
HEREIN, COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

CERTIFICATE OF CONFORMANCE - ALL ITEMS FURNISHED IN THE SHIPMENT ARE IN
FULL CONFORMANCE WITH ALL P.O. AND SPEC. REQ.; AND THAT THE T.R.'S
REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED ON THE ORDER, AND
THAT THE TEST RESULTS ARE IN FULL CONFORMANCE WITH ALL P.O. & SPEC. REQ.
RECORDS TO SUBSTANTIATE THE ABOVE ARE ON FILE IN

OUR PLANT AND WILL BE MAINTAINED FOR A PERIOD OF 7 YRS. FROM THE DATE OF
THE SHIPMENT UNLESS FURNISHED TO THE PURCHASER IN ADVANCE OF OR AT TIME OF
SHIPMENT. WHEN RECORDS ARE RETAINED BY US, WE AGREE TO FURNISH SAME TO THE
PURCHASER AT ANY TIME DURING THE ABOVE PERIOD UPON REQUEST.

HEAT TREAT PROC. NO. MIL-STD-1684D

B/L #11522 JONES MOTOR CO.

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

*Elinore Zaplitny*

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

103

# ArcelorMittal USA
## Ultrasonic (Thickness and Internal Soundness)
## Micrometer, Brinell, and Plate Inspection Report

| Customer | Mill Order No. | Item | Plate Spec. | Date |
|---|---|---|---|---|
| #2822 | 31350 | 001 | NAVSE TECH-PUB-T9074 002 HY80-TYI | 5-18-10 |
| | Customer P.O. No. E257-451 | | Size .250 X 96 X 240 | Melt & Slab R2452-1AD |
| N.D.T. Procedure | | | Mark No. | Assigned No. 1702 |

**INTERNAL SOUNDNESS**

Over ½" Thru 2½"
- ☐ Static Test on 24" Centers
- ☐ 100%

Over 2½"
- ☐ Grid & 1 Diagonal 24" Centers
- ☐ Static Test on 8"
- ☐ 100%
- ☐ Other

**THICKNESS**
ULTRASONIC THICKNESS CHECK ON 2' CENTERS STARTING 6" FROM PLATE EDGE. MICROMETER THICKNESS CHECK, THREE EACH SIDE, TWO EACH END, ALL EQUALLY SPACED.

| ULTRASONIC | 0.5' | 2.5' | 4.5' | 6.5' | 8.5' | 10.5' | 12.5' | 14.5' | |
|---|---|---|---|---|---|---|---|---|---|
| MICROMETER | 268 | 271 | | | | | | | MICROMETER |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.5' | | | | | | | | | |
| 2.5' | | 264 | "T" | | | | | | |
| 4.5' | | | | | 264 | | | | |
| 6.5' | | | | | | | | | |
| 8.5' | | | | | | | | | |
| 10.5' | | | | | | | | | |
| 12.5' | | 260 | | | 262 | | | | |
| 14.5' | | | | | | | | | |
| 16.5' | | | | | | | | | |
| 18.5' | | | | | | | | | |
| 20.5' | | | | | | | | | |
| 22.5' | | | | | | | | | |
| 24.5' | | 261 | | | 273 | | | | |
| 26.5' | | | | | | | | | |
| 28.5' | | | 271 | 275 | | | | | |
| 30.5' | | | | | | | | | |
| 32.5' | | | | | | | | | |
| 34.5' | | | | | | | | | |
| 36.5' | | | | | | | | | |
| 38.5' | | | | | | | | | |
| 40.5' | | | | | | | | | |
| 42.5' | | | | | | | | | |
| 44.5' | | | | | | | | | |
| 46.5' | | | | | | | | | |
| 48.5' | | | | | | | | | |

MICROMETER    "T" = Reference Thickness Starting Point    MICROMETER

### VISUAL
☑ TOP    ☑ BOTTOM    ☑ EDGES

| Flat | ☑ | Within _____ |
|---|---|---|
| Camber OK | ☑ | Within _____ |

Length 240-5/8  240-1/2    Width 96-7/16  96-1/2  96-7/16

Brinell Hardness
(1) ____    (2) 104    (AVG)

### THICKNESS
Instr. Mfr/Model/No. C-3

Plate Gauge  ☑ Satis  ☐ Unsatis

| Min Allow 240 | Found 262 |
|---|---|
| Max Allow 277AVG | Found 275 |

Remarks:

OK PER SPEC.

### SOUNDNESS
Instr. Mfr/Model/No.

Crystal (Straight Beam)
2.25 MHz    1" Dia.

☐ Satis  ☐ Unsatis    Couplant:

Supple. Sheet Req.  ☐ Yes  ☐ No

Inspector (LEVEL I SNT-TC-1A)

Inspection Supervisor (LEVEL II SNT-TC-1A)

# Ronson Technical Products
### RECEIVING INSPECTION REPORT

Shipper# BT11522

VENDOR: Arcelormittal Plate LLC
PO#: E257-451 / E257-235,-254
LOCATION: Conshohocken, PA. 19428
VIA: Jones Motor Co.
INSPECTED BY: Dennis Hudson
DATE: 5-25-10

| ITEM | SPECIFICATION | QUAN. | SIZE | HEAT/LOT · SLAB | STOCK# | COLOR CODE | COST |
|---|---|---|---|---|---|---|---|
| 1 | HY80 Ty.I | 1 | 1/4X96X240 | R2452-01AD | 411006 | | |
| 2 | AH/DH36 | 1 | 3/16X96X480 | R4292-39C | 261680 | | |
| 3 | | 1 | 3/16X96X480 | R4292-39C | 261681 | | |
| 4 | | 1 | 3/16X96X480 | R4292-39C | 261682 | | |
| 5 | | 1 | 3/16X96X480 | R4292-39C | 261683 | | |
| 6 | | 1 | 3/16X96X480 | R4292-39C | 261684 | | |
| 7 | HSLA100 Ty.2 | 1 | 5/8X96X480 | R4705-39CA | 510092 | | |
| 8 | HSLA100 Ty.2 | 1 | 3/4X96X480 | R4705-01AA | 510093 | | |
| 9 | HSLA100 Ty.I | 1 | 1/2X96X480 | R4553-01FB | 510090 | | |
| 10 | | 1 | 1/2X96X480 | R5008-39AA | 510091 | | |

STOCK

CUSTOMER

S.O.#

COMMENTS

QA DOCUMENTS RECEIVED        44,921#

QA REVIEW BY                         DATE                         DMR #

QA RELEASE BY                        DATE

COMMENTS

10

SHIP TO:    ARCELORMITTAL PLATE LLC    T E S T   C E R T I F I C A T E

SHIP TO:
RONSON TECHNICAL PRODUCTS
C/O HUDSON METAL PROCESSING    **ORIGINAL**
1500 NATIONAL CEMETARY ROAD
FLORENCE SC  29506

PAGE NO: 01 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AB
DATE: 11/26/09

SOLD TO:
ENERGY & PROCESS CORPORATION    SEND TO:
A FERGUSON ENTERPRISE
P.O. BOX 125    01-C
TUCKER GA  30085-0125

# P L A T E   D I M E N S I O N S  /  D E S C R I P T I O N

| TOTAL QTY | GAUGE | WIDTH | LENGTH | DESCRIPTION | PIECE WEIGHT |
|---|---|---|---|---|---|
| 1 | 1/4" | 96" | 240" | RECTANGLE | 1634# |

# C U S T O M E R   I N F O R M A T I O N

CUSTOMER PO: E257-451

CONTRACT NO. CD8-46079-08

PART NO. HY8014N

# S P E C I F I C A T I O N ( S )

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE
ORDER REQUIREMENTS AND SPECIFICATION(S).

NAVSE TECH-PUB-T9074 REV 0 YR 02 HY80-TY.I
MIL S-16216K(SH) 87 GRADE HY80 TYPE I
NAVSEA TECH. PUBLICATION T9074-BD-GIB-010/0300
REVISION 0 DATED 08/09/02 HY80-TYI
WITH ACN 1 OF 11 DEC. 2002.
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED
TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE
NO. 006928).

# C H E M I C A L   C O M P O S I T I O N

| | C | MN | P | S | CU | SI | NI | CR | MO |
|---|---|---|---|---|---|---|---|---|---|
| MELT:R2452 PROD ANALYSIS | .13 | .31 | .005 | .002 | .14 | .20 | 2.16 | 1.11 | .24 |
| | .12 | .30 | .004 | .002 | .13 | .20 | 2.06 | 1.07 | .22 |

| | V | TI | AL | CB | SB | AS | SN | | |
|---|---|---|---|---|---|---|---|---|---|
| MELT:R2452 PROD ANALYSIS | .003 | .001 | .016 | .001 | .0010 | .0030 | .007 | | |
| | .003 | .001 | .018 | .001 | .0010 | .0030 | .005 | | |

# M A N U F A C T U R E

ELECTRIC FURNACE QUALITY - FINELINE - VACUUM DEGASSED - FINE GRAIN
PRACTICE

Q.A. APPROVED
RONSON TECHNICAL PRODUCTS

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA  19320

*Elinore Zaplitny*

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

410930

ORIGINAL     TEST CERTIFICATE

PAGE NO: 02 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AB
DATE: 11/26/09

## HEAT TREAT CONDITION

| MATL OR TEST | HEAT TREAT DESCRIPTION | NOM TEMP | HOLD MINS | COOL MTHD |
|---|---|---|---|---|
| PL/TEST | HARDEN | 1659F | 16 | W.QUENCH |
| PL/TEST | TEMPER | 1280F | 27 | AIR COOL |

## TENSILE PROPERTIES

| SLAB NO. | LOC | DIR | YIELD STRENGTH PSI X 100 | TENSILE STRENGTH PSI X 100 | ELONGATION GAGE LGTH | % |
|---|---|---|---|---|---|---|
| 1AB | BOT. | TRANS. | 939 | 1031 | 2.00" | 30.0 |
| 1AB | TOP | TRANS. | 945 | 1033 | 2.00" | 27.0 |

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

*Elinore Zaplitny*

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

ORIGINAL

PAGE NO: 03 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AB
DATE: 11/26/09

## GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A. PRODUCED IN ACCORDANCE WITH INSPECTION SYSTEM REQUIREMENTS OF MIL-I-45208A AMEND #1. MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED FOR SULFIDE SHAPE CONTROL. FINELINE MOD FOR SULPHUR NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC. THE TEST RESULTS SHOWN IN THIS REPORT ARE THE RESULTS OF TESTING PERFORMED BY OUR ORGANIZATION. LOW MELTING ALLOYS OR LOW MELTING COMPOUNDS ARE NOT USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS OTHER THAN AS DEOXIDIZING AGENTS. MERCURY OR MERCURY COMPOUNDS ARE NOT USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS.

NDT, VISUAL AND DIMENSIONAL INSPECTION AS REQUIRED BY THE SPECIFICATION WAS SATISFACTORILY PERFORMED.

MATERIAL HAS BEEN SAMPLED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE SPECIFICATION REQUIREMENTS. THE MANUFACTURER HAS MAINTAINED MANUFACTURING PROCEDURES AND PRACTICES WHICH PRODUCE PLATES WHICH MEET THE MINIMUM PROPERTY REQUIREMENTS THROUGHOUT THE PLATE. THE MATERIAL MEETS ALL SPECIFICATION REQUIREMENTS.

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED, PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED AND HEAT TREATMENT.

KNOWINGLY AND WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT ENTRIES OR REPRESENTATIONS HEREIN, COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

CERTIFICATE OF CONFORMANCE - ALL ITEMS FURNISHED IN THE SHIPMENT ARE IN FULL CONFORMANCE WITH ALL P.O. AND SPEC. REQ.; AND THAT THE T.R.'S REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED ON THE ORDER, AND THAT THE TEST RESULTS ARE IN FULL CONFORMANCE WITH ALL P.O. & SPEC. REQ. RECORDS TO SUBSTANTIATE THE ABOVE ARE ON FILE IN

OUR PLANT AND WILL BE MAINTAINED FOR A PERIOD OF 7 YRS. FROM THE DATE OF THE SHIPMENT UNLESS FURNISHED TO THE PURCHASER IN ADVANCE OF OR AT TIME OF SHIPMENT. WHEN RECORDS ARE RETAINED BY US, WE AGREE TO FURNISH SAME TO THE PURCHASER AT ANY TIME DURING THE ABOVE PERIOD UPON REQUEST.

HEAT TREAT PROC. NO. MIL-STD-1684D

B/L #77808 JONES MOTOR CO.

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

*Elinore Zaplitny*

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

Form No. 1360 (R 4/09)

# ArcelorMittal USA
## Ultrasonic (Thickness and Internal Soundness)
## Micrometer, Brinell, and Plate Inspection Report

| Customer | 2822 | Mill Order No. 31350 | Item 001 | Plate Spec. NAUSE Tech Pub T8074-0-02-H480-T/1 | | Date 10/2/09 |
|---|---|---|---|---|---|---|

| N.D.T. Procedure | Customer P.O. No. E257-451 | Size .250 X 96 X 240 | Melt & Slab R2452-1AB |
|---|---|---|---|

Mark No.

Assigned No. Lc# 1700

### INTERNAL SOUNDNESS

**Over ½" Thru 2 ½"**
- ☐ Static Test on 24" Centers
- ☐ 100%

**Over 2 ½"**
- ☐ Grid & 1 Diagonal 24" Centers
- ☐ Static Test on 8"
- ☐ Other

### THICKNESS
ULTRASONIC THICKNESS CHECK ON 2' CENTERS STARTING 6" FROM PLATE EDGE, MICROMETER THICKNESS CHECK, THREE EACH SIDE, TWO EACH END, ALL EQUALLY SPACED.

| ULTRASONIC | 0.5' | 2.5' | 4.5' | 6.5' | 8.5' | 10.5' | 12.5' | 14.5' | |
|---|---|---|---|---|---|---|---|---|---|
| **MICROMETER** | | | | | | | | | **MICROMETER** |
| 0.5' | | | ✗265 | 268 ✗ | | | | | |
| 2.5' | | ✗265 "T" | | | | | | | |
| 4.5' | | | | | | 264 ✗ | | | |
| 6.5' | | | | | | | | | |
| 8.5' | | | | | | | | | |
| 10.5' | | ✗266 | | | | | | | |
| 12.5' | | | | | | 264 ✗ | | | |
| 14.5' | | | | | | | | | |
| 16.5' | | ✗264 | | | | | | | |
| 18.5' | | | | | | 266 ✗ | | | |
| 20.5' | | | | | | | | | |
| 22.5' | | | ✗265 | 267 ✗ | | | | | |
| 24.5' | | | | | | | | | |
| 26.5' | | | | | | | | | |
| 28.5' | | | | | | | | | |
| 30.5' | | | | | | | | | |
| 32.5' | | | | | | | | | |
| 34.5' | | | | | | | | | |
| 36.5' | | | | | | | | | |
| 38.5' | | | | | | | | | |
| 40.5' | | | | | | | | | |
| 42.5' | | | | | | | | | |
| 44.5' | | | | | | | | | |
| 46.5' | | | | | | | | | |
| 48.5' | | | | | | | | | |

**MICROMETER**

'T' = Reference Thickness Starting Point

**MICROMETER**

### VISUAL
☑ TOP ☑ BOTTOM ☑ EDGES

| Flat | ☑ | Within 3/4 |
|---|---|---|
| Camber OK | ☑ | Within 1/4 |

| Length | 240 3/4 | Width | 96 4/2 |
|---|---|---|---|
| | 240 4/16 | | 96 9/16 |
| | | | 96 7/16 |

Brinell Hardness

(1)     (2)     (AVG)

### THICKNESS
Instr. Mfr/Model/No. C6

Plate Gauge ☑ Satis ☐ Unsatis

Min Allow .240

Max Allow .257486

Found .264

Found .268

Remarks:

### MICROMETER
**SOUNDNESS**

Instr. Mfr/Model/No.

☐ Satis ☐ Unsatis

Crystal (Straight Beam)
2.25 MHz   1" Dia.

Couplant:

Supple. Sheet Req.  ☐ Yes  ☐ No

Inspector (LEVEL 1 SNT-TC-1A)

109

Inspection

# Ronson Technical Products
## RECEIVING INSPECTION REPORT

**VENDOR:** Arcelormittal Plate LLC
**LOCATION:** Conshohocken, PA

**PO#:** E257-451,-381 Add#1,-451 Add#1
**VIA:** Jones Motor Co.

**Shipper # BT77808**
**INSPECTED BY:** Dennis Phelps
**DATE:** 12-1-09

| ITEM | SPECIFICATION | QUAN. | SIZE | HEAT/LOT · SLAB | STOCK # | COLOR CODE | COST |
|------|---------------|-------|------|-----------------|---------|------------|------|
| 1 | HY80-TY.1 | 1 | 1/4 X 96 X 240 | R2452-01AA | 410929 | | |
| 2 | | 1 | 1/4 X 96 X 240 | R2452-01AB | 410930 | | |
| 3 | | 1 | 1/4 X 96 X 240 | R2496-39AJ | 410931 | | |
| 4 | EH36T | 1 | 3/8 X 96 X 480 | R2339-02FA | 310525 | | |
| 5 | | 1 | 3/8 X 96 X 480 | R2339-02FB | 310526 | | |
| 6 | | 1 | 3/8 X 96 X 480 | R2339-02FC | 310523 | | |
| 7 | | 1 | 3/8 X 96 X 480 | R2651-01CA | 310528 | | |
| 8 | | 1 | 3/8 X 96 X 480 | R2651-01DA | 310524 | | |
| 9 | | 1 | 3/8 X 96 X 480 | R2651-01DC | 310522 | | |
| 10 | HY80-TY.1 | 1 | 1/2 X 96 X 480 | R2490-04GA | 410941 | | |
| | | 1 | 1/2 X 96 X 480 | R2490-04GB | 410942 | | |

**STOCK**

**CUSTOMER**

**S.O.:**

**COMMENTS**

**QA DOCUMENTS RECEIVED**

**QA REVIEW BY** _____ **DATE** _____

**QA RELEASE BY** _____ **DATE** _____

**COMMENTS**

47,376 #

410935

# TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
RONSON TECHNICAL PRODUCTS
C/O HUDSON METAL PROCESSING
1500 NATIONAL CEMETARY ROAD
FLORENCE SC  29506

PAGE NO: 01 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AC
DATE: 02/09/10

SOLD TO:
ENERGY & PROCESS CORPORATION
A FERGUSON ENTERPRISE
P.O. BOX 125
TUCKER GA  30085-0125

SEND TO:                          01-C

## PLATE DIMENSIONS / DESCRIPTION

| TOTAL QTY | GAUGE | WIDTH | LENGTH | DESCRIPTION | PIECE WEIGHT |
|-----------|-------|-------|--------|-------------|--------------|
| 1 | 1/4" | 96" | 240" | RECTANGLE | 1634# |

## CUSTOMER INFORMATION

CUSTOMER PO: E257-451

CONTRACT NO. CD8-46079-08                    PART NO. HY8014N

## SPECIFICATION(S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE
ORDER REQUIREMENTS AND SPECIFICATION(S).

NAVSE TECH-PUB-T9074 REV 0 YR 02 HY80-TY.I
MIL S-16216K(SH) 87 GRADE HY80 TYPE I
NAVSEA TECH. PUBLICATION T9074-BD-GIB-010/0300
REVISION 0 DATED 08/09/02 HY80-TYI
WITH ACN 1 OF 11 DEC. 2002.
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED
TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE
NO. 006928).

## CHEMICAL COMPOSITION

| | C | MN | P | S | CU | SI | NI | CR | MO |
|---|---|----|---|---|----|----|----|----|----|
| MELT:R2452 | .13 | .31 | .005 | .002 | .14 | .20 | 2.16 | 1.11 | .24 |
| PROD ANALYSIS | .12 | .30 | .004 | .002 | .13 | .20 | 2.06 | 1.07 | .22 |

| | V | TI | AL | CB | SB | AS | SN |
|---|---|----|----|----|----|----|----|
| MELT:R2452 | .003 | .001 | .016 | .001 | .0010 | .0030 | .007 |
| PROD ANALYSIS | .003 | .001 | .018 | .001 | .0010 | .0030 | .005 |

## MANUFACTURE

ELECTRIC FURNACE QUALITY - FINELINE - VACUUM DEGASSED - FINE GRAIN
PRACTICE

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA  19320

*Elinore Zaplitny*

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

111

410935

TEST CERTIFICATE

PAGE NO: 02 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AC
DATE: 02/09/10

## HEAT TREAT CONDITION

| MATL OR TEST | HEAT TREAT DESCRIPTION | NOM TEMP | HOLD MINS | COOL MTHD |
|---|---|---|---|---|
| PL/TEST | HARDEN | 1659F | 16 | W.QUENCH |
| PL/TEST | TEMPER | 1280F | 27 | AIR COOL |

## TENSILE PROPERTIES

| SLAB NO. | LOC | DIR | YIELD STRENGTH PSI X 100 | TENSILE STRENGTH PSI X 100 | ELONGATION GAGE LGTH | % |
|---|---|---|---|---|---|---|
| 1AC | BOT. | TRANS. | 937 | 1038 | 2.00" | 26.0 |
| 1AC | TOP | TRANS. | 943 | 1037 | 2.00" | 26.0 |

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA  19320

*Elinore Zaplitny*

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

410935

TEST CERTIFICATE

PAGE NO: 03 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AC
DATE: 02/09/10

## GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
PRODUCED IN ACCORDANCE WITH INSPECTION SYSTEM
REQUIREMENTS OF MIL-I-45208A AMEND #1.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED
FOR SULFIDE SHAPE CONTROL.  FINELINE MOD FOR SULPHUR
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
THE TEST RESULTS SHOWN IN THIS REPORT ARE THE
RESULTS OF TESTING PERFORMED BY OUR ORGANIZATION.
LOW MELTING ALLOYS OR LOW MELTING COMPOUNDS ARE NOT
USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC
PRODUCTS OTHER THAN AS DEOXIDIZING AGENTS.
MERCURY OR MERCURY COMPOUNDS ARE NOT USED IN THE
MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS.

NDT, VISUAL AND DIMENSIONAL INSPECTION AS REQUIRED BY THE SPECIFICATION
WAS SATISFACTORILY PERFORMED.

MATERIAL HAS BEEN SAMPLED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE
SPECIFICATION REQUIREMENTS. THE MANUFACTURER HAS MAINTAINED MANUFACTURING
PROCEDURES AND PRACTICES WHICH PRODUCE PLATES WHICH MEET THE MINIMUM
PROPERTY REQUIREMENTS THROUGHOUT THE PLATE. THE MATERIAL MEETS ALL
SPECIFICATION REQUIREMENTS.

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED,
PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED AND HEAT TREATMENT.

KNOWINGLY AND WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS
FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT ENTRIES OR REPRESENTATIONS
HEREIN, COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

CERTIFICATE OF CONFORMANCE - ALL ITEMS FURNISHED IN THE SHIPMENT ARE IN
FULL CONFORMANCE WITH ALL P.O. AND SPEC. REQ.; AND THAT THE T.R.'S
REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED ON THE ORDER, AND
THAT THE TEST RESULTS ARE IN FULL CONFORMANCE WITH ALL P.O. & SPEC. REQ.
RECORDS TO SUBSTANTIATE THE ABOVE ARE ON FILE IN

OUR PLANT AND WILL BE MAINTAINED FOR A PERIOD OF 7 YRS. FROM THE DATE OF
THE SHIPMENT UNLESS FURNISHED TO THE PURCHASER IN ADVANCE OF OR AT TIME OF
SHIPMENT. WHEN RECORDS ARE RETAINED BY US, WE AGREE TO FURNISH SAME TO THE
PURCHASER AT ANY TIME DURING THE ABOVE PERIOD UPON REQUEST.

HEAT TREAT PROC. NO. MIL-STD-1684D

B/L #03107 JONES MOTOR CO.

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA  19320

*Elinore Zaplitny*

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY          113

Form No. 1360 (R 4/09)

**ArcelorMittal USA**
Ultrasonic (Thickness and Internal Soundness)
Micrometer, Brinell, and Plate Inspection Report

| Customer 2822 | Mill Order No. 31350 | Item 001 | Plate Spec. NAVSE Tech Pub T90740-02-H480-T/1 | Date 1-15-10 |
|---|---|---|---|---|
| | Customer P.O. No. E257-451 | Size 250 X96 X240 | Melt & Slab R2452-1AC | |
| N.D.T. Procedure | | Mark No. | Assigned No. Lc# 1703 | |

**INTERNAL SOUNDNESS**

Over ½" Thru 2 ½"
☐ Static Test on 24" Centers
☐ 100%

Over 2 ½"
☐ Grid & 1 Diagonal 24" Centers
☐ Static Test on 8"
☐ Other

**THICKNESS**
ULTRASONIC THICKNESS CHECK ON 2' CENTERS STARTING 6" FROM PLATE EDGE, MICROMETER THICKNESS CHECK, THREE EACH SIDE, TWO EACH END, ALL EQUALLY SPACED.

| ULTRASONIC | 0.5' | 2.5' | 4.5' | 6.5' | 8.5' | 10.5' | 12.5' | 14.5' | |
|---|---|---|---|---|---|---|---|---|---|
| MICROMETER | | 271 * | | 265 * | | | | | MICROMETER |
| 0.5' | | "T" | | | | | | | |
| 2.5' | 264* | | | | | 263* | | | |
| 4.5' | | | | | | | | | |
| 6.5' | | | | | | | | | |
| 8.5' | | | | | | | | | |
| 10.5' | 263* | | | | | 263* | | | |
| 12.5' | | | | | | | | | |
| 14.5' | | | | | | | | | |
| 16.5' | 262* | | | | | 269* | | | |
| 18.5' | | | | | | | | | |
| 20.5' | | 261* | | 259* | | | | | |
| 22.5' | | | | | | | | | |
| 24.5' | | | | | | | | | |
| 26.5' | | | | | | | | | |
| 28.5' | | | | | | | | | |
| 30.5' | | | | | | | | | |
| 32.5' | | | | | | | | | |
| 34.5' | | | | | | | | | |
| 36.5' | | | | | | | | | |
| 38.5' | | | | | | | | | |
| 40.5' | | | | | | | | | |
| 42.5' | | | | | | | | | |
| 44.5' | | | | | | | | | |
| 46.5' | | | | | | | | | |
| 48.5' | | | | | | | | | |

| MICROMETER | "T" = Reference Thickness Starting Point | MICROMETER |

**VISUAL**

☑ TOP   ☑ BOTTOM   ☑ EDGES

Flat ☑   Within 3/4
Camber OK ☑   Within 1/4

Length 240 5/8
       240 11/16

Width 96 7/16
      96 42
      96 1/2

Brinell Hardness 14

**THICKNESS**
Instr. Mfr/Model/No. C6
Plate Gauge ☑ Satis ☐ Unsatis
Min Allow .240   Found 259
Max Allow 271 AVG   Found 271

Remarks: OK Per Spec

**SOUNDNESS**
Instr. Mfr/Model/No.
Crystal (Straight Beam)
2.25 MHz   1" Dia.
☐ Satis ☐ Unsatis
Couplant:
Supple. Sheet Req. ☐ Yes / ☐ No

Inspector (LEVEL I SNT-TC-1A)

Inspection Supervisor (LEVEL II SNT-TC-1A)

VENDOR: Arcelormittal Plate LLC
LOCATION: Conshohocken, PA.
PO#: E257-451,-381 Add#1,451 Add#2, F257-65,-118
VIA: Jones Motor Co.
Shipper # BT63107
INSPECTED BY: Deno Rhoden
DATE: 2-9-10

| ITEM | SPECIFICATION | QUAN. | SIZE | HEAT/LOT-SLAB | STOCK # | COLOR CODE | COST |
|---|---|---|---|---|---|---|---|
| 1 | HY80 Ty.1 | 1 | 1/4x96x240 | R2452-01AC | 410935 | | |
| 2 | EH36T | 1 | 3/8x96x478 | R2651-01DB | 310527 | | |
| 3 | HY80 Ty.1 | 1 | 3/16x60x240 | R2994-01AA | 410950 | | |
| 4 | | 1 | 3/16x60x240 | R2994-01AJ | 410951 | | |
| 5 | | 1 | 3/16x60x240 | R2994-01AK | 410960 | | |
| 6 | | 1 | 3/16x60x240 | R2994-01AL | 410963 | | |
| 7 | HSLA80 Ty.II | 1 | 3/4x96x480 | R2968-04EA | 800845 | | |
| 8 | HSLA80 Ty.II | 1 | 5/8x96x480 | R3010-01AA | 860842 | | |
| 9 | HY100 Ty.II | 1 | 3/4x96x480 | R3549-01CA | 400281 | | |
| 10 | | 1 | 3/4x96x480 | R3672-39AA | 400282 | | |

STOCK

CUSTOMER:

S.O.#:

COMMENTS:

QA DOCUMENTS RECEIVED: 47,149#

QA REVIEW BY:

QA RELEASE BY:                    DATE:                    DMR #

COMMENTS:

115

This page intentionally left blank.

# Annex E    Vendor Cut and Plate Layout Drawings

This page intentionally left blank.

240 Nominal
(TYP)

96 Nominal
(TYP)

A    P1S1    B  |  B    P1S2    C

TOP        TOP

BOTTOM        BOTTOM

$142^{+.25}_{-.00}$ (TYP)

plate cut line

TOP        TOP

A    P2S1    B  |  B    P2S2    C

BOTTOM        BOTTOM

TOP        TOP

A    P3S1    B  |  B    P3S2    C

BOTTOM        BOTTOM

NOTES:
(1) Each plate shall be clearly marked as indicated using a permanent marker or paint pen. No etching, scribing or stamping is permitted.
(2) Markings will be on the same side of both sections for each plate (i.e. P1S1 and P1S2 marked on same side for Plate 1).
(3) Nominal dimensions are for reference only. Plates will **not** be cut by vendor to these dimensions.
(4) Plates will be cut on a burn table and will not be cut by hand or by a hand torch.

COMMENTS:

MATERIAL
HY80

| | NAME | DATE |
|---|---|---|
| DRAWN | DSS | 10Sept21 |
| CHECKED | CMT | 10Sept21 |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | Tol. | T.I.R. | Finish |
|---|---|---|---|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

C-FER
Technologies

Design & Construction
F034

Vendor Plate Cuts

| SIZE | DWG. NO. | REV. |
|---|---|---|
| A | CFER-F034-07  119 | 0 |

SCALE:1:50  WEIGHT:        SHEET 8 OF 12

| REV. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| B | RE-ISSUED FOR REVIEW | DSS | Jan 14, 2011 |

SCRAP

CUT LINE

142.00

133.25 (TYP)

SPARE MATERIAL

67.00

96
NOMINAL

1.181 (30-mm)
(TYP FOR ALL)

0.250

COMMENTS:
Need 12 strips cut.

MATERIAL
HY80

| | NAME | DATE |
|---|---|---|
| DRAWN | DSS | 14Jan11 |
| CHECKED | | |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | Tol. | T.I.R. | Finish |
|---|---|---|---|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

C-FER
Technologies

Design & Construction
F034
Cylinder Plate Layout

SIZE A   DWG. NO. CFER-F034-PL-01   REV. B

SCALE:1:24 WEIGHT:978.45 Lbs   SHEET 1 OF 4

Coupon Plate

Spare Plate

2.5
31.25
1.2
1.0
98 NOMINAL
4.0 (TYP)
96 NOMINAL
1.0
14.25
4.0
0.250

| REV. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| A | ISSUED FOR REVIEW | DSS | Jan 12, 2011 |

MATERIAL
HY80

| | NAME | DATE |
|---|---|---|
| DRAWN | DSS | 12Jan11 |
| CHECKED | CMT | 12Jan11 |

DIMENSIONS ARE IN INCHES
TOLERANCES UNLESS OTHERWISE NOTED:
1) Decimal: x.xxx Tol. ±0.005" T.I.R. 0.005" Finish 63μinch Ra
   x.xx ±0.015" 0.015" 125μinch Ra
   x.x ±0.030" 0.030" 250μinch Ra
2) Angular: x.x ±0.5"
   x. ±1.0

C-FER Technologies

Design & Construction
F034
Cylinder Plate Layout

SIZE A | DWG. NO. CFER-F034-PL-02 | REV. A
SCALE:1:24 | WEIGHT:675.91 Lbs | SHEET 2 OF 4

121

120.00°

R22.388

36.526

1.299 (33-mm)

0.250

122

C-FER
Technologies

Design & Construction
F034
Cut Web Detail

COMMENTS:

MATERIAL
HY80

| | NAME | DATE |
|---|------|------|
| DRAWN | DSS | 12Jan11 |
| CHECKED | CMT | 12Jan11 |

DIMENSIONS ARE IN INCHES
TOLERANCES UNLESS OTHERWISE NOTED:

| | Tol. | T.I.R. | Finish |
|---|------|--------|--------|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

SIZE: A  DWG. NO. CFER-F034-PL-03  REV. A

SCALE:1:5  WEIGHT:  SHEET 3 OF 4

| REV. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| A | ISSUED FOR REVIEW | DSS | Jan 12, 2011 |

## COUPON PLATE

9.50

13.25

0.250

## SPARE PLATE

11.811
(30-cm)

11.811
(30-cm)

0.250

**COMMENTS:**

**MATERIAL**
HY80

| | NAME | DATE |
|---|---|---|
| DRAWN | DSS | 12Jan11 |
| CHECKED | CMT | 12Jan11 |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | Tol. | T.I.R. | Finish |
|---|---|---|---|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

**C-FER Technologies**

Design & Construction
F034

**Spare and Coupon Plate Detail**

SIZE **A** | DWG. NO. **CFER-F034-PL-04** | REV. **A**

SCALE:1:5 | WEIGHT: | SHEET 4 OF 4

This page intentionally left blank.

# Annex F    Fabrication Procedure

This page intentionally left blank.

# Petersen's Welding

**Fabrication Procedure for Collapse Cylinders**

The T-framed collapse cylinder shells will be fabricated following the steps listed below.  All welding will conform to the enclosed weld procedure specification documents.

1) The HY-80 plate material will be water jet cut following the layout drawings supplied by C-FER Technologies.  All material will be tracked accordingly to ensure each collapse cylinder is constructed from a single sheet of material.
2) The water jet parts that require cold forming will be cold rolled to the desired diameters.  The collapse cylinder shell and T-frame flanges will be rolled, the seam weld of the parts will then be tacked, and then the parts will be re-rolled to remove any crimping that may occur near the longitudinal seam.  In addition to rolling the HY-80 material, two ¾" thick strips of QT100 plate will be cold rolled for a transition ring from the end caps to the collapse cylinder.
3) Three of the arcs that are water jet cut will be tacked together to form the web of each T-frame.  The rolled flange will then be tack welded into position on the web of each T-frame.  After assembly the butt welds between web pieces will be made.  The flange will be stitch weld using 4 mm fillet welds on either side of the flange to web connection.  Stitch welding will be used to control distortions.  A complete fillet weld will be made on either side of the flange to web connection at completion of welding
4) After three T-frames are fabricated they will be NDE inspected following the requirements in the work scope provided by C-FER.
5) After passing weld inspections the remaining T-frames will be welded and then all T-frames will be measured according to the work scope provided by C-FER.
6) The shell of the collapse cylinder will be tack welded along the seam to provide dimensional stability.  The T-frames will be inserted into the ID of the shell and subsequently welded into place.  As each T-frame is welded to the shell, the seam weld of the collapse cylinder will be welded between T-frames except for the last cap pass.  The last cap pass of the seam weld will be done once the collapse cylinder assembly is complete.  The seam weld will be capped from the ID and OD of the collapse cylinder.
7) Grid markings will be placed on the cylinder according to the work scope document provided by C-FER.  These grid markings will be protected for the remaining fabrication and transport to C-FER allowing for measurements to be taken at multiple stages of the remaining fabrication.
8) The measurements listed in the scope of work provided by C-FER will be completed.
9) The ends of the collapse cylinder will then be cut and beveled perpendicular to the rolling axis.  The end caps will be positioned and tack welded in place.
10) The end caps will then be preheated to 250 F while the collapse cylinder body will remain at 70 F.  The end caps will be welded using a full penetration weld with a cap back up.
11) All circumferential welds will be done in a 1G position.
12) Upon return of the first collapse cylinder, the end caps will be torch cut from the collapse cylinder and subsequently prepared by grinding to be welded to the next collapse cylinder.  This process will be repeated with the second and third cylinders.

# Petersen's Welding

**End Cap Fabrication**

1) 6" plate material having a minimum yield of 50 ksi will be oxy-fuel torch cut to the rough diameters listed on the drawings.
2) The center cap will be machined to provide sealing surfaces and the desired holes.
3) A bushing will be machined with o-ring grooves and threaded holes to provide a seal surface for the center cap to be attached.
4) After machining the bushing will be inserted into the one end cap that was cut to provide material for the center cap.
5) The bushing will be welded into the end cap by fillet welds on either side of the bushing as marked on the drawings provided by C-FER.
6) Lifting eye holes will be drilled and tapped to facilitate handling of the end caps during fabrication and at C-FER.
7) The opposite end of the collapse cylinder will have a solid 6" thick plate with a minimum yield of 50 ksi will be welded to seal the cylinder.
8) For both end caps the ¾" thick QT100 strip that was cold rolled during cylinder fabrication will be beveled and welded to the end cap as per the drawings supplied by C-FER.  The ring will be welded using a full penetration weld to the end cap and then transition to 0.25" thick following a 4:1 transition as per the drawings.  This edge will subsequently be welded to the shell of the collapse cylinder.

**Simulated Corrosion**

1) A simulated corrosion defect will be installed on the desired cylinders by grinding or machining the wall thickness of the collapse cylinder shell to the desired wall loss.  The method of metal removal will need to be determined after the collapse cylinder has been welded.  This is necessary to determine the deformations that have occurred due to welding.  Once the deformations have been quantified the best suited machining method will be determined.
2) After a simulated corrosion defect has been machined a fine grid pattern will be marked across the area to allow for measurements to be taken.  Once again the grid lines will be protected to ensure they are present throughout the remaining fabrication.

**Weld Buttering**

1) Weld buttering will be done by using a short-arc GMAW welding process with ER100S-1 welding consumables.  Multiple passes will be placed side by side across the simulated corrosion defect until the thickness of the collapse cylinder shell is greater than the original thickness of the HY-80 plate.  The local temperature will be monitored and sufficient time between welding passes will be taken to allow the material to still air cool to within the maximum specified interpass temperature.
2) The weld passes will then be manually blended with a grinder/sander with the original plate material surrounding the simulated repair method.

128

3) After weld buttering and blending the fine grid pattern will be marked across the area in the original pattern to allow for measurements to be taken.  Once again the grid lines will be protected to ensure they are present throughout the remaining fabrication.

This page intentionally left blank.

# Annex G    NDE Report

This page intentionally left blank.

| **Applus RTD Canada** 5504 – 36 Street Edmonton, Ab. T6B 3P3 T 780 440 6600 F 780 440 2538 www.applusrtd.ca | **NDE REPORT #** | 031711-001 |
|---|---|---|

**Applus⊕ RTD**

| | |
|---|---|
| **NDE REPORT #** | 031711-001 |
| Date (m/d/y): 3/17/11 | Page 1 of 1 |
| RTD Job #: | |
| RTD Dep. #: | |

| | | | |
|---|---|---|---|
| Client: Randy Petersen | Job location: | Applus RTD shop | |
| Address: | Procedure(s): | ASME V | Rev. #: |
| | Code(s): | ASME VIII | |
| PO/WO: | Client Rep.: | | |

Part(s) Examined: (3) Welded T-frame, fillet welds and butt welds

Calibration Standard:

Surface Condition: ☒ Weldment ☐ Ground ☐ Machined ☐ Sandblasted ☐ Painted ☐ Other

Method: ☒ MT ☐ PT ☐ VT ☐ Other ___ Surface Temp (C°): ☐ < 5 > 5 ☒ < 60 ☒ > 60

## Equipment

| Type | RTD Asset # | Cal. Due Date (m/d/y) | Test Medium | Family | Batch # | Technique | |
|---|---|---|---|---|---|---|---|
| ☐ Yoke | 7064 | 03/28/11 | ☐ Wet Fluorescent | | | **MPI** | **LPI** |
| ☐ Perm. Magnet | | | ☐ Dry Powder | | | ☒ AC | ☐ Water Washable |
| ☐ Coil | | | ☒ Wet Magnetic Ink | 7HF | | ☐ DC | ☐ Post Emulsified |
| ☐ Black Light | | | ☒ Contrast | WCP-2 | | ☒ Continuous | ☐ Solvent Removable |
| ☐ Alloy Analyzer | | | ☐ Visible Dye | | | ☐ Residual | ☐ Other |
| ☐ Hardness Tester | | | ☐ Fluorescent Dye | | | ☐ Other | Dwell Time: ___ min |
| ☐ Other | | | ☐ Developer | | | | Develop Time: ___ min |

| Blacklight Intensity ≥ 1000 μW/cm² @ 18" from surface of part: ☐ Accept | Whitelight Intensity ≥ 100 fc @ surface of part: ☒ Accept |
|---|---|

## INSPECTION DETAILS

Scope: MPI of 3 welded T-frames, fillet welds and butt welds

Results: No evidence of any cracking, acceptable to code.

| Assistant 1: | Technician: **Peter den Boer** |
|---|---|
| Assistant 2: | ☐ CGSB ☐ ASNT ☒ SNT Level:☐ 1 ☒ 2 ☐ 3 |
| ☐ CGSB ☐ ASNT ☐ SNT Level:☐ 1 ☐ 2 | Discipline: ☐ UT ☒ MT ☐ PT ☐ ET ☐ RT ☐ VT |
| Discipline: ☐ UT ☐ MT ☐ PT ☐ ET ☐ RT ☐ VT | Signature: *Peter den Boer* |
| Client Name: | Client Signature: | | Date:(m/d/y) 3/17/2011 |

*Results are an interpretation of the inspection method, not a guarantee. Client signature indicates acceptance of report, results and applicable charges.

This page intentionally left blank.

# Annex H    Dimensional Check Measurements

This page intentionally left blank.

## T-FRAME MEASUREMENTS - Post-welding (flange-web)

(to be done following welding but prior to cylinder installation)



**Web Depth (D)**

| | Measurement (Tolerance: L1 = ±2 mm, L2 = ±4 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 33.70 | 32.40 | 33.30 | 33.50 | 32.40 | 33.60 | 33.60 | 34.00 | 32.60 | 32.20 | 33.00 |
| 270° | 33.00 | 33.00 | 33.70 | 33.40 | 32.90 | 34.10 | 33.50 | 34.10 | 33.40 | 33.20 | 32.80 |

**Web Thickness (t,w)**

| | Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 6.89 | 6.84 | 6.80 | 6.75 | 6.81 | 6.92 | 6.93 | 6.86 | 6.80 | 6.76 | 6.86 |
| 270° | 6.88 | 6.80 | 6.86 | 6.78 | 6.95 | 6.72 | 6.74 | 6.84 | 6.95 | 6.91 | 6.90 |

**Flange Width (W)**

| | Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 29.20 | 30.60 | 30.20 | 30.00 | 29.80 | 29.80 | 30.00 | 30.00 | 30.80 | 30.50 | 30.20 |
| 270° | 30.60 | 29.20 | 30.20 | 30.70 | 29.10 | 29.40 | 29.40 | 30.70 | 30.30 | 29.10 | 29.60 |

**Flange Thickness (t,fl)**

| | Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 6.77 | 6.80 | 6.76 | 6.90 | 6.81 | 6.81 | 6.93 | 6.76 | 6.82 | 6.79 | 6.85 |
| 270° | 6.72 | 6.75 | 6.74 | 6.75 | 6.85 | 6.90 | 6.76 | 6.77 | 6.90 | 6.75 | 6.70 |

**Flange Centre (W,fl)**

| | Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 16.30 | 15.70 | 15.65 | 15.35 | 15.35 | 14.75 | 14.90 | 14.80 | 14.15 | 15.45 | 16.00 |
| 270° | 14.95 | 15.55 | 15.40 | 14.20 | 15.35 | 14.05 | 15.90 | 15.75 | 14.85 | 16.40 | 15.35 |

**Angle between Flange and Web (θ,fl)**

| | Measurement (Tolerance: L1 = ±2.5°, L2 = ±5°) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 89.5 | 89.8 | 89.8 | 87.8 | 87.3 | 89.2 | 88.3 | 87.9 | 89.6 | 89.5 | 87.8 |
| 270° | 87.0 | 88.1 | 88.2 | 87.2 | 87.0 | 87.9 | 87.6 | 88.2 | 87.2 | 87.9 | 89.7 |

**NOTES:** (1) Web and Flange thickness measurements are with respect to average values from individual mill certs

| Measurements Taken By: | Date: | Title: | C-FER Technologies |
|---|---|---|---|
| **Petersen's Welding** | | **Post-welding (flange-web)** | |
| Approved By: | Date: | Specimen Identification: | Page 1 of 2 |
| | | **Specimen A - 410930** | |

Submarine Hull Collapse
C-FER File: F034

## CYLINDER MEASUREMENTS
(to be done following cylinder fabrication)



**Interframe and End Bay Spacing (L,f & L,e):**
(Tolerance: L1 = ±2 mm, L2 = ±4 mm)

|  | 90° (in) | 270° (in) |
|---|---|---|
| End A to Fr 1 | - | - |
| Fr 1 to Fr 2 | 159.9 | 159.4 |
| Fr 2 to Fr 3 | 161.5 | 158.5 |
| Fr 3 to Fr 4 | 159.8 | 159.2 |
| Fr 4 to Fr 5 | 159.1 | 160.8 |
| Fr 5 to Fr 6 | 160.6 | 158.7 |
| Fr 6 to Fr 7 | 158.9 | 159.9 |
| Fr 7 to Fr 8 | 160.5 | 159.6 |
| Fr 8 to Fr 9 | 158.8 | 159.8 |
| Fr 9 to Fr 10 | 160.2 | 159.3 |
| Fr 10 to Fr 11 | 158.5 | 159.8 |
| Fr 11 to End B | - | - |

**Tilt Angle between Shell and Web (θ,t):**
(see Detail 1)      (Tolerance: L1 = ±2.5°, L2 = ±5°)

|  | 90° (deg) | 270° (deg) |
|---|---|---|
| Fr 1 | 89.3 | 87.4 |
| Fr 2 | 89.5 | 89.5 |
| Fr 3 | 87.2 | 89.8 |
| Fr 4 | 88.9 | 89.0 |
| Fr 5 | 89.8 | 87.6 |
| Fr 6 | 88.1 | 89.8 |
| Fr 7 | 88.5 | 87.5 |
| Fr 8 | 87.2 | 87.7 |
| Fr 9 | 87.1 | 87.8 |
| Fr 10 | 87.7 | 88.8 |
| Fr 11 | 88.7 | 88.8 |

**Cylinder Length (L,c):**
90° _____ in
270° _____ in

DETAIL 1

| Measurements Taken By: **Petersen's Welding** | Date: | Title: **Post-fabrication Sheet 2** | C-FER Technologies |
|---|---|---|---|
| Approved By: | Date: | Specimen Identification: **Specimen A - 410930** | Page 2 of 2 |

Submarine Hull Collapse
C-FER File: F034
138

## T-FRAME MEASUREMENTS - Post-welding (flange-web)

(to be done following welding but prior to cylinder installation)

**Web Depth (D)**

| | Measurement (Tolerance: L1 = ±2 mm, L2 = ±4 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 33.30 | 34.10 | 33.00 | 33.40 | 32.10 | 32.40 | 33.60 | 32.70 | 33.10 | 32.40 | 34.10 |
| 270° | 32.90 | 32.70 | 33.50 | 32.20 | 32.70 | 33.40 | 33.30 | 32.20 | 33.20 | 32.90 | 33.80 |

**Web Thickness (t,w)**

| | Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 6.88 | 6.80 | 6.94 | 6.79 | 6.89 | 6.78 | 6.81 | 6.88 | 6.94 | 6.76 | 6.83 |
| 270° | 6.72 | 6.72 | 6.74 | 6.86 | 6.72 | 6.71 | 6.74 | 6.70 | 6.95 | 6.73 | 6.89 |

**Flange Width (W)**

| | Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 30.30 | 29.80 | 29.80 | 29.20 | 30.40 | 29.00 | 30.00 | 29.20 | 30.40 | 29.90 | 30.80 |
| 270° | 29.70 | 30.60 | 30.80 | 29.80 | 30.20 | 29.30 | 30.30 | 30.40 | 29.50 | 29.00 | 29.10 |

**Flange Thickness (t,fl)**

| | Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 6.85 | 6.83 | 6.81 | 6.91 | 6.78 | 6.87 | 6.89 | 6.75 | 6.78 | 6.78 | 6.93 |
| 270° | 6.89 | 6.86 | 6.72 | 6.83 | 6.74 | 6.73 | 6.82 | 6.82 | 6.90 | 6.71 | 6.85 |

**Flange Centre (W,fl)**

| | Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 16.30 | 15.60 | 16.00 | 14.85 | 15.90 | 15.90 | 16.10 | 15.25 | 14.85 | 15.45 | 14.70 |
| 270° | 15.20 | 14.55 | 15.00 | 16.05 | 16.15 | 15.40 | 14.70 | 15.25 | 15.80 | 15.70 | 14.85 |

**Angle between Flange and Web (θ,fl)**

| | Measurement (Tolerance: L1 = ±2.5°, L2 = ±5°) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 89.5 | 87.7 | 88.7 | 87.3 | 88.6 | 87.0 | 88.9 | 88.8 | 88.4 | 87.6 | 89.3 |
| 270° | 87.3 | 87.3 | 88.1 | 89.4 | 89.4 | 89.4 | 89.3 | 88.7 | 87.4 | 88.9 | 87.6 |

**NOTES:** (1) Web and Flange thickness measurements are with respect to average values from individual mill certs

| Measurements Taken By:<br>**Petersen's Welding** | Date: | Title:<br>**Post-welding (flange-web)** | C-FER Technologies |
|---|---|---|---|
| Approved By: | Date: | Specimen Identification:<br>**Specimen B - 411006** | Page 1 of 2 |

Submarine Hull Collapse
C-FER File: F034

## CYLINDER MEASUREMENTS
(to be done following cylinder fabrication)



**Interframe and End Bay Spacing (L,f & L,e):**
(Tolerance: L1 = ±2 mm, L2 = ±4 mm)

|  | 90° (in) | 270° (in) |
|---|---|---|
| End A to Fr 1 | - | - |
| Fr 1 to Fr 2 | 161.0 | 160.6 |
| Fr 2 to Fr 3 | 160.2 | 160.5 |
| Fr 3 to Fr 4 | 158.5 | 161.3 |
| Fr 4 to Fr 5 | 161.0 | 160.5 |
| Fr 5 to Fr 6 | 159.0 | 160.6 |
| Fr 6 to Fr 7 | 159.2 | 160.5 |
| Fr 7 to Fr 8 | 158.8 | 160.5 |
| Fr 8 to Fr 9 | 159.5 | 159.2 |
| Fr 9 to Fr 10 | 158.9 | 160.2 |
| Fr 10 to Fr 11 | 159.2 | 159.9 |
| Fr 11 to End B | - | - |

**Cylinder Length (L,c):**
90° _____ in
270° _____ in

**Tilt Angle between Shell and Web (θ,t):**
(see Detail 1)   (Tolerance: L1 = ±2.5°, L2 = ±5°)

|  | 90° (deg) | 270° (deg) |
|---|---|---|
| Fr 1 | 89.4 | 89.5 |
| Fr 2 | 88.2 | 87.9 |
| Fr 3 | 88.2 | 87.8 |
| Fr 4 | 87.2 | 87.9 |
| Fr 5 | 87.9 | 87.8 |
| Fr 6 | 89.2 | 88.0 |
| Fr 7 | 88.0 | 88.1 |
| Fr 8 | 88.7 | 88.6 |
| Fr 9 | 87.8 | 89.6 |
| Fr 10 | 88.5 | 88.5 |
| Fr 11 | 87.9 | 89.8 |

DETAIL 1

| Measurements Taken By: Petersen's Welding | Date: | Title: Post-fabrication Sheet 2 | C-FER Technologies |
|---|---|---|---|
| Approved By: | Date: | Specimen Identification: Specimen B - 411006 | Page 2 of 2 |

Submarine Hull Collapse
C-FER File: F034

## T-FRAME MEASUREMENTS - Post-welding (flange-web)

(to be done following welding but prior to cylinder installation)



### Web Depth (D)

| | Measurement (Tolerance: L1 = ±2 mm, L2 = ±4 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 33.60 | 33.50 | 33.00 | 33.80 | 33.70 | 33.50 | 32.80 | 33.60 | 33.70 | 33.00 | 32.30 |
| 270° | 33.10 | 32.20 | 33.80 | 33.10 | 32.40 | 32.90 | 32.20 | 33.90 | 33.70 | 33.60 | 33.30 |

### Web Thickness (t,w)

| | Measurement (Mill Cert Average = 6.68 mm, Tolerance: L1 = ±3%, L2 = ±6%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 6.86 | 6.72 | 6.74 | 6.83 | 6.84 | 6.76 | 6.81 | 6.94 | 6.90 | 6.70 | 6.76 |
| 270° | 6.92 | 6.84 | 6.83 | 6.87 | 6.72 | 6.95 | 6.86 | 6.81 | 6.83 | 6.86 | 6.79 |

### Flange Width (W)

| | Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 30.50 | 29.60 | 29.00 | 29.70 | 29.70 | 29.30 | 29.60 | 30.10 | 29.80 | 29.90 | 29.90 |
| 270° | 29.00 | 29.20 | 30.70 | 30.00 | 30.70 | 30.50 | 29.00 | 30.40 | 29.20 | 30.60 | 29.60 |

### Flange Thickness (t,fl)

| | Measurement (Mill Cert Average = 6.68 mm, Tolerance: L1 = ±3%, L2 = ±6%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 6.89 | 6.78 | 6.83 | 6.84 | 6.73 | 6.85 | 6.70 | 6.91 | 6.79 | 6.88 | 6.83 |
| 270° | 6.72 | 6.91 | 6.92 | 6.83 | 6.78 | 6.71 | 6.82 | 6.70 | 6.88 | 6.90 | 6.95 |

### Flange Centre (W,fl)

| | Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 14.20 | 15.50 | 14.20 | 14.45 | 14.95 | 14.60 | 14.95 | 14.60 | 15.70 | 16.10 | 15.00 |
| 270° | 14.55 | 16.00 | 15.95 | 14.40 | 16.10 | 14.20 | 16.15 | 14.55 | 15.80 | 14.35 | 14.30 |

### Angle between Flange and Web (θ,fl)

| | Measurement (Tolerance: L1 = ±2.5°, L2 = ±5°) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fr 1 | Fr 2 | Fr 3 | Fr 4 | Fr 5 | Fr 6 | Fr 7 | Fr 8 | Fr 9 | Fr 10 | Fr 11 |
| 90° | 88.9 | 89.6 | 89.6 | 89.1 | 88.8 | 87.1 | 88.6 | 88.5 | 89.4 | 87.9 | 88.6 |
| 270° | 88.9 | 87.1 | 87.4 | 88.7 | 88.2 | 89.9 | 90.0 | 88.2 | 89.2 | 88.7 | 87.6 |

**NOTES:** (1) Web and Flange thickness measurements are with respect to average values from individual mill certs

| Measurements Taken By: Petersen's Welding | Date: | Title: Post-welding (flange-web) | C-FER Technologies |
|---|---|---|---|
| Approved By: | Date: | Specimen Identification: Specimen C - 410935 | Page 1 of 2 |

## CYLINDER MEASUREMENTS
(to be done following cylinder fabrication)



### Interframe and End Bay Spacing (L,f & L,e):
(Tolerance: L1 = ±2 mm, L2 = ±4 mm)

|  | 90° (in) | 270° (in) |
|---|---|---|
| End A to Fr 1 | - | - |
| Fr 1 to Fr 2 | 160.6 | 159.6 |
| Fr 2 to Fr 3 | 160.4 | 161.1 |
| Fr 3 to Fr 4 | 161.5 | 160.7 |
| Fr 4 to Fr 5 | 159.7 | 160.2 |
| Fr 5 to Fr 6 | 158.7 | 160.5 |
| Fr 6 to Fr 7 | 160.1 | 158.8 |
| Fr 7 to Fr 8 | 160.2 | 160.1 |
| Fr 8 to Fr 9 | 161.2 | 158.8 |
| Fr 9 to Fr 10 | 160.9 | 160.0 |
| Fr 10 to Fr 11 | 160.4 | 160.5 |
| Fr 11 to End B | - | - |

### Tilt Angle between Shell and Web (θ,t):
(see Detail 1)     (Tolerance: L1 = ±2.5°, L2 = ±5°)

|  | 90° (deg) | 270° (deg) |
|---|---|---|
| Fr 1 | 89.8 | 87.2 |
| Fr 2 | 88.2 | 87.3 |
| Fr 3 | 87.8 | 89.5 |
| Fr 4 | 87.7 | 88.6 |
| Fr 5 | 87.9 | 87.2 |
| Fr 6 | 87.5 | 89.5 |
| Fr 7 | 88.2 | 89.2 |
| Fr 8 | 88.6 | 89.5 |
| Fr 9 | 90.0 | 88.3 |
| Fr 10 | 87.2 | 88.5 |
| Fr 11 | 88.0 | 87.5 |

### Cylinder Length (L,c):
90° _____ in
270° _____ in



DETAIL 1

| Measurements Taken By:  **Petersen's Welding** | Date: | Title:  **Post-fabrication Sheet 2** | C-FER Technologies |
|---|---|---|---|
| Approved By: | Date: | Specimen Identification:  **Specimen C - 410935** | Page 2 of 2 |

Submarine Hull Collapse
C-FER File: F034

# Annex I    Wall Thickness Measurements

This page intentionally left blank.

# Baseline Model (no corrosion patch <u>or</u> weld buttering)

**Welded and no corrosion defects**

| | | AXIAL LOCATIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| C I R C U M E R E N T I A L   L O C A T I O N S   ( d e g r e e s ) | 10 | 6.54 | 6.50 | 6.69 | 6.41 | 6.47 | 6.43 | 6.56 | 6.44 | 6.38 | 6.33 |
| | 20 | 6.46 | 6.51 | 6.49 | 6.48 | 6.39 | 6.45 | 6.58 | 6.57 | 6.48 | 6.45 |
| | 30 | 6.86 | 6.83 | 6.81 | 6.89 | 6.79 | 6.86 | 6.84 | 6.83 | 6.76 | 6.79 |
| | 40 | 6.87 | 6.77 | 6.89 | 6.87 | 6.78 | 6.85 | 6.85 | 6.89 | 6.83 | 6.76 |
| | 50 | 6.88 | 6.82 | 6.84 | 6.84 | 6.78 | 6.81 | 6.95 | 6.93 | 6.82 | 6.73 |
| | 60 | 6.82 | 6.82 | 6.78 | 6.89 | 6.83 | 6.83 | 6.79 | 6.77 | 6.73 | 6.72 |
| | 70 | 6.87 | 6.86 | 6.88 | 6.85 | 6.81 | 6.82 | 6.79 | 6.76 | 6.79 | 6.72 |
| | 80 | 6.87 | 6.87 | 6.92 | 6.85 | 6.84 | 6.85 | 6.74 | 6.87 | 6.81 | 6.72 |
| | 90 | 6.93 | 6.89 | 6.90 | 6.94 | 6.82 | 6.90 | 6.89 | 6.97 | 6.77 | 6.72 |
| | 100 | 6.94 | 6.96 | 6.88 | 6.94 | 6.83 | 6.86 | 6.87 | 6.83 | 6.82 | 6.78 |
| | 110 | 6.95 | 6.92 | 6.86 | 6.95 | 6.79 | 6.82 | 6.86 | 6.77 | 6.75 | 6.74 |
| | 120 | 6.85 | 6.85 | 6.87 | 6.82 | 6.80 | 6.79 | 6.79 | 6.77 | 6.73 | 6.75 |
| | 130 | 6.93 | 6.88 | 6.85 | 6.88 | 6.79 | 6.80 | 6.79 | 6.82 | 6.82 | 6.77 |
| | 140 | 6.84 | 6.83 | 6.86 | 6.92 | 6.80 | 6.80 | 6.82 | 6.79 | 6.75 | 6.77 |
| | 150 | 6.86 | 6.85 | 6.82 | 6.84 | 6.82 | 6.88 | 6.84 | 6.83 | 6.72 | 6.76 |
| | 160 | 6.82 | 6.87 | 6.82 | 6.83 | 6.82 | 6.84 | 6.81 | 6.75 | 6.72 | 6.74 |
| | 170 | 6.81 | 6.85 | 6.84 | 6.83 | 6.74 | 6.82 | 6.80 | 6.93 | 6.76 | 6.74 |
| | 180 | 6.81 | 6.87 | 6.83 | 6.83 | 6.73 | 6.85 | 6.82 | 6.75 | 6.72 | 6.79 |
| | 190 | 6.81 | 6.79 | 6.80 | 6.88 | 6.89 | 6.80 | 6.80 | 6.79 | 6.82 | 6.84 |
| | 200 | 6.80 | 6.82 | 6.78 | 6.83 | 6.82 | 6.75 | 6.81 | 6.81 | 6.79 | 6.78 |
| | 210 | 6.84 | 6.82 | 6.95 | 6.85 | 6.78 | 6.77 | 6.78 | 6.80 | 6.79 | 6.75 |
| | 220 | 6.85 | 6.86 | 6.87 | 6.84 | 6.75 | 6.74 | 6.77 | 6.77 | 6.81 | 6.83 |
| | 230 | 6.84 | 6.84 | 6.79 | 6.85 | 6.85 | 6.73 | 6.82 | 6.81 | 6.72 | 6.74 |
| | 240 | 6.82 | 6.84 | 6.82 | 6.89 | 6.81 | 6.73 | 6.85 | 6.81 | 6.72 | 6.72 |
| | 250 | 6.87 | 6.83 | 6.81 | 6.85 | 6.79 | 6.78 | 6.78 | 6.79 | 6.77 | 6.72 |
| | 260 | 6.86 | 6.86 | 6.85 | 6.82 | 6.68 | 6.72 | 6.80 | 6.78 | 6.72 | 6.68 |
| | 270 | 6.93 | 6.85 | 6.79 | 6.89 | 6.37 | 6.62 | 6.78 | 6.75 | 6.71 | 6.69 |
| | 280 | 6.83 | 6.86 | 6.82 | 6.88 | 6.50 | 6.71 | 6.80 | 6.77 | 6.75 | 6.71 |
| | 290 | 6.83 | 6.78 | 6.78 | 6.80 | 6.49 | 6.59 | 6.81 | 6.80 | 6.72 | 6.71 |
| | 300 | 6.86 | 6.81 | 6.77 | 6.82 | 6.52 | 6.58 | 6.78 | 6.72 | 6.74 | 6.86 |
| | 310 | 6.82 | 6.79 | 6.78 | 6.80 | 6.43 | 6.78 | 6.78 | 6.80 | 6.69 | 6.74 |
| | 320 | 6.80 | 6.80 | 6.79 | 6.79 | 6.42 | 6.70 | 6.81 | 6.90 | 6.74 | 6.72 |
| | 330 | 6.77 | 6.74 | 6.72 | 6.75 | 6.53 | 6.69 | 6.89 | 6.82 | 6.71 | 6.72 |
| | 340 | 6.79 | 6.79 | 6.81 | 6.86 | 6.75 | 6.74 | 6.81 | 6.80 | 6.86 | 6.74 |
| | 350 | 6.76 | 6.79 | 6.74 | 6.86 | 6.79 | 6.82 | 6.83 | 6.78 | 6.85 | 6.83 |
| | 360 (seam weld) | 8.54 | 8.96 | 7.35 | 9.25 | 9.27 | 9.76 | 11.20 | 8.40 | 10.38 | 9.01 |

☐ corrosion patch area (not on this model)

**Fine Grid**

| | | AXIAL LOCATIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 |
| C U M F E R E N T I A L | 160 | 6.79 | 6.77 | 6.77 | | 6.80 | 6.83 | 6.84 | | 6.82 | 6.85 | 6.89 |
| | 165 | 6.76 | 6.84 | 6.79 | F r a m e 5 | 6.81 | 6.84 | 6.80 | F r a m e 6 | 6.84 | 6.85 | 6.88 |
| | 170 | 6.82 | 6.79 | 6.80 | | 6.79 | 6.83 | 6.80 | | 6.81 | 6.85 | 6.86 |
| | 175 | 6.81 | 6.78 | 6.77 | | 6.78 | 6.82 | 6.83 | | 6.83 | 6.86 | 6.81 |
| | 180 | 6.84 | 6.78 | 6.78 | | 6.80 | 6.79 | 6.85 | | 6.82 | 6.86 | 6.84 |
| | 185 | 6.84 | 6.80 | 6.79 | | 6.81 | 6.80 | 6.80 | | 6.81 | 6.87 | 6.84 |
| | 190 | 6.83 | 6.83 | 6.84 | | 6.83 | 6.82 | 6.82 | | 6.85 | 6.87 | 6.85 |
| | 195 | 6.85 | 6.87 | 6.85 | | 6.83 | 6.83 | 6.83 | | 6.84 | 6.86 | 6.87 |
| | 200 | 6.84 | 6.87 | 6.84 | | 6.84 | 6.83 | 6.86 | | 6.87 | 6.86 | 6.86 |

# Damaged Model (has corrosion patch <u>but</u> no weld buttering)

**Welded and no corrosion defects**

| | | AXIAL LOCATIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| C I R C U M E R E N T I A L   L O C A T I O N S   ( d e g r e e s ) | 10 | 6.76 | 6.71 | 6.71 | 6.76 | 6.76 | 6.86 | 6.83 | 6.73 | 6.78 | 6.78 |
| | 20 | 6.71 | 6.78 | 6.73 | 6.73 | 6.78 | 6.76 | 6.81 | 6.76 | 6.76 | 6.78 |
| | 30 | 6.68 | 6.68 | 6.71 | 6.76 | 6.73 | 6.76 | 6.81 | 6.73 | 6.76 | 6.78 |
| | 40 | 6.68 | 6.76 | 6.73 | 6.71 | 6.76 | 6.73 | 6.73 | 6.73 | 6.76 | 6.73 |
| | 50 | 6.63 | 6.71 | 6.71 | 6.71 | 6.76 | 6.86 | 6.81 | 6.76 | 6.78 | 6.78 |
| | 60 | 6.68 | 6.68 | 6.73 | 6.73 | 6.73 | 6.76 | 6.76 | 6.76 | 6.78 | 6.76 |
| | 70 | 6.68 | 6.71 | 6.73 | 6.76 | 6.73 | 6.76 | 6.78 | 6.76 | 6.78 | 6.76 |
| | 80 | 6.73 | 6.73 | 6.73 | 6.73 | 6.71 | 6.76 | 6.76 | 6.76 | 6.78 | 6.76 |
| | 90 | 6.63 | 6.68 | 6.68 | 6.71 | 6.73 | 6.73 | 6.76 | 6.76 | 6.78 | 6.76 |
| | 100 | 6.68 | 6.71 | 6.68 | 6.71 | 6.76 | 6.76 | 6.73 | 6.76 | 6.76 | 6.81 |
| | 110 | 6.65 | 6.68 | 6.68 | 6.73 | 6.78 | 6.78 | 6.76 | 6.78 | 6.78 | 6.81 |
| | 120 | 6.65 | 6.68 | 6.71 | 6.73 | 6.76 | 6.76 | 6.78 | 6.76 | 6.78 | 6.76 |
| | 130 | 6.68 | 6.71 | 6.71 | 6.73 | 6.76 | 6.78 | 6.76 | 6.76 | 6.71 | 6.76 |
| | 140 | 6.68 | 6.71 | 6.73 | 6.76 | 6.81 | 6.78 | 6.78 | 6.81 | 6.81 | 6.78 |
| | 150 | 6.71 | 6.81 | 6.78 | 6.76 | 6.78 | 6.81 | 6.81 | 6.78 | 6.81 | 6.78 |
| | 160 | 6.65 | 6.73 | 6.81 | 6.73 | 6.76 | 6.81 | 6.76 | 6.78 | 6.83 | 6.81 |
| | 170 | 6.68 | 6.78 | 6.78 | 6.78 | 6.76 | 6.81 | 6.78 | 6.81 | 6.78 | 6.78 |
| | 180 | 6.73 | 6.76 | 6.71 | 6.73 | 6.76 | 6.83 | 6.81 | 6.78 | 6.78 | 6.78 |
| | 190 | 6.65 | 6.73 | 6.73 | 6.73 | 6.73 | 6.78 | 6.81 | 6.76 | 6.81 | 6.78 |
| | 200 | 6.68 | 6.68 | 6.71 | 6.73 | 6.71 | 6.78 | 6.76 | 6.83 | 6.78 | 6.76 |
| | 210 | 6.65 | 6.71 | 6.73 | 6.68 | 6.76 | 6.88 | 6.73 | 6.78 | 6.78 | 6.83 |
| | 220 | 6.68 | 6.73 | 6.73 | 6.76 | 6.73 | 6.78 | 6.73 | 6.76 | 6.78 | 6.81 |
| | 230 | 6.68 | 6.68 | 6.78 | 6.78 | 6.78 | 6.83 | 6.83 | 6.78 | 6.86 | 6.78 |
| | 240 | 6.68 | 6.71 | 6.78 | 6.81 | 6.81 | 6.78 | 6.78 | 6.81 | 6.83 | 6.83 |
| | 250 | 6.68 | 6.68 | 6.78 | 6.83 | 6.78 | 6.81 | 6.81 | 6.86 | 6.86 | 6.81 |
| | 260 | 6.76 | 6.73 | 6.76 | 6.73 | 6.76 | 6.78 | 6.76 | 6.86 | 6.81 | 6.81 |
| | 270 | 6.73 | 6.71 | 6.76 | 6.73 | 6.76 | 6.81 | 6.78 | 6.78 | 6.78 | 6.81 |
| | 280 | 6.68 | 6.71 | 6.76 | 6.83 | 6.83 | 6.99 | 6.81 | 6.81 | 6.83 | 6.81 |
| | 290 | 6.71 | 6.71 | 6.73 | 6.76 | 6.78 | 6.78 | 6.83 | 6.78 | 6.78 | 6.76 |
| | 300 | 6.71 | 6.71 | 6.76 | 6.76 | 6.73 | 6.76 | 6.73 | 6.76 | 6.78 | 6.73 |
| | 310 | 6.73 | 6.78 | 6.76 | 6.78 | 6.76 | 6.78 | 6.73 | 6.73 | 6.76 | 6.81 |
| | 320 | 6.81 | 6.83 | 6.78 | 6.78 | 6.76 | 6.78 | 6.76 | 6.76 | 6.76 | 6.86 |
| | 330 | 6.76 | 6.78 | 6.81 | 6.73 | 6.78 | 6.81 | 6.73 | 6.76 | 6.76 | 6.76 |
| | 340 | 6.78 | 6.76 | 6.76 | 6.76 | 6.78 | 6.78 | 6.76 | 6.73 | 6.76 | 6.73 |
| | 350 | 6.76 | 6.78 | 6.86 | 6.81 | 6.78 | 6.88 | 6.81 | 6.88 | 6.76 | 6.76 |
| | 360 (seam weld) | 6.76 | 8.20 | 9.50 | 9.58 | 8.00 | 8.05 | 7.70 | 9.07 | 7.04 | 8.10 |

☐ corrosion patch area

**With Corrosion Patch - Fine Grid**

| | | AXIAL LOCATIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 |
| C U M F E R E N T I A L | 160 | 6.80 | 6.80 | 6.81 | | 6.82 | 6.78 | 6.78 | | 6.78 | 6.79 | 6.83 |
| | 165 | 6.78 | 6.77 | 6.77 | F | 6.79 | 6.75 | 6.76 | F | 6.78 | 6.79 | 6.80 |
| | 170 | 6.77 | 6.77 | 6.80 | r | 6.80 | 6.79 | 6.76 | r | 6.80 | 6.77 | 6.81 |
| | 175 | 6.79 | 6.81 | 6.85 | a | 5.67 | 5.58 | 5.51 | a | 6.81 | 6.80 | 6.79 |
| | 180 | 6.81 | 6.83 | 6.86 | m | 5.60 | 5.39 | 5.45 | m | 6.85 | 6.80 | 6.79 |
| | 185 | 6.83 | 6.84 | 6.89 | e | 5.51 | 5.43 | 5.39 | e | 6.85 | 6.83 | 6.82 |
| | 190 | 6.83 | 6.84 | 6.86 | | 6.86 | 6.84 | 6.80 | | 6.83 | 6.83 | 6.84 |
| | 195 | 6.83 | 6.84 | 6.86 | 5 | 6.86 | 6.84 | 6.82 | 6 | 6.86 | 6.82 | 6.82 |
| | 200 | 6.83 | 6.87 | 6.85 | | 6.86 | 6.87 | 6.81 | | 6.85 | 6.85 | 6.79 |

# Repaired Model (has corrosion patch <u>and</u> weld buttering)

**Welded and no corrosion defects**

| | | AXIAL LOCATIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| **C I R C U M E R E N T I A L   L O C A T I O N S   ( d e g r e e s )** | 10 | 6.63 | 6.38 | 6.48 | 6.58 | 6.68 | 6.65 | 6.71 | 6.76 | 6.68 | 6.65 |
| | 20 | 6.63 | 6.45 | 6.43 | 6.48 | 6.63 | 6.53 | 6.38 | 6.40 | 6.45 | 6.45 |
| | 30 | 6.65 | 6.53 | 6.50 | 6.45 | 6.65 | 6.58 | 6.45 | 6.38 | 6.43 | 6.53 |
| | 40 | 6.58 | 6.50 | 6.45 | 6.55 | 6.76 | 6.78 | 6.68 | 6.71 | 6.68 | 6.58 |
| | 50 | 6.55 | 6.65 | 6.45 | 6.63 | 6.76 | 6.63 | 6.38 | 6.35 | 6.55 | 6.48 |
| | 60 | 6.55 | 6.71 | 6.60 | 6.68 | 6.58 | 6.68 | 6.31 | 6.31 | 6.45 | 6.60 |
| | 70 | 6.60 | 6.73 | 6.71 | 6.58 | 6.58 | 6.68 | 6.43 | 6.37 | 6.35 | 6.68 |
| | 80 | 6.65 | 6.73 | 6.73 | 6.65 | 6.53 | 6.76 | 6.73 | 6.55 | 6.35 | 6.73 |
| | 90 | 6.60 | 6.63 | 6.71 | 6.55 | 6.48 | 6.73 | 6.60 | 6.33 | 6.18 | 6.63 |
| | 100 | 6.50 | 6.73 | 6.71 | 6.58 | 6.58 | 6.73 | 6.58 | 6.32 | 6.30 | 6.68 |
| | 110 | 6.45 | 6.78 | 6.65 | 6.50 | 6.71 | 6.76 | 6.65 | 6.32 | 6.40 | 6.65 |
| | 120 | 6.35 | 6.73 | 6.60 | 6.40 | 6.50 | 6.71 | 6.63 | 6.30 | 6.33 | 6.53 |
| | 130 | 6.50 | 6.68 | 6.63 | 6.45 | 6.65 | 6.68 | 6.68 | 6.27 | 6.22 | 6.53 |
| | 140 | 6.58 | 6.65 | 6.65 | 6.60 | 6.63 | 6.68 | 6.63 | 6.58 | 6.43 | 6.40 |
| | 150 | 6.68 | 6.68 | 6.65 | 6.65 | 6.73 | 6.68 | 6.65 | 6.55 | 6.38 | 6.40 |
| | 160 | 6.68 | 6.63 | 6.48 | 6.68 | 6.73 | 6.71 | 6.60 | 6.55 | 6.58 | 6.35 |
| | 170 | 6.71 | 6.68 | 6.42 | 6.68 | 6.78 | 6.73 | 6.53 | 6.38 | 6.50 | 6.48 |
| | 180 | 6.65 | 6.73 | 6.40 | 6.71 | 6.76 | 6.73 | 6.55 | 6.45 | 6.43 | 6.63 |
| | 190 | 6.48 | 6.65 | 6.58 | 6.68 | 6.71 | 6.68 | 6.55 | 6.37 | 6.34 | 6.68 |
| | 200 | 6.53 | 6.65 | 6.63 | 6.68 | 6.68 | 6.68 | 6.65 | 6.60 | 6.30 | 6.65 |
| | 210 | 6.43 | 6.63 | 6.63 | 6.68 | 6.68 | 6.63 | 6.78 | 6.65 | 6.35 | 6.63 |
| | 220 | 6.53 | 6.65 | 6.65 | 6.73 | 6.78 | 6.65 | 6.63 | 6.65 | 6.60 | 6.40 |
| | 230 | 6.55 | 6.68 | 6.71 | 6.76 | 6.76 | 6.68 | 6.65 | 6.68 | 6.45 | 6.28 |
| | 240 | 6.68 | 6.68 | 6.68 | 6.71 | 6.71 | 6.65 | 6.73 | 6.68 | 6.22 | 6.23 |
| | 250 | 6.58 | 6.65 | 6.65 | 6.68 | 6.71 | 6.65 | 6.68 | 6.68 | 6.00 | 5.95 |
| | 260 | 6.45 | 6.65 | 6.63 | 6.68 | 6.71 | 6.65 | 6.71 | 6.68 | 5.94 | 6.04 |
| | 270 | 6.45 | 6.65 | 6.63 | 6.68 | 6.73 | 6.65 | 6.68 | 6.71 | 5.74 | 6.02 |
| | 280 | 6.38 | 6.68 | 6.68 | 6.68 | 6.71 | 6.68 | 6.68 | 6.71 | 6.14 | 6.12 |
| | 290 | 6.58 | 6.76 | 6.71 | 6.71 | 6.73 | 6.73 | 6.71 | 6.71 | 6.31 | 6.32 |
| | 300 | 6.58 | 6.68 | 6.63 | 6.63 | 6.63 | 6.65 | 6.60 | 6.71 | 6.35 | 6.35 |
| | 310 | 6.68 | 6.63 | 6.58 | 6.68 | 6.68 | 6.65 | 6.68 | 6.68 | 6.38 | 6.43 |
| | 320 | 6.65 | 6.63 | 6.45 | 6.65 | 6.68 | 6.65 | 6.65 | 6.65 | 6.40 | 6.48 |
| | 330 | 6.65 | 6.63 | 6.43 | 6.71 | 6.65 | 6.68 | 6.63 | 6.68 | 6.45 | 6.48 |
| | 340 | 6.68 | 6.68 | 6.45 | 6.71 | 6.68 | 6.63 | 6.63 | 6.68 | 6.63 | 6.45 |
| | 350 | 6.71 | 6.68 | 6.48 | 6.68 | 6.71 | 6.65 | 6.63 | 6.71 | 6.63 | 6.50 |
| | 360 (seam weld) | 9.07 | 9.32 | 12.45 | 9.40 | 10.21 | 9.78 | 9.63 | 9.63 | 9.78 | 9.14 |

☐ corrosion patch area

**With Corrosion Patch - Fine Grid**

| | | AXIAL LOCATIONS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 |
| **C** | 160 | 6.75 | 6.70 | 6.78 | | 6.85 | 6.71 | 6.79 | | 6.82 | 6.72 | 6.75 |
| **U** | 165 | 6.80 | 6.75 | 6.82 | F | 6.79 | 6.79 | 6.73 | F | 6.79 | 6.76 | 6.73 |
| **M** | 170 | 6.79 | 6.73 | 6.80 | r | 6.81 | 6.81 | 6.79 | r | 6.83 | 6.72 | 6.76 |
| **F** | 175 | 6.78 | 6.78 | 6.84 | a | 5.47 | 5.54 | 5.43 | a | 6.81 | 6.77 | 6.80 |
| **E** | 180 | 6.82 | 6.77 | 6.79 | m | 5.52 | 5.55 | 5.46 | m | 6.82 | 6.71 | 6.76 |
| **R** | 185 | 6.82 | 6.75 | 6.85 | e | 5.57 | 5.55 | 5.57 | e | 6.80 | 6.78 | 6.74 |
| **E** | 190 | 6.77 | 6.72 | 6.74 | | 6.75 | 6.75 | 6.76 | | 6.78 | 6.70 | 6.75 |
| **N** | 195 | 6.77 | 6.75 | 6.78 | 5 | 6.75 | 6.76 | 6.74 | 6 | 6.77 | 6.76 | 6.76 |
| **T** | 200 | 6.74 | 6.65 | 6.72 | | 6.73 | 6.72 | 6.74 | | 6.76 | 6.66 | 6.78 |

**With Weld Buttering - Fine Grid**

| | | AXIAL LOCATIONS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 |
| **C** | 160 | 6.88 | 6.84 | 6.78 | | 6.84 | 6.80 | 6.77 | | 6.76 | 6.74 | 6.73 |
| **U** | 165 | 6.84 | 6.83 | 6.93 | F | 6.83 | 6.86 | 6.77 | F | 6.80 | 6.79 | 6.75 |
| **M** | 170 | 6.80 | 6.89 | 6.89 | r | 6.74 | 6.83 | 6.71 | r | 6.89 | 6.76 | 6.78 |
| **F** | 175 | 6.95 | 6.92 | 6.75 | a | 8.36 | 8.33 | 7.64 | a | 6.80 | 6.79 | 6.80 |
| **E** | 180 | 6.88 | 6.80 | 6.78 | m | 8.64 | 8.00 | 8.30 | m | 6.79 | 6.75 | 6.74 |
| **R** | 185 | 6.98 | 6.79 | 6.78 | e | 7.95 | 8.05 | 7.53 | e | 6.78 | 6.73 | 6.74 |
| **E** | 190 | 6.84 | 6.77 | 6.73 | | 6.69 | 6.73 | 6.67 | | 6.76 | 6.72 | 6.70 |
| **N** | 195 | 6.86 | 6.79 | 6.79 | 5 | 6.79 | 6.79 | 6.81 | 6 | 6.78 | 6.73 | 6.72 |
| **T** | 200 | 6.85 | 6.81 | 6.82 | | 6.89 | 6.87 | 6.80 | | 6.83 | 6.73 | 6.72 |

148

# Annex J    Coupon Test Procedure

This page intentionally left blank.

**TESTING OF STEEL CYLINDERS**

**Procedure for Tension Coupon Tests**

## 1. Test Description

1.1 A total of 10 coupons are to be machined from three separate ¼" HY80 plates: six from one plate and two from each of the other plates.

1.2 Coupon tensile test coupons were taken with orientations in the longitudinal and transverse directions.

1.3 Coupons are to be tested at room temperature.

## 2. Instrumentation and Data Acquisition

2.1. Instrumentation consists of the MTS load cell, the MTS stroke, the MTS hydraulic grips, a strain measurement device (one 2-in. gauge length extensometer for tension coupon tests).

2.2. All data shall be acquired via C-FER's computer-controlled software and signal conditioning system.

2.3. Computer software shall be set-up to calculate, from the strain measurements, and display the elastic slopes corresponding to values of 195 GPa, 207 GPa and 220 GPa.

2.4. Only equipment that has been calibrated according to C-FER's established calibration procedure shall be used.

2.5. The following file naming convention will be used for the testing:

- Coupon ID – Test date – Cycle number (ex. P1L1-Mar 24-2)

## 3. Pretest Measurements, Installation, and Test Set-up

3.1. Mark and measure specimens as shown in the attached measurement sheets.

3.2. Test specimens in C-FER's 1,000-kN capacity MTS machine.

3.3. Install tension specimens in hydraulic MTS grips.

3.4. Attach strain measurement device as follows:

3.4.1. For the tension tests, attach one 2-in gauge length extensometer to the specimen.

3.4.2. For the tension tests, where Poisson's Ratio will be measured, attach one 2-in gauge length extensometer and two biaxial strain gauges (spaced 180º apart).

3.5. Set up data acquisition and signal conditioning to record the instruments indicated in Section 2.1.

3.6. Balance and zero instrumentation prior to proceeding with testing.

## 4. Procedure for Tension Tests

4.1. Set automatic read capability of data acquisition system to take reads at approximately every 100-lb, approximately every 0.001-in of MTS stroke and every 3 seconds.

4.2. Apply a tension load to the specimen at a machine actuator movement rate of approximately **0.009 in/min**. This is to be maintained until the specimen has reached a load of **6,000-lb**, at which point the load will be removed and the extensometer zeroed. This cycle will be repeated one more time. A new data file will be created prior to starting the next cycle (the naming convention listed in Section 2.5 shall be used).

4.3. On the third cycle, apply a tension load to the specimen at a machine actuator movement rate of approximately **0.009 in/min**. This is to be maintained until the specimen has reached its ultimate tensile strength.

4.4. The modulus curves corresponding to values of 195 GPa and 220 GPa will constitute acceptable upper and lower limits of the slope of the stress-strain curve in the elastic region. If the slope of the elastic portion of the stress-strain curve of the test specimen deviates from this range, the test shall be stopped and repeated.

4.5. The extensometer is to be removed from the specimen shortly after achieving the peak load and a drop in the load carrying capacity of the specimen is noticeable. Specimen loading can be briefly paused while removing the extensometer.

4.6. Once the extensometer has been removed, increase the movement rate to **0.09 in/min** and continue specimen loading until complete specimen failure occurs.

4.7. After specimen failure, measure and record total elongation and reduction in area of the fractured specimen.

4.8. Check and backup computer file containing test results.

0.787±0.005
(20 mm)

3.937±0.005
(100 mm)

63

0.059±0.005
(1.5 mm)

NOTES:

1. Coupons shall be fabricated in strict accordance with ASTM E1426-98
2. **All** paired surfaces shall be parallel within 0.0005-in/in.
3. **All** surfaces shall be perpendicular to the adjacent surfaces to within 3-ft of arc.
4. Coupons shall be cold cut as close to the final dimensions as possible before machining to minimize curling due to residual stresses.

COMMENTS:

MATERIAL
HY80

| | NAME | DATE |
|------|------|------|
| DRAWN | DSS | 24Feb11 |
| CHECKED | | |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | | Tol. | T.I.R. | Finish |
|--|--|------|--------|--------|
| 1) Decimal: | x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| | x.xx | ±0.015" | 0.015" | 125µinch Ra |
| | x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: | x.x | ± 0.5° | | |
| | x. | ±1.0 | | |

**C-FER Technologies**

Design & Construction
F034
mXRD Coupon

| SIZE | DWG. NO. | | REV. |
|------|----------|--|------|
| A | CFER-F034-300 153 | | B |

SCALE:1:1  WEIGHT:  SHEET 1 OF 7

TOP

0.750

0.250

0.500±0.005
(gauge width)

2.000±0.003
(gauge length)

3.00
(reduced section)

R0.500
(TYP)

2.25
(TYP)

BOTTOM

NOTES:

1. Coupons shall be fabricated in strict accordance with ASTM E8.
2. The ends of the reduced section shall not differ by more than 0.001in.
3. There may be a gradual increase in width from the ends to the center, but the width at each end shall not be more than 0.003in larger than the width at the center.
4. TOP and BOTTOM surfaces will be parallel to within 0.001-in/in and perpendicular to the lateral surfaces to within 3-ft of arc.

COMMENTS:

MATERIAL
HY80

| | NAME | DATE |
|--------|------|--------|
| DRAWN | DSS | 24Feb11 |
| CHECKED | | |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | | Tol. | T.I.R. | Finish |
|---|---|------|--------|--------|
| 1) Decimal: | x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| | x.xx | ±0.015" | 0.015" | 125µinch Ra |
| | x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: | x.x | ± 0.5° | | |
| | x. | ±1.0 | | |

**C-FER Technologies**

Design & Construction
F034
Coupon Layout

| SIZE | DWG. NO. | REV. |
|------|----------|------|
| A | CFER-F034-301 | B |
| SCALE:1:1 | WEIGHT: | SHEET 3 OF 7 |

154

**TOP**

1.13
(TYP)

0.34
(TYP)

1.00
(TYP)

C1

C2

1.00
(TYP)

1.125

0.75
(TYP)

L2

L1

**FRONT**

13.25

9.50

**PANELS**
**P2 (w/ BLUE paint strip)**
**P3 (w/ YELLOW paint strip)**

NOTES:

1. See drawings CFER-F034-300 and CFER-F034-301 for coupon dimensions.

2. All coupons shall be fabricated using cold cutting techniques (e.g. saw cutting, lathe machining).

3. This extends to the use of cutting and/or machining techniques that would introduce sufficient heat to alter the material properties of the coupons.

4. Coupon Types are indicated in RED. See drawing CFER-F034-304 for a table of corresponding Coupon ID.

155

COMMENTS:

MATERIAL
HY80

|  | NAME | DATE |
|--|------|------|
| DRAWN | DSS | 24Feb11 |
| CHECKED |  |  |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | Tol. | T.I.R. | Finish |
|--|------|--------|--------|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

**C-FER Technologies**

Design & Construction
Templates

Coupon Layout

| SIZE | DWG. NO. | REV. |
|------|----------|------|
| A | CFER-F034-302 | B |

SCALE:1:2  WEIGHT:1.60 Lbs   SHEET 6 OF 7

| REV. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| B | ISSUED FOR FABRICATION | Feb 25, 2011 | DSS |

**TOP**

0.625 (TYP)

1.00 (TYP)

1.13 (TYP)

0.75 (TYP)

1.00 (TYP)

C1
C2
C3
C4

0.50 (TYP)

1.027

1.00 (TYP)

ML1 ML2 ML3

MC1
MC2
MC3

**FRONT**

1.00 (TYP)

1.12 (TYP)

9.83

13.25

9.50

0.250

A

0.125

0.250

all mXRD coupons to be taken from the mid-wall of the plate

**DETAIL A**
**SCALE 1 : 1.5**

**PANELS**
**P1 (w/ RED paint strip)**

NOTES:

1. See drawings CFER-F034-300 and CFER-F034-301 for coupon dimensions.

2. All coupons shall be fabricated using cold cutting techniques (e.g. saw cutting, lathe machining). This extends to the use of cutting and/or machining techniques that would introduce sufficient heat to alter the material properties of the coupons.

3. Coupon Types are indicated in RED. See drawing CFER-F034-304 for a table of corresponding Coupon ID.

COMMENTS:

MATERIAL
HY80

| | NAME | DATE |
|---|---|---|
| DRAWN | DSS | 24Feb11 |
| CHECKED | | |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

| | Tol. | T.I.R. | Finish |
|---|---|---|---|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

**C-FER Technologies**

Design & Construction Templates

Coupon Layout

SIZE: A
DWG. NO.: CFER-F034-303
REV.: B

SCALE:1:2 | WEIGHT:1.60 Lbs

SHEET 5 OF 7

| PANEL | | COUPON | |
|-------|------|--------|-----|
| **ID** | **TYPE** | **TYPE** | **ID** |
| | | L1 | P1L1 |
| | | L2 | P1L2 |
| | | L3 | P1L3 |
| | | L4 | P1L4 |
| | | C1 | P1C1 |
| | | C2 | P1C2 |
| | | C3 | P1C3 |
| P1 | 16 Coupons | C4 | P1C4 |
| | | ML1 | P1ML1 |
| | | ML2 | P1ML1 |
| | | ML3 | P1ML3 |
| | | ML4 | P1ML4 |
| | | MC1 | P1MC1 |
| | | MC2 | P1MC2 |
| | | MC3 | P1MC3 |
| | | MC4 | P1MC4 |
| | | L1 | P2L1 |
| P2 | 4 Coupons | L2 | P2L2 |
| | | C1 | P2C1 |
| | | C2 | P2C2 |
| | | L1 | P3L1 |
| P3 | 4 Coupons | L2 | P3L2 |
| | | C1 | P3C1 |
| | | C2 | P3C2 |

## NOTES:

1. All coupons shall be identified using the corresponding coupon ID following fabrication (i.e. P1L1, P1MC4, etc.).
2. "L" and "C" series coupons may have the Coupon ID scribed or marked on the tab section only.
3. "ML" or "MC" series coupons **may not** be marked on any surface. They will be placed in individually labeled plastic bags or plastic wrap after fabrication.

COMMENTS:

MATERIAL
HY80

| | NAME | DATE |
|-------|------|--------|
| DRAWN | DSS | 24Feb11 |
| CHECKED | | |

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:
| | Tol. | T.I.R. | Finish |
|---|------|--------|--------|
| 1) Decimal: x.xxx | ±0.005" | 0.005" | 63µinch Ra |
| x.xx | ±0.015" | 0.015" | 125µinch Ra |
| x.x | ±0.030" | 0.030" | 250µinch Ra |
| 2) Angular: x.x | ± 0.5° | | |
| x. | ±1.0 | | |

**C-FER Technologies**

Design & Construction
F034
Coupon Identification

SIZE: A  DWG. NO. CFER-F034-304  157  REV. B

SCALE:1:1  WEIGHT:  SHEET 7 OF 7

This page intentionally left blank.

# Annex K    Coupon Test Reports

This page intentionally left blank.

# C-FER Technologies

# Coupon Test Report

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P1C2
Cylinder: Model A
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Hoop

## Initial Measurements

Initial Width: 12.87 mm
Initial Thickness: 6.75 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 50.91 mm
Coupon initial Area: 86.9 mm$^2$

## Final Measurements

Final Width: 3.95 mm
Final Thickness: 7.94 mm
Final Marked Gauge Length: 63.09 mm
Coupon Final Area: 31.4 mm$^2$

## Results Summary

Test Date: 25-Mar-11
Young's Modulus, run #1: 194 GPa
Young's Modulus, run #2: 195 GPa
Young's Modulus, run #3: 194 GPa
Young's Modulus, E, ave.: 194 GPa
Yield Strength (@ 0.2% offset): 634 MPa
Ultimate Strength: 720 MPa
Strain at Ultimate: 8.6 %
Elongation: 23.9 %
Area Reduction: 64 %

## Comments:

# Coupon Test Report

**Coupon Identification**

C-FER Project Number: F034
Coupon Number: P1C3
Cylinder: Model A
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Hoop

**Initial Measurements**

Initial Width: 12.87 mm
Initial Thickness: 6.75 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 51.01 mm
Coupon initial Area: 86.8 mm$^2$

**Final Measurements**

Final Width: 3.14 mm
Final Thickness: 8.14 mm
Final Marked Gauge Length: 63.12 mm
Coupon Final Area: 25.6 mm$^2$

**Results Summary**

Test Date: 26-Mar-11
Young's Modulus, run #1: 200 GPa
Young's Modulus, run #2: 205 GPa
Young's Modulus, run #3: 208 GPa
Young's Modulus, E, ave.: 204 GPa
Yield Strength (@ 0.2% offset): 637 MPa
Ultimate Strength: 722 MPa
Strain at Ultimate: 8.6 %
Elongation: 23.7 %
Area Reduction: 71 %

**Comments:**

# Coupon Test Report

**C-FER Technologies**

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P1C2
Cylinder: Model A
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Hoop

## Initial Measurements

Initial Width: 12.87 mm
Initial Thickness: 6.75 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 50.91 mm
Coupon initial Area: 86.9 mm$^2$

## Final Measurements

Final Width: 3.95 mm
Final Thickness: 7.94 mm
Final Marked Gauge Length: 63.09 mm
Coupon Final Area: 31.4 mm$^2$

## Results Summary

Test Date: 30-Mar-11
Young's Modulus, run #1: 198 GPa
Young's Modulus, run #2: 199 GPa
Young's Modulus, run #3: 197 GPa
Young's Modulus, E, ave.: 198 GPa
Yield Strength (@ 0.2% offset): 635 MPa
Ultimate Strength: 721 MPa
Strain at Ultimate: 8.2 %
Elongation: 23.9 %
Area Reduction: 64 %

**Comments:**

# Coupon Test Report

**C-FER Technologies**

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P1L1
Cylinder: Model A
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Longitudinal

## Initial Measurements

Initial Width: 12.86 mm
Initial Thickness: 6.74 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 51.11 mm
Coupon initial Area: 86.7 mm$^2$

## Final Measurements

Final Width: 3.35 mm
Final Thickness: 8.05 mm
Final Marked Gauge Length: 62.10 mm
Coupon Final Area: 27.0 mm$^2$

## Results Summary

Test Date: 26-Mar-11
Young's Modulus, run #1: 208 GPa
Young's Modulus, run #2: 208 GPa
Young's Modulus, run #3: 212 GPa
Young's Modulus, E, ave.: 209 GPa
Yield Strength (@ 0.2% offset): 644 MPa
Ultimate Strength: 719 MPa
Strain at Ultimate: 7.9 %
Elongation: 21.5 %
Area Reduction: 69 %

**Comments:**



Legend:
- Extensometer
- True Stress-Strain
- 207 GPa
- 0.2% Offset

X-axis: Strain (%ε)
Y-axis: Stress (MPa)

![C-FER Technologies logo]

# Coupon Test Report

**Coupon Identification**

C-FER Project Number: F034
Coupon Number: P1L2
Cylinder: Model A
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Longitudinal

**Initial Measurements**

Initial Width: 12.79 mm
Initial Thickness: 6.78 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 51.21 mm
Coupon initial Area: 86.6 mm$^2$

**Final Measurements**

Final Width: 3.47 mm
Final Thickness: 8.27 mm
Final Marked Gauge Length: 62.13 mm
Coupon Final Area: 28.7 mm$^2$

**Results Summary**

Test Date: 26-Mar-11
Young's Modulus, run #1: 201 GPa
Young's Modulus, run #2: 196 GPa
Young's Modulus, run #3: 195 GPa
Young's Modulus, E, ave.: 197 GPa
Yield Strength (@ 0.2% offset): 645 MPa
Ultimate Strength: 717 MPa
Strain at Ultimate: 8.4 %
Elongation: 21.3 %
Area Reduction: 67 %

**Comments:**

# Coupon Test Report

**C-FER Technologies**

## Coupon Identification

| | |
|---|---|
| C-FER Project Number: | F034 |
| Coupon Number: | P1L3 |
| Cylinder: | Model A |
| Coupon Type: | Strip |
| Test Type: | Tension |
| Orientation (w.r.t. cylinder): | Longitudinal |

## Initial Measurements

| | |
|---|---|
| Initial Width: | 12.83 mm |
| Initial Thickness: | 6.77 mm |
| Extensometer Gauge Length: | 50.8 mm |
| Initial Marked Gauge Length: | 51.02 mm |
| Coupon initial Area: | 86.8 mm$^2$ |

## Final Measurements

| | |
|---|---|
| Final Width: | 3.26 mm |
| Final Thickness: | 8.19 mm |
| Final Marked Gauge Length: | 62.02 mm |
| Coupon Final Area: | 26.7 mm$^2$ |

## Results Summary

| | |
|---|---|
| Test Date: | 25-Mar-07 |
| Young's Modulus, run #1: | 196 GPa |
| Young's Modulus, run #2: | 196 GPa |
| Young's Modulus, run #3: | 193 GPa |
| Young's Modulus, E, ave.: | 195 GPa |
| Yield Strength (@ 0.2% offset): | 644 MPa |
| Ultimate Strength: | 717 MPa |
| Strain at Ultimate: | 8.5 % |
| Elongation: | 21.6 % |
| Area Reduction: | 69 % |

**Comments:**

# Coupon Test Report

**C-FER Technologies**

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P2C2
Cylinder: Model B
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Hoop

## Initial Measurements

Initial Width: 12.90 mm
Initial Thickness: 6.68 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 51.01 mm
Coupon initial Area: 86.1 mm$^2$

## Final Measurements

Final Width: 3.35 mm
Final Thickness: 8.36 mm
Final Marked Gauge Length: 63.45 mm
Coupon Final Area: 28.0 mm$^2$

## Results Summary

Test Date: 4-Apr-11
Young's Modulus, run #1: 201 GPa
Young's Modulus, run #2: 197 GPa
Young's Modulus, run #3: 200 GPa
Young's Modulus, E, ave.: 199 GPa
Yield Strength (@ 0.2% offset): 632 MPa
Ultimate Strength: 717 MPa
Strain at Ultimate: 8.9 %
Elongation: 24.4 %
Area Reduction: 67 %

**Comments:**

# Coupon Test Report

![C-FER Technologies logo]

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P2L1
Cylinder: Model B
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Longitudinal

## Initial Measurements

Initial Width: 12.89 mm
Initial Thickness: 6.67 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 51.34 mm
Coupon initial Area: 85.9 mm$^2$

## Final Measurements

Final Width: 3.80 mm
Final Thickness: 8.30 mm
Final Marked Gauge Length: 62.83 mm
Coupon Final Area: 31.5 mm$^2$

## Results Summary

Test Date: 26-Mar-11
Young's Modulus, run #1: 209 GPa
Young's Modulus, run #2: 198 GPa
Young's Modulus, run #3: 206 GPa
Young's Modulus, E, ave.: 204 GPa
Yield Strength (@ 0.2% offset): 638 MPa
Ultimate Strength: 718 MPa
Strain at Ultimate: 9.0 %
Elongation: 22.4 %
Area Reduction: 63 %

## Comments:

# Coupon Test Report

**C-FER Technologies**

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P3C2
Cylinder: Model C
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Hoop

## Initial Measurements

Initial Width: 12.89 mm
Initial Thickness: 6.70 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 50.94 mm
Coupon initial Area: 86.4 mm$^2$

## Final Measurements

Final Width: 3.92 mm
Final Thickness: 8.53 mm
Final Marked Gauge Length: 61.94 mm
Coupon Final Area: 33.4 mm$^2$

## Results Summary

Test Date: 29-Mar-11
Young's Modulus, run #1: 204 GPa
Young's Modulus, run #2: 202 GPa
Young's Modulus, run #3: 204 GPa
Young's Modulus, E, ave.: 203 GPa
Yield Strength (@ 0.2% offset): 634 MPa
Ultimate Strength: 720 MPa
Strain at Ultimate: 8.8 %
Elongation: 21.6 %
Area Reduction: 61 %

**Comments:**

# Coupon Test Report

**C-FER Technologies**

## Coupon Identification

C-FER Project Number: F034
Coupon Number: P3L1
Cylinder: Model C
Coupon Type: Strip
Test Type: Tension
Orientation (w.r.t. cylinder): Longitudinal

## Initial Measurements

Initial Width: 12.89 mm
Initial Thickness: 6.67 mm
Extensometer Gauge Length: 50.8 mm
Initial Marked Gauge Length: 51.69 mm
Coupon initial Area: 86.0 mm$^2$

## Final Measurements

Final Width: 4.18 mm
Final Thickness: 8.13 mm
Final Marked Gauge Length: 63.54 mm
Coupon Final Area: 34.0 mm$^2$

## Results Summary

Test Date: 29-Mar-11
Young's Modulus, run #1: 206 GPa
Young's Modulus, run #2: 205 GPa
Young's Modulus, run #3: 202 GPa
Young's Modulus, E, ave.: 205 GPa
Yield Strength (@ 0.2% offset): 635 MPa
Ultimate Strength: 720 MPa
Strain at Ultimate: 8.5 %
Elongation: 22.9 %
Area Reduction: 60 %

## Comments:



Legend:
- Extensometer
- True Stress-Strain
- 207 GPa
- 0.2% Offset

X-axis: Strain (%ε)
Y-axis: Stress (MPa)

# Annex L    Instrumentation Layout

This page intentionally left blank.

**Cylinder** **Model A**
**Corrosion** **None**

| Internal Gauges | Uni-axial | 22 |
|---|---|---|
| | Bi-axial | 0 |
| External Gauges | Uni-axial | 0 |
| | Bi-axial | 36 |

**Notes:**
Uni-axial gauges are to be oriented in the circumferential direction
Bi-axial gauges are to be aligned with the longitudinal and circumferential axes

**Gauges on the Inside of the Cylinder**

| Angle (degrees) | Axial Location | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FR 1 | FR 2 | FR 3 | FR 4 | FR 5 | FR 6 | FR 7 | FR 8 | FR 9 | FR 10 | FR 11 |
| | | 120 mm | 280 mm | 440 mm | 600 mm | 760 mm | 920 mm | 1080 mm | 1240 mm | 1400 mm | 1560 mm | 1720 mm |
| 0 | | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial |
| 30 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 60 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 90 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 120 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 150 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 180 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 210 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 240 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 270 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 300 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 330 | | None | None | None | None | None | Uni-axial | None | None | None | None | None |

**Cylinder**  **Model A**
Corrosion   None

**Gauges on the Outside of the Cylinder**

| Angle (degrees) | Axial Location | | |
|---|---|---|---|
| | Outside Shell B/W FRs 1 & 2 FR 1.5 200 mm | Outside Shell B/W FRs 5 & 6 FR 5.5 840 mm | Outside Shell B/W FRs 10 & 11 FR 10.5 1640 mm |
| 0 | Bi-axial | Bi-axial | Bi-axial |
| 15 | None | Bi-axial | None |
| 30 | None | Bi-axial | None |
| 45 | None | Bi-axial | None |
| 60 | Bi-axial | Bi-axial | Bi-axial |
| 75 | None | Bi-axial | None |
| 90 | None | Bi-axial | None |
| 105 | None | Bi-axial | None |
| 120 | Bi-axial | Bi-axial | Bi-axial |
| 135 | None | Bi-axial | None |
| 150 | None | Bi-axial | None |
| 165 | None | Bi-axial | None |
| 180 | Bi-axial | Bi-axial | Bi-axial |
| 195 | None | Bi-axial | None |
| 210 | None | Bi-axial | None |
| 225 | None | Bi-axial | None |
| 240 | Bi-axial | Bi-axial | Bi-axial |
| 255 | None | Bi-axial | None |
| 270 | None | Bi-axial | None |
| 285 | None | Bi-axial | None |
| 300 | Bi-axial | Bi-axial | Bi-axial |
| 315 | None | Bi-axial | None |
| 330 | None | Bi-axial | None |
| 345 | None | Bi-axial | None |

# Cylinder    Model B & Model C

**Corrosion**    160x160x1.27mm thinning (clad welded for Model C)

| Internal Gauges | Uni-axial | 24 | | **Per Model Totals** | |
|---|---|---|---|---|---|
| | Bi-axial | 2 | | Uni-axial | 24 |
| | Rosette | 7 | | Bi-axial | 17 |
| External Gauges | Uni-axial | 0 | | Rosette | 14 |
| | Bi-axial | 15 | | | |
| | Rosette | 7 | | | |

**Notes:**

Uni-axial gauges are to be oriented in the circumferential direction.

Bi-axial gauges are to be aligned with the longitudinal and circumferential axes.

45° rosettes are to be aligned with two of the gauges in the longitudinal and circumferential directions.

The strain gauge positions are based on a coordinate system with the corrosion patch centred between FRs 5 & 6 at 0°.

**Gauges on the Inside of the Cylinder**

| Angle (degrees) | Axial Location | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange | Frame Flange |
| | FR 1 | FR 2 | FR 3 | FR 4 | FR 5 | FR 6 | FR 7 | FR 8 | FR 9 | FR 10 | FR 11 |
| | 120 mm | 280 mm | 440 mm | 600 mm | 760 mm | 920 mm | 1080 mm | 1240 mm | 1400 mm | 1560 mm | 1720 mm |
| 0 | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial | Uni-axial |
| 15 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 30 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 60 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 90 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 120 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 150 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 180 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 210 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 240 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 270 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 300 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 330 | None | None | None | None | None | Uni-axial | None | None | None | None | None |
| 345 | None | None | None | None | None | Uni-axial | None | None | None | None | None |

# Cylinder    Model B & Model C
## Corrosion    160x160x1.27mm thinning (clad welded for Model C)

Legend:

- ▢ Uni-axial gauge inside cylinder on frame flange
- ○ Bi-axial gauge outside cylinder shell
- ● Bi-axial gauges outside and inside cylinder shell
- ■ Rosettes outside and inside cylinder shell

Diagram (angles / dimensions):

Angles (top to bottom): 330°, 345°, 349°, 355°, 0°, 5°, 11°, 15°, 30°

Axial dimensions: 150.5 mm, 40.5 mm, 60 mm, 50 mm, 50 mm, 60 mm, 40.5 mm, 150.5 mm

Patch region dimensions: 80 mm, 50 mm

Frame locations: FR 4, FR 5, FR 6, FR 7

160x160 mm Corrosion Patch

---

**Gauges on the Inside of the Cylinder**

| Angle (degrees) | Inside Shell B/W FRs 4 & 5 FR 4.5 680 mm | Inside Shell B/W FRs 5 & 6 FR 5.1875 790 mm | Inside Shell B/W FRs 5 & 6 FR 5.5 840 mm | Inside Shell B/W FRs 5 & 6 FR 5.5 840 mm | Inside Shell B/W FRs 5 & 6 FR 5.8125 890 mm | Inside Shell B/W FRs 6 & 7 FR 6.5 1000 mm |
|---|---|---|---|---|---|---|
| 0 | None | Rosette | Rosette | Rosette | Rosette | None |
| 5 | None | None | Rosette | Rosette | None | None |
| 11 | None | None | None | Rosette | None | None |
| 15 | None | None | None | Bi-axial | None | None |
| 30 | None | None | None | None | None | None |
| 60 | None | None | None | None | None | None |
| 90 | None | None | None | None | None | None |
| 120 | None | None | None | None | None | None |
| 150 | None | None | None | None | None | None |
| 180 | None | None | None | None | None | None |
| 210 | None | None | None | None | None | None |
| 240 | None | None | None | None | None | None |
| 270 | None | None | None | None | None | None |
| 300 | None | None | None | None | None | None |
| 330 | None | None | None | None | None | None |
| 345 | None | None | None | Bi-axial | None | None |
| 349 | None | None | None | Rosette | None | None |
| 355 | None | None | None | Rosette | None | None |

---

**Gauges on the Outside of the Cylinder**

| Angle (degrees) | Outside Shell B/W FRs 4 & 5 FR 4.5 680 mm | Outside Shell B/W FRs 5 & 6 FR 5.1875 790 mm | Outside Shell B/W FRs 5 & 6 FR 5.5 840 mm | Outside Shell B/W FRs 5 & 6 FR 5.5 840 mm | Outside Shell B/W FRs 5 & 6 FR 5.8125 890 mm | Outside Shell B/W FRs 6 & 7 FR 6.5 1000 mm |
|---|---|---|---|---|---|---|
| 0 | Bi-axial | Rosette | Rosette | Rosette | Rosette | Bi-axial |
| 5 | None | None | Rosette | Rosette | None | None |
| 11 | None | None | Bi-axial | Rosette | None | None |
| 15 | None | None | Bi-axial | Bi-axial | None | None |
| 30 | None | None | Bi-axial | Bi-axial | None | None |
| 60 | None | None | Bi-axial | Bi-axial | None | None |
| 90 | None | None | Bi-axial | Bi-axial | None | None |
| 120 | None | None | Bi-axial | Bi-axial | None | None |
| 150 | None | None | Bi-axial | Bi-axial | None | None |
| 180 | None | None | Bi-axial | Bi-axial | None | None |
| 210 | None | None | Bi-axial | Bi-axial | None | None |
| 240 | None | None | Bi-axial | Bi-axial | None | None |
| 270 | None | None | Bi-axial | Bi-axial | None | None |
| 300 | None | None | Bi-axial | Bi-axial | None | None |
| 330 | None | None | Bi-axial | Bi-axial | None | None |
| 345 | None | None | Bi-axial | Bi-axial | None | None |
| 349 | None | None | Rosette | Rosette | None | None |
| 355 | None | None | Rosette | Rosette | None | None |

**Model A**

| Internal Gauges | | |
|---|---|---|
| T-Frame No. | External Specimen Reference | Gauge |
| 1 | 180 | iFR1 0 |
| 2 | 180 | iFR2 0 |
| 3 | 180 | iFR3 0 |
| 4 | 180 | iFR4 0 |
| 5 | 180 | iFR5 0 |
| 6 | 180 | iFR6 0 |
| 6 | 210 | iFR6 30 |
| 6 | 240 | iFR6 60 |
| 6 | 270 | iFR6 90 |
| 6 | 300 | iFR6 120 |
| 6 | 330 | iFR6 150 |
| 6 | 360 | iFR6 180 |
| 6 | 30 | iFR6 210 |
| 6 | 60 | iFR6 240 |
| 6 | 90 | iFR6 270 |
| 6 | 120 | iFR6 300 |
| 6 | 150 | iFR6 330 |
| 7 | 180 | iFR7 0 |
| 8 | 180 | iFR8 0 |
| 9 | 180 | iFR9 0 |
| 10 | 180 | iFR10 0 |
| 11 | 180 | iFR11 0 |

**Model A**

| External Gauges | | |
|---|---|---|
| T-Frame No. | External Specimen Reference | Gauge |
| 1.5 | 180 | FR 1.5 0 X |
| 1.5 | 180 | FR 1.5 0 y |
| 1.5 | 240 | FR 1.5 60 X |
| 1.5 | 240 | FR 1.5 60 Y |
| 1.5 | 300 | FR 1.5 120 X |
| 1.5 | 300 | FR 1.5 120 Y |
| 1.5 | 0 | FR 1.5 180 X |
| 1.5 | 0 | FR 1.5 180 Y |
| 1.5 | 60 | FR 1.5 240 X |
| 1.5 | 60 | FR 1.5 240 Y |
| 1.5 | 120 | FR 1.5 300 X |
| 1.5 | 120 | FR 1.5 300 Y |
| 5.5 | 180 | FR 5.5 0 X |
| 5.5 | 180 | FR 5.5 0 Y |
| 5.5 | 195 | FR 5.5 15 X |
| 5.5 | 195 | FR 5.5 15 Y |
| 5.5 | 210 | FR 5.5 30 X |
| 5.5 | 210 | FR 5.5 30 Y |
| 5.5 | 225 | FR 5.5 45 X |
| 5.5 | 225 | FR 5.5 45 Y |
| 5.5 | 240 | FR 5.5 60 X |
| 5.5 | 240 | FR 5.5 60 Y |
| 5.5 | 255 | FR 5.5 75 X |
| 5.5 | 255 | FR 5.5 75 Y |
| 5.5 | 270 | FR 5.5 90 X |
| 5.5 | 270 | FR 5.5 90 Y |
| 5.5 | 285 | FR 5.5 105 X |
| 5.5 | 285 | FR 5.5 105 Y |
| 5.5 | 300 | FR 5.5 120 X |
| 5.5 | 300 | FR 5.5 120 Y |
| 5.5 | 315 | FR 5.5 135 X |
| 5.5 | 315 | FR 5.5 135 Y |
| 5.5 | 330 | FR 5.5 150 X |
| 5.5 | 330 | FR 5.5 150 Y |
| 5.5 | 345 | FR 5.5 165 X |
| 5.5 | 345 | FR 5.5 165 Y |
| 5.5 | 0 | FR 5.5 180 X |
| 5.5 | 0 | FR 5.5 180 Y |
| 5.5 | 15 | FR 5.5 195 X |
| 5.5 | 15 | FR 5.5 195 Y |
| 5.5 | 30 | FR 5.5 210 X |
| 5.5 | 30 | FR 5.5 210 Y |
| 5.5 | 45 | FR 5.5 225 X |
| 5.5 | 45 | FR 5.5 225 Y |
| 5.5 | 60 | FR 5.5 240 X |
| 5.5 | 60 | FR 5.5 240 Y |
| 5.5 | 75 | FR 5.5 255 X |
| 5.5 | 75 | FR 5.5 255 Y |
| 5.5 | 90 | FR 5.5 270 X |
| 5.5 | 90 | FR 5.5 270 Y |
| 5.5 | 105 | FR 5.5 285 X |
| 5.5 | 105 | FR 5.5 285 Y |
| 5.5 | 120 | FR 5.5 300 X |

**Model A**

<table>
<thead>
<tr><th colspan="3">External Gauges</th></tr>
<tr><th>T-Frame No.</th><th>External Specimen Reference</th><th>Gauge</th></tr>
</thead>
<tbody>
<tr><td>5.5</td><td>120</td><td>FR 5.5 300 Y</td></tr>
<tr><td>5.5</td><td>135</td><td>FR 5.5 315 X</td></tr>
<tr><td>5.5</td><td>135</td><td>FR 5.5 315 Y</td></tr>
<tr><td>5.5</td><td>150</td><td>FR 5.5 330 X</td></tr>
<tr><td>5.5</td><td>150</td><td>FR 5.5 330 Y</td></tr>
<tr><td>5.5</td><td>165</td><td>FR 5.5 345 X</td></tr>
<tr><td>5.5</td><td>165</td><td>FR 5.5 345 Y</td></tr>
<tr><td>10.5</td><td>180</td><td>FR 10.5 0 X</td></tr>
<tr><td>10.5</td><td>180</td><td>FR 10.5 0 Y</td></tr>
<tr><td>10.5</td><td>240</td><td>FR 10.5 60 X</td></tr>
<tr><td>10.5</td><td>240</td><td>FR 10.5 60 Y</td></tr>
<tr><td>10.5</td><td>300</td><td>FR 10.5 120 X</td></tr>
<tr><td>10.5</td><td>300</td><td>FR 10.5 120 Y</td></tr>
<tr><td>10.5</td><td>0</td><td>FR 10.5 180 X</td></tr>
<tr><td>10.5</td><td>0</td><td>FR 10.5 180 Y</td></tr>
<tr><td>10.5</td><td>60</td><td>FR 10.5 240 X</td></tr>
<tr><td>10.5</td><td>60</td><td>FR 10.5 240 Y</td></tr>
<tr><td>10.5</td><td>120</td><td>FR 10.5 300 X</td></tr>
<tr><td>10.5</td><td>120</td><td>FR 10.5 300 Y</td></tr>
</tbody>
</table>

Decimals in T-frame No. represents the fraction of total
mid-bay length the gauge extends toward the next T-frame

**Model B & C**

| Internal Gauges | | |
|---|---|---|
| T-Frame No. | External Specimen Reference | Gauge |
| 1 | 180 | iFR1 0 y |
| 2 | 180 | iFR2 0 y |
| 3 | 180 | iFR3 0 y |
| 4 | 180 | iFR4 0 y |
| 5 | 180 | iFR5 0 y |
| 5-1875 | 180 | iFR 5-1875 0 x |
| 5-1875 | 180 | iFR 5-1875 0 xy |
| 5-1875 | 180 | iFR 5-1875 0 y |
| 5.5 | 180 | iFR 5-5 0 x |
| 5.5 | 180 | iFR 5-5 0 xy |
| 5.5 | 180 | iFR 5-5 0 y |
| 5.5 | 175 | iFR 5-5 5 x |
| 5.5 | 175 | iFR 5-5 5 xy |
| 5.5 | 175 | iFR 5-5 5 y |
| 5.5 | 169 | iFR 5-5 11 x |
| 5.5 | 169 | iFR 5-5 11 xy |
| 5.5 | 169 | iFR 5-5 11 y |
| 5.5 | 165 | iFR 5-5 15 x |
| 5.5 | 165 | iFR 5-5 15 y |
| 5.5 | 345 | iFR 5-5 165 x |
| 5.5 | 345 | iFR 5-5 165 y |
| 5.5 | 349 | iFR 5-5 169 x |
| 5.5 | 349 | iFR 5-5 169 xy |
| 5.5 | 349 | iFR 5-5 169 y |
| 5.5 | 355 | iFR 5-5 175 x |
| 5.5 | 355 | iFR 5-5 175 xy |
| 5.5 | 355 | iFR 5-5 175 y |
| 5.8125 | 180 | iFR 5-8125 0 x |
| 5.8125 | 180 | iFR 5-8125 0 xy |
| 5.8125 | 180 | iFR 5-8125 0 y |
| 6 | 180 | iFR6 0 y |
| 6 | 165 | iFR6 15 y |
| 6 | 150 | iFR6 30 y |
| 6 | 120 | iFR6 60 y |
| 6 | 90 | iFR6 90 y |
| 6 | 60 | iFR6 120 y |
| 6 | 30 | iFR6 150 y |
| 6 | 360 | iFR6 180 y |
| 6 | 330 | iFR6 210 y |
| 6 | 300 | iFR6 240 y |
| 6 | 270 | iFR6 270 y |
| 6 | 240 | iFR6 300 y |
| 6 | 210 | iFR6 330 y |
| 6 | 225 | iFR6 345 y |
| 7 | 180 | iFR7 0 y |
| 8 | 180 | iFR8 0 y |
| 9 | 180 | iFR9 0 y |
| 10 | 180 | iFR10 0 y |
| 11 | 180 | iFR11 0 y |

Decimals in T-frame No. represents the fraction of total
mid-bay length the gauge extends toward the next T-frame

| External Gauges | | |
|---|---|---|
| T-Frame No. | External Specimen Reference | Gauge |
| 4.5 | 180 | FR 4-5 0 X |
| 4.5 | 180 | FR 4-5 0 Y |
| 5.1875 | 180 | FR 5-1875 0 X |
| 5.1875 | 180 | FR 5-1875 0 XY |
| 5.1875 | 180 | FR 5-1875 0 Y |
| 5.5 | 180 | FR 5-5 0 X |
| 5.5 | 180 | FR 5-5 0 XY |
| 5.5 | 180 | FR 5-5 0 Y |
| 5.5 | 185 | FR 5-5 5 X |
| 5.5 | 185 | FR 5-5 5 XY |
| 5.5 | 185 | FR 5-5 5 Y |
| 5.5 | 191 | FR 5-5 11 X |
| 5.5 | 191 | FR 5-5 11 XY |
| 5.5 | 191 | FR 5-5 11 Y |
| 5.5 | 195 | FR 5-5 15 X |
| 5.5 | 195 | FR 5-5 15 Y |
| 5.5 | 210 | FR 5-5 30 X |
| 5.5 | 210 | FR 5-5 30 Y |
| 5.5 | 240 | FR 5-5 60 X |
| 5.5 | 240 | FR 5-5 60 Y |
| 5.5 | 270 | FR 5-5 90 X |
| 5.5 | 270 | FR 5-5 90 Y |
| 5.5 | 300 | FR 5-5 120 X |
| 5.5 | 300 | FR 5-5 120 Y |
| 5.5 | 330 | FR 5-5 150 X |
| 5.5 | 330 | FR 5-5 150 Y |
| 5.5 | 0 | FR 5-5 180 X |
| 5.5 | 0 | FR 5-5 180 Y |
| 5.5 | 30 | FR 5-5 210 X |
| 5.5 | 30 | FR 5-5 210 Y |
| 5.5 | 60 | FR 5-5 240 X |
| 5.5 | 60 | FR 5-5 240 Y |
| 5.5 | 90 | FR 5-5 270 X |
| 5.5 | 90 | FR 5-5 270 Y |
| 5.5 | 120 | FR 5-5 300 X |
| 5.5 | 120 | FR 5-5 300 Y |
| 5.5 | 150 | FR 5-5 330 X |
| 5.5 | 150 | FR 5-5 330 Y |
| 5.5 | 165 | FR 5-5 345 X |
| 5.5 | 165 | FR 5-5 345 Y |
| 5.5 | 169 | FR 5-5 349 X |
| 5.5 | 169 | FR 5-5 349 XY |
| 5.5 | 169 | FR 5-5 349 Y |
| 5.5 | 175 | FR 5-5 355 X |
| 5.5 | 175 | FR 5-5 355 XY |
| 5.5 | 175 | FR 5-5 355 Y |
| 5.8125 | 180 | FR 5-8125 0 X |
| 5.8125 | 180 | FR 5-8125 0 XY |
| 5.8125 | 180 | FR 5-8125 0 Y |
| 6.5 | 180 | FR 6-5 0 X |
| 6.5 | 180 | FR 6-5 0 Y |

Decimals in T-frame No. represents the fraction of total
mid-bay length the gauge extends toward the next T-frame

This page intentionally left blank.

# Annex M   Collapse Test Procedure

This page intentionally left blank.

**DRDC-ATLANTIC COLLAPSE TEST PROGRAM**

**Procedure for Collapse Tests**

## 1. Test Description

The project involves the design and collapse testing of three large-scale ring-stiffened cylinders. The intent is for one "baseline" cylinder to be tested, followed by one with simulated corrosion damage and then one with similar damage that has been repaired by weld buttering. Collapse testing involves subjecting each specimen to a progressively increasing external pressure until a sudden reduction in external pressure is noticed, signifying collapse.

## 2. Instrumentation and Data Acquisition

2.1. Instrumentation will consist of two (2) calibrated pressure transducers (DEC and specimen interior pressure), two (2) water volume meters and the following number and type of strain gauges:

    2.1.1. Model A

        &#10148;    Exterior: 36 biaxial strain gauges

        &#10148;    Interior: 22 uniaxial strain gauges

    2.1.2. Models B & C:

        &#10148;    Exterior: 24 uniaxial, 2 biaxial and 7 rosette strain gauges

        &#10148;    Interior: 15 biaxial and 7 rosette strain gauges

2.2. All data shall be acquired via C-FER's computer-controlled software and signal conditioning system.

## 3. Installation, Test Preparations

3.1. All specimens are to be tested in C-FER's 8,500-psi Deepwater Experimental Chamber (DEC).

3.2. Prior to specimen installation, test engineer is to confirm completion of all pretest geometric measurements.

3.3. Photographs are to be taken of pertinent operations (specimen setup, transport, installation, removal).

3.4. Apply internal strain gauges and confirm that they pass waterproofing verification.

3.5. Weld caps on to specimen.

3.6. Apply external strain gauges and confirm that they all pass waterproofing verification.

3.7. Install assembly in DEC, ensuring that no strain gauges or strain gauges wires are damaged in the process.

3.8. Hook up high pressure fill and vent lines to end cap fittings.

3.9. Close DEC doors, and fill the DEC and specimen with water.

3.10. Set-up instrumentation to record interior DEC pressure, interior specimen pressure and water volume.

3.11. Balance and zero instrumentation prior to proceeding with testing.

3.12. Set automatic read capability of data acquisition system to record pressure and strain at rate of 100 Hz, and every five (5) seconds.

## 4. Test Procedure

4.1. Confirm that the specimen vent line valve is closed.

4.2. Simultaneously pressurize both DEC and specimen at a rate not exceeding 300 psi/minute and ensure that the net pressure (DEC pressure minus specimen pressure) does not exceed 100-psi.

4.3. Stop pumping once the DEC pressure reaches 1,000-psi. Visually inspect the DEC for any possible leaks and ensure that the DEC and specimen pressures are maintained during the inspection.

4.4. After the inspection, continue to pressurize the DEC and specimen until they reach a pressure greater than the predicted collapse pressure but no greater than 2,000-psi (max. pressure rating of pressure transducers).

4.5. Stop pumping and isolate the DEC and specimen.

4.6. Slowly open the needle valve that restricts the specimen vent and allow water to bleed out.

4.7. Continue to bleed water out of the specimen until collapse occurs.

4.8. During intervals where the inlet water tank to the DEC requires refilling or the specimen vent tank requires emptying, the specimen and DEC shall be isolated to ensure that no water can exit either the specimen or the DEC.

4.9. Upon completion of testing, drain specimen and DEC, open DEC doors, and remove specimen from DEC.

4.10. Check and backup computer file containing test results.

4.11. Take photographs.

# Distribution list

Document No.: DRDC Atlantic CR 2011-334

## LIST PART 1: Internal Distribution by Centre

2    Project Authority (1 paper copy, 1 CD)
3    DRDC Atlantic Library (1 paper copy, 2 CDs)
1    Christopher Bayley, Group Leader, CM (1 CD)
1    Ian Thompson, Defence Scientist, WP (1 CD)
1    Liam Gannon, Defence Scientist, WP (1 CD)

8    TOTAL LIST PART 1

## LIST PART 2: External Distribution by DRDKIM

2    NDHQ/DNPS 4, Mr. Jocelyn Turgeon (1 paper copy, 1 CD)
2    NDHQ/DNPS 4-2, LCdr Alain Sauvé (1 paper copy, 1 CD)
1    NDHQ/DNPS 2-4-3, Dr. James Huang (1 paper copy)
1    DRDKIM (1 CD)
1    Library & Archive Canada (1 CD)
     Attn: Military Archivist, Government Records Branch

7    TOTAL LIST PART 2

**15   TOTAL COPIES REQUIRED**

This page intentionally left blank.

# DOCUMENT CONTROL DATA

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)*

| | |
|---|---|
| 1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.)<br><br>C-FER Technologies (1999) Inc.<br>200 Karl Clark Road<br>Edmonton AB  T6N 1H2 | 2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.)<br><br>UNCLASSIFIED<br>(NON-CONTROLLED GOODS)<br>DMC A<br>REVIEW: GCEC JUNE 2010 |

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls: Final Report

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Swanek, D.S.; Timms, C.M.; Link, R.

| | | |
|---|---|---|
| 5. DATE OF PUBLICATION (Month and year of publication of document.)<br><br>February 2012 | 6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)<br><br>204 | 6b. NO. OF REFS (Total cited in document.)<br><br>18 |

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Contract Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – Atlantic
9 Grove Street
P.O. Box 1012
Dartmouth, Nova Scotia B2Y 3Z7

| | |
|---|---|
| 9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)<br><br>11ga08-07 | 9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)<br><br>W7707-098210 |
| 10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)<br><br>Contractor's Document Number: C-FER Report F034 | 10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)<br><br>DRDC Atlantic CR 2011-334 |

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

C-FER Technologies (1999) Inc. ("C-FER") was awarded Contract Number W7707-098210/001/HAL with Public Works and Government Services Canada ("PWGSC") to design, fabricate and test large scale ring stiffened cylinders. The objective of this project was to assess the impact on the collapse pressure of submarine pressure hulls of metal loss due to corrosion, with and without subsequent weld buttering repair. C-FER and Martec Limited ("Martec") contributed to the preparation of this report and the work. Martec was responsible for the final cylinder design and finite element (FE) analysis, while C-FER was responsible for providing technical support on the end cap design, collapse testing facilities, testing expertise and overall project coordination. The three specimens, designated as Specimen A – Baseline, Specimen B – Damaged and Specimen C – Repaired, were fabricated and tested, and the resulting collapse pressures were 7.75, 7.31 and 7.66 MPa, respectively. The simulated corrosion damage (i.e. metal loss) reduced the collapse capacity by 5.9%, whereas repair of simulated corrosion damage by metal replacement through weld buttering recovered 4.8% of that capacity. The findings indicate that weld buttering can be an effective corrosion repair technique.

C-FER Technologies (1999) Inc. s'est vue attribuer le contrat W7707-098210/001/HAL par Travaux publics et Services gouvernementaux Canada (TPSGC) pour la conception, la fabrication et l'essai de cylindres à grande échelle renforcés à l'aide d'anneaux. L'objectif de ce projet était d'évaluer l'impact, sur la pression d'effondrement de coques épaisses de sous-marins, de la perte de métal par corrosion, avec et sans beurrage subséquent. C-FER et Martec Limited ont contribué à la préparation du présent rapport et aux travaux. Martec était responsable de la conception finale des cylindres et de l'analyse par éléments finis, alors que C-FER était chargée de fournir du soutien technique portant sur la conception du bouchon d'extrémité, ainsi que les installations d'essai d'effondrement, l'expertise d'essai, et de faire la coordination du projet. Les trois spécimens, désignés de la façon suivante : spécimen A – point de comparaison, spécimen B – endommagé, et spécimen C – réparé, ont été fabriqués et testés, et les pressions d'effondrement résultantes étaient de 7,75, 7,31 et 7,66 MPa respectivement. Les dommages par corrosion simulés (c.-à-d. les pertes de métal) ont réduit la capacité d'effondrement de 5,9 %, alors que la réparation des dommages par corrosion simulés par remplacement de métal par beurrage a permis de récupérer 4,8 % de cette capacité. Les conclusions indiquent que le beurrage peut être une technique de réparation de la corrosion efficace.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

submarine pressure hull; corrosion damage; hull thinning; weld repair; buttering; collapse pressure; experimental mechanics

This page intentionally left blank.

## Defence R&D Canada

Canada's leader in defence
and National Security
Science and Technology

## R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE **R&D** DÉFENSE

**www.drdc-rddc.gc.ca**