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Accelerated ageing of composites

Equipment and experimental protocol design and development

Royale S. Underhill
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Scientific Report
DRDC-RDDC-2016-R109
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Abstract

Composites have the potential to be lightweight, durable, corrosion- and cavitation-free materials. The technology has been incorporated successfully into aircraft and commercial sea vessels. The Cooperative Research Ships (CRS), Composite Propeller Working Group (COMPROP) is investigating the feasibility of using composites for marine propellers. One aspect of the work is to develop an understanding of how composites age when immersed in seawater for extended periods of time. Ageing can be examined with immersion in real-time, but this is not practical for material screening and selection purposes. One can accelerate ageing by elevating the temperature of the samples, using the principle of time-temperature superposition.

This work documents the design and manufacture of an environmental immersion chamber (EIC) for use in accelerated ageing experiments. The second part of this document reports the design and manufacture of extensions for a four-point bend jig that would allow testing of samples up to 455 mm long. The EIC was shown to maintain seawater at 60°C for 24 hours at a tolerance of ±1°C. The four-point bend jig had sufficient capability for deflection for the longest composite samples that will be aged.

Significance for defence and security

Composite materials use in shipbuilding has increased in recent years due to benefits in terms of weight and durability. Some estimates predict that composite propellers may reduce weight up to 70%, increase overall fuel efficiency up to 5% and reduce noise up to 5 dB. In order to select appropriate composite materials, they must be characterized with respect to how they degrade when immersed in seawater. This report outlines the design of equipment and methodology for studying such a degradation.

Résumé

Parmi les composites, il existe des matériaux légers, durables, exempts de corrosion et de cavitation. Cette technologie est déjà utilisée avec succès sur les aéronefs et les navires commerciaux. Le groupe de travail sur les hélices en composite (COMPROP) de l'organisme Cooperative Research Ships (CRS) étudie la faisabilité d'utiliser des composites dans la fabrication d'hélices de navire. Une partie du travail consiste à comprendre l'effet de l'eau de mer sur le vieillissement des composites immergés pendant de longues périodes. On peut étudier le vieillissement grâce à l'immersion en temps réel, mais cette méthode n'est pas pratique pour la présélection et la sélection des matériaux. Il est possible d'accélérer le vieillissement en augmentant la température des échantillons, en vertu du principe d'équivalence temps-température.

Ce travail documente la conception et la fabrication d'une chambre climatique d'immersion (CCI) utilisée pour mener des expériences de vieillissement accéléré. La deuxième partie de ce document rend compte de la conception et de la fabrication d'extensions de gabarits de flexion quatre points, ce qui permettrait de mettre à l'épreuve des échantillons d'une longueur maximale de 455 mm. La CCI peut maintenir la température de l'eau de mer à 60°C pendant 24 heures avec une tolérance de ±1°C. La capacité du gabarit de flexion quatre points est suffisante pour dévier les plus longs échantillons de composite qui seront vieillis.

Importance pour la défense et la sécurité

Le recours aux matériaux composites dans la construction navale a augmenté au cours des dernières années en raison de leurs avantages sur le plan du poids et de la durabilité. Selon certaines estimations, les hélices en composite pourraient permettre jusqu'à 70% de réduction du poids, jusqu'à 5% d'augmentation du rendement énergétique global et jusqu'à 5 dB de réduction du bruit. Pour pouvoir choisir les matériaux composites appropriés, il faut savoir comment ils se dégradent lorsqu'on les immerge dans l'eau de mer. Le présent rapport porte sur la conception de l'équipement et la méthodologie utilisée pour étudier cette dégradation.

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Acknowledgements

Thanks are given to Mr. Tomasz Lemczyk for his technical help in the heating and design of the environmental immersion chamber (EIC), the minor adaptations needed for the actual use of the four-point bend apparatus, and some of the photography used in this report.

Thanks are given to Ms. Nancy Hervé for her help in design of both the EIC and the four-point bend test system, and some of the photography used in this report.

Thanks are given to Mr. Irv Keough for performing the DSC analysis.

Thanks are given to Dr. Allison Nolting for her guidance in designing the four-point bend test system.

Further acknowledgment is given to the machinists from Fleet Maintenance Facility Cape Scott, who manufactured the various EIC parts.

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1 Introduction

Due to an increasing interest in using fibre reinforced polymers (FRP) for the construction of marine parts, DRDC Atlantic Research Centre, Dockyard Laboratory (Atlantic) has undertaken experiments to evaluate FRP ageing in seawater. This research is part of the COMPosite PROPeller Work Group (COMPROP WG) of the Cooperative Research Ships (CRS).

FRPs are a subset of composite materials, in which a polymer matrix is reinforced with fibres. By reinforcing the matrix, the material receives important benefits, such as being nonconductive and having high strength, while leaving it lighter than metallic materials such as steel and bronze. This makes FRPs excellent candidates for potential improvements to naval vessel parts.

One disadvantage of polymers is that they can absorb water. This often leads to degradation, and lowering the strength and stiffness of the composite. The purpose of the study at DRDC Atlantic Research Centre is to explore the degradation of FRP when immersed in seawater for extended periods of time. Ageing an immersed sample under normal operational conditions (temperature, pressure), can take a long period of time; the ageing process can be accelerated by using elevated temperatures and the theory of time/temperature superposition. One of the main goals of the DRDC Atlantic Research Centre study is to determine whether accelerated ageing can be used to predict the degradation that occurs under normal conditions. The variables to be examined in the accelerated aging of FRPs are the water temperature that the samples are immersed in, the sample thicknesses, and the type of fibre. Two different temperatures will be investigated. Two different thicknesses of samples will be immersed (nominally 6 mm and 12 mm), and three different reinforcing fiber layouts will be used (carbon unidirectional, carbon woven, and glass woven). Two environmental immersion chambers (EIC) were built to facilitate these experiments.

This report will discuss the design and manufacture of the EICs and their operating procedure, as well as the assembly of the four-point bend jig machined for use with the DRDC Atlantic Research Centre, Dockyard Laboratory (Atlantic) MTS load frame.

2 Background

2.1 Fibre reinforced polymers

Fibre-reinforced polymer (FRP) (sometimes referred to as fibre-reinforced plastic) is a composite with a polymer matrix and fibre filler. In industrial applications, the fibres are usually glass or carbon, but can also be aramid (an aromatic polyamide). For this ageing study, the FRPs were manufactured by Airborne International (the Netherlands) and consist of an epoxy matrix with carbon or glass fibre reinforcements.

2.2 Marine context

FRPs offer additional anticipated advantages over metallic propeller materials. FRPs make a strong yet light and more adaptive blade. Using FRPs is expected to reduce noise and improve cavitation performance and low frequency electric signatures [1]. Furthermore, being non-metallic materials, the FRP propellers are non-corroding. These advantages make FRPs a good material for marine applications.

2.3 Accelerated ageing

The primary goal of this design project was to create an Environmental Immersion Chamber (EIC) to accelerate ageing of FRP samples. Accelerated ageing can be achieved by manipulating: temperature, stress levels or sample thickness [2]. For this study, elevated temperature, and different sample thicknesses were chosen. No stress will be applied to the sample during the immersion since the flexural properties were desired once the material is aged.

Our EIC utilizes elevated temperatures. By examining FRP response at more than one temperature, one can employ time-temperature superposition, which will help determine the validity of the accelerated testing on the FRP degradation (if any).

The two EICs will be filled with Halifax harbour water, maintained at two different temperatures, with samples immersed for four different periods of time, removed from the water, dried, weighed and the flexural modulus determined via four-point bending. The results will be compared to immersion in a natural environment (experiments performed at Airborne in the Netherlands) to determine if the EIC was accurate in simulating accelerated ageing.

2.4 Flexural properties

The flexural properties of the FRP will be measured, and compared between “dry” and immersed samples. The “dry” samples are controls that will not be immersed, and testing will occur on the as-received specimens. Flexural properties can be determined using either three-point or four-point bending. While three-point bend tests (see Figure 1) are easier to set up and measure, they also selectively cause the sample to break at the center load because it has the largest bending moment [3]. A four-point bend test (see Figure 2) will have a uniform bending moment between the two most central loads, allowing the sample to break along the inherent flaws present in this area [3]. Four-point bend tests are more representative of the true mode of failure. The disadvantage to four-point bend testing is that the deflection is more difficult to measure as it does not occur under one of the load points, but at the center.

The four-point bend test was chosen for this experiment. The flexural properties ob-

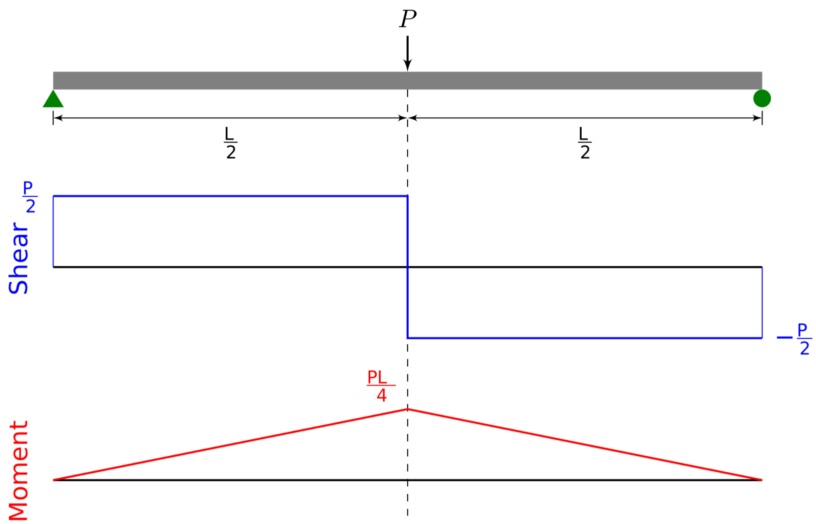


Figure 1: *Three-point bend method, reproduced from Wikipedia under the Creative Commons ShareAlike 3.0 license.*

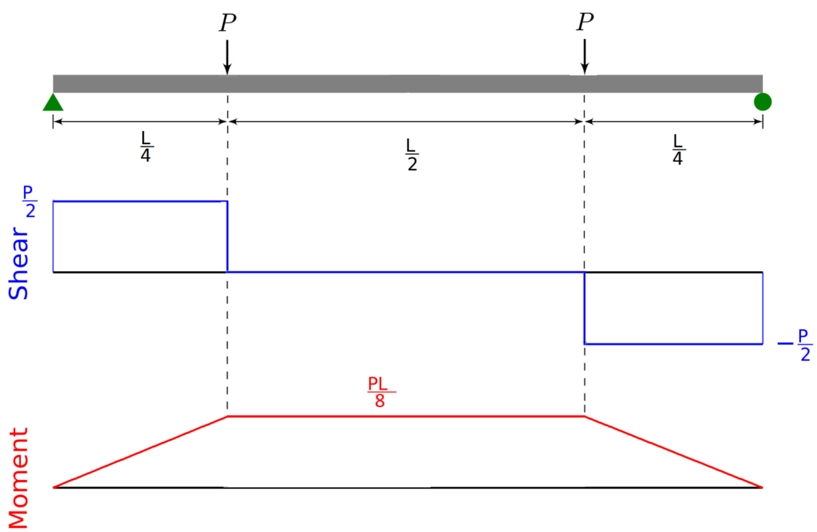


Figure 2: *Four-point bend method, reproduced from Wikipedia under the Creative Commons ShareAlike 3.0 license.*

served will be yield stress and strain, ultimate bending stress and strain, and rupture stress and strain. These properties will be measured by bending the samples in a servo hydraulic load frame fitted with a four-point bend jig, the development of which is discussed later in this report.

2.5 Intended accelerated ageing experiment

2.5.1 Samples

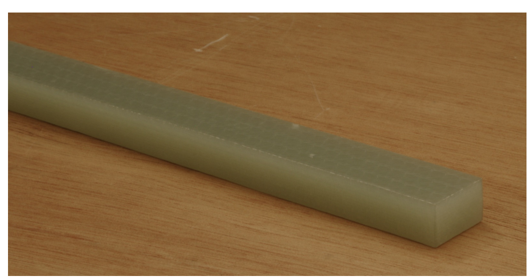
The samples used for this experiment were manufactured by Airborne International. The matrix was an epoxy of Epikote 862 resin with Lonzacure Dedta 80 hardener. Three different fibre layouts were examined: uni-directional carbon fibre (CF UD), woven roving carbon fibre (CF WR) (see Figure 3(a)), and woven roving glass fibre (GF WR) (see Figure 3(b)). The uni-directional carbon layups were either 0° or 90°, while the woven roving layups were either 0° or 45°.

Five different dimension sets were supplied by Airborne International. Those dimension sets are:

- 6 mm thick by 13 mm wide by 120 mm long,
- 6 mm thick by 18 mm wide by 227.5 mm long,
- 6 mm thick by 18 mm wide by 310 mm long,
- 12 mm thick by 18 mm wide by 240 mm long, and
- 12 mm thick by 36 mm wide by 455 mm long.

The samples were given the names of small, medium 1, medium 3, medium 2 and large respectively. Samples medium 1 and medium 3 are the same with the exception

(a) carbon fibre



(b) glass fibre

Figure 3: *Composite samples, woven reinforcements, nominal thickness: 12 mm. Uni-directional carbon fibre samples have the same macroscopic appearance as the woven ones.*

of length and medium 3 only came in CF UD, while medium 1 only came in CF WR and GF WR.

The thicknesses were varied to observe the effect on ageing since a lot of literature focuses on thin composites, but less on thick composites. The varying lengths allow the samples to have a span to depth (or thickness) ratio (16:1) for four-point bend testing as required by ASTM standard D6272 [4].

Samples were divided in three groups: a control (no immersion (i.e. room temperature (RT) and t=0)), those to be immersed in water at 40°C, and those to be immersed in water at 60°C. These samples will be immersed for either 4, 8, 16 or 32 weeks, to simulate ageing. For an overview of the sample layout see Table 1.

A total of 1080 samples will be tested (including the control group), 960 of which will be conditioned at elevated temperatures in an immersion chamber before weighing and four-point bend testing.

Table 1: *A sample overview. Note that this only represents one of the three FRP systems, and that 10 replicates of each sample are made in order to have statistical relevance.*

Ageing Durations (weeks)	Sample Thickness (mm)			
	S	M1&M3	M2	L
t= 0	RT	RT	RT	RT
t= 4	45°C or 60°C	45°C or 60°C	45°C or 60°C	45°C or 60°C
t= 8	45°C or 60°C	45°C or 60°C	45°C or 60°C	45°C or 60°C
t= 16	45°C or 60°C	45°C or 60°C	45°C or 60°C	45°C or 60°C
t= 32	45°C or 60°C	45°C or 60°C	45°C or 60°C	45°C or 60°C

2.5.2 General ageing procedure

The samples are to be weighed to determine their initial, dry weight. The sample holders shall be loaded with the samples and arranged in the two EICs. The EICs are then filled with Halifax harbour water and heated to the desired temperature (either 40°C or 60°C). The temperature of the EICs will be monitored using a data logger placed between the outside of the barrel and the insulation. The intermediate lid and final top are sealed to the barrel with silicone grease to minimize evaporation. Tap water will be used to maintain the water level to account for loss due to evaporation. Once a month, the water in the barrel will be completely drained and exchanged for fresh seawater.

On weeks 4, 8, 16 and 32 samples will be removed from the EIC, gently dried using paper towel and weighed to determine the amount of water absorbed. Once weighed, the samples will be stored in plastic bags to maintain a constant humidity until they can be mechanically tested. Testing will be on a custom four-point bend test jig mounted on a MTS servo hydraulic load frame, with a load capacity of 25kN. The load and deflection data will be recorded and the sample's yield stress & strain, ultimate bending stress & strain, and rupture stress & strain will be calculated.

2.6 Intended four-point bend experiment

The intended four-point bend experiment will follow the ASTM International standard test method for flexural properties of unreinforced and reinforced plastics and electrical insulting materials [4]. The distance between the loading noses (i.e. the load span) will be one half of the support span. A 16:1 support span-to-depth ratio shall be used. The specimens will be deflected until either: (1) rupture occurs in the outer fibres, (2) a maximum fibre strain of 5% is reached, or (3) the machine force reaches max 24 kN, whichever comes first.

3 Design of the environmental immersion chambers

3.1 Design requirements

During the design of the EIC, there were several requirements and restrictions. These involved temperature, size/form, water quality, strength and cost.

With respect to temperature, the samples needed to be immersed at two different designated temperatures. These temperatures needed to be chosen such that the FRP matrix remains below the glass transition temperature (Tg). It is generally accepted that if the specimens are kept below the Tg, then the accelerated ageing will have similar degradation mechanisms to real-time ageing [2]. The water temperature had to be held constant with a tolerance of $\pm 1°C$, spanning months.

It was necessary to immerse a total of 960 samples in an EIC, not necessarily all at once. Fewer sequential runs of the ageing are desirable to minimize the length of time for the experiment. Therefore, the ideal design size would fit 480 samples, all together. Alternatively, two EICs, each holding 240 samples was also considered. The sample holders also needed to be large enought to allow water to flow freely past the samples' midsection.

For water quality, the liquid medium to be used in the EIC needed to be as similar to sea water as possible. Simultaneously, water circulation, algae growth and material selection (possible electrolytic reaction) had to be considered.

The structural integrity of the EIC also needed to be considered. The EIC needed to support the weight of sample holders and samples, even without the supporting force of buoyancy.

Finally, the design needed to be cost effective. Whenever possible, the EIC should be designed from readily available, inexpensive materials.

3.2 Final design

The final design can be seen in Figure 4; the EIC pictured was cross sectioned in order to see two rows of sample holders. The blue barrel is commercial-off-the-shelf and made of polyethylene and is insulated with green polyurethane foam. The intermediate lid is made of polyoxymethylene (POM) and the top is made of black neoprene foam. Finally, the supporting rods, as seen in Figure 5, which hold the sample holders, are made of stainless steel.

The sample holders, as seen in Figure 6, are made of POM and threaded onto stainless steel $\frac{1}{4}''$-20 threaded rods, using $\frac{1}{4}''$-20 stainless steel nuts and stainless steel pins to divide the sample levels. For drafting sheets on sub-assemblies and the full assembly of the EIC, see Annex A.

The EIC was filled with Halifax harbour water heated to either 40°C or 60°C, temperatures below the Tg of the specimens to be aged. The Tg of the epoxy used in the composite specimens was determined by differental scanning calorimetry (TA instruments DSC Q100), performed on all three variations of filler; GF WR, CF WR and CF UD. The Tg of the epoxy was determined to be 124–132°C (Figure 7). To heat the water, constant temperature immersion heaters were suspended in the tops of the EICs (VWR circulator model 1110 or VWR MX open bath).

Figures 8 and 9 show the EIC in operation.

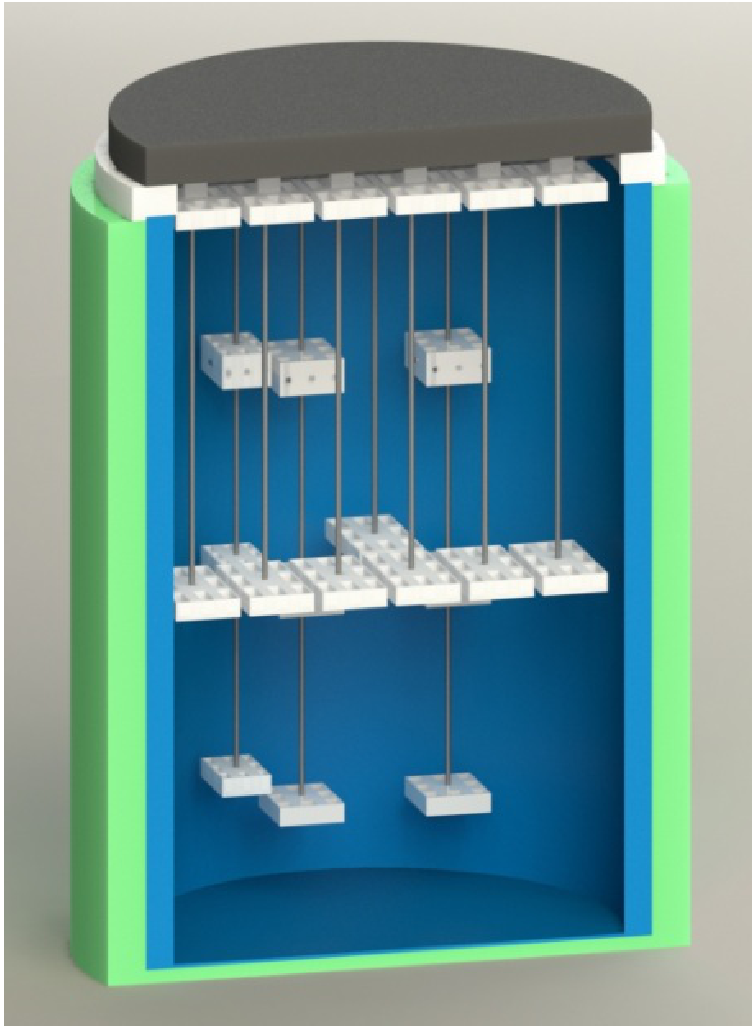


Figure 4: *A cross-section of the final EIC design without samples.*

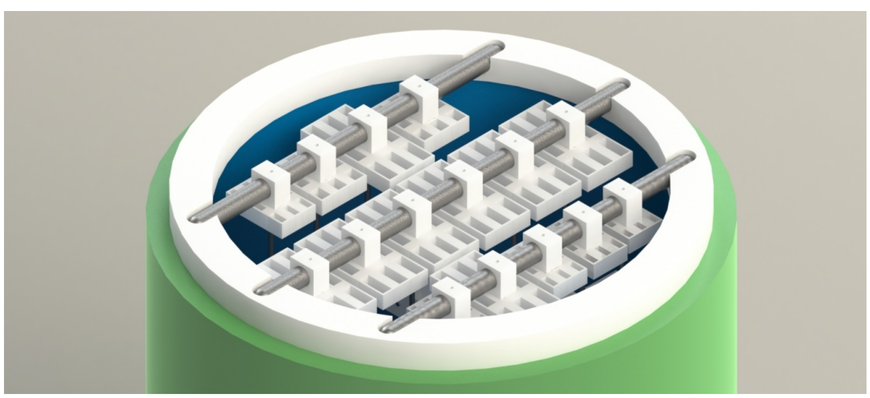


Figure 5: *Top view of the EIC without the cover.*

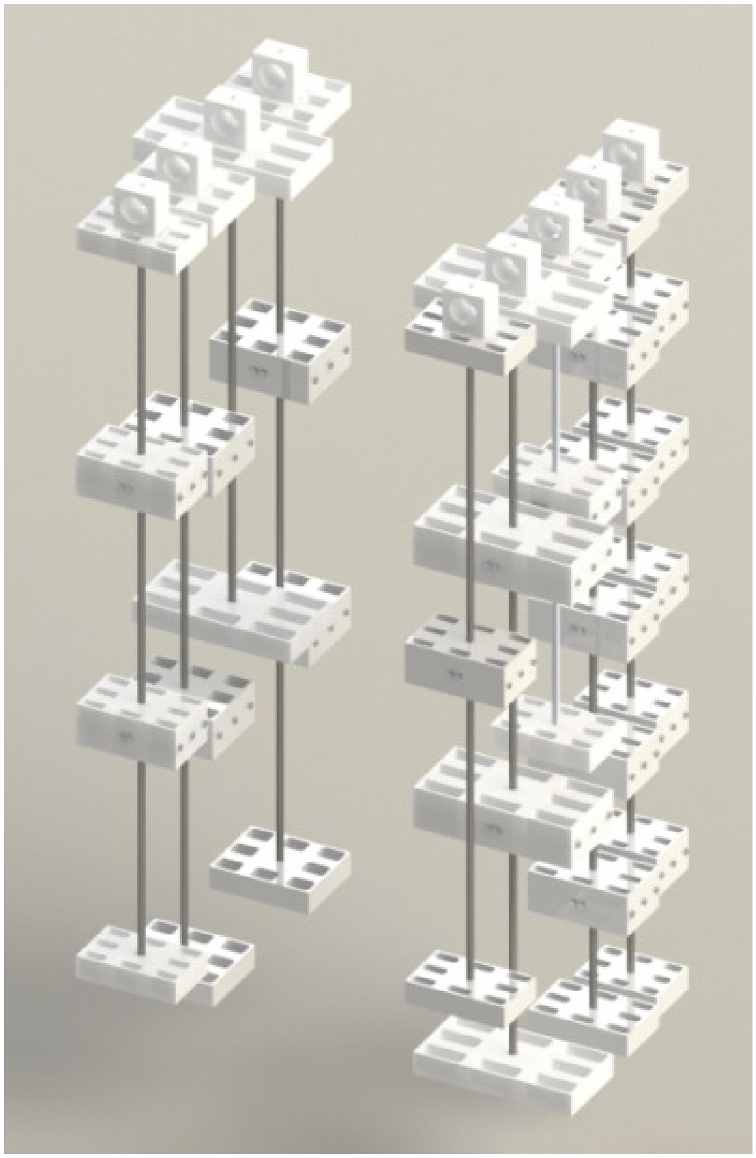


Figure 6: *A preview of the different types of sample holders.*

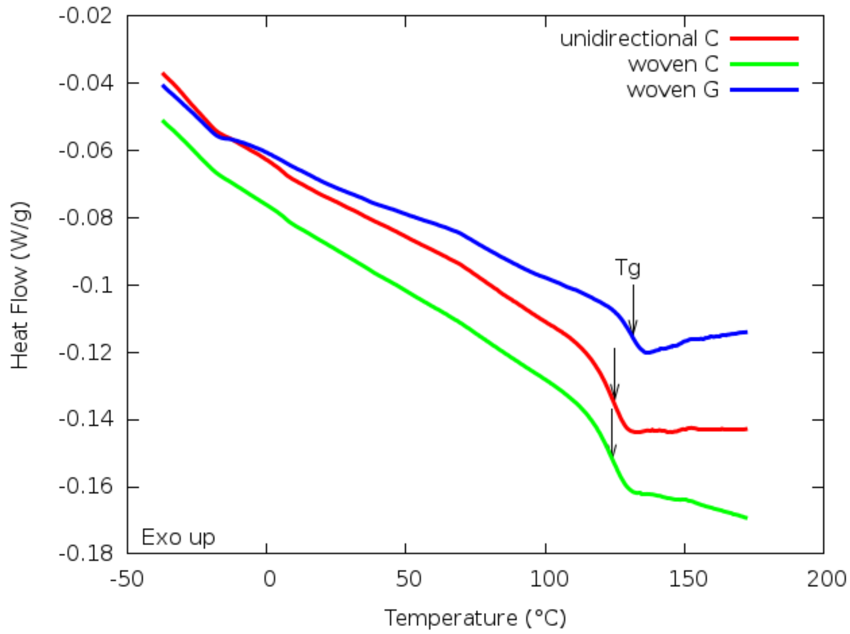


Figure 7: *Differential Scanning Calorimetry results showing glass transition temperatures (Tg).*

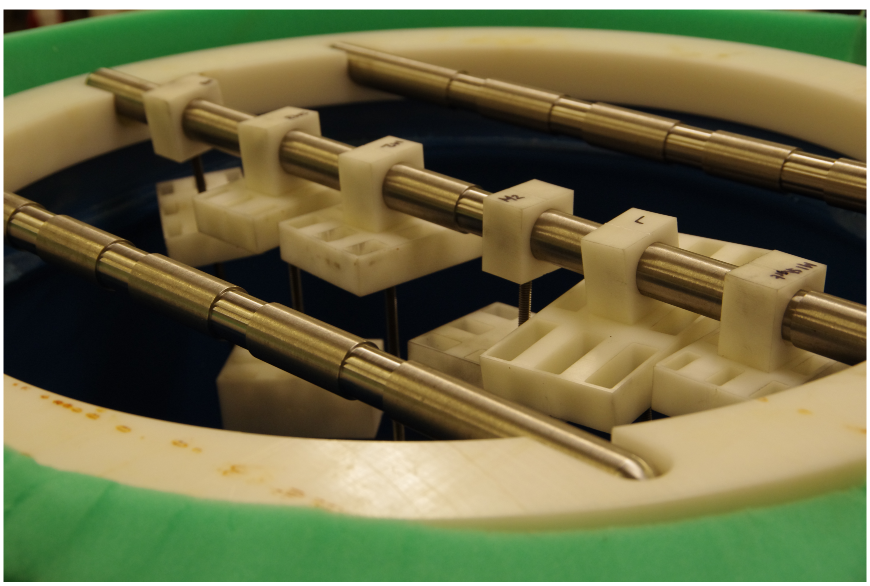


Figure 8: *Partially assembled EIC.*

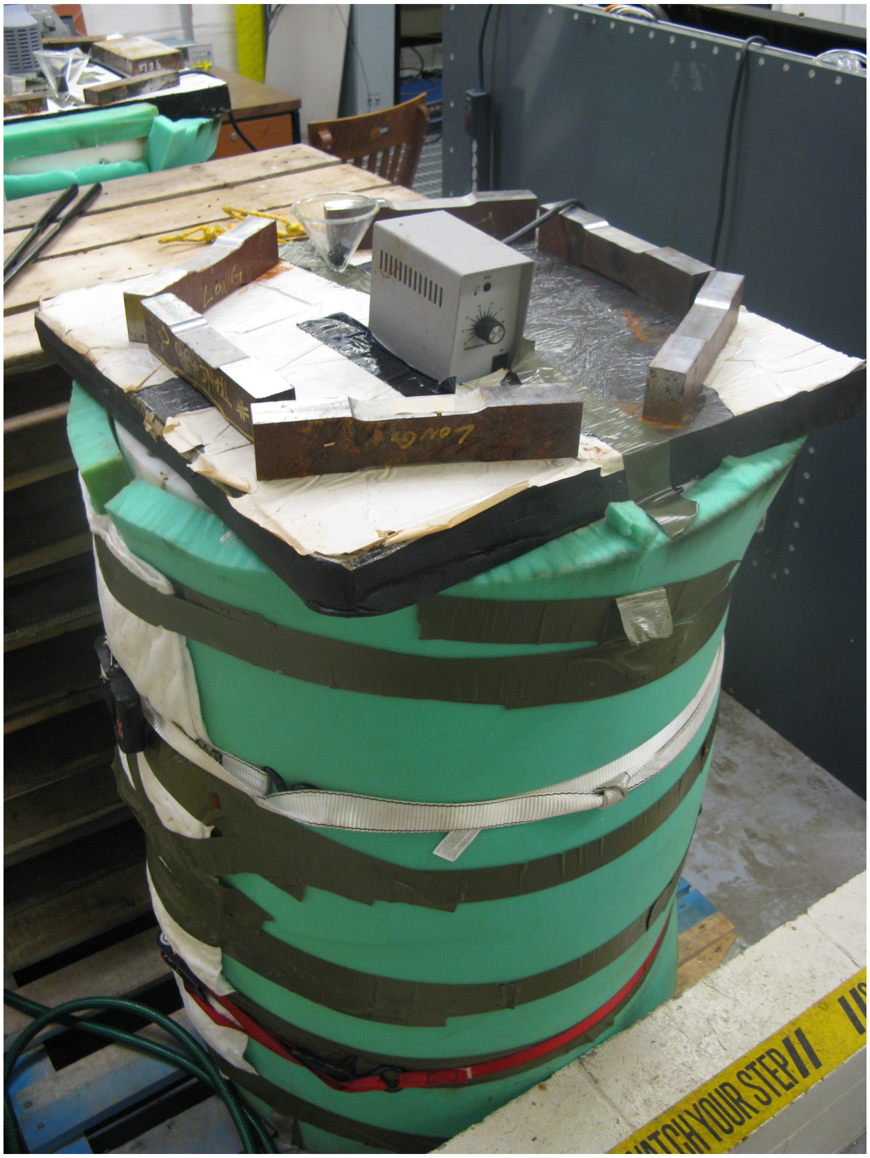


Figure 9: *EIC completely assembled and fully functional.*

4 Four-point bend jig

With a smaller scale four-point bend testing mount already available, only two extensions (one to add to the top, and another for the bottom) were needed to test the largest samples. Therefore two simple aluminum extensions were designed.

4.1 Design requirements

During the design of the extensions, requirements included strength, fitting into the original mounts and alterations to accomodate additional flexion.

For strength, the extensions had to be made much stiffer then the samples being tested, in order to test the flexural properties of the FRP samples and not the properties of the extension. Aluminum was chosen.

For fitting into the original mounts (as seen in Figure 10), the extensions needed to have a T-slot design made in the top (to fit the stand-offs as seen in Figure 11), a bump on the bottom (to fit in the original T-slot as seen on Figure 12) and holes for the bolts which will hold the extension to the original base through its T-slot.

The system had to allow for extra room for deflection, as it was anticipated that composite samples would deflect more than allowed by the original setup which was designed for metallic specimens. To accomodate the deflection, space must be provided in the centre of the bottom extension. The jig also needed to facilitate the continuous measurement of the deflection at the center of the sample. A laser displacement system was chosen to measure the deflection at the center top of the sample. The top extension must have an opening to mount the laser with double-sided tape.

4.2 Final design

The final design for the two extensions can be seen in Figures 13 and 14. These fit into the original mount using bolts threaded into the T-slots. For drafting sheets of the two extensions, see Annex B. The entire setup with original mount and extensions installed can be seen in Figure 15.

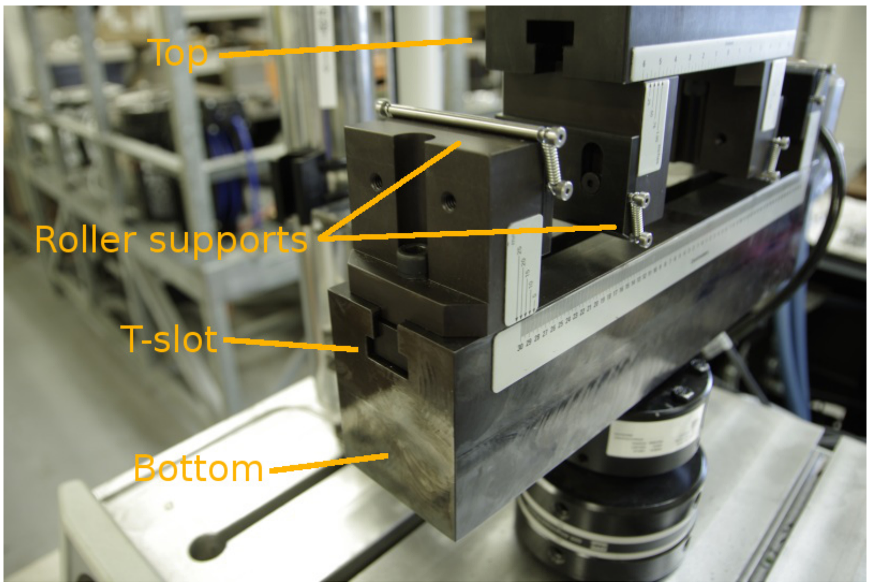


Figure 10: *Original four-point bend mounts with roller supports.*

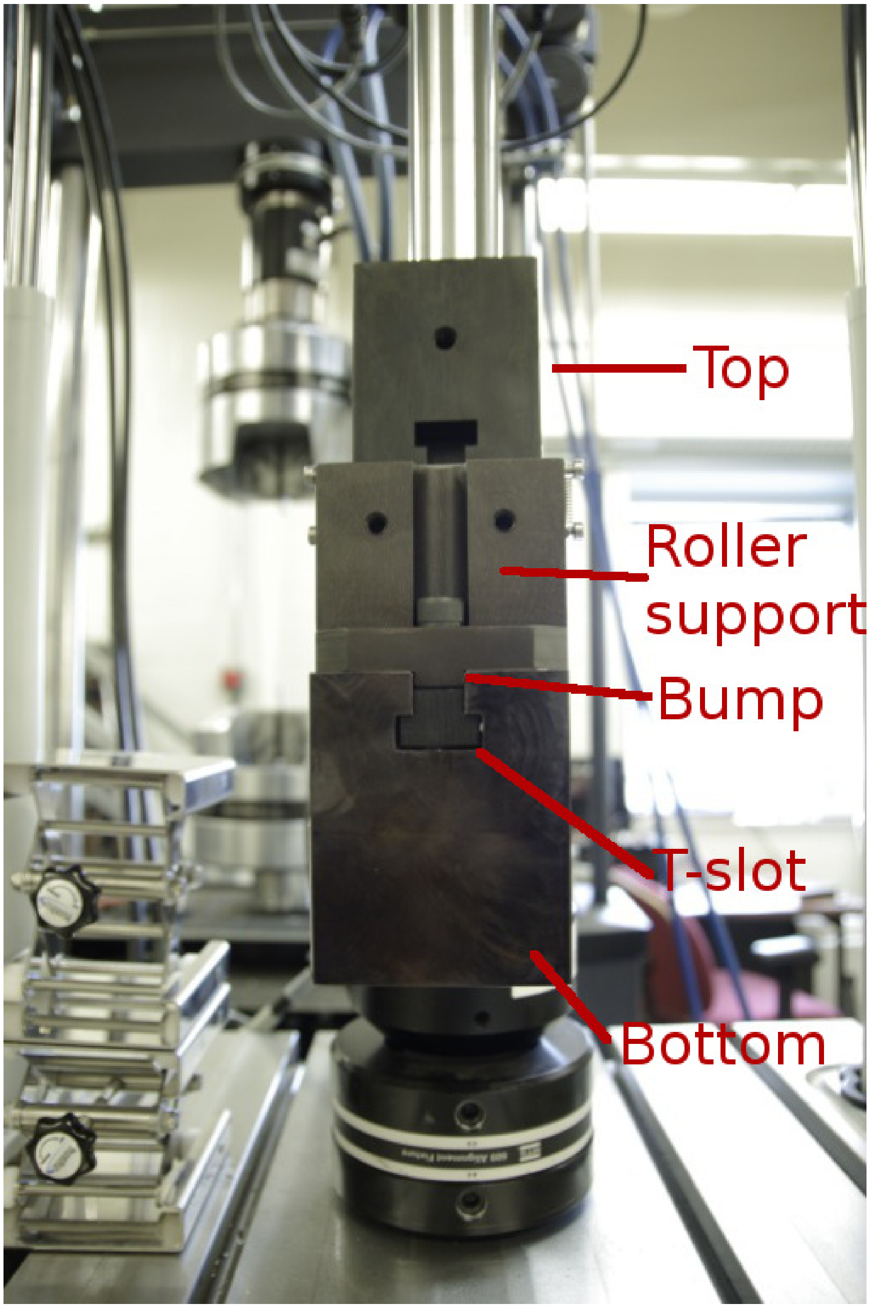


Figure 11: *Roller support fitted into the T-slot of the original mount.*

Figure 12: *Bottom of the roller support showing bump and bolt hole, bump is needed for good fit into the T-slot.*

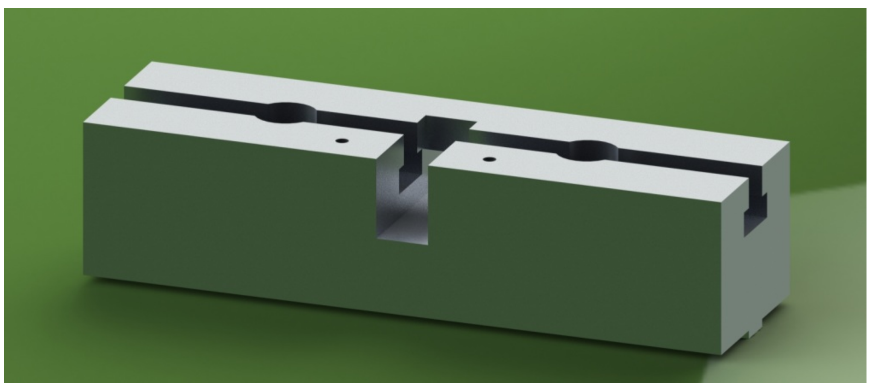


Figure 13: *Four-point bend system top extension.*

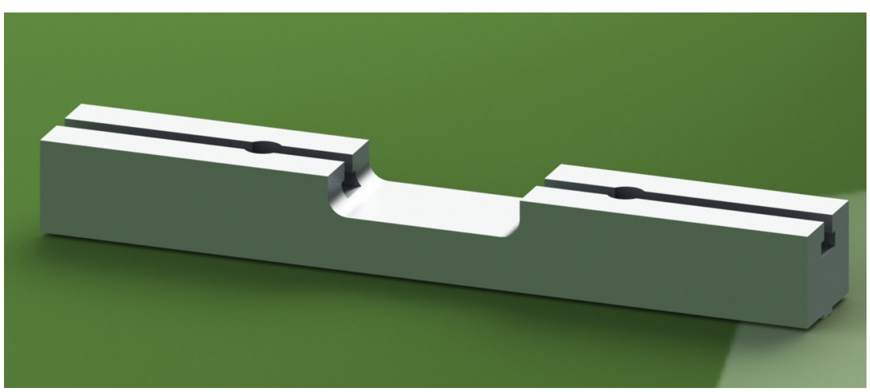


Figure 14: *Four-point bend system bottom extension.*

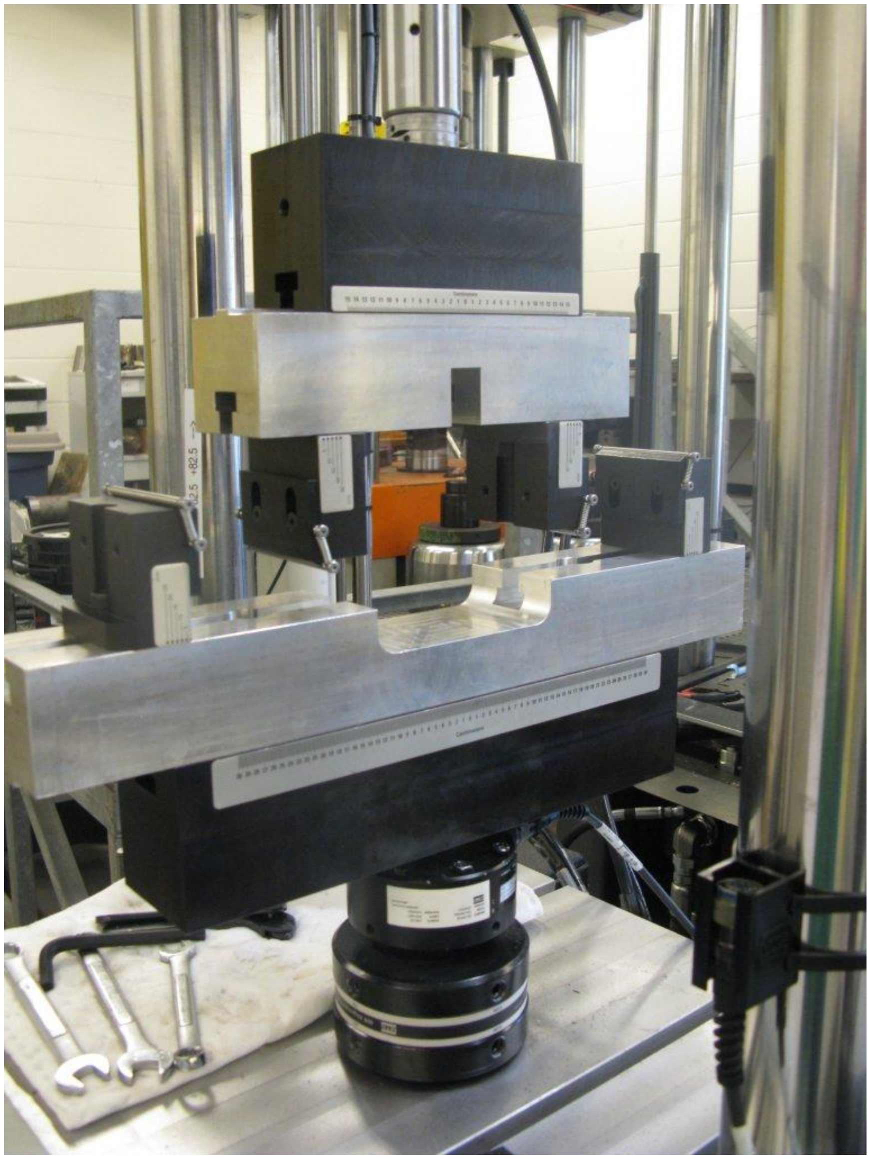


Figure 15: *Four-point bend extensions installed. The original fixture is black, the new extensions are silver aluminum.*

5 Experimental verification

In order to verify that the EIC were able to complete their primary task, the chamber was assembled, filled with Halifax harbour water and heated up 40°C. The EIC were left for 24 hours to allow the temperature to equilibrate, and then the temperatures were measured using NIST calibrated thermometers. They were found to be 40.1°C and 40.2°C. The EIC were then heated to 60°C, and were shown to maintain their temperatures to within ±1°C for 24h.

The four-point bend test system was evaluated by bending one of the longest unaged unidirectional carbon fibre samples (12 mm by 36 mm by 625 mm) and ensuring it had sufficient room to bend (see Figure 16). It was found that the original bottom support was sufficient for all the samples sizes to be tested, even the longest at 625 mm. As such the bottom extension was not used.

The large travel distance laser purchased to measure deflection was found to have insufficient resolution, and so a shorter travel distance laser was substituted. This required some additional machining of the top extension to accomodate the cable plug. The original large travel distance laser would have been fully seated in the top extension allowing the upper roller supports to be installed fully together for the short load spans. Unfortunately, the short travel distance laser protruded from the top extension, blocking the top roller supports. To compensate, the top roller supports were installed in reverse for the short small load spans, allowing the rollers to be brought closer together (see Figure 17). This still resulted in a deviation from the originally planned 40 mm load span to 44 mm as this was the closest the top roller supports could be placed. The top rollers were installed in reverse for only the short, 44 mm, setup. They were installed correctly for all other setups.

The test showed that samples may not bend to rupture, and so it is anticipated that the condition of deflection until a maximum fibre strain of 5% is reached will be most relevant.

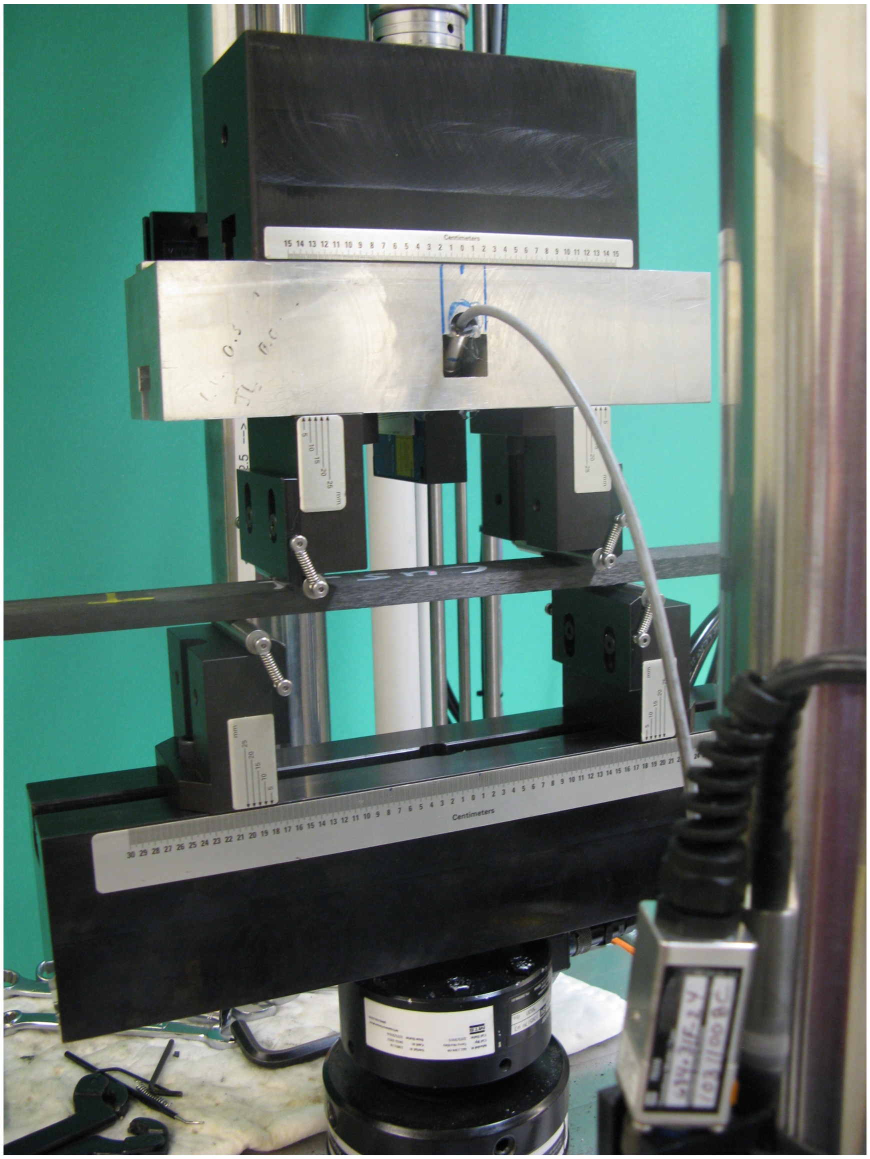


Figure 16: *Four-point bend system with a long FRP sample. Note that the bottom extension was not needed.*

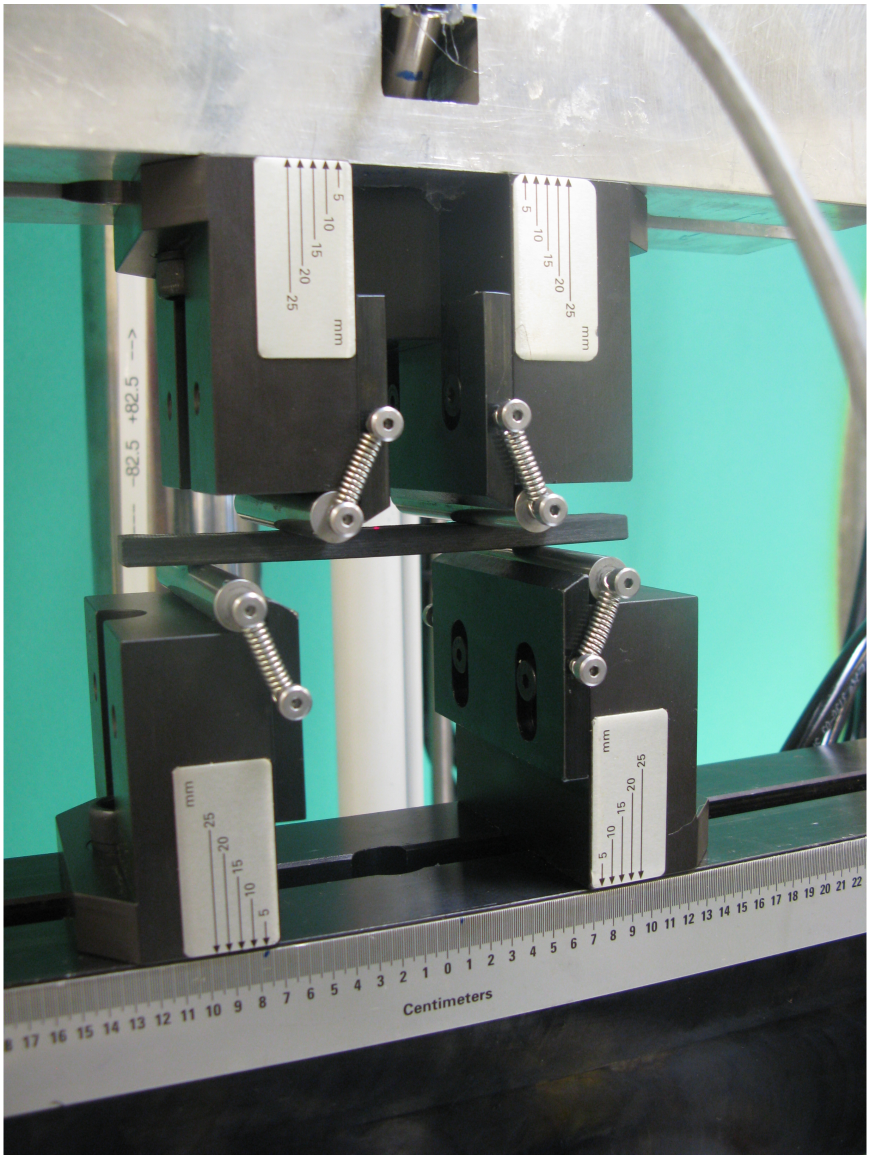


Figure 17: *Four-point bend system with a short FRP sample. The top roller supports are installed in reverse, compared to the previous figure.*

6 Conclusion

This report documents the design and manufacture of an environmental immersion chamber (EIC) to hold FRPs in heated water for periods up to 32 weeks. This report also documents the design and manufacture of two four-point bend extensions used to facilitate the use of an already available setup with the FRP samples.

Experimental verification showed that the EIC was able to hold its temperature for 24 hours without deviating from its set temperature more that ± 1°C.

It was found that the bottom extension for the four-point bend jig wasn't needed. The large travel distance laser was found to have insufficient resolution, and was substituted for a shorter travel distance laser. Changing the laser resulted in a 10% deviation in the testing methodology for the shortest samples. They will be tested with a load span of 44 mm instead of 40 mm because the new laser prevents the top roller supports from being placed any closer together. With these modifications, the four-point bend test functions properly according to ASTM method D6272.

References

[1] Black, S. (2011), Composite propeller for Royal Navy minehunter, *High-Performance Composites*.

[2] Davies, P. and Rajapakse, Y., (Eds.) (2014), Accelerated Aging Tests for Marine Energy Applications, Vol. 208 of *Durability of Composites in a Marine Environment*, p. 170, Waterloo: Springer.

[3] XFEM Skier (2013), Shear Moment Diagram [Illustration] (online), Wikipedia.org, https://en.wikipedia.org/wiki/Shear_and_moment_diagram (Access Date: 2016-05-04). Permission to copy and modify by Wikipedia.org under the Creative Commons ShareAlike 3.0 license.

[4] ASTM Standard D6272-10, 201 (2008), Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending.

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Annex A: EIC draft sheets

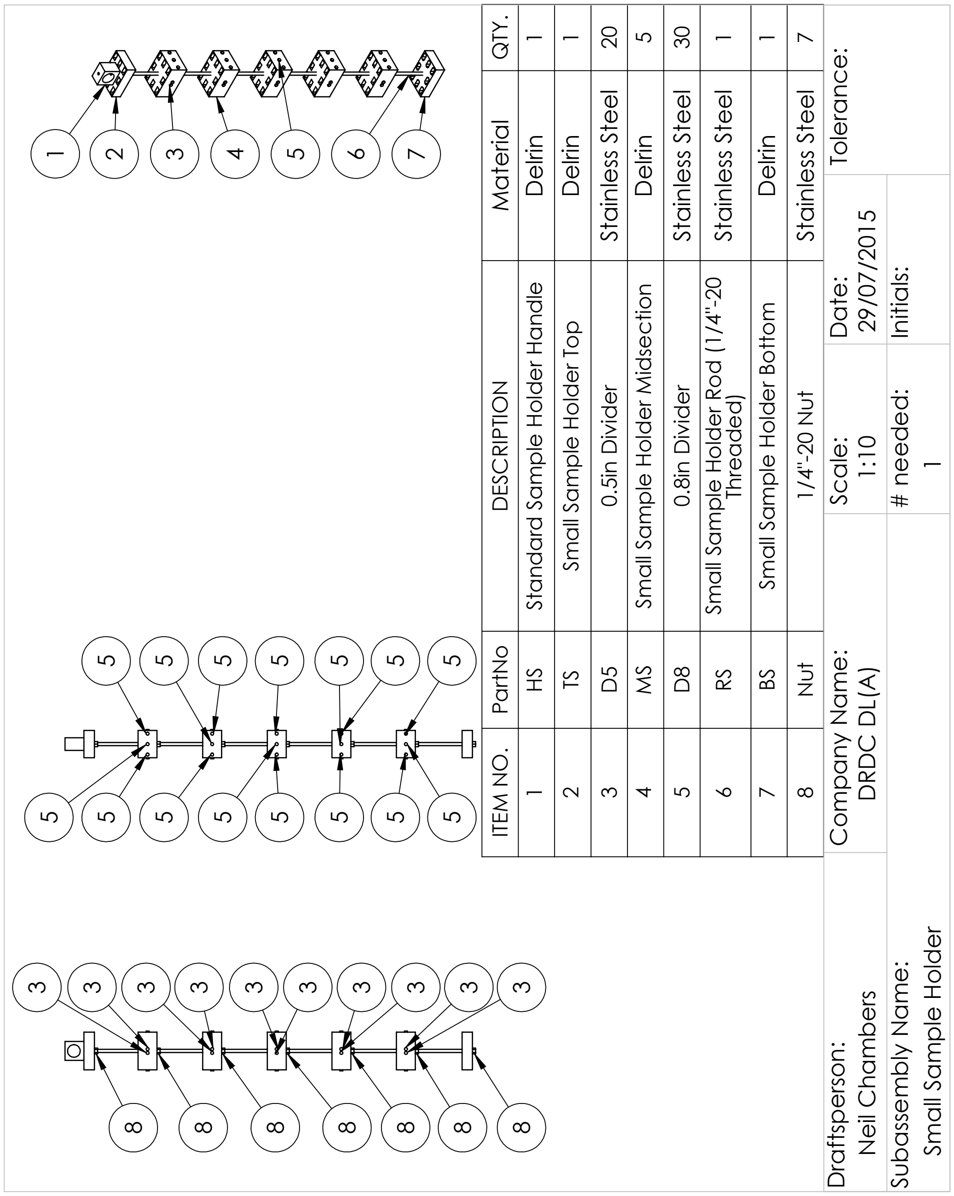
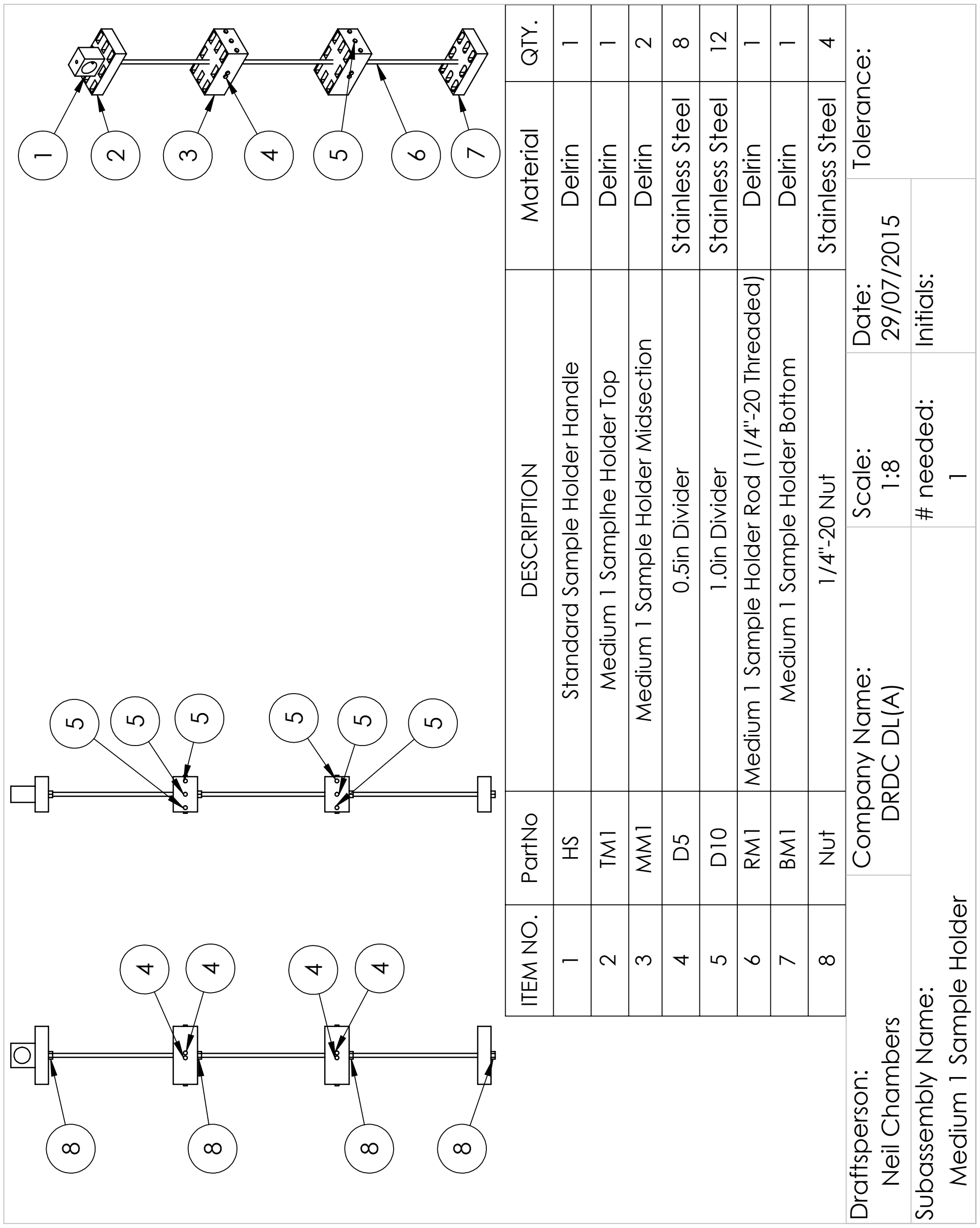


Figure A.1: *Small sample holder.*



ITEM NO.	PartNo	DESCRIPTION	Material	QTY.
1	HS	Standard Sample Holder Handle	Delrin	1
2	TM1	Medium 1 Samplhe Holder Top	Delrin	1
3	MM1	Medium 1 Sample Holder Midsection	Delrin	2
4	D5	0.5in Divider	Stainless Steel	8
5	D10	1.0in Divider	Stainless Steel	12
6	RM1	Medium 1 Sample Holder Rod (1/4"-20 Threaded)	Delrin	1
7	BM1	Medium 1 Sample Holder Bottom	Delrin	1
8	Nut	1/4"-20 Nut	Stainless Steel	4

Figure A.2: *Medium 1 sample holder.*

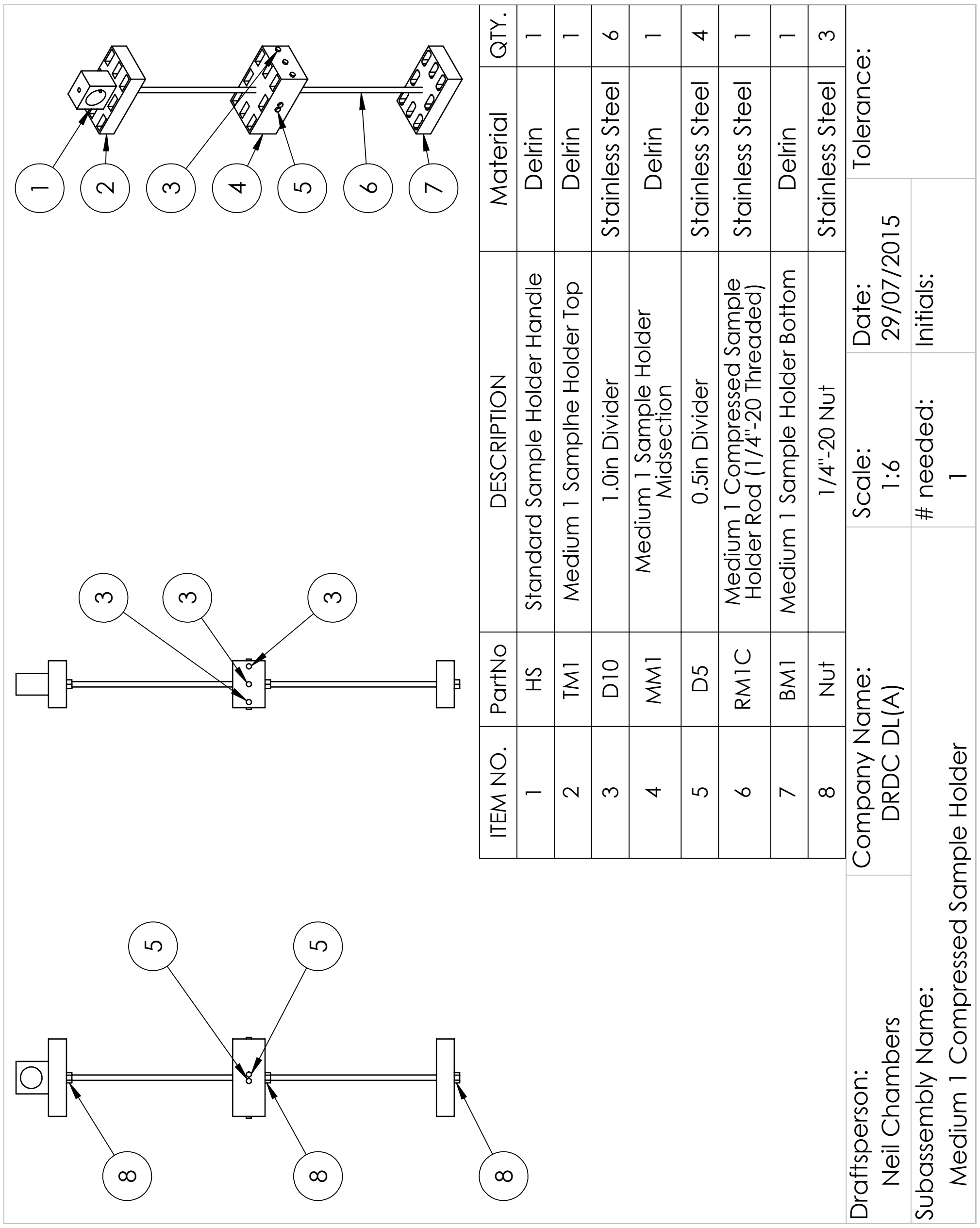


Figure A.3: *Medium 1 compressed sample holder.*

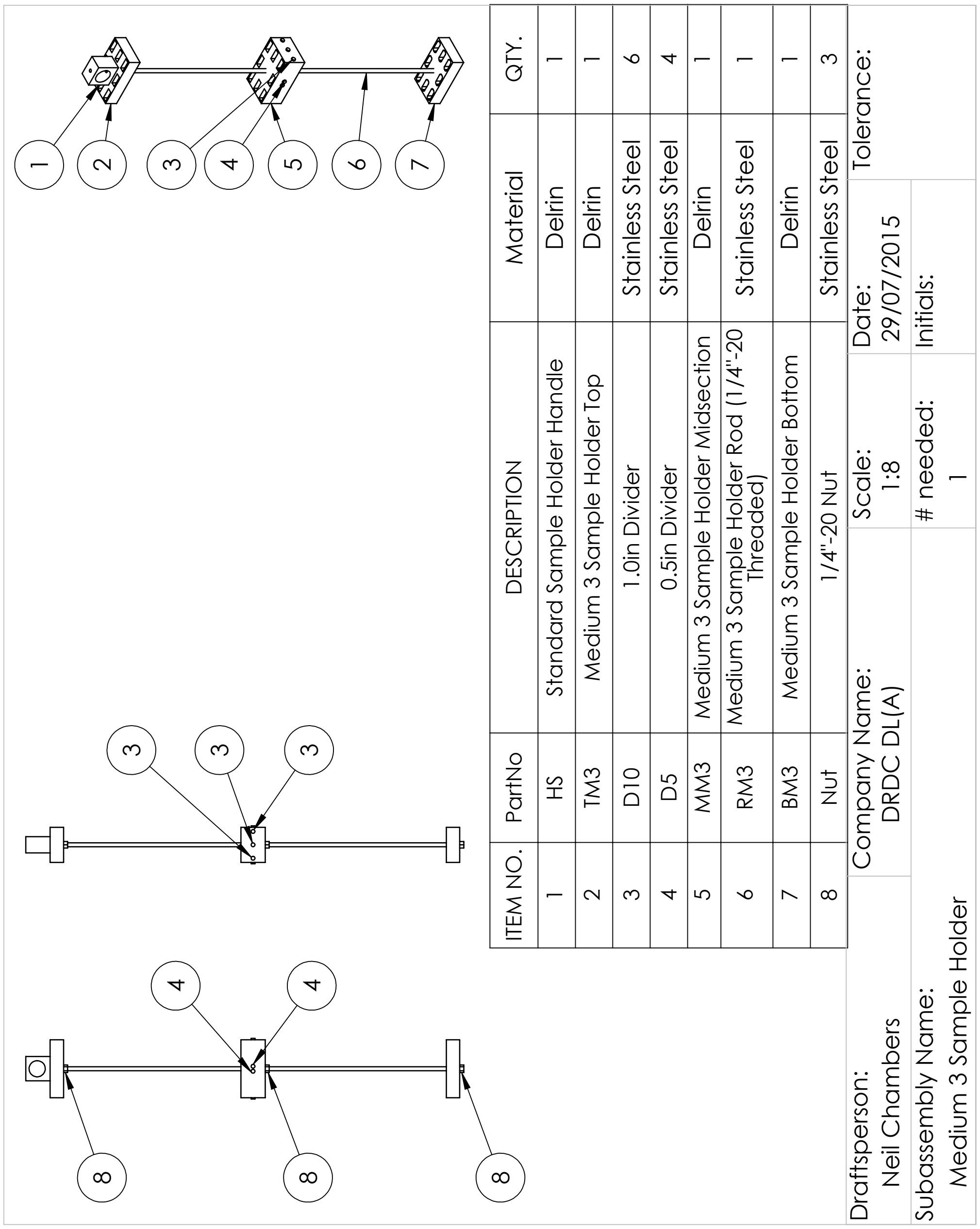


Figure A.4: *Medium 3 sample holder.*

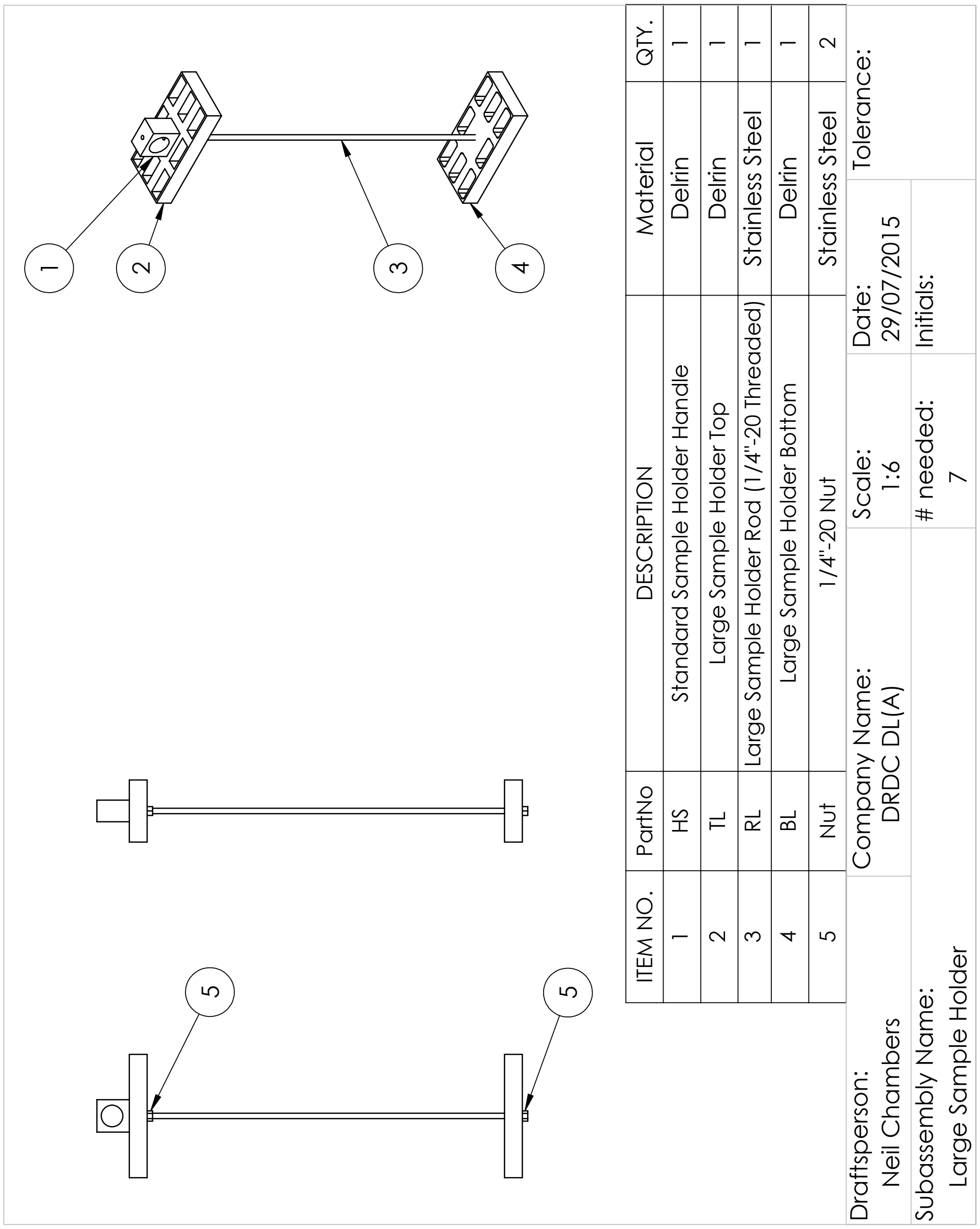
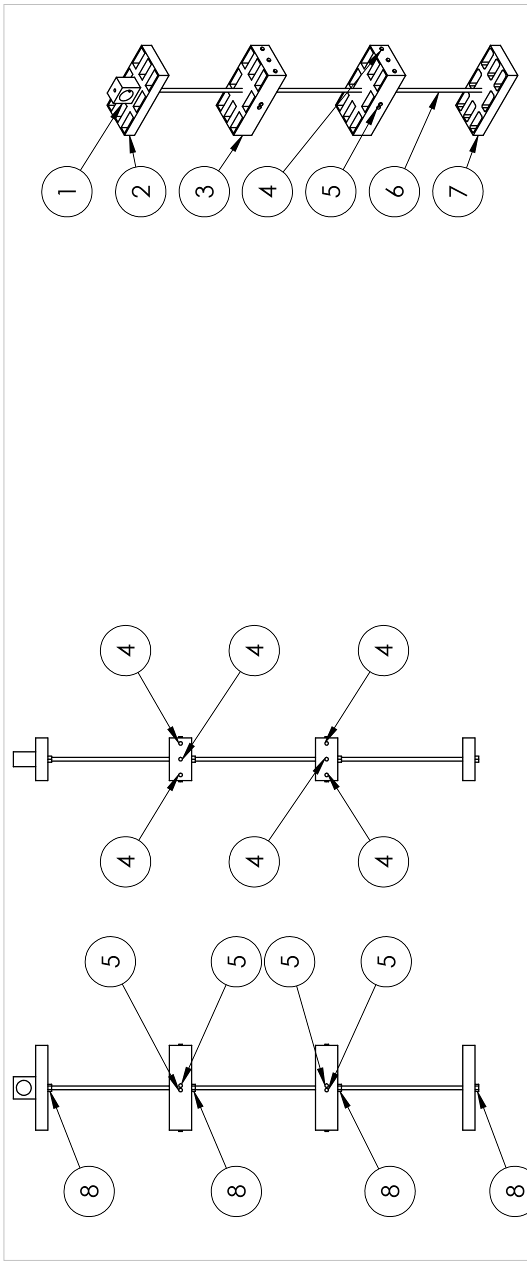


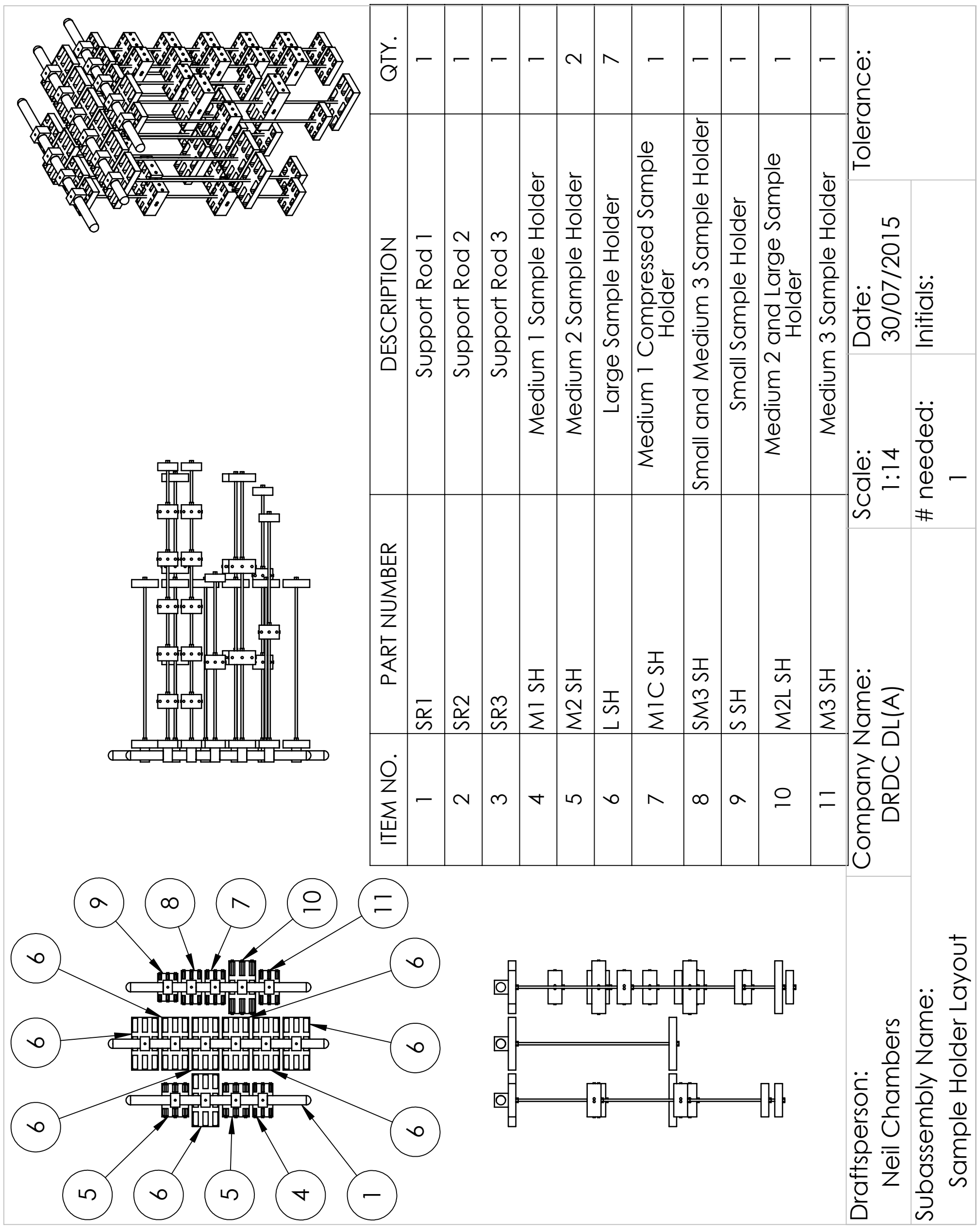
Figure A.5: *Large sample holder.*



ITEM NO.	PartNo	DESCRIPTION	Material	QTY.
1	HS	Standard Sample Holder Handle	Delrin	1
2	TL	Large Sample Holder Top	Delrin	1
3	ML	Large Sample Holder Midsection	Delrin	2
4	D18	1.8in Divider	Stainless Steel	12
5	D8	0.8in Divider	Stainless Steel	8
6	RM2	Medium 2 Sample Holder Rod (1/4"-20 Threaded)	Stainless Steel	1
7	BL	Large Sample Holder Bottom	Delrin	1
8	Nut	1/4"-20 Nut	Stainless Steel	4

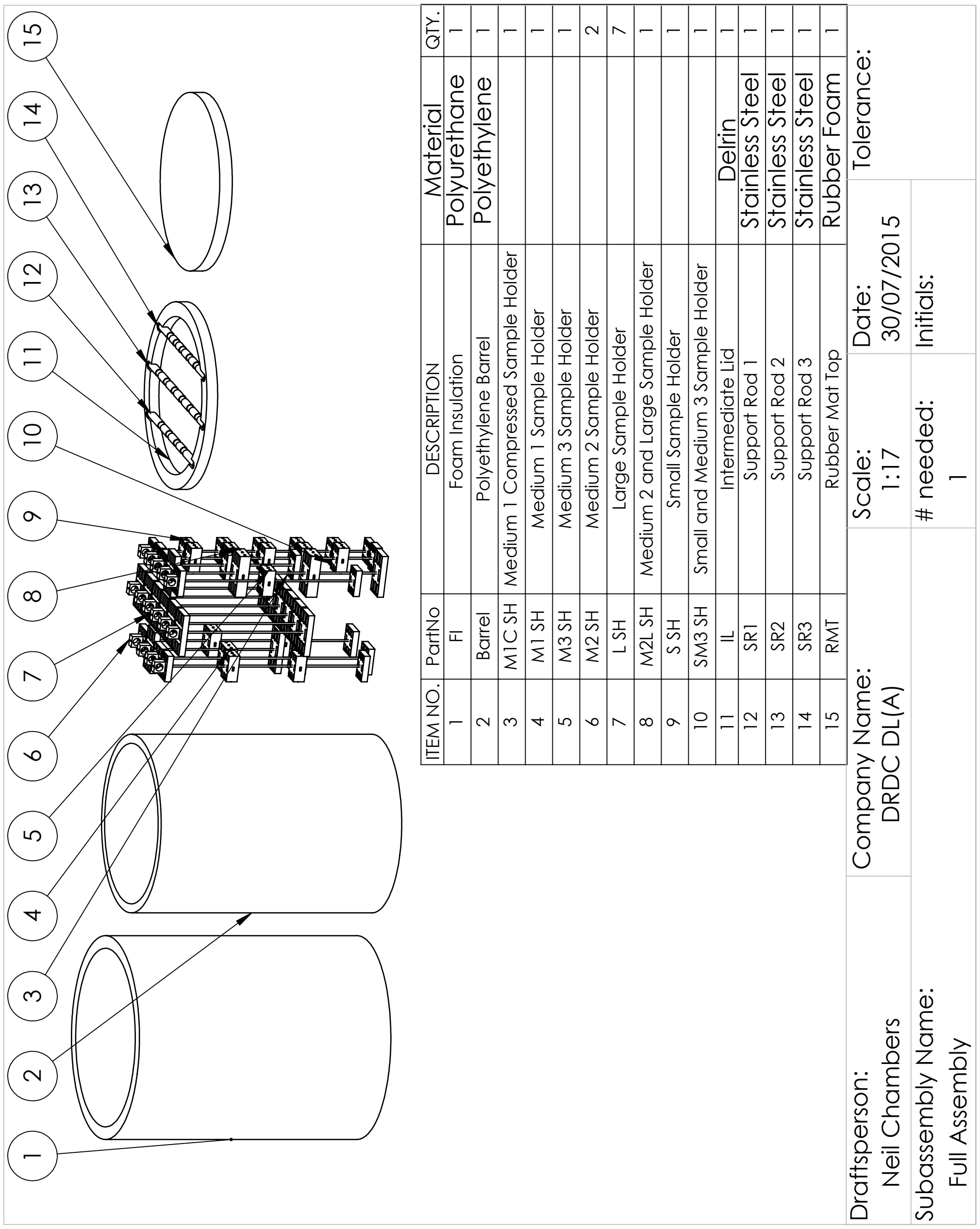
Draftsperson: Neil Chambers	Company Name: DRDC DL(A)	Scale: 1:9	Date: 29/07/2015	Tolerance:
Subassembly Name: Medium 2 and Large Sample Holder		# needed: 1	Initials:	

Figure A.6: *Medium 2 and large sample holder.*



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SR1	Support Rod 1	1
2	SR2	Support Rod 2	1
3	SR3	Support Rod 3	1
4	M1 SH	Medium 1 Sample Holder	1
5	M2 SH	Medium 2 Sample Holder	2
6	L SH	Large Sample Holder	7
7	M1C SH	Medium 1 Compressed Sample Holder	1
8	SM3 SH	Small and Medium 3 Sample Holder	1
9	S SH	Small Sample Holder	1
10	M2L SH	Medium 2 and Large Sample Holder	1
11	M3 SH	Medium 3 Sample Holder	1

Figure A.7: *Sample holder layout.*



ITEM NO.	PartNo	DESCRIPTION	Material	QTY.
1	FI	Foam Insulation	Polyurethane	1
2	Barrel	Polyethylene Barrel	Polyethylene	1
3	M1C SH	Medium 1 Compressed Sample Holder		1
4	M1 SH	Medium 1 Sample Holder		1
5	M3 SH	Medium 3 Sample Holder		1
6	M2 SH	Medium 2 Sample Holder		2
7	L SH	Large Sample Holder		7
8	M2L SH	Medium 2 and Large Sample Holder		1
9	S SH	Small Sample Holder		1
10	SM3 SH	Small and Medium 3 Sample Holder		1
11	IL	Intermediate Lid	Delrin	1
12	SR1	Support Rod 1	Stainless Steel	1
13	SR2	Support Rod 2	Stainless Steel	1
14	SR3	Support Rod 3	Stainless Steel	1
15	RMT	Rubber Mat Top	Rubber Foam	1

Figure A.8: *Full assembly.*

Annex B: Four-point bend system draft sheets

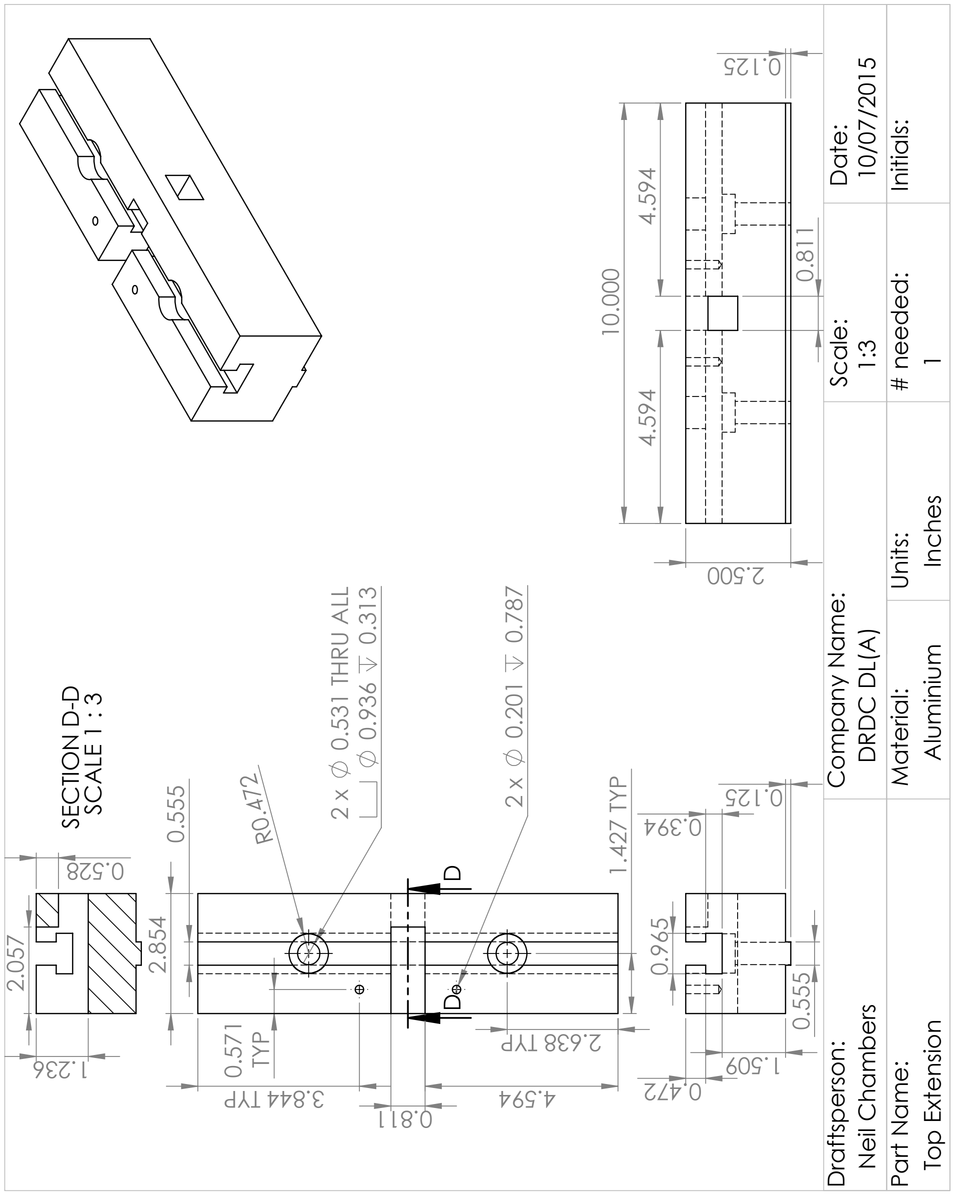


Figure B.1: *Top extension.*

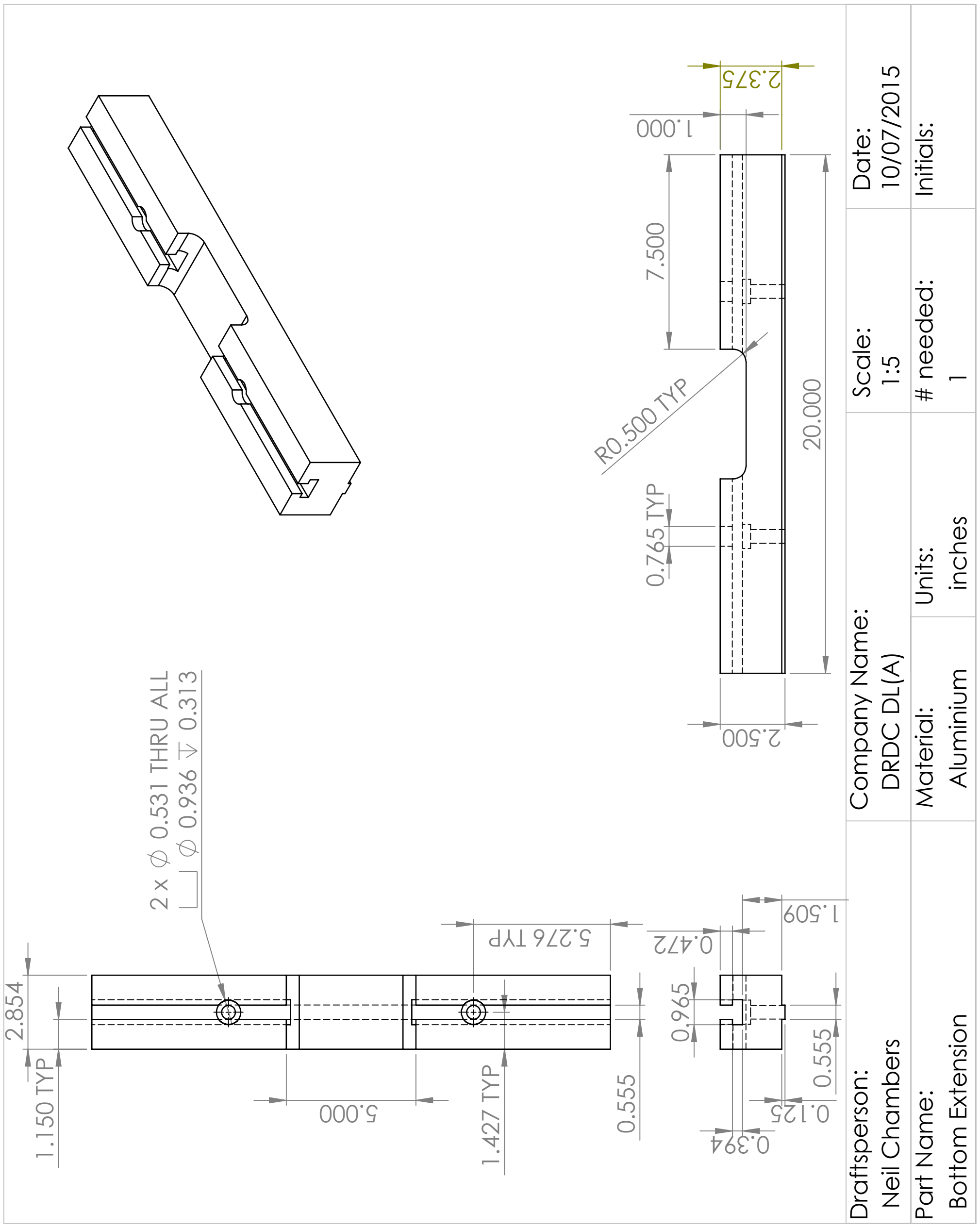


Figure B.2: *Bottom extension.*

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Composites have the potential to be lightweight, durable, corrosion- and cavitation-free materials. The technology has been incorporated successfully into aircraft and commercial sea vessels. The Cooperative Research Ships (CRS), Composite Propeller Working Group (COMPROP) is investigating the feasibility of using composites for marine propellers. One aspect of the work is to develop an understanding of how composites age when immersed in seawater for extended periods of time. Ageing can be examined with immersion in real-time, but this is not practical for material screening and selection purposes. One can accelerate ageing by elevating the temperature of the samples, using the principle of time-temperature superposition.

This work documents the design and manufacture of an environmental immersion chamber (EIC) for use in accelerated ageing experiments. The second part of this document reports the design and manufacture of extensions for a four-point bend jig that would allow testing of samples up to 455 mm long. The EIC was shown to maintain seawater at 60°C for 24 hours at a tolerance of ± 1°C. The four-point bend jig had sufficient capability for deflection for the longest composite samples that will be aged.

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polymer matrix composite; accelerated ageing; composite propeller