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Alternative Material Selection for Oyster Restoration with an Emphasis on Living Docks

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Alternative Material Selection for Oyster Restoration with an Emphasis on Living Docks

by

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Abstract

Title: Alternative Material Selection for Oyster Restoration with an Emphasis on Living Docks

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Oyster restoration efforts, including Living Shoreline and Living Dock projects, utilize aquaculture-grade plastic oyster mats to mitigate the decline of benthic communities. Aquaculture-grade plastic are known for strength, durability, and resilience to degradation in seawater. Over time, plastics break into microscopic segments commonly referred to as microplastics. Microplastics represent a major concern as marine organisms mistake the small particles for food. Plastics bioaccumulate in marine species, which impacts the marine food web and humans. In order to reduce further negative anthropogenic impacts, natural fibers and nature-inspired concrete mixtures were utilized across a series of experiments in order to determine an appropriate alternative material to replace plastic in Living Dock projects. In Phase 1, coconut coir, jute, resin-coated basalt, and uncoated basalt replaced plastic oyster mats. Preliminary results revealed coconut and burlap materials are desirable for Living Dock projects and marine organism settlement, however the basalt material lacked the strength properties conducive for this usage. For Phase 2, coconut coir, two strengths of jute, and cement-coated basalt were tested. Assessment resulted in coconut coir as the recommended natural fiber for replacement in Living Docks. Phase 3 assessed the feasibility of concrete-coated natural fiber mats as an alternative. Compression strength, flexural strength, and community settlement resulted in concrete coated coconut coir being the recommended material from Phase 3. While continued research is recommended, from results across the three phases of this study, coconut coir – with or without concrete – was the most suitable replacement for plastic in the Living Dock application.

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List of Variables

b	Average width of specimen at fracture (mm)
d	Average depth of specimen at fracture (mm)
D	Average measured diameter (mm)
f_{cm}	Compressive strength (MPa)
f_c'	Specified compressive strength (psi)
f_r	Modulus of rupture (psi)
L	Average measured length (mm)
P	Maximum applied load (N)
P_{max}	Maximum load (kN)

Chapter 1
Introduction

The Indian River Lagoon

Overview

The Indian River Lagoon (IRL) is not only a biologically diverse community, but a center for tourism, local economy, and community involvement. The Indian River Lagoon, Figure 1, is an intercostal waterway which spans roughly 195 miles of central Florida (Smith, 1987, 1990; Weaver et al., 2017). The lagoon is relatively narrow, 2-4 km in width, with depths around 1-3 m (Smith, 1990). Saltwater influx comes from a five widely spaced inlets, which classifies the IRL as a restricted lagoon (Kjerfve, 1986; Smith, 1990). The tidal cycle in the IRL is typically less than 10 cm, however this can increase greatly near a tidal inlet (Smith, 1987; Steward & Green, 2007).

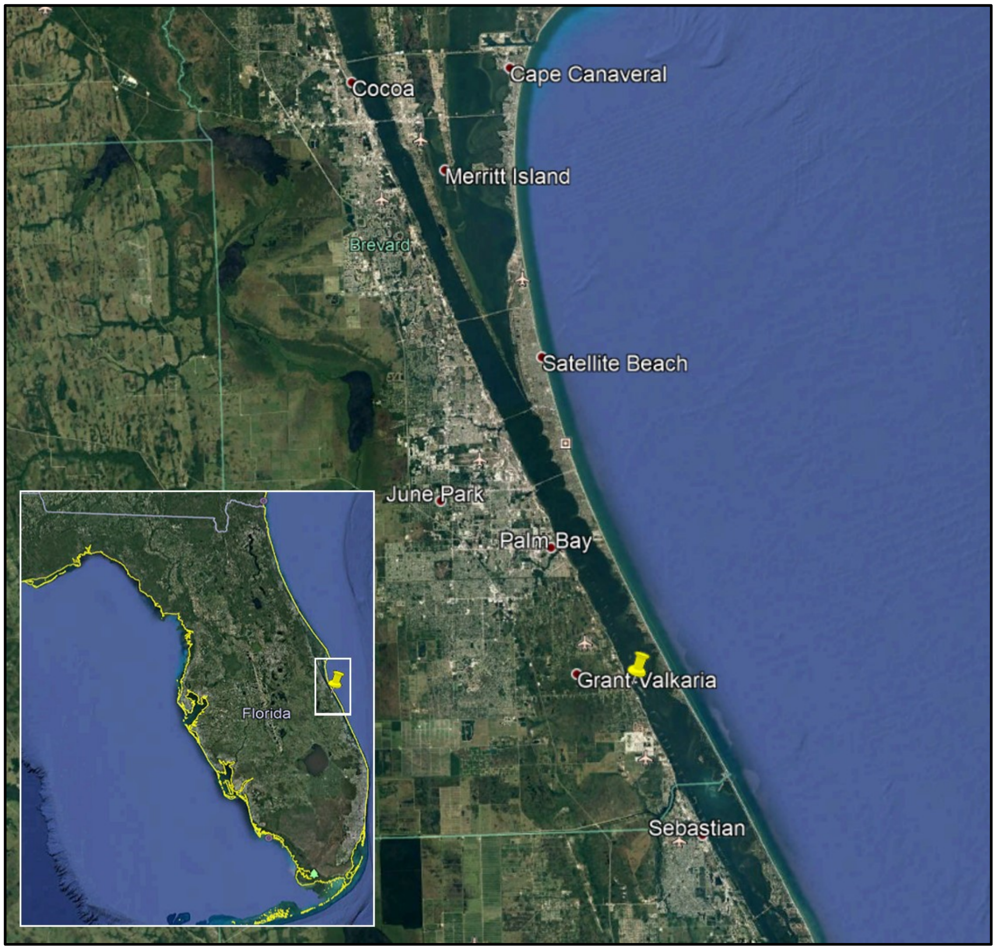

Figure 1: Indian River Lagoon and Grant, FL test site (27.93^{o}N, 80.53^{o}W). This 84 km span of the IRL represents the southern portion of the northern IRL and the central IRL. The yellow pin indicates the location of the Grant, FL test platform.

Restricted lagoons are characterized by a low tidal range, low/medium wave energy, and are connected to the ocean by two or more channels which remain open continuously (Kjerfve, 1986). Due to these characteristics, restricted estuaries are less likely to undergo extreme tidal, salinity, and temperature fluctuations due to the water column being well-mixed (Kjerfve, 1986). Restricted lagoons are, however, susceptible to changes in water quality.

Water Quality Decline

Recently, water quality in the Indian River Lagoon has seen a rapid decline, resulting in increased community attention. Water quality is impacted by both anthropogenic and environmental means. Anthropogenic influences include stormwater runoff, pollution, waste water discharge, and fertilizers which modify the natural nutrient levels in the IRL (Howarth & Marino, 2006; Tetra Tech Inc. & CloseWaters LLC., 2019; Trefry, Fox, Trocine, Fox, & Voelker, 2017). On the environmental side, increased water temperatures and heavy seasonal rainfall can greatly influence the planktonic population in the lagoon (Phlips et al., 2015). Both of these factors can create conditions for harmful algal blooms (HABs), muck, and loss of marine plants and organisms (Tetra Tech Inc. & CloseWaters LLC., 2019).

Legislative Response

With the passage of the Clean Water Act in 1972, the water quality of the Indian River Lagoon was brought to the forefront for the community (EPA, 2012; St. Johns River Water Management District, Program, & Indian River Lagoon National Estuary, 2007). Nineteen seventy-two brought the passing of the Water Resources Act which created regional water management districts, and the Coastal Zone Management Act, which managed coastal development (St. Johns River Water Management District et al., 2007). In 1990 the Indian River Lagoon was nominated for the National Estuary Program and subsequently included in 1991 (St. Johns River Water Management District et al., 2007). With the creation of the Indian River Lagoon Program, the health and resiliency of the Indian River became a priority for the state.

Established in 2016, the Save Our IRL Plan (SOIRLP) was implemented by Brevard County Department of Natural Resources to expedite the recovery of the lagoon (Tetra Tech Inc. & CloseWaters LLC., 2016, 2019; Weaver et al., 2018). Brevard county implemented a sales tax increase which allocated half a cent of every dollar spent in the county to the restoration of the lagoon (Tetra Tech Inc. & CloseWaters LLC., 2016, 2019; Weaver et al., 2018). The SOIRLP intends to improve the lagoon by focusing on preventative maintenance on anthropogenic influences as well as restoring shorelines for organism and seagrass habitat. Over 10 years, the SOIRLP will educate the public, upgrade sewer plants, convert septic to sewer, address stormwater outfall, address muck by dredging and interstitial treatment, and restore oysters and seagrasses through planted shorelines (Tetra Tech Inc. & CloseWaters LLC., 2019).

Harmful Algal Blooms

Harmful algal blooms (HABs), sometimes referred to as red, green, or brown tides, are a result of increased phytoplankton blooms in coastal waters (Phlips et al., 2015; Tetra Tech Inc. & CloseWaters LLC., 2019). Harmful algal blooms are influenced by many factors. Strong changes in climate or unusually harsh seasons influence different phytoplankton species survival (Phlips et al., 2015). Eutrophication is the other main influence in phytoplankton blooms – nutrient excess or limitation will also result in an excess of one type of phytoplankton and can therefore lead to blooms (Phlips et al., 2015; Steward & Green, 2007; Trefry et al., 2017).

One recent example of a HAB in the IRL is the 2011 “green tide” and 2012 brown tides, which greatly impacted seagrass coverage in the lagoon (Tetra Tech Inc. & CloseWaters LLC., 2019). Recurring brown tides in the IRL and across Florida waterways have become prominent in recent years and often result in large fish kills due to low dissolved oxygen content in the waterways (Tetra Tech Inc. & CloseWaters LLC., 2019). As the algae begins to decay, it becomes a decomposing suspended solid, influencing muck levels in the IRL.

Muck

Muck has become a source of competition for all living aspects of the lagoon. Muck is fine-grained sediment characterized by having high organic nutrients and high water content (Florida Sea Grant, n.d.; Trefry et al., 2017; Trefry, Johnson, Shenker, & Zarillo, 2016; Trefry et al., 1990). An estimated 6,700 acres of the lagoon bottom suffer from muck deposition (Tetra Tech Inc. & CloseWaters LLC., 2019). Due to the fine grained nature of the sediment it is easily stirred into the water column, which limits light availability, decreases photosynthetic growth, releases nutrients, and covers the natural substrate of the lagoon (Tetra Tech Inc. & CloseWaters LLC., 2019).

Muck poses a threat to communities which rely on the natural physiology of the lagoon: a sandy substrate, steady nutrient cycles, and clear water. The loss of a sandy substrate has resulted in detrimental effects to sea grasses and benthic communities (Trefry et al., 1990). With muck levels reaching 1m thick in some areas of the central IRL, benthic communities and sea grasses are at high risk for habitat loss (Trefry et al., 1990). Regions most greatly affected by muck are those near tributary sources such as Turkey Creek or Crane Creek in Melbourne, FL (Trefry et al., 1990).

Oyster Restoration in the Indian River Lagoon

With the Save Our IRL Plan (SOIRLP) in place, there have been numerous proposals for oyster restoration in the Indian River Lagoon. In Brevard county, 20 miles of shoreline has been recommended for restoration in the IRL (Tetra Tech Inc. & CloseWaters LLC., 2016). According to the 2019 Save our Lagoon Project Plan, this restoration effort would likely cost $10 million and result in a reduction of over 21,000 pound/foot/year of total nitrogen and over 7,000 pound/foot/year total phosphorus loading (Tetra Tech Inc. & CloseWaters LLC., 2016).

Many coastal efforts have been to combine community restoration with shoreline stabilization in the form of "living shoreline" projects. A living shoreline is the method in which vegetation is utilized either alone, or as part of a structure, to stabilize shorelines along estuaries, bays, and other coastal environments (Bulleri, Chapman, Bulleri, & Chapman, 2016; Florida Sea Grant, University of Florida, & Brevard County Natural Resources Management Department, n.d.; NOAA, 2019; Tetra Tech Inc. & CloseWaters LLC., 2019; Weaver et al., 2017). Many of these living shoreline projects focus on the restoration of seagrasses and the natural shore face of the lagoon, with oyster community growth being a secondary goal. Oyster restoration as a primary goal is often to reduce the total nitrogen and total phosphorous loading in the water body.

Microplastics in the Indian River Lagoon

In recent years, microplastic levels have become a topic of concern as they greatly effect filter feeders such as benthic organisms (Sussarellu et al., 2016). Microplastic particles (MP) are any plastic particles (i.e. beads or fragments) that are smaller than 5mm (Arthur, Baker, & Bamford, 2009; Li, Yang, Li, Jabeen, & Shi, 2015; Sussarellu et al., 2016; Waite, Donnelly, & Walters, 2018). In the northern region of the Indian River Lagoon, Mosquito Lagoon has increased levels of MP as compared to global estuary studies (Desforges, Galbraith, Dangerfield, & Ross, 2014; Waite et al., 2018; Zhao, Zhu, Wang, & Li, 2014) with an average of 21.4 ± 13.1 MP pieces per liter (Waite et al., 2018).

The main concern behind MP on benthic organisms is that MP can accumulate in organisms and effect higher trophic levels, even humans (Farrell & Nelson, 2013; Li et al., 2015; Watts et al., 2014). While oysters are known to feed on MP, they are also know to pass MP particles; therefore, do not bioaccumulate MP in the gut (Sussarellu et al., 2016).

For the Living Dock application a high-density polyethylene (HDPE) is used as it is resistant to biodegradation in aquatic and marine environments (Lusher, Hollman, & Mandoza-Hill, 2017; Sudhakar, Priyadarshini, Doble, Sriyutha Murthy, & Venkatesan, 2007). HDPE does show signs of degradation in high temperature (over 100 C) and high oxygen environments (Sudhakar et al., 2007), however coastal waterways do not come near these temperatures. There is a chance for biological growth to cause degradation of HDPE by creating grooves and scratches (Sudhakar et al., 2007), however in aquaculture uses, this is usually from the removal of biofouling organisms (Lusher et al., 2017) which is not the purpose of the Living Docks application.

Chapter 2
Background

Living Dock Projects

A "living dock" is similar in nature to a living shoreline aside from one major difference: instead of implementing a structure along the shore of a body of water, the new substrate is affixed to the piles of a dock (Weaver et al., 2018). Living docks aim to improve local water quality by promoting the growth of filter feeding benthic organisms.

Figure 2: Living Dock oyster mats prior to deployment.

The living dock design utilizes aquaculture grade plastic mesh and oyster shells to create a more hospitable substrate for benthic settlement (Figure 2). The standard mats are roughly 60 cm in width and 60 cm in height with 50-80 oyster shells affixed. Shells are affixed using UV-resistant zip ties and the mats are attached to the dock piles using the same zip ties. It is important to note that the shells used for restoration are dead and dried. The oyster shells are acquired through the Marine Discovery Center Program “Shuck and Share” in which local restaurants dispose of their shellfish waste in special bins so that the shells can be collected reused for restoration instead of being taken to a landfill (Marine Discovery Center, n.d.). Once collected, the shells are then left in the sun to dry out and kill any remaining living organisms. The Shuck and Share program has been a key factor behind the increase in community-based restoration projects along the IRL, whether through Living Docks, oyster bed restoration, living shorelines, or oyster gardening programs through the Brevard Zoo and University of Central Florida (Brevard Zoo, n.d.; Marine Discovery Center, n.d.).

Benthic Restoration Design Criteria

Aside from the biological goals of the living dock project, there are certain constraints the design needs to meet: 1) keep mats out of the muck, 2) no-permitting necessary implementation, 3) near surface for optimal conditions, and 4) minimal-to-no maintenance.

The purpose of the design criteria is to create an environment for restoration success and improve efficiency of deployment. Oyster settlement in a native environment is traditionally on the bottom substrate of the estuary. As previously discussed, much of the central Indian River Lagoon has a layer of muck covering the natural sandy bottom. Significant burial of the oyster (over 70%) results in an increased mortality rate, and with burial over 108% guaranteeing mortality (Colden & Lipcius, 2015). Due to the concerns of high mortality, it is crucial that oyster restoration efforts remain out of the influence of this muck layer. Instead of placing the oyster mats on the bottom of the lagoon, these mats are wrapped around dock piles. By wrapping the mats around the dock piles, the mats are not affected by the muck on the bottom of the lagoon.

Another benefit to utilizing a current permanent structure is that these projects do not require permitting. Permitting can cause projects to have significant delays and may reduce the ability to incorporate community efforts in the creation and deployment of the mats. In order to construct anything in the wetlands or deep water habitats of the Indian River Lagoon, a wetlands/deep water habitat alteration permit must be issued by the county environmental planning staff (Indian River County FL, 2020). Living dock projects are also ideal in areas where seagrass restoration and living shoreline projects are ongoing as they do not compete for substrate space (Tetra Tech Inc. & CloseWaters LLC., 2016).

The current design is a set-and-forget style where maintenance is not required. Living Docks are designed to promote organism recruitment, so regular cleaning would result in a loss of organisms. Any maintenance done on these mats is in the event of breakage – most likely due to a storm. In the event a mat should fall off, once recovered, it can be reattached to the piles and continue to be beneficial.

Benthic Recruitment

Previous studies on living dock projects show that this design is capable of introducing a more diverse population of benthic organisms. Traditionally, dock pile communities consist of ivory barnacles as they are capable of attaching to the heavily treated wood. By introducing a more hospitable substrate, more organisms are able to settle and build an ecosystem.

Figure 3: An example of an oyster shell which has developed a healthy benthic community, consisting of oysters, barnacles, tubeworms, green algae, encrusting bryozoan, and sponges

Figure 3 illustrates an oyster shell three months after deployment into the Indian River Lagoon. On this shell there are not only oysters, but barnacles, tube worms, bryozoans, and sponges. Despite many restoration efforts aiming to only recruit oysters, the recruitment of these other benthic organisms is still beneficial.

Adult oysters are known as being the heavy hitters of the filtrating organisms as they can filter 20 to 50 gallons of water per day (Fulford, Breitburg, Newell, Kemp, & Luckenbach, 2007; Galimany et al., 2017; Newell & Koch, 2004; Riisgård, 1988; Weaver et al., 2018). Encrusting bryozoans, which are a colonial organism, are capable of filtering large volumes of water in relation to their body size. A colony of 2,000,000 individuals can reach up to 1.6 feet in length and can filter roughly 2,500 gallons of water per day (Bullivant, 1967, 1968; Weaver et al., 2018; Winston, 1995). It is therefore important to note that regardless of the benthic community composition, water filtration and localized water quality improvements are occurring.

Chapter 3
Purpose

Research Problem

One of the most common questions asked by the community members during a Living Dock project is why plastic is the material of choice. The purpose of this study is to address this community question by identifying an alternative material to recommend for the current Indian River Lagoon Research Institute Living Dock design.

Research Questions

The methodology of this study was, in some ways, testing and modification. The problem was addressed in a step wise approach, where completion of each step provided guidance and allowed modifications for subsequent steps. The following three questions guided the assessment:

1. Can the alternative materials withstand submersion in the testing environment?
2. Can the natural fibers succeed in the Living Dock application?
3. Can concrete coated natural fibers succeed in the living dock application?

Through each study, materials will be eliminated or recommended based on their ability to perform in the Living Dock environment. Materials which successfully withstand constant submersion in the Indian River Lagoon during Phase 1 were further assessed in Phase 2. Phase 2 assessed the successful materials from Phase 1 and any modified options in a scale Living Dock deployment. Phase 3 assessed the feasibility of using concrete as an option in the Living Dock application.

Experimental Setup

Testing Location

Each study was completed at the Florida Institute of Technology floating research platform (Figure 4) located in Grant, Florida (27.93ºN, 80.53ºW).

Figure 4: Florida Institute of Technology floating research platform located in Grant, FL

This platform location is ideal due to its proximity to Sebastian Inlet. Located roughly 7.75 miles from the inlet, this region still has a small tidal range of roughly 10 cm (Smith, 1987) and stable polyhaline salinities of 20-35% (R. G. Gilmore, 1977; R Grant Gilmore, 1995; Wilcox & Gilmore, 1976). Oceanic tidal influences at this station are minimal as the tidal prism for Sebastian is estimated at 1.5 x $10^7 m^3$(Smith, 1987). The platform was moved to a different location in the IRL for the final 13 days of deployment. The new location was situated near the mouth of Crane Creek (28° 4'36.74"N, 80°36'1.85"W), which has slightly different water quality conditions. Due to the freshwater inflow from Crane Creek and Turkey Creek, this testing location has lower salinities, around 19 ppt, and higher nutrient levels.

Assessment of Organism Recruitment

For each phase of this project, organism recruitment was recorded visually using ASTM standard D6990 (ASTM, 2011). The purpose of this assessment was to determine if there were significant differences in recruitment for each material. This analysis was completed manually by comparing organisms to a list of common benthic organisms found in the Indian River lagoon and seen at the test site (Table 1). By analyzing benthic settlement, overarching trends of common benthic organisms found determined potential settlement preference.

Table 1: List of common biofouling organisms along with common species in the Indian River Lagoon and Port Canaveral, FL. Modified from (Lieberman, 2016).

Fouling Type	Definition	Common Species
Incipient fouling	Recently settled and juvenile forms of macrofouling	N/A
Silt	Adsorbed organic and inorganic chemicals, trapped silt and detritus, and unidentified slimes	N/A
Biofilm	Diatoms, initial algae germination, and low form algae, bacterial growth	N/A
Algae	Fully established alga types and larger forms	*Ulva lactuca*
Hydrozoan	Low form, highly branching organisms	*Obelia bidentate*
Encrusting Bryozoans	Colonial animals forming an encrusting layer over the surface; these layers are generally 1-2 mm thick and have rough texture	*Cryptosula pallasiana*
Arborescent Bryozoans	Colonial animals forming a turf like mat rarely exceeding 3 cm in length; they may be mistaken for plants	*Bugula neritina*
Barnacles	A hard-shelled crustacean that cements itself permanently to a substrate and is difficult to remove; the outer shell is generally whitish in color and shaped like a truncated cone. The barnacles in this area may grow to 2 cm in height and 2 cm in width at the base	*Amphibalanus eburneus*
Calcareous tubeworms	Tubeworms that form a hard calcareous exoskeleton which becomes cemented to the substrate; the individuals rarely exceed 2 cm in length and may show some coiling	*Hydroides dianthus*
Molluscs	Animals with two hard shells, hinged along one edge; typical examples are oysters and mussels	*Anomia simplex*
Sponges	Soft animals with sponge like texture forming thin surface cover or thicker accumulations, often brightly colored	*Hymeniacidon heliophila*
Tunicates	Soft animals that may be solitary or colonial; solitary types may reach several centimeters in height and colonial forms tend to form a think cover over the surface	*Styela plicata*
Sea Anemones	Soft animals, with a solitary tube-like body and a ring of stinging tentacles around the oral opening.	*Aiptasia pallida*

Chapter 4
Phase 1: Pilot Study

Methodology

Preliminary material testing began with the identification of biodegradable or natural materials. The base criteria for material selection was non-plastic, non-metal materials. The selection of materials was also limited based on availability, affordability, and design of material.

Natural fiber selection is limited by cost, availability, and longevity of material. In order to improve upon the current oyster mat design, the natural fiber selected needed to match some of the properties of the plastic as well as be environmentally neutral in impact. The materials selected were chosen first based on availability as natural fibers in a loosely woven mesh are not as common as chopped strand mat. The materials were chosen second on longevity; the materials needed to withstand months of submersion while the benthic communities grow to fully encrust the material. Cost was not a deciding factor for the preliminary testing as much of the material was available from previous studies.

Coconut coir is a natural fiber material commonly used for agricultural purposes. Often used as erosion protection in construction of living shorelines, coconut coir matting is rolled into logs and stuffed with more coconut fiber to create a barrier around stabilization structures or oyster bag reefs (Kreeger, Cole, Bushek, Kraeuter, & Adkins, 2011; National Oceanic and Atmospheric Administration, 2015; Samonte, Edwards, Royster, Ramenzoni, & Morlock, 2017; Zabin, Attoe, Grosholz, & Coleman-Hulbert, 2010). The coconut coir used in this study is a small section remaining from a large agricultural roll from a prior study. The burlap bag material is also repurposed from a prior research study. The burlap bags were recycled industrial coffee bags. The burlap ribbon is from a fabric store for crafting. The basalt materials are from a basalt matting manufacturer (basalt-fiber.com).

Mat Construction

Based on the initial criteria, four materials were selected: resin-coated basalt, coconut coir, uncoated basalt, and burlap ribbon (Figure 5). The edges of each material were folded or braided and then dipped in beeswax to minimize fraying. Beeswax was selected as it does not break down in water and it is a natural material.

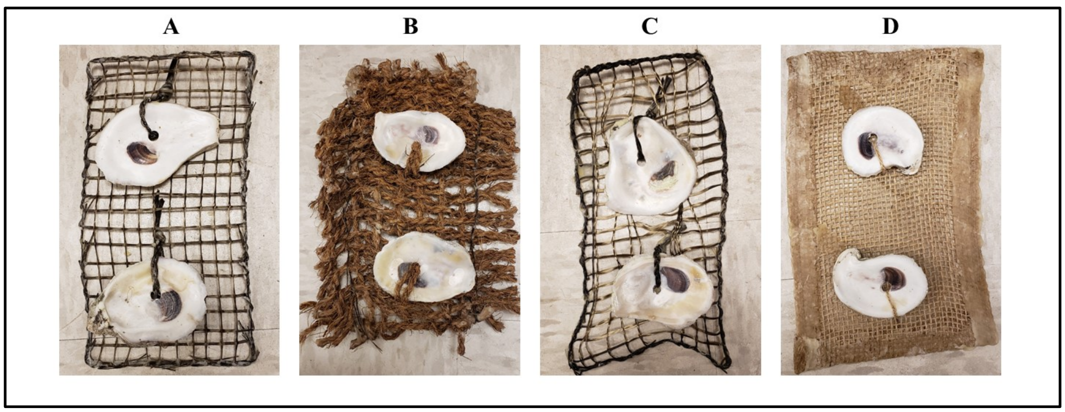

Figure 5: Phase 1 Mats - resin-coated basalt (A), coconut coir (B), uncoated basalt (C), and burlap ribbon (D) – each with two dead oyster shells affixed using the mat material

For replicability in each sample, four mats of each material were tested. Each mat was roughly 10 cm wide and 20 cm long and had two oyster shells affixed (Figure 6). The shells were affixed using the same mat material. Only two shells were attached to ensure that benthic settlement was due to material preference, not shell density. Each mat was zip-tied to the PVC frame to eliminate a source of premature failure. The frames were immersed at the Grant, Florida test location from March 2019 to May 2019 and were assessed weekly.

Figure 6: Phase 1 Test Apparatus – two mats of each material are affixed to the PVC frame. From left to right: uncoated basalt, resin-coated basalt, coconut coir, burlap ribbon, uncoated basalt, coconut coir, resin-coated basalt, and burlap ribbon.

Results

Material Assessment

The resin-coated mats failed within the first two weeks of deployment. Failure was either from a loss of shells or mat detachment from frame. In Figure 7, it can be seen that only three of the four replicates deployed were still affixed to the frame. For the coated basalt mats, replicate A had lost one of two shells and replicate B had lost both shells and was only attached on one end to the frame. Replicate C had also lost both shells and replicate D was no longer affixed to the frame and therefore cannot be assessed.

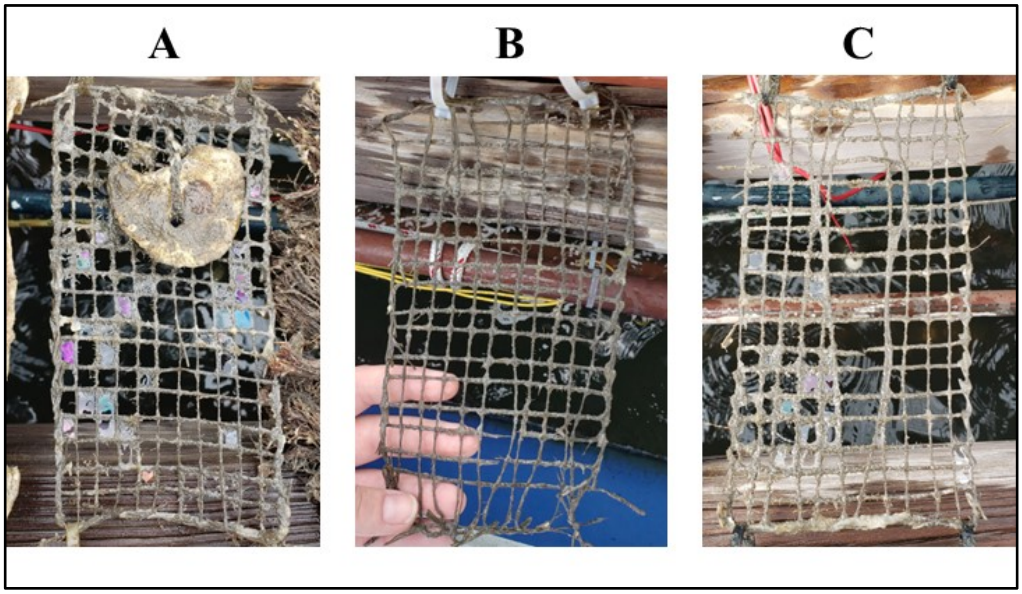

Figure 7: Resin-coated basalt mats at two-week assessment - Replicate A is missing one of two shells, Replicate B is missing both shells and top attachment points, Replicate C is missing both shells, and the Replicate D was no longer affixed to the frame.

The uncoated basalt also failed within the first two weeks of deployment. As seen in Figure 8, only three of the four replicates were still affixed to their frame. For the uncoated basalt, replicate A is no longer attached on the right side and has one shell remaining, replicate D is no longer affixed to the frame and therefore cannot be assessed, replicate B is affixed at one corner and has both shells, however both shells have fallen to the bottom section of the mat, and replicate C is affixed in 3 corners but has lost both shells.

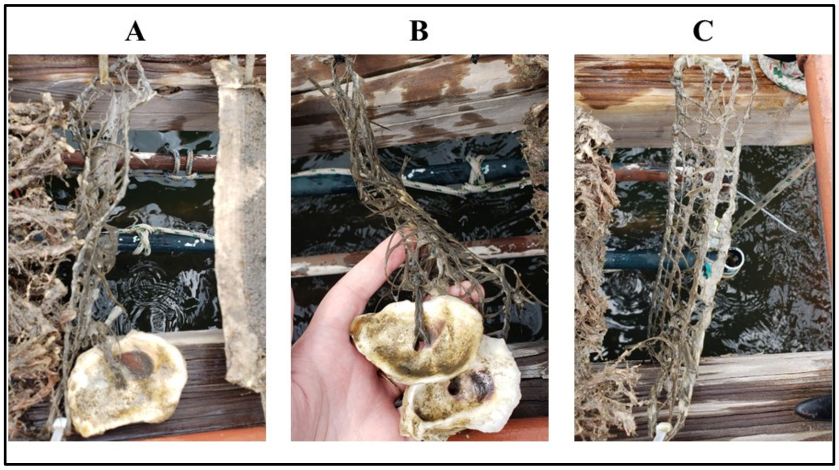

Figure 8: Uncoated basalt mats at two-week assessment - Replicate A is missing one shell and is affixed in one corner, replicate D is missing, replicate B is affixed in one corner and has both shells, and replicate 4 is affixed in C corners and lost both shells.

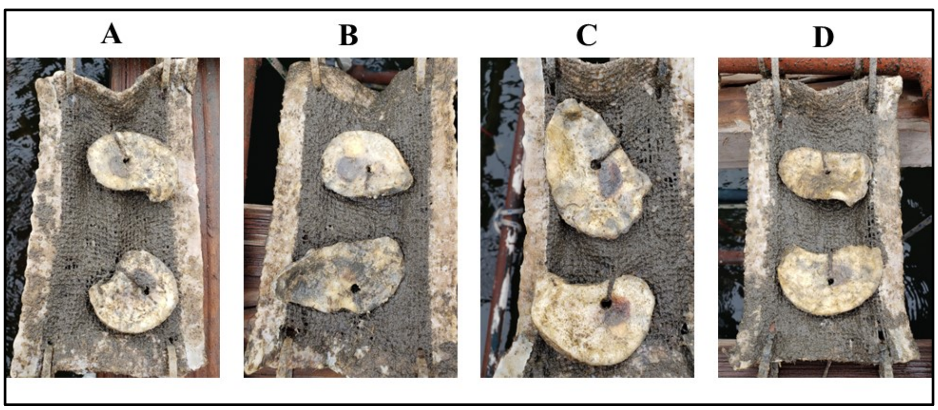

Figure 9: Burlap ribbon at one-month assessment - All four replicates are fully attached to their frames and have both shells still securely affixed. Minor wear can be seen in corners where the zip-ties are located.

As seen in the figure 9, the burlap mats were able to withstand submersion for the full month of testing with only minor wear in the corners at the zip ties. The mat material shows signs of sedimentation accumulation within the weave.

The coconut coir mats (Figure 10) were also able to withstand submersion with no significant wear or degradation of the mat material and no shell loss. The only sign of deformation is on replicate C and replicate D at the zip tie attachment along the top where the top-most strand is bowed upward under the tension of the ties.

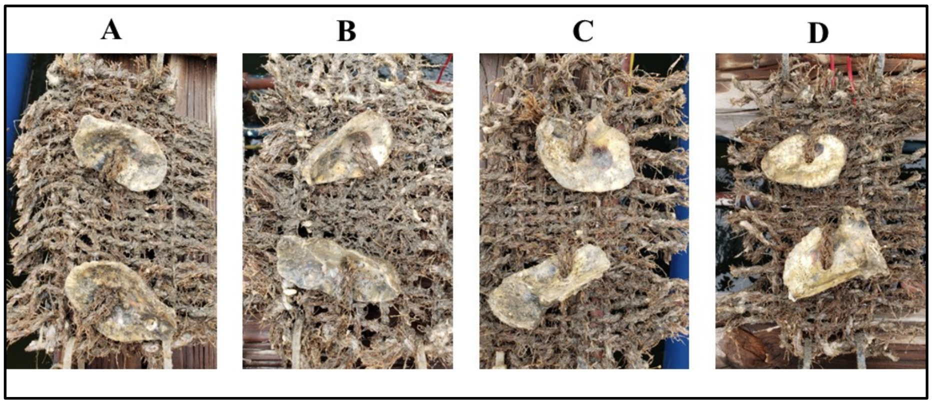

Figure 10: Coconut-coir at one-month assessment - All four replicates successfully withstood one month of submersion. There is minor wear on replicate C and D where the top strands have bowed at the zip-tie attachment point.

Summary

Phase 1: Pilot Study resulted in only half of the materials being acceptable in a submerged environment. The coated and un-coated basalt materials failed within the first two weeks of this study. The burlap ribbon and coconut-coir both successfully withstood the one-month submersion testing with minimal wear or degradation. From the results of Phase 1, the following materials were recommended for further testing: coconut coir and burlap. In order to make basalt a viable option for constant submersion, it needed to be coated in a strong material, such as concrete, to reduce breakage and wear of the fibers.

Chapter 5
Phase 2: Scaled Design Study

Purpose

Phase 2: scaled design study methodology incorporated the material selection from Phase 1 and the oyster mat design of the Living Dock application. The material selection was influenced from Phase 1 results and included the addition of concrete as a new material. Construction followed a 1:3 scaled design replicating the traditional Living Dock oyster restoration mats. Phase 2 tested the ability for the selected material to perform under the same conditions as a full-scale living dock oyster mat as well as benthic community recruitment for each material.

Methodology

Phase 2 introduced a second burlap material – recycled coffee bag. The coffee bag burlap was used in prior research projects, resulting in spare material. Coffee bag burlap and burlap ribbon have different weave characteristics; the burlap ribbon has fewer strands per inch as compared to the coffee bag burlap.

A third form of basalt was utilized for this study – basalt roving. Roving is a continuous strand comprised of a bundle of many smaller strands of basalt. The roving is not resin-coated and therefore can be manipulated similar to string. The concrete selection for Phase 2 was based on selecting a pre-mixed concrete that is similar in composition to the naturally occurring coquina rock found in Florida. The concrete mixture used in this application was a pre-mixed lime-based mortar mix.

This mixture was readily available in home-improvement stores and required only the addition of water.

Construction

The natural fiber mats were assembled to minimize fray by either knotting (coconut coir) or folding (burlap) the edges and then dipping in beeswax. Each sample, excluding the concrete-coated basalt had 10 dead and dried oyster shells affixed; shells were attached using the same material as the mat. Shell number was scaled from the 50-80 shells found on the full sized Living Docks mats. For the cement-coated basalt, the roving was submerged in the cement mixture to ensure an even coating, then placed over half of a PVC pipe to mold it into a curved shape. The cement mixture was mixed according to the directions on the bag. Water was added as needed to keep mixture consistent.

Immersion

The testing apparatus was comprised of 24 PVC pipes which represented a 3:1 scale dock pile. Each test frame was immersed at the Grant test location from May 2019 to August 2019 with a visual assessment in June 2019. The 7.6-cm diameter pipes were coated in a copper antifouling paint to ensure community growth on the pile did not exceed the strength of the testing frame and to ensure growth on the pile exterior was strictly a result of material selection. Each pile had four holes drilled into the top and bottom to allow for installation onto the frames, and holes drilled through the center of each pile to ensure the mats would not slide down the smooth face of the pile. Each frame was equipped with one replicate of each material (Figure 11).

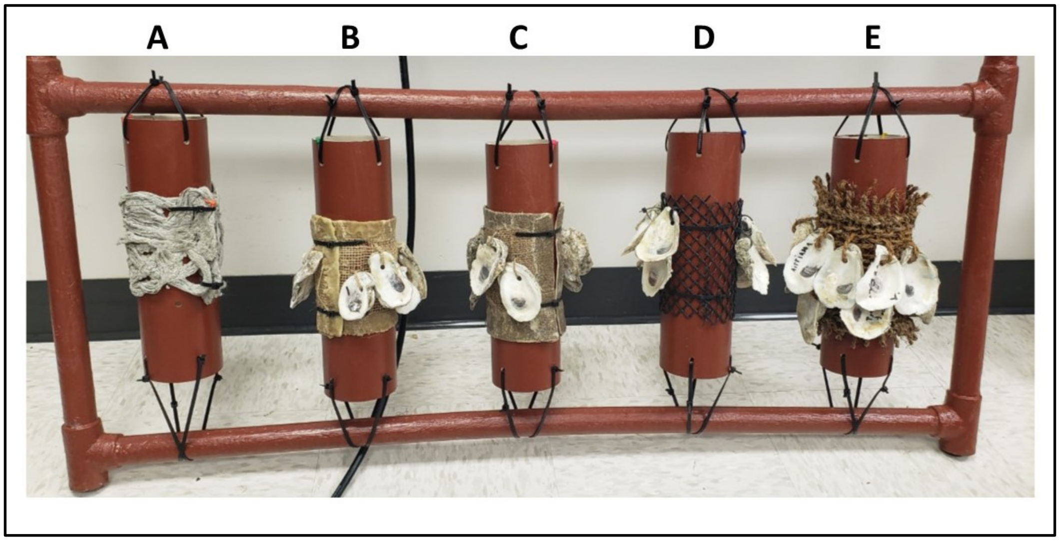

Figure 11: Scale Testing Apparatus – concrete-coated basalt (A), burlap ribbon (B), burlap bag (C), Aquaculture-grade plastic (D), coconut coir (E).

Results

Phase 2 replicates were assessed at one month (June 2019) and three months (August 2019). At the one month mark, the replicates were assessed visually for any indicators of success or failure as well as qualitative notes on organism settlement. At the three-month mark, the replicates were removed from the water for assessment per ASTM D6990 (ASTM, 2011). The material assessment includes the qualitative assessment of condition, rate of shell loss, and the change in weight from initial deployment.

One-Month Material Assessment

At the one-month mark it was clear that neither burlap materials were suitable for the Living Dock application. As seen in Figure 12 and Figure 13, the only part of the mat remaining for both materials was the beeswax dipped edges which were secured using zip-ties. Only one shell remained on the burlap coffee bag mat (rep. C) the remaining shells on either burlap material were no longer affixed.

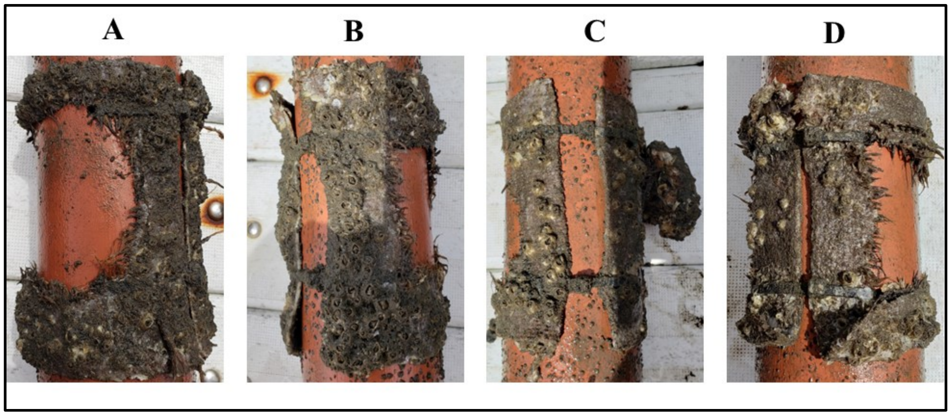

Figure 12: Burlap Coffee Bag at 1-month assessment – Replicate C with one shell remaining

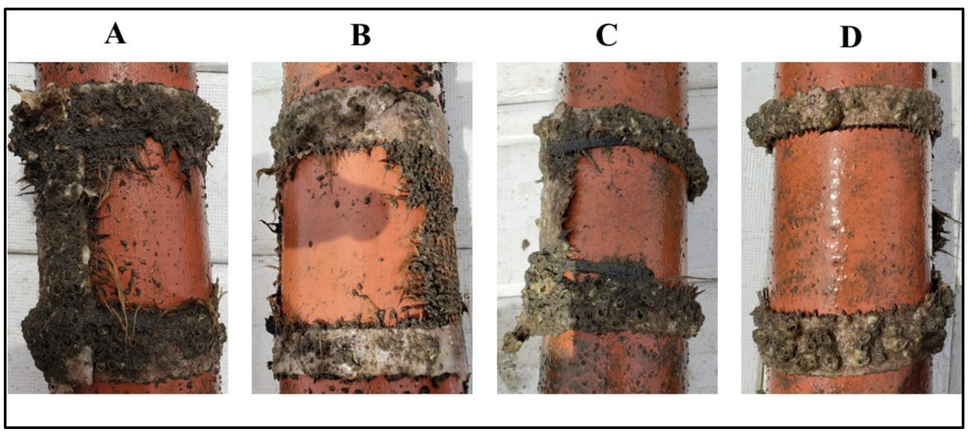

Figure 13: Burlap Ribbon at 1-month assessment– No replicates have shells remaining

The cement-coated basalt replicates were beginning to show signs of wear at the one month mark. The cement showed signs of peeling away from the basalt and abrasion wear from contact with other replicates or the side of the frame.

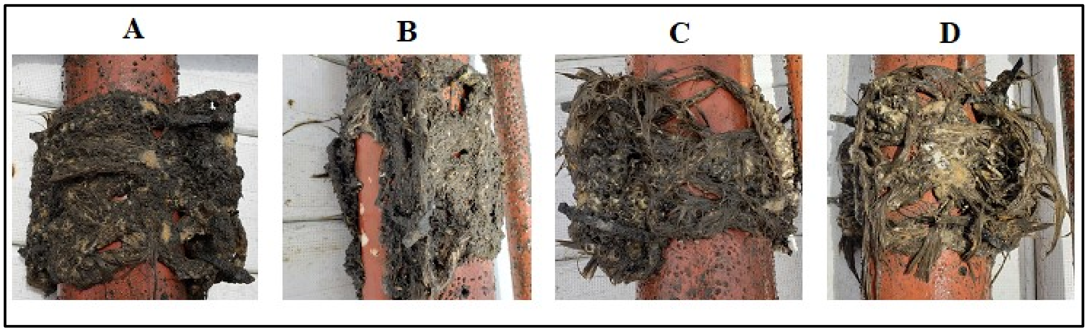

Figure 14: Concrete-Coated Basalt at 1-month assessment- Replicate B indicates wear due to abrasion, Replicates A, C, and D indicate cement failure

The coconut-coir at this stage was the most promising. There was minimal shell loss and minimal wear of the material. The main sign of wear was in the shell attachment.

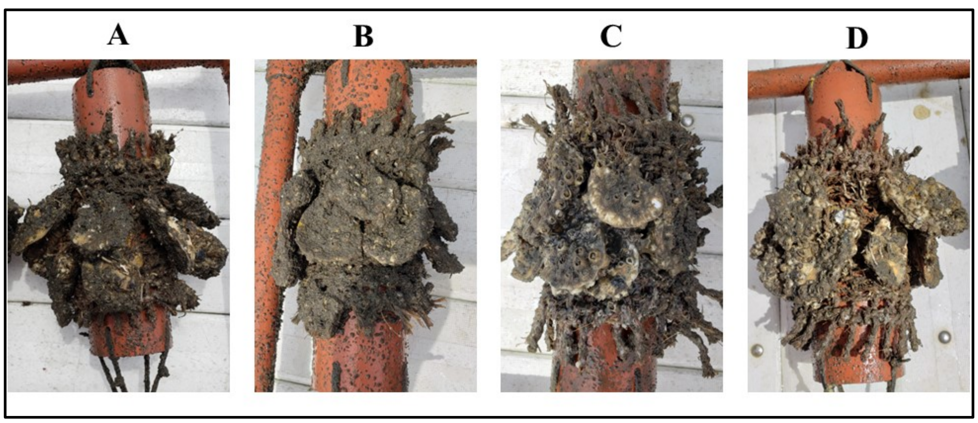

Figure 15: Coconut-coir at 1-month assessment

The plastic replicates at the one-month assessment were performing as expected. There was no apparent wear or material degradation.

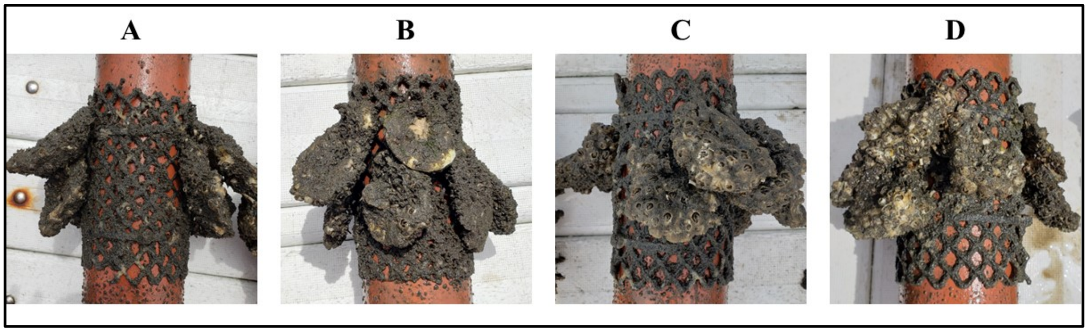

Figure 16: Plastic at 1-month assessment

One-Month Organism Settlement

As mentioned before, the organism settlement and percent coverage measurements were not assessed at this stage. Qualitative notes in reference to the organism settlement can be seen in Appendix A.

Three-Month Material Assessment

The replicates at the three month point were in similar condition as at the one-month assessment. The burlap replicates remained as only the outer edges. The cement coated basalt showed an increase in degradation. Many of the replicates had little to no cement coating remaining on the outer exposed portions and showed signs of increased wear in the fibers. The coconut coir and plastic replicates were in similar condition as at the one-month assessment.

As noted in the one-month assessment, both burlap materials exhibited extensive shell loss. At the three-month assessment, all eight burlap replicates were without shells. This coincides with a 100% loss in shells over a 3-month period. The coconut coir replicates exhibited a smaller shell loss rate at only 30%. This shell loss rate does include the three shells that were lost during the collection of replicates from the test platform. Plastic replicates performed as expected with only 3% shell loss which equates to a single shell lost during the testing period. The cement-coated basalt replicates were excluded as there were no shells affixed.

There was also a documented increase in total weight for the plastic and coconut coir reps. This is to be expected as the shells were heavily fouled. The change in weight can be seen in Figure 17.

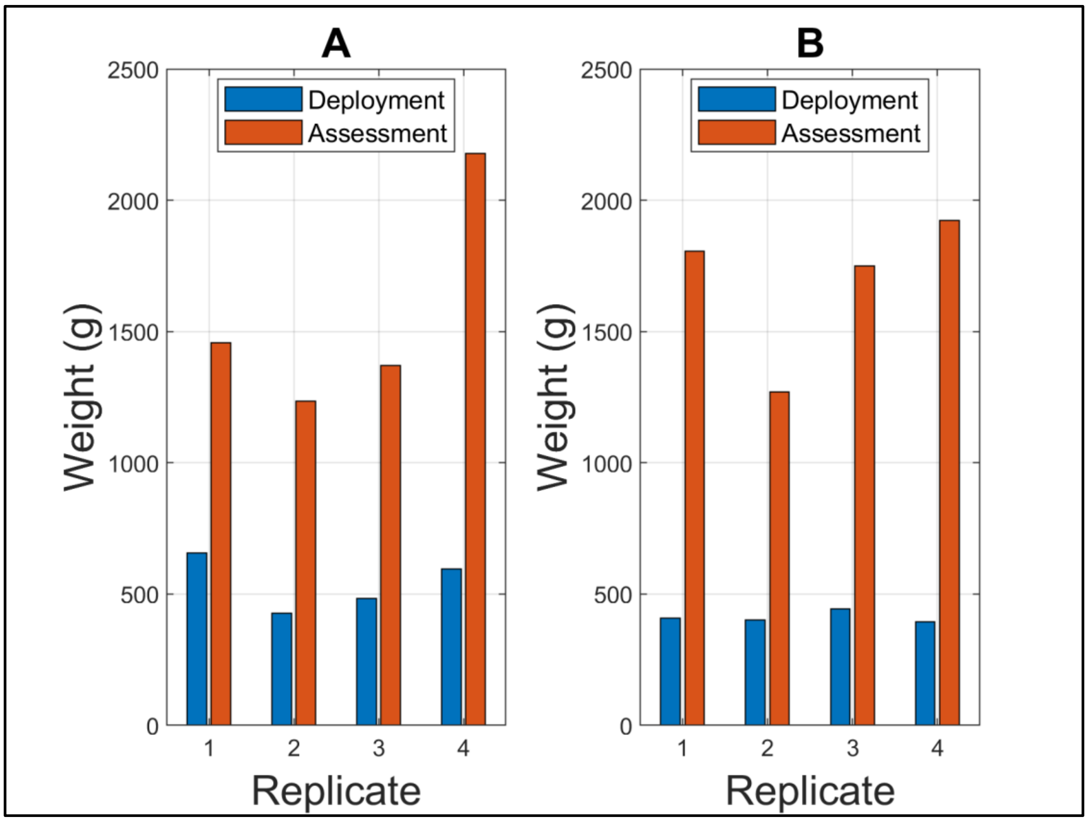

Figure 17: Change in weight for coconut coir (A) and plastic (B) replicates from deployment (May 2019) to 3-month assessment (August 2019)

Three-Month Organism Settlement

At the three-month assessment, the replicates were removed from the test site and assessed visually as per ASTM D6990 (ASTM, 2011). Each shell was removed from the mat, photographed, and assessed for organism percent coverage.

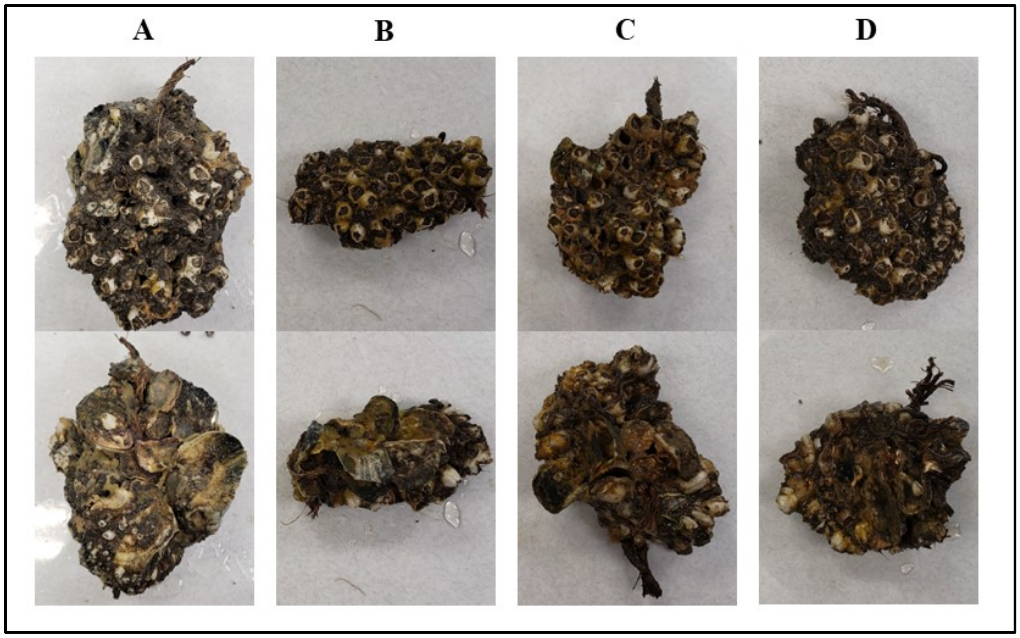

Figure 18: Phase 2 coconut coir three-month shell assessment. Each sample shell was selected to represent the average settlement found for each replicate. The top row represents the front face of the oyster shell, the bottom row represents the back face of the oyster shell.

Figure 18 and Figure 19 represent a selection of fouled shells from the Phase 2 three-month assessment. Each replicate represents a single shell from each of the four scale mats deployed. From Figure 18, it can be seen that barnacle settlement is predominantly on the front of the oyster shell. This is most prominently seen on replicate A and replicate B.

From figure 19, barnacle growth is also predominantly on the front of the oyster shell, but also covers a portion of the back face of the shell. This is most prominently seen on replicate C and replicate D.

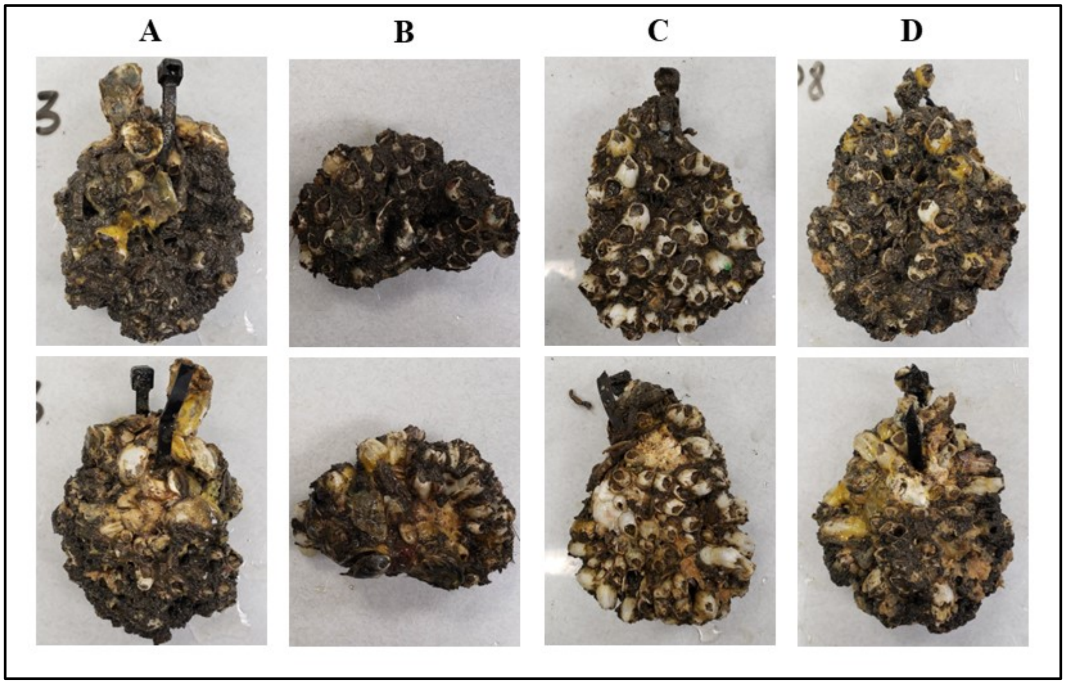

Figure 19:Phase 2 plastic three-month shell assessment. Each sample shell was selected to represent the average settlement found for each replicate. The top row represents the front face of the oyster shell, the bottom row represents the back face of the oyster shell.

The percent coverage of the major fouling organisms can be seen in Figure 20. These organisms were selected as their average percent coverage exceeded 3%. As previously noted, the burlap materials failed to retain any shells after 3 months and are therefore not represented in organism settlement. The largest organism settlement observed on both plastic and coconut coir res was from barnacles (BARN) at 64% and 46%, respectively. The second highest abundance was from oysters, or mollusks (MOL), with coconut coir having 34% average coverage and plastic having 21% average coverage.

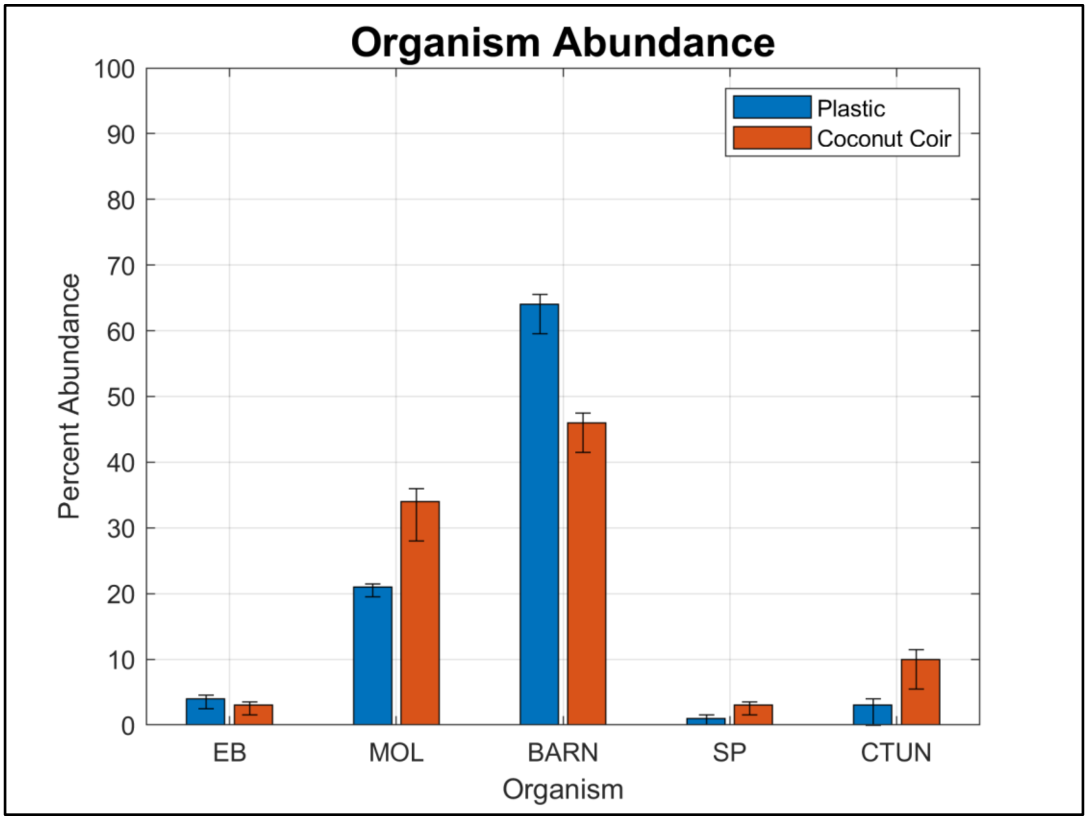

Figure 20: Average organism abundance on shells for plastic and coconut coir materials – Encrusting Bryozoan (EB), Mollusk (MOL), Barnacle (BARN), Sponge (SP), and Colonial Tunicate (CTUN)

Summary

Phase 2 led to the elimination of burlap as a material replacement in the Living Dock application. Both the burlap coffee bag and the burlap ribbon replicates failed within the first month of testing. The centers of all replicates were missing and therefore resulted in a 100% shell loss rate. This failure was likely due to the weave being unable to support the shear force or weight of the oyster shells. There was minimal growth on the remaining edges of the burlap.

Phase 2 also resulted in a need for further assessment of the viability of a fiber-reinforced concrete option. The concrete-coated basalt samples all showed signs of sulphate attack, wear, and fiber breakage.

After three months, coconut coir was the most viable option for replacing plastic in the Living Dock application. The coconut coir replicates were in good condition, however poor shell attachment design led to a 30% loss in shells. The shells remaining were 100% fouled and had a diverse community of organisms.
Naturally, plastic was still the most desirable material with respect to long-term durability. The overall organism abundance was lower as compared to the coconut coir especially with respect to growth on the mat material itself. The plastic had mainly bryozoan and colonial tunicate growth.

Chapter 6
Phase 3: Reinforced Concrete Design Study

Purpose

The purpose of Phase 3: reinforced concrete design study was to address whether a reinforced concrete material is suitable for the Living Dock application. Materials utilized in this study include coconut coir and basalt roving as the reinforcement in a custom concrete mixture. The mixture was assessed based on the strength properties of the concrete, observations of how the deployed mats withstood the design environment, and organism recruitment over the tree-month study period.

Methodology

Concrete is essentially a mixture of Portland cement, sand, aggregate, and water. The main modifications to a mixture are cement type, aggregate size, and the addition of admixtures which can change the properties of the concrete to suit specific needs. There are two main types of cement: hydraulic and air-set cement (Mitchell, 1962; Ortego, 2006). For the design of this project, a hydraulic cement which hardens due to the reaction with water is necessary (Mitchell, 1962; Ortego, 2006).

Portland cement is the most common hydraulic cement and comes in five types: type 1 (normal purpose), type II (moderate sulfate resistance), type III (high early strength), type 4 (low heat of hydration), and type IV (high sulfate resistance) (Kett, 2009; Ortego, 2006). Concrete is composed of a mixture of cement and aggregate. Aggregates are grouped based on grain size. Course aggregates are particles which are retained on a 5-mm (No.4) sieve, and fine aggregates are the particles which pass the 5-mm (no. 4) sieve (Kett, 2009). The final ingredient to a concrete mixture is water. Water is added at varying ratios depending on the strength criteria of the cement. More water will make the concrete more workable, however the hardened concrete will be weaker. Less water in a mixture will make the concrete thicker and stronger once cured.

Strength of concrete is strongly dependent on time. While most concrete is considered safe for use after a few weeks, the chemical reaction continue to occur for years(Mitchell, 1962). The figure below shows how type I, type II, and type III Portland cement gain in compressive strength over time. This gives a relative baseline for the compressive strength of a design mixture.

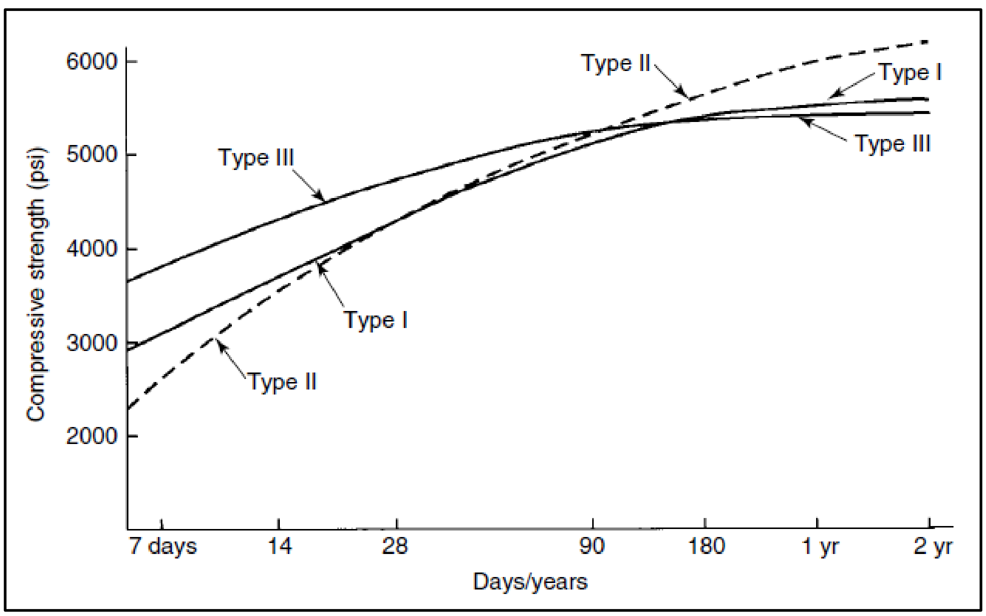

Figure 21: Compressive strength of concrete as it cures over time (Mitchell, 1962; Somayaji, 2001)

In order to implement a concrete structure in harsh, saline environments, a sulfate-resistant Portland cement is necessary. Optimally, type V Portland cement is used as it has the highest sulfate resistance. Type V cement is unfortunately often inaccessible for non-commercial users and therefore type I or type II Portland cement is often used. It is also common to find a combination mixture such as type I/II Portland cement in home improvement stores. The type I/II cement combines the strength and chemical properties of type I and type II cement such as higher sulfate resistance in the type II and a higher initial strength from the type I cement.

To prevent sulfate attack in concrete, admixtures such as pozzolans must be incorporated. Pozzolans are a siliceous material which increases the strength (Kett, 2009), reduces heat generation, and improves workability of the concrete due to the reaction with water (Ortego, 2006). Pozzolans are also a source of cost reduction as they can replace up to 20% of the cement needed for a concrete mixture (Kett, 2009).

Metakaolin is a clay-based pozzolan which is commonly referred to as "china clay". Many pozzolans are the byproduct of fume waste, however, this makes their composition potentially inconsistent in composition. Metakaolin is purposefully created and therefore varies in composition minimally`. Metakaolin aids in the prevention of sulfate attack by reacting with the Ca(OH)2 in the concrete mixture to create calcium silicate hydrates, which aids in the overall structure and strength of the material (Ženíšek, Vlach, & Laiblová, 2017).

Construction

Phase 3 tested a non-fiber-reinforced control sample, a basalt reinforced sample, and a coconut coir- reinforced sample. The deployment design was similar to Phase 2. The concrete half-shell mats were 10.16cm by 27.94cm (4in x 11 in). Four mats were made to create two full pile wraps for each material (Figure 22).

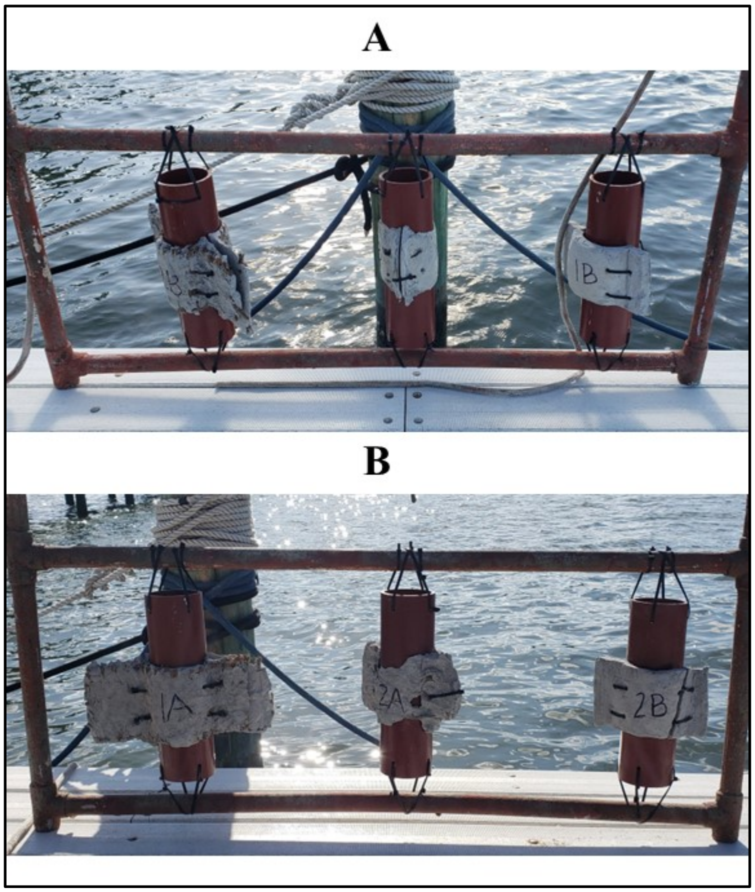

Figure 22: Concrete scale mats pre-deployment

Material Testing

Material testing for Phase 3 included compression and flexural strength assessment of the concrete mixture as well as visual assessment of the deployed mats. Compression and flexural strength testing allowed for the assessment of the concrete mixture alone, identifying if the mixture was capable of withstanding the forces necessary for the design environment. The visual assessment of the deployed materials assessed whether the material, in the scaled design and test environment, was capable for use in the Living Dock application.

Compression Strength of Concrete

Compression testing quantifies the change in strength properties of the concrete material over time. Compression testing for this study did not include fiber reinforcement so that the properties of the mixture used across the design was assessed. Compression strength is measured, most commonly, through the usage of cylinders (ASTM, 2015). Plastic cylinders were filled using a portion of the experimental batch mixture. A series of 7.62cm by 15.24cm (3in x 6in) cylinders were tested at 3, 7, and 28 days into the curing processes. The specimens were removed after 24 hours and placed in water to continue the wet curing process.

The test apparatus is a servo-operated machine which allows for steady and constantly increasing pressure application. The machine stops once the cylinder has failed. The common failure types can be seen Figure 23.

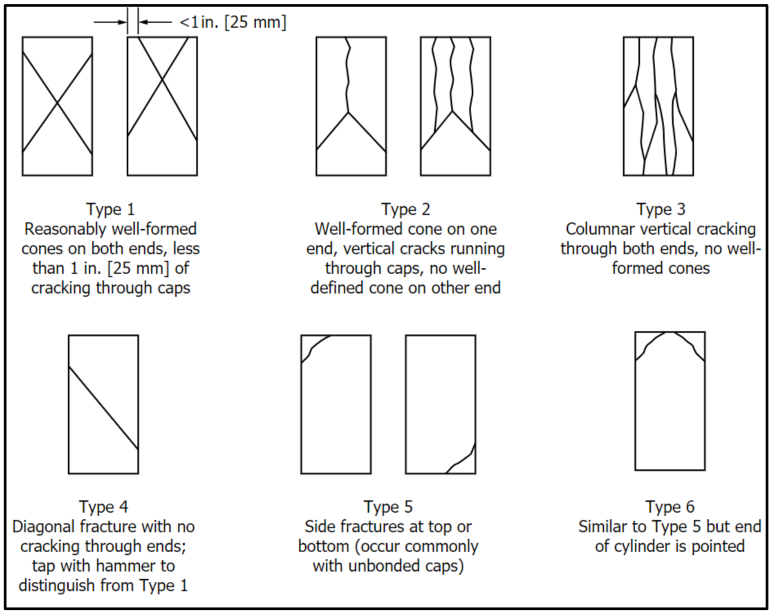

Figure 23: ASTM C39/C39M FIG 2 - Schematic of Typical Fracture Patterns. Fracture patterns were identified upon completion of compression testing of molded cylinders

The system produced a plot for compressive strength which was further assessed using the Equation 1 for compressive strength (ASTM, 2015).

$$f_{cm} = \frac{4000\, P_{max}}{\pi D^2} \qquad \textbf{Eq.1}$$

Flexural Strength of Concrete

Flexural testing quantifies the flexibility of the concrete material and essentially the tensile strength of the concrete. Flexural strength was assessed through a center-point load test (ASTM, 2013). The flexural testing panels were similar in thickness to the normal mats however these samples were flat 2.5 cm by 2.5 cm by 15.875 cm (1in x 1in x 6.25 in) panels. Three panels of each fiber reinforced concrete were created using metal molds. The specimens were removed after 24 hours and placed in water to continue the wet curing process. The specimens were then tested on day 14 and day 28 of the curing process.

In order to accurately assess the flexural strength, a servo-controlled machine was used as a hand-cranked machine does not allow for constant steady force to be applied to the test specimen. The concrete-fiber mixture was molded into flat bars which then spanned a bar and a roller (Figure 24). The third point was applied from the bearing plate on the head of the testing machine. The bearing plate applied the force to the center of the specimen span, inducing flexural motion.

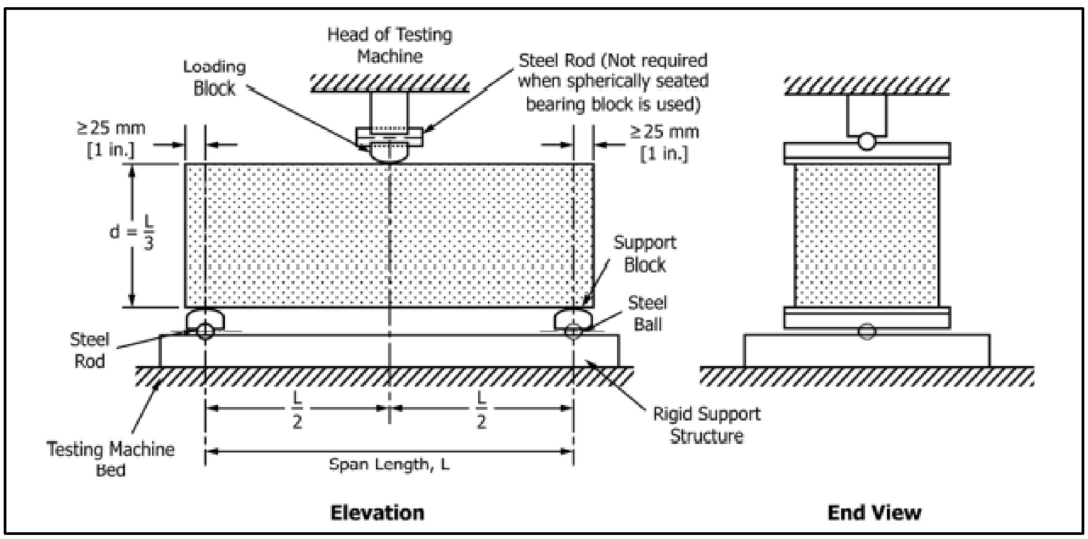

Figure 24: ASTM C293/C293M-16 Schematic of a Suitable Apparatus for Flexure Test of Concrete by Center-Point Loading Method

It is important to note that the specimens tested in this experiment were significantly smaller than the industry recommended test sample. This was for two reasons: the concrete scaled design application was a thin-layer of concrete coating the natural fibers, and larger test samples result in a decrease of flexural strength as the likelihood of an internal flaw in the specimen was greater (Mitchell, 1962).

From the flexural testing outputs, modulus of rupture, or bending strength, was determined from Equation 2 (ASTM, 2013). The bending strength can be estimated from the specified compressive strength using Equation 3 (ACI 318-95, 1995) when flexural testing is not possible.

$$\boldsymbol{R = \frac{3PL}{2bd^2}} \qquad \textbf{Eq. 2}$$

$$\boldsymbol{f_r = 7.5\sqrt{f'_c}} \qquad \textbf{Eq. 3}$$

It is also important to note that the center-point loading flexural strength tests result in bending strengths significantly greater as compared to the results of the three-point bend test found in ASTM C78/C78M (ASTM, 2013).

Results

For Phase 3, two separate concrete pours occurred; the first on February 24^{th}, 2020 and the second on June 2^{nd}, 2020. The two pours are due to an inadequate availability of molds to pour both the 14 and 28-day flexural specimens at the same time. Following the ASTM guidelines for laboratory test conditions, compression cylinders were needed for both pours as they occurred more than 24 hours apart (ASTM, 2019).

Concrete Design

From the results of Phase 2, the use of a pre-mixed concrete was deemed inadequate for the test environment. Therefore, the concrete mixture used for Phase 3 testing required a custom mix with a pozzolan to reduce the effects of sulfate attack.

As mentioned in the materials selection section, the addition of up to 20% metakaolin results in a sulfate-resistant concrete mixture. The decision of only adding 15% metakaolin was due to workability; the more metakaolin added into the mixture, the harder the concrete is to work with. A water/cementious ratio of 0.4 is common in the construction industry as it creates a strong and workable mixture. Additional water may be added to increase workability, however additional water will lower the total strength of the concrete.

Table 2: Concrete design mixture for Phase 3: reinforced concrete design study

		Design Mix		
		SG	W (lbs)	V (ft^3)
Cementous Material				
85 %	Portland Cement	3.15	700	3.56
15 %	Metakaolin	2.30	105	0.73
100 %	Total Cementous		805	4.29
Fine Aggregate				
100 %	Sand	2.65	3273	19.79
100 %	Total Aggregate		3273	19.79
Water				
Water		1.00	280	4.49
Aggregate Absorption		1.00	98	1.57
Total Water			182	2.91
Cement/Cementious Ratio		0.85		
Water/Cementious Ratio		0.4		
Density (lb/ft^3)		158		
Yield ft^3		27		

Compression Testing

From Phase 3, two sets of compression tests were completed. The first set of cylinder replicates (reps) were from the same mixture used for the fiber-reinforced concrete mats. The figure below displays the results of the compression tests for day 3, 7 and 28. For each test day, 3 cylinders were tested.

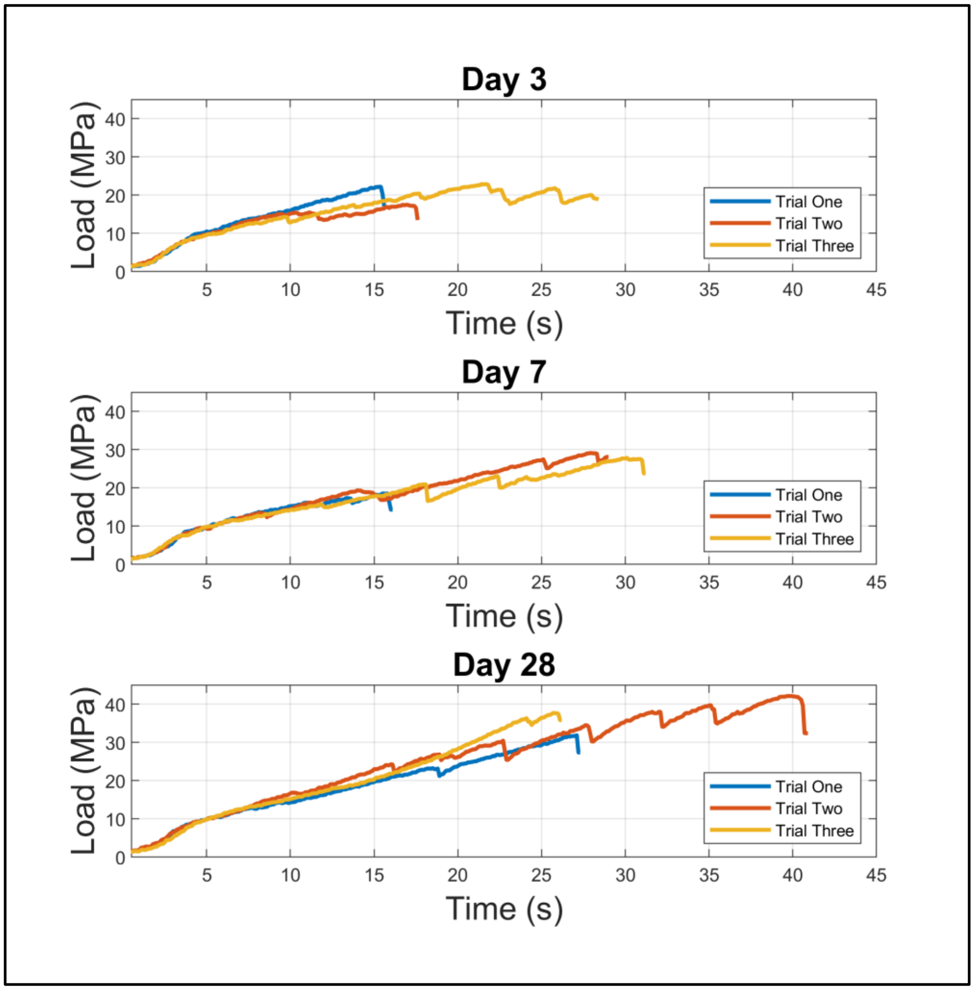

Figure 25: Compression load over time for non-reinforced concrete mixture– dates correspond to the February 2020 pour date

The second set of compression testing corresponds with the concrete mixture used for the 14-day flexural testing specimens. Again, 3 cylinders were assessed for each test day (Figure 26).

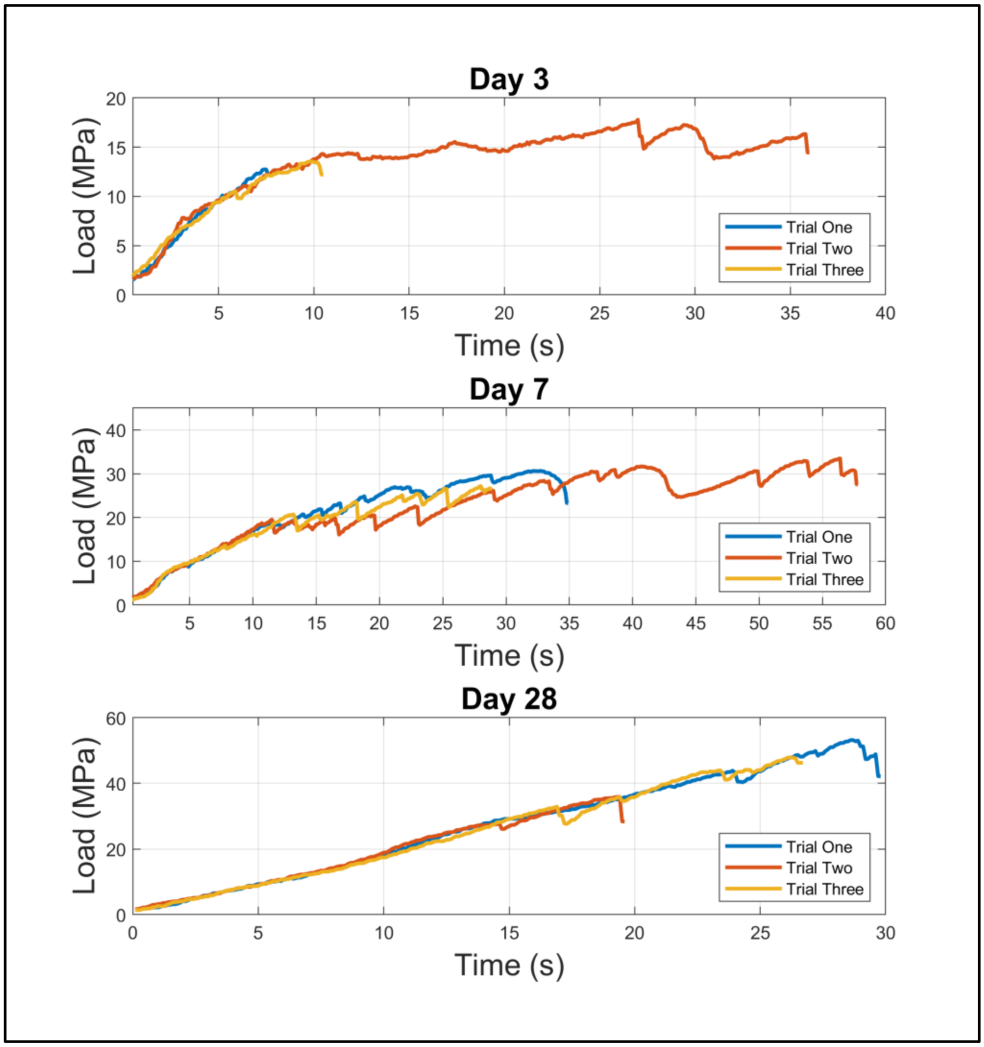

Figure 26: Compression load over time for non-reinforced concrete mixture – dates correspond to the June 2020 pour date

Figure 27 represents the compression force as calculated from Equation 1. Graph A represents the February 2020 replicates and graph B represents the June 2020 reps. The compression force between pours follows the expected trend, with the mixture increasing in strength with cure time.

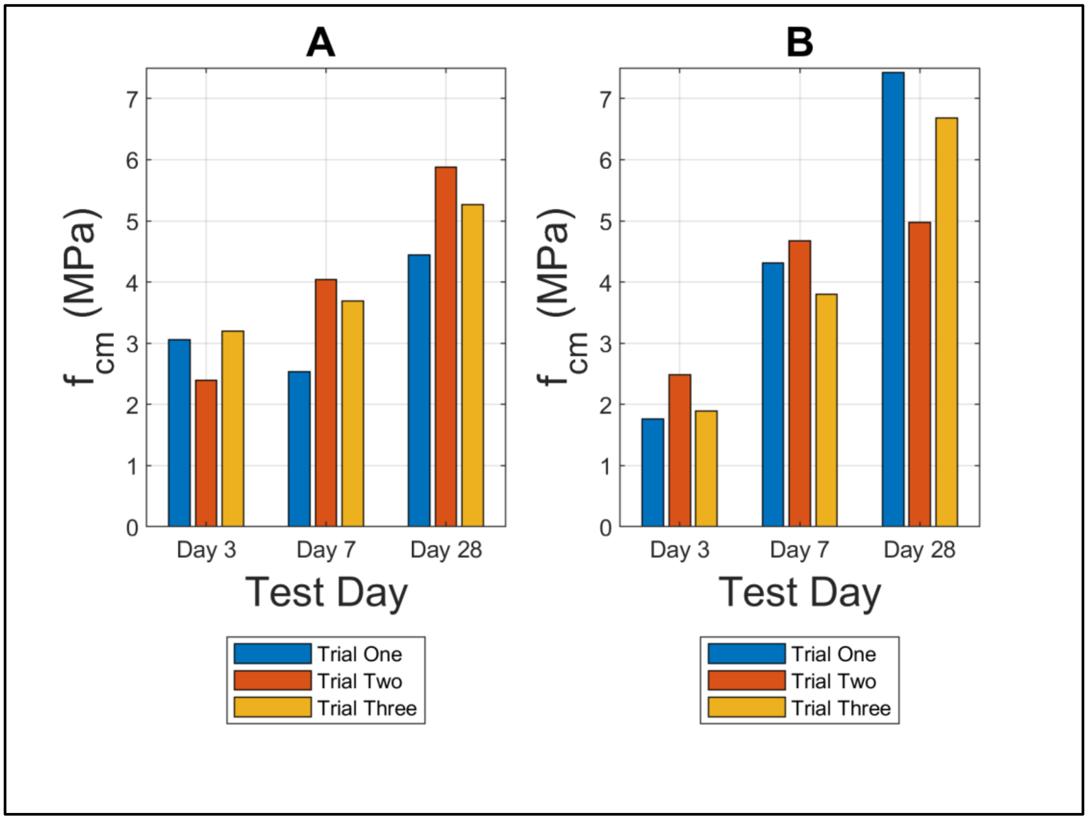

Figure 27: Compression force (f_{cm}) over time - February pour (A) and June pour (B)

Flexural Testing

Flexural test replicates were created from both pours of concrete. The 14-day replicates from the June 2nd, 2020 date and the 28-day replicates from the February 24th, 2020 date. The testing apparatus does not allow for the raw data to be saved, but outputs summary files and plots, from which key data points were collected to create the flexural load figures below.

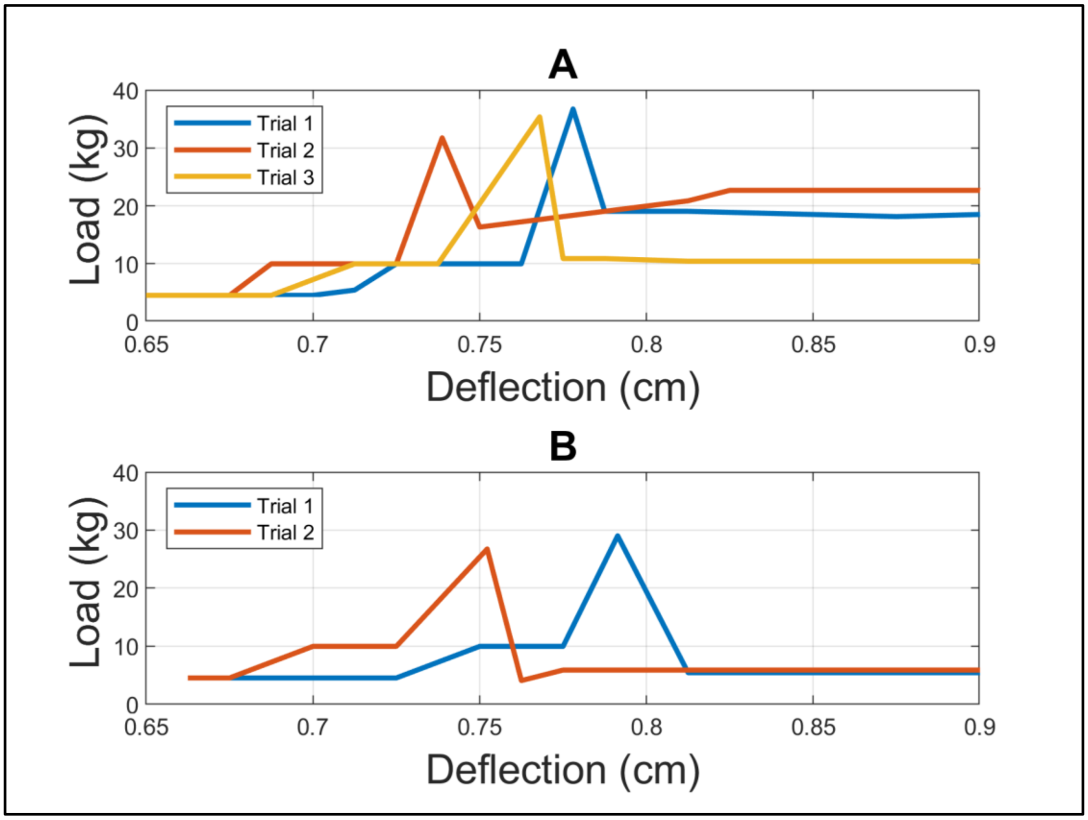

Figure 28: 14-day flexural load vs. deflection for basalt-reinforced concrete (A) and coconut coir-reinforced concrete (B).

From Figure 28, the maximum load vs. deflection at the 14-day assessment was overall higher for the basalt-reinforced concrete replicates (A). The missing trial from the coconut coir-reinforced replicate (B) is due to miscalibration of the machine pre-load weight, resulting in no data collection. The average maximum load for the basalt (A) and coconut coir (B) reinforced replicates was 34.6 kg at 0.76 cm and 27.8 kg at 0.77 cm, respectively.

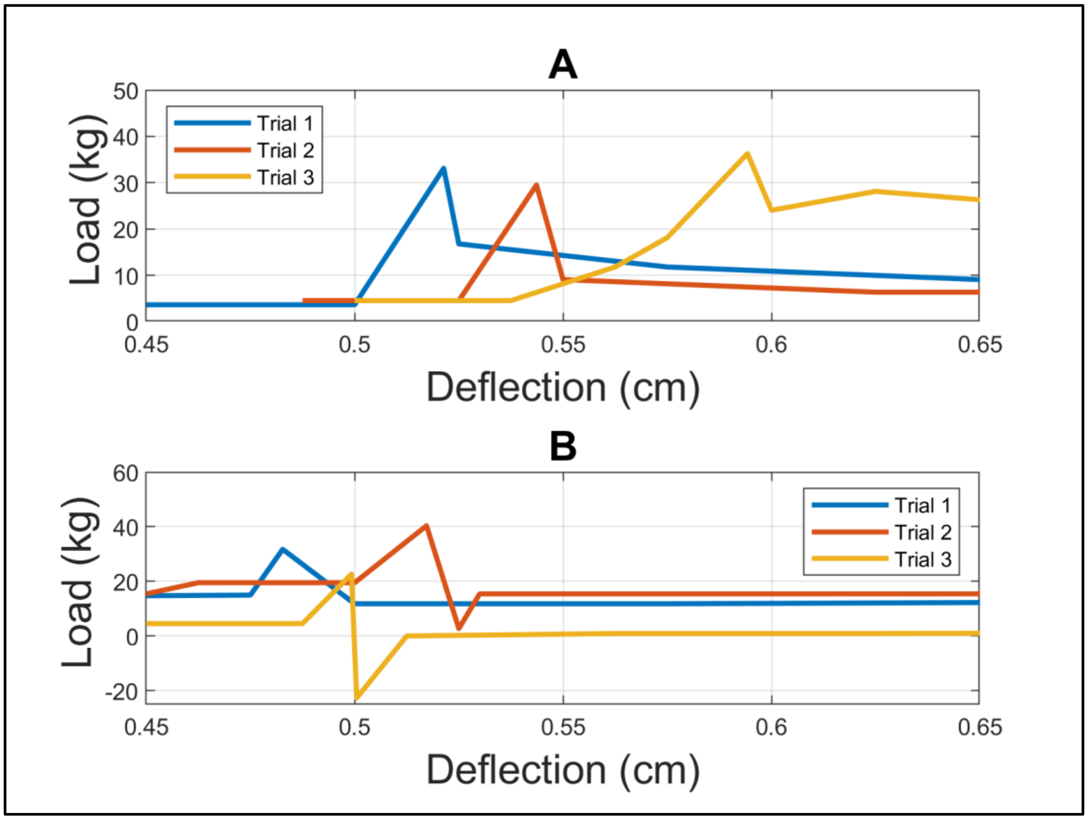

Figure 29: 28-day flexural load vs. deflection for basalt-reinforced concrete (A) and coconut coir-reinforced concrete (B).

From Figure 29, the maximum flexural load vs. displacement at the 28-day mark was, on average, higher for the basalt-reinforced replicates (A). The average maximum load for the basalt (A) and coconut coir (B) reinforced replicates was 33.0 kg at 0.55 cm and 31.6 kg at 0.50 cm, respectively.

The bending strength for the three specimens for both the coconut coir and basalt on each test day can be seen below (Figure 30). The 14-day coconut coir results only have data for trial 2 and trial 3 as the testing apparatus was improperly calibrated and did not collect data for replicate 1.

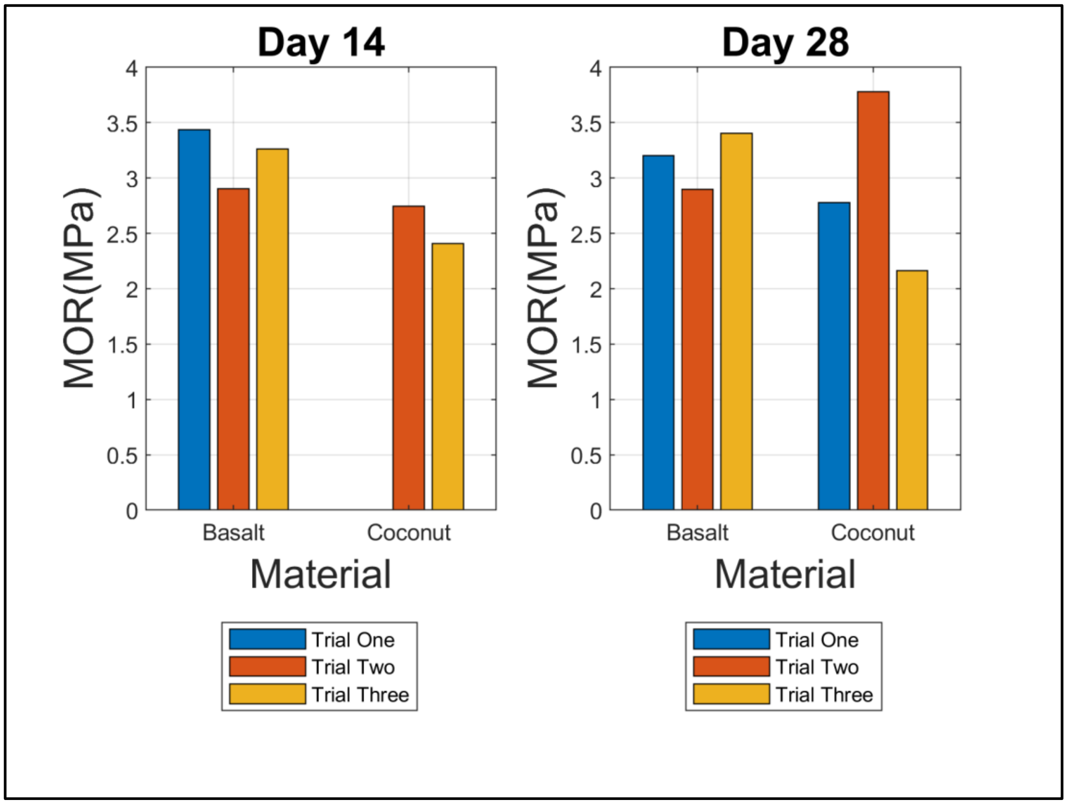

Figure 30: Bending strength of basalt and coconut coir-reinforced concrete replicates

From Figure 31, the average bending strength for the basalt and coconut fiber reinforced replicates can be seen. The average maximum bending strength for the 14-day basalt and coconut coir reinforced beams was 3.20 MPa and 2.58 MPa, respectively. The average maximum bending strength for the 28-day basalt and coconut coir reinforced beams was 3.17 MPa and 2.91 MPa, respectively.

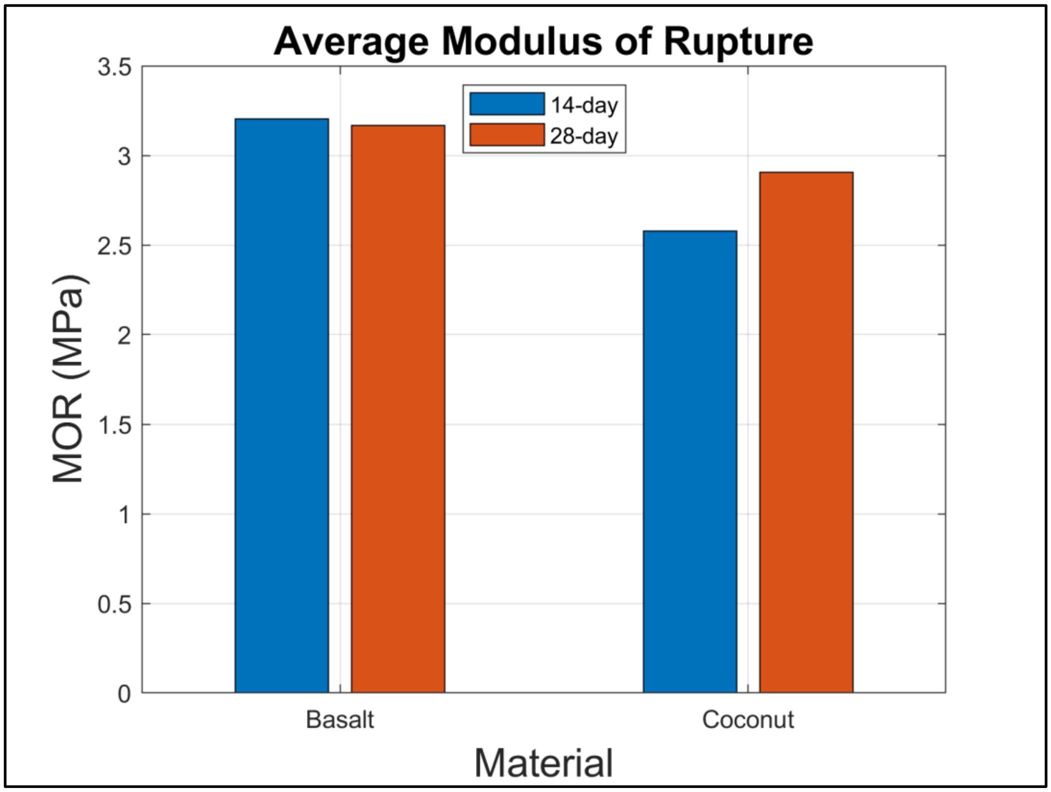

Figure 31: Average bending strength for basalt and coconut coir-reinforced concrete

Phase 3 Design Resiliency in Test Environment

Ideally, the Phase 3 replicates would have been assessed monthly starting with pre-deployment observations for the March 18th, 2020 deployment date. Due to a global pandemic, results for the one-month or two-month assessments could not be collected. Qualitative observations at the 10-week and 11-week marks were collected with the full assessment occurring after 3-months.

Pre-deployment Observations

When applying the mats onto the mini-piles, two of the non-reinforced replicates cracked in half. This resulted in only 2 replicates being tested. The basalt and coconut-reinforced replicates were flexible enough to attach to the scale piles successfully. Measurements taken at the pre-deployment stage can be found in Appendix B.

Three-month Reinforced Concrete Design Assessment

At the three-month assessment, each replicate was measured for average thickness and average height, weighed, and overall condition noted. Organism percent coverage was taken to identify any major differences between materials as it pertains to benthic recruitment. Figure 32 represents a selection of one replicate per material from the Phase 3 three-month assessment. From this, it can be seen that there was light fouling on the outer-facing surfaces (top row), and harder fouling on the inner-facing surfaces (bottom row).

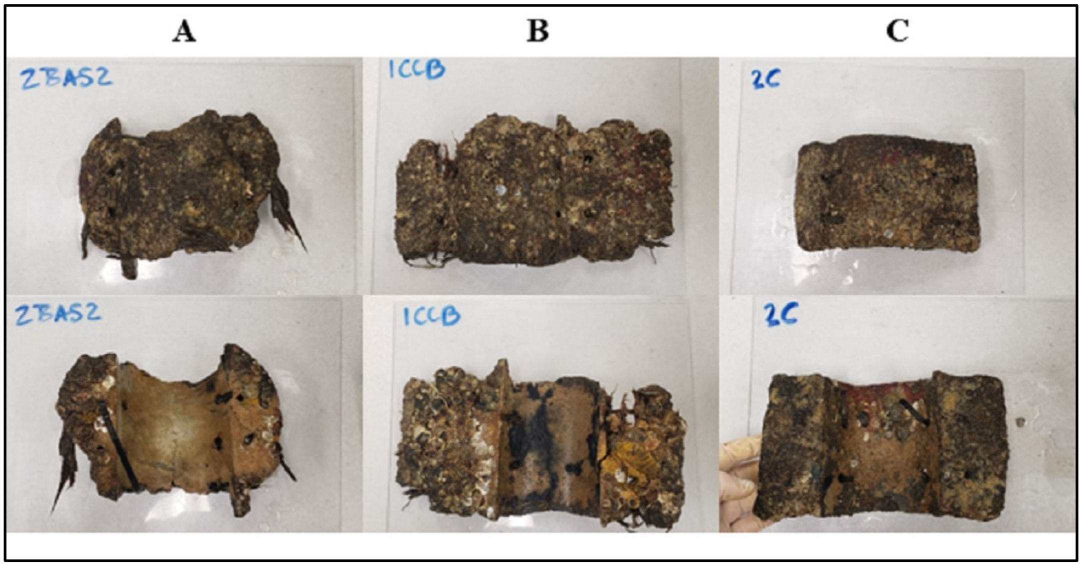

Figure 32: Phase 3: three-month assessment. Basalt-reinforced concrete (A), Coconut coir-reinforced concrete (B), Concrete control (C). Replicate A has moderate wear along edges causing exposed fibers near attachment points. Replicate B has minimal wear near the top, causing exposed fibers near the attachment point. Replicate C has no distinguishable wear.

Table 3, below, shows the average change in height, thickness, and width for each material. Note that the concrete control data does not include data for replicates 1 or 3 as these replicates broke and were therefore unsuitable for deployment. The concrete control replicates had the largest increase in weight, followed by coconut coir-reinforced concrete, and then basalt-reinforced concrete.

Table 3: Average change in weight, percent change in weight, average change in thickness, and average change in height for basalt-reinforced concrete, coconut coir-reinforced concrete, and concrete control materials

Material	Change in Weight (g)	% Change in Weight	Change in Thickness (cm)	Change in Height (cm)
Basalt	24	10	0.80	-1.63
Coconut Coir	174	29	0.72	-0.03
Concrete Control	444	64	0.38	0.08

Percent coverage was taken to assess settlement trends and identify whether certain materials created more favorable conditions for certain organisms. The following figure shows the percent coverage for organisms which had coverage over 3%. Organisms with under 3% coverage were omitted for visual clarity.

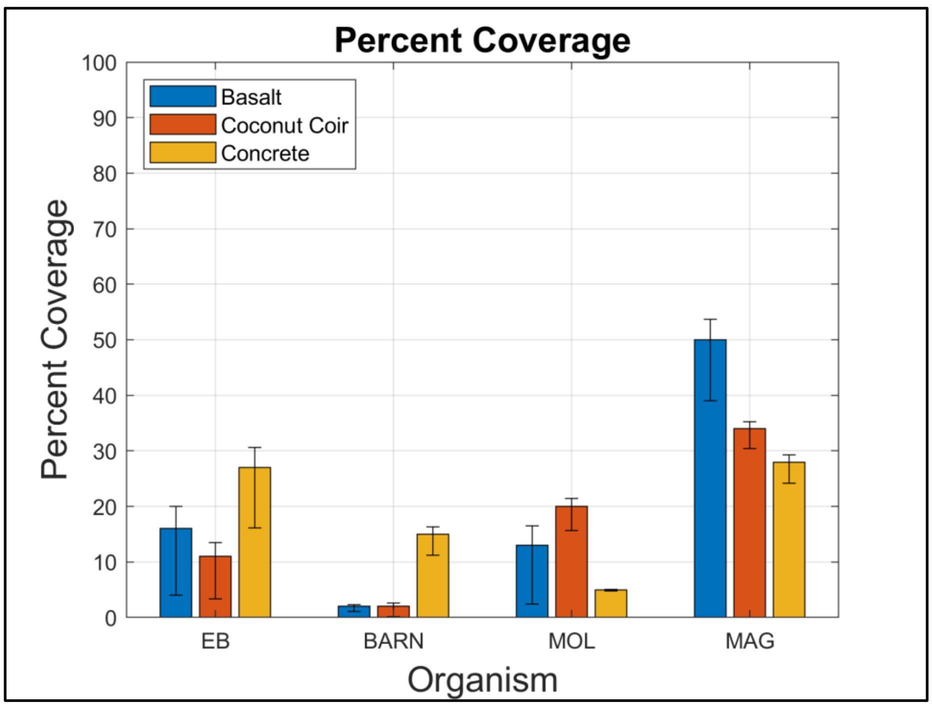

Figure 33: Reinforced concrete design organism percent coverage by organism - Encrusting Bryozoan (EB), Barnacle (BARN), Mollusk (MOL), Green Algae (MAG).

Chapter 7
Discussion

Overall, the success of a material, and therefore the final recommendation for the replacement of plastic in the Living Dock application was evaluated based on the following three parameters:

1. Ability to withstand constant submersion in an estuarine environment;
2. Ability to withstand the Living Dock application;
3. Percent coverage of organisms

Phase 1: Pilot Study

The purpose of Phase 1 was to address the research question: can the alternative materials withstand submersion in the testing environment? From the results of chapter 4, it can be seen that the coconut coir and burlap replicates were both capable of continued submersion while the basalt replicates fell short. The coated and un-coated basalt replicates failed within the first two weeks of this study. Resin-coated basalt replicates failed due to their inability to support the affixed oyster shells as well as detachment from the test frame. Of the four replicates tested, one replicate was lost after the first two weeks. From the three remaining reps, only a single shell on replicate A remained and replicate B was only attached at one end by 2 zip ties. Replicate B was lost by the three-week assessment. At the one-month assessment, replicate A was still affixed to the frame with one shell, and replicate C remained in the same condition as before.

The burlap ribbon replicates showed signs of slight deformation around the borders but had no shell loss or separation from the testing frame. Potential sources for failure are the edges of the material. While folding and coating the ends successfully eliminated any fraying, the folded edges became a habitat for settlement. The edges supported barnacle and arborescent bryozoan settlement, while the material supported a few sea squirts, but mainly trapped silt in the tight weave. The shells had light coverage resulting in roughly 30% coverage. Most fouling was encrusting bryozoan and algae, with one small oyster on a shell from replicate C. Burlap showed potential and was therefore recommended for assessment in Phase 2.

Coconut coir withstood submersion with minimal wear or degradation and showed potential for organism settlement on both the oyster shells and the mat material. At the one-month assessment, there was light fouling on the shells resulting in roughly 30% coverage. Most fouling was from encrusting bryozoan, algae, and barnacles. There was one small oyster on the top shell from replicate A. The material, alone, showed promising results as there were many small sea squirts, tubeworms, and arborescent bryozoans settling within the fibers of the mat itself. Due to these findings, the coconut coir mats were the recommended material from Phase 1 for potential replacement of plastic in the Living Dock application.

Phase 2: Scaled Design Study

The purpose of Phase 2 was to address the research question: can the natural fibers succeed in the living dock application? From the results of Chapter 5, it can be seen that the coconut coir and concrete-coated basalt were able to withstand the Living Dock application to an extent, while burlap was unable to withstand this application.

Material Assessment

The burlap replicates suffered catastrophic failure within the first month of testing. Burlap, or jute, fibers have a relatively low tensile strength (Xia, Yu, Cheng, Liu, & Wang, 2009) that is largely dependent on the treatment of the fibers. Burlap is often used as a reinforcing fiber in composites as it can increase flexibility, however the moisture levels and chemical absorption of the fibers can lead to a reduction in flexibility and strength over time (Shahzad, 2012). Therefore, the combination of constant submersion and high shear stress from the oyster shells is the likely cause for failure.

The cement-coated basalt showed promise at the one-month assessment, all four replicates were worn, but still attached and showing signs of organism settlement, At the three-month assessment, however, only replicate A was still fully intact, a small portion of replicate B was intact, and replicate C and D were gone. The concrete design mixture for this study was chosen as it was a hydraulic cement, with no large aggregate, and had ingredients commonly found in nature in Florida, i.e. a lime-based mix. In a freshwater application, this mixture may have worked as there are little to no salts found in freshwater, however, the sulfate attack on the concrete was the likely source of failure for this material (Berkovitch, 1984; Kett, 2009; Mitchell, 1962). Sulfate attack was due to saltwater impacting the chemical reactions during curing, causing a crystallized structure which cracks easily. This cracking was evident at the one-month assessment as the concrete appeared to be chipping off of the basalt fibers, leaving the fragile fibers completely exposed.

Coconut coir was, once again, the most viable option for replacing plastic in the Living Dock application thus far. The replicates showed minimal signs of degradation or wear after three months. The major source of failure for the replicates came from shell attachment. A 30% total loss in shells, with 50% loss in replicate A, 30% in replicate B, 40% in replicate C and 0% from replicate D, is significant, but not detrimental. Three of the shells reported as "lost" detached during the removal of the test frames for final assessment. This shell detachment was due to the manner in which the shells were affixed as the fibers were woven together instead of knotted. Weaving the ties allowed the mats to lay flush against the pile whereas knots would have created a gap between the pile and the mat. Knots, however, would likely have resulted in little to no shell loss as the knots along the mat edges remained intact throughout the deployment period. Despite the shell loss, the coconut coir was the most suitable alternative to plastic for the Living Dock application.

Organism Settlement

Organism settlement was taken at the three-month assessment. Each mat was weighed with and without shells affixed. Percent coverage was assessed for each individual shell and mat material. As previously discussed, the burlap materials and concrete coated basalt had so little material remaining at the three month point that there was little to assess. The burlap replicates both had minor barnacle settlement along the beeswax edges but had little to no community diversity. The concrete-coated basalt replicates showed signs of barnacle and tubeworm settlement in the fibers, but organism settlement was almost entirely on the surfaces in which the two halves of the replicates connected around the pile.

The coconut coir and plastic replicates had similar organism settlement with all shells reaching 100% coverage. The coconut coir surpassed the plastic in diversity, mollusk (MOL) settlement, and organism settlement on the shells and mat material. As seen in Figure 20, barnacles were the predominant species for both plastic and coconut coir at average coverages of 64% and 46%, respectively. The main difference in coverage was from MOL (oyster/mussel) settlement. Average MOL settlement for the plastic material was 21%, where for coconut coir it was 34%.

The coconut coir mat also created a habitat more suitable for the success of soft fouling organisms such as colonial tunicates and sponges. Community diversity has been found to be key in minimizing predation (Grabowski, 2004; Strain et al., 2018). The plastic mat itself had mainly encrusting bryozoan settlement, which is believed to potentially limit oyster spat settlement due to competition (Galtsoff, 1964). The total average coverage for the plastic and coconut coir mat materials were 9% and 39%, respectively. On the coconut coir matting, the predominant organisms settling were barnacles at 23% coverage and sedimentary tubeworms (PSED) at 10%. Results show that not only is the coconut coir material able to withstand the Living Dock application, but it is a more hospitable environment for organism settlement and diversity.

Phase 3: Reinforced Concrete Design Study

The purpose of Phase 3 was to address the research question: can concrete coated natural fibers succeed in the living dock application? It is important to note that the concrete mixture is a key component of measuring success as the mixture ratios can vary depending on design requirements. As seen in Chapter 6, the concrete mixture utilized was a Portland cement, metakaolin, and sand mixture. Mixtures vary for design purposes to include more admixtures to modify chemical reactions and different aggregate sizes and volume to modify strength and consistency (Mitchell, 1962). These modifications allow for concrete mixtures to be tailored to a specific environment. For this study, the main purpose was to create a baseline concrete mixture that was resistant to sulfate attack to see if a natural fiber reinforced concrete could withstand the Living Dock application. From the results of chapter 6, it was seen that yes, concrete-coated fibers were able to withstand the Living Dock application, but that coconut coir as a reinforcement was preferred.

Compression Testing

The overall trend for compression strength was positive, as expected. Compression strength should always increase over time as concrete continues to cure over its lifetime (Mitchell, 1962; Somayaji, 2001). Traditionally, concrete compressive strength is around 17 MPa (2,500 psi) for residential structures (National Ready Mixed Concrete Association, 2003). This value is roughly 3 times higher than the 5.3 (789 psi) MPa found in Phase 3. This deviation was due to one main factor – there was no coarse aggregate used in this design mixture. This mixture lies between a mortar mix and a concrete mixture and therefore exhibits lower compressive strengths closer to a mortar mix. Having a lower compression strength, however, does not play a major effect for this application as the forces applied to the oyster mats are far below the forces expected from residential construction.

An interesting correlation can be drawn between the compression results and the fracture type. When assessing the plots, one or two replicates from every test day far exceeded the others in time and, in some cases, strength. When looking at fracture pattern (Figure 23) tests that took longer and had higher strengths all had the type VI fracture pattern. Type VI is commonly associated with unbonded cap testing, which is the manner in which all cylinders were tested.

Flexural Testing

Flexural testing is not as predominant in the industry setting as compression testing. This is due to the chance of high variability in results as curing specifications are difficult to meet and small deviations can cause large deviations in flexural strength (Mitchell, 1962). Due to this variability, bending strength is often estimated from the compression strength using Equation 3. Therefore, from the 28-day concrete compression load of 40 MPa (5801 psi), the bending strength should be 3.9 MPa (571 psi). The average bending strength of the 28-day coconut coir and basalt reinforced concrete samples were 2.91 MPa and 3.17 MPa, respectively. These values are slightly lower than expected, however this is likely due to the fact that the compression test sample did not include any fiber reinforcement and the specimens tested are significantly smaller than the standard specimen dimensions (ASTM, 2013; National Ready Mixed Concrete Association, 2000).

Traditionally, bending strength increases over time which can be seen in the coconut results. However, the basalt results show a slight decrease of 0.034 MPa (4.9437) psi between the 14 and 28-day tests. As per ASTM C293, the reporting of values need only be accurate to the nearest 0.05MPa (5 psi), making this deviation insignificant. A high bending strength allows for the material to flex under load conditions. A high flexural strength is ideal as the Living Dock application puts more flexural stress on the concrete than direct compressional stress. Both materials exhibited the ability to withstand flexure in the laboratory and design environment. In the laboratory environment, basalt-reinforced concrete out-performed the coconut coir-reinforced specimens in bending strength and maximum deflection under load. The discrepancy between the two materials is minor, and therefore does not allow for one material to be recommended over another solely based on flexural performance.

Deployed Material Assessment

The materials were assessed prior to deployment for weight and average thickness. The purpose for this was to quantify any deterioration from the estuarine environment. During pre-deployment, two of the four non-reinforced concrete control mats cracked in half. This was due to the material being brittle and having little flexibility, which was to be expected of thin concrete. The basalt reinforced replicates were also quite brittle and showed signs of small cracks while being affixed to the piles. The coconut coir was by far the easiest to work with as the replicates had decent flexibility and did not crack or chip when handled.

The replicates were visually assessed at the 10-week point and appeared to be in the same structural condition as when deployed. Between week 10 and week 11, the research platform was moved to a new location. During transportation, one of the basalt-reinforced replicates broke. It is unclear if this damage occurred during transportation, re-deployment, or if the drying and wetting of the concrete caused the material to crack. Neither the coconut coir reinforced concrete nor concrete control panels appeared structurally effected at this point.

At the three-month assessment, each replicate was assessed for any visual deformities and measured for change in weight, thickness, and height. Change in weight was used to estimate organism settlement. Change in thickness was used to determine if material lost was due to shearing forces as well as quantify how much thickness was from settled organisms. Change in height determined if the replicate was deteriorating along the top and bottom edges due to a combination of shearing and compression forces (Table 3).

Concrete Control

The concrete control reps, as previously stated, mainly failed prior to deployment. Replicates 1 and 3 both cracked along the center of the curved portion during handling prior to deployment. Replicate 2 cracked during deployment when the frame was knocked over due to high winds. Replicate 2 showed no signs of further wear from deployment. Replicate 4 was the only control mat to successfully weather the 3-month testing period. However, replicate 4 did not fit fully onto the pile. Due to how brittle the replicates were after one month of curing, the replicate was secured to the pile, but did not lay flush against the pile as the other replicates did. From Table 3, concrete control replicates resulted in the largest increase in weight (64%) and largest increase in height (0.72 cm). This result indicated that the concrete mixture, alone, did not deteriorate in the design environment, but gained thickness and weight from settled organisms. This mixture showed no signs of sulfate attack (cracking and peeling) as seen in the Phase 2 results (Chapter 5).

Basalt-Reinforced Concrete

The basalt replicates, however showed signs of deterioration. Basalt replicates 1 and 2 were extremely deteriorated, mainly in the center of the mats. This deterioration led to the failure of replicate 2, and the near-failure of replicate 1. Basalt replicates 3 and 4 were in better condition with replicate 3 showing signs of wear mainly around the attachment points with a single hairline crack through the center of the arched portion. Replicate 4 had fully cracked along one side of the arched portion, exposing the basalt fibers. From Table 3, it can be seen that the basalt-reinforced concrete mats had the smallest increase in weight (10%), and the largest decrease in height (1.63 cm). Height deterioration was not uniform across all reps, however both replicate 3 and 4, which were attached to each other, had significant deterioration through the mid-section. Similar to the results from Phase 2, the concrete appeared to crack or peel away from the basalt fibers. This result led to the conclusion that either the concrete was unable to permeate the glass-like basalt fibers, or the basalt fibers suffered a reduction in strength due to the thermal reaction during concrete curing (Bhat, Fortomaris, Kandare, & Mouritz, 2018). This resulted in basalt-reinforced concrete not considered as a desirable material choice for the Living Dock application.

Coconut Coir-Reinforced Concrete

The coconut coir-reinforced mats were the most resilient through Phase 3. Replicate A had minimal wear or deterioration aside from a hairline crack through the center of the curved portion. Replicate B had minor wear along the attachment points, which broke off some concrete, exposing the fiber on the edges. Replicate B also had a hairline crack through the center of the curved portion of the mat. Replicate C had minor wear along the edges of the curved portion exposing fibers as well as a hairline crack through the middle of the curved portion. Replicate D had the most deterioration. The flat, attachment segments had separated from the curved center portion of the mat. This separation exposed the fibers underneath but did not cause the mat to fail. Replicate 4 was the only coconut coir-reinforced mat that did not have a hairline crack through the center of the curved portion. These cracks were likely due to the concrete flexing while being affixed to the piles. The cracks would then be exacerbated from increased stresses due to organism settlement between the mat and the pile. From Table 3, coconut coir-reinforced concrete had an average increase in weight of 29% and minimal decrease in height (0.32 cm). This reduction in height is due to the outer edges of the mats wearing to expose the coconut fibers. The change in thickness was minimal and therefore did not pose a substantial threat to the success of the material. Therefore, the coconut coir-reinforced concrete mats should be considered for future use in the Living Dock application.

Organism Settlement

From initial observations, organism settlement on the concrete mats was minimal over the three-month testing period. This was to be expected since concrete continues to change on the chemical level while curing (Mitchell, 1962; Somayaji, 2001). The lack of organism settlement was likely due to the concrete having not reached chemical equilibrium and therefore making it a less desirable substrate for all organisms. Concrete mixtures, especially when submerged in a high sulfate environment can take at a minimum, 3 months for the surface layers to reach equilibrium (Chatellier, Dangla, Thiery, & Chaussadent, 2013; Duchesne & Bérubé, 2003).

The majority of organism settlement was concentrated in the regions where the two halves of the mats joined as well as between the mat and the pile. Each mat was assessed for percent coverage of settled organisms. The following organisms were found on one or more mats: incipient fouling (IF), calcareous tubeworms (PCAL), Intermediate Bryozoan (IntBRY), encrusting bryozoan (EB), mollusk (MOL), barnacle (BARN), sponge (SP), arborescent bryozoan (ARBR), and Green Algae (MAG). The majority of coverage was from EB, MOL, BARN, and MAG, which together resulted in over 65% coverage on all three materials tested. As seen in Figure 33 MAG was the dominating organism across all three materials. In Phase 3, four replicates of each mixture were deployed alongside each other, thereby exposing all replicates to identical testing conditions. What is interesting about the findings of Phase 3 is that each material resulted in a different organism settlement regime. Concrete control replicates exhibited similar results to the plastic in Phase 2 with high EB (27%) and BARN (15%) settlement with some MOL (5%) settlement. Basalt-reinforced concrete replicates were characterized with the highest MAG settlement (50%), moderate EB (16%) and MOL (13%) settlement, and low BARN (2%) settlement. Coconut coir-reinforced concrete replicates had the highest average MOL settlement at 20% and low BARN settlement at 2%. The difference in settlement regime is not uncommon as the chemical composition of each substrate will differ slightly, resulting in a unique biofilm settlement and therefore unique settlement ques which can influence variances in adult densities (Dunn, Eggleston, & Lindquist, 2014; Faimali, Garaventa, Terlizzi, Chiantore, & Cattaneo-Vietti, 2004). Based on organism diversity, coconut coir reinforced-concrete was the recommended material from this study, however, this recommendation stands on the desire to promote MOL settlement over other benthic organisms.

Comparison of Scaled Design Results

When comparing the results from Phase 2 and Phase 3, the main differences come from organism settlement. Phase 2 had significantly higher barnacle settlement for plastic (64%) and coconut coir (46%) as compared to the concrete control (15%) and the coconut coir-reinforced concrete (2%) from Phase 3. This finding suggests that the concrete designs, at least initially, were less likely to attract barnacles, reducing space competition (Galtsoff, 1964) for more desirable benthic settlement. Reduction in settlement on the concrete replicates as compared to natural fiber may be a factor of time. In many concrete restoration studies, organism coverage peaks around 6 months – 1 year, with adult oyster communities seeing peak settlement after the 1-year mark (Dunn et al., 2014). Comparing the oyster/mollusk (MOL) coverage from Phase 2 and Phase 3 resulted in coconut coir alone having the highest average MOL settlement at 34%, followed by plastic at 21%, coconut coir-reinforced concrete at 20%, basalt-reinforced concrete at 13% and concrete control at 5%. These findings suggest that coconut-coir mats with dead and dried oyster shells was the optimal material for replacing plastic in the Living Dock application.

The finding of coconut coir, with or without concrete, as an option to replace plastic can be supported by external studies. Many aquaculture industries utilize fibrous materials for spat collection (Ompi, Lomoindong, & Mandagi, 2018).

Traditionally, nylon or polypropylene rope is utilized, however coconut fiber was determined to be a suitable alternative to the use of plastic in aquaculture spat collection (Ompi et al., 2018). It has been noted, however, that spat settlement is influenced by substrate texture with fibrous materials preferred over hard or non-porous materials, regardless of whether the fiber is natural or artificial (Arini & Jaya, 2011; Libini, Manjumol, Idu, Kripa, & Mohamed, 2013; Ompi et al., 2018). Therefore, as a plain fibrous material, coconut coir is likely to out-perform plastic mats in organism settlement and recruitment due to texture preference of benthic organisms.

It is important, however, to focus on the location of settlement for these organisms as the percent coverage may give a biased result. MOL settlement on shells was predominantly on the rough side of the shell which faced toward the mat with BARN settlement predominantly on the outer-facing surfaces. MOL settlement on all reinforced concrete mats was on the inside of the replicates either between the replicate attachment points, or between the replicates and the pile. BARN settlement on the concrete replicates was, again, predominantly on the outer-facing surfaces. This indicated a preference for MOL settlement on the inside or protected side of a substrate and BARN settlement on the outer-facing side of substrate, regardless of texture or material. Therefore, creating a design which maximizes angled surface area to benefit the settlement of both communities is ideal. The mats with dead and dried oyster shells creates this scenario – there was a mat for organisms to grow on directly, while the shells created angular surface area for oyster and barnacle settlement. Settlement is also influenced by sedimentation on the substrate with regions of increased sedimentation receiving less settlement, regardless of angle (Lipcius & Burke, 2018). This settlement preference, however, is not a major concern for the Living Dock application as the substrate hangs from the piles, it is not resting on the lagoon bottom.

Future Recommendations

From the three completed studies, coconut coir either alone or concrete coated, was the best alternative to plastic for the Living Dock application. That said, there is still room for improvement and continued study. The coconut coir material was difficult to manage as it comes in long rolls and requires the edges to be woven, braided, or knotted to ensure the weave stays intact. Each scale mat took one person roughly 2.5 hours to complete. Ideally, being able to purchase the mat material pre-cut with pre-woven edges would be ideal in order to minimize construction time and increase citizen science/community involvement opportunities. An improved manner for fastening the shells to the mat is also needed. Re-braiding the material and then dipping in beeswax was not durable enough for a set-and-forget style project, however no knots used to secure the edges of the mat failed. The overall design of the coconut coir mats, while successful in testing, is not ideal for community involvement/citizen science. As community interaction is part of the design criteria for the Living Dock project, identifying ways to make the design more efficient is key. Identifying a manner in which to purchase mats with all edges pre-woven or secured would be ideal but potentially expensive. Identifying if simply tying knots around the edges is suitable would be an affordable, but more tedious option that would still allow for community involvement.

The concrete mixture design also requires further research. As seen from Phase 3, large benthic organism coverage was minimal. Minimal benthic coverage is likely due to material composition and the fact that the study lengths were all under three months, not allowing for long-term settlement trends to be established. One area of interest is adding dead and dried oyster shells or ground oyster shell “dust” to the concrete mixture as a potential method of increasing the settlement rate of oysters and other benthic organisms. The addition of oyster dust or waste oyster shell may aid in making the concrete mixture more resistant to sulfate attack (Kuo, Wang, Shu, & Su, 2013). There is significant research around concrete and marl structure success for oyster restoration (Dunn et al., 2014; George, De Santiago, Palmer, & Beseres Pollack, 2015; Theuerkauf, Eggleston, Theuerkauf, & Puckett, 2017) as well as patents for the combination of concrete and fibrous materials used in oyster restoration (Patent No. US 2018/0049410 A1, 2018). Concrete or lime rock structures result in the highest oyster settlement density whereas concrete or shell structures result in the highest fauna settlement (Graham, Palmer, & Beseres Pollack, 2017). By understanding the settlement preference of key benthic organisms, a targeted concrete-shell-fiber substrate can be created to best ensure benthic diversity and settlement.

As seen in the Phase 3 results and discussion, organisms settled mainly in the area where the two halves of the mat connected as well as between the mats and the pile. A potential modification would be to test different geometric shapes that can fit together, creating more crevices for organisms that prefer a sheltered location. Another possibility would be to create panels which overlap in a roofing shingle design. This would mimic the coverage given by the oyster shells on the tradition mat design, while still utilizing concrete as the substrate. This design change would also allow for silicon molds to be utilized and therefore improve potential for community involvement.

As community interaction is part of the design criteria for the Living Dock project, identifying ways to make the design more efficient is key. Creating build-you-own mat kits would allow community members to have pre-portioned supplies for any Living Dock project, regardless of the materials used. For the current plastic or proposed coconut coir mates, kits would include pre-cut mats, the exact number of shells needed, and zip ties/material to affix the shells and the mat to the pile. For the concrete designs, necessary molds, pre-mixed batches of the metakaolin, sand, and cement would need to be created so that it can be used similar to store-bought "just add water" concrete. By creating these kits, it would allow the community to remain involved while streamlining the construction process.

Chapter 8
Conclusion

There is ongoing work in the Indian River Lagoon to aid in the restoration and rehabilitation of the ecological communities. Through the Save our IRL Plan and efforts by the Indian River Lagoon Research Institute at Florida Tech as well as many other organizations, oyster restoration as well as shoreline restoration is becoming increasingly prevalent. To build off of current restoration efforts, these studies aim to reduce potential microplastic entry into the Indian River Lagoon without changing the parameters and overall design of the Living Dock project. Through the three completed studies, coconut coir – either alone or concrete-coated – was the most promising material for replacing plastic in the Living Dock application. Coconut coir mats showed minimal degradation in water, despite being completely biodegradable, and resulted in more diverse benthic community settlement than any other tested material. The most noticeable difference in organism settlement was the increase in mollusk (predominantly oyster) settlement and the decrease in barnacle settlement. The coconut coir-reinforced concrete application shows promise but needs continued research into improving the concrete mixture as well as mat design to aid in recruitment of larger biofouling communities.

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Appendix A
Phase 2 One-Month Settlement Observations

One-month organism settlement observations for the scaled-design test

Material	Mat Number	Organism Notes
Coconut Coir	1	**Front:** Mainly Barn, many sedimentary and calcareous tubeworms. **Back:** small oysters, small sponges, many small crabs
	2	**Front:** Mainly Barn, many sedimentary and calcareous tubeworms. **Back:** small oysters, small sponges, many small crabs
	3	**Front:** Mainly barnacles. Colonial tunicate acts as adhesive to keep shells on entire matt interconnected.
	4	**Front:** Mainly barnacles, small oysters on both sides. **Back:** Barnacles and small sponges Sedimentary tubeworms settlement on mat under shells
Plastic	1	Almost entirely barnacles, some tubeworms, small colonial tunicate growth on barnacles
	2	Almost entirely barnacles, some tubeworms, small colonial tunicate growth on barnacles
	3	Almost entirely barnacles, some tubeworms, small colonial tunicate growth on barnacles
	4	Almost entirely barnacles, some tubeworms, small colonial tunicate growth on barnacles
Coffee Burlap	1	Barnacles growing on beeswax
	2	Little to no organism growth on remaining material, some encrusting bryozoan growth
	3	Some barnacles growing on beeswax
	4	Some barnacles growing on beeswax
Burlap Ribbon	1	Barnacles growing on beeswax
	2	Barnacles growing on beeswax
	3	Barnacles growing on beeswax
	4	Barnacles growing on beeswax
Concrete-coated Basalt	1A	Barnacles growing on exposed fibers
	1B	
	2A	Barnacles growing on exposed fibers
	2B	
	3A	Barnacle growth along mat attachment points (most remining cementous segment)
	3B	
	4A	Barnacle growth on fiber intersections and in areas of some remaining cementous material
	4B	

Appendix B
Phase 3 Pre-Deployment Measurements

May Deployment Mat Measurements				
Material	**Mat Number**	**Dry Weight (g)**	**Width (in)**	**Length (in)**
Coconut Coir	1	657.42	4	11.8
	2	426.43	5.14	10.4
	3	483.12	5.12	11.9
	4	595.73	6.5	12.3
Plastic	1	409.3	6	11.14
	2	402.5	6.2	12.15
	3	442.87	6.1	11.13
	4	395.23	5.15	11.12
Coffee Burlap	1	410.73	6.5	11.8
	2	417.48	6.1	10.8
	3	303.18	5.12	10.9
	4	376.71	5	11.5
Burlap Ribbon	1	332.47	5.3	13.7
	2	367.01	5.4	12.4
	3	380.88	5.4	12.12
	4	374.48	5.3	12.1
Basalt Cement	1A	151.81	4.5	5.5
	1B	148	5	
	2A	122.7	4.75	
	2B	90.14	4.5	
	3A	106.07	3.5	
	3B	124.65	3.5	
	4A	103.86	4.5	
	4B	100.42	4.75	