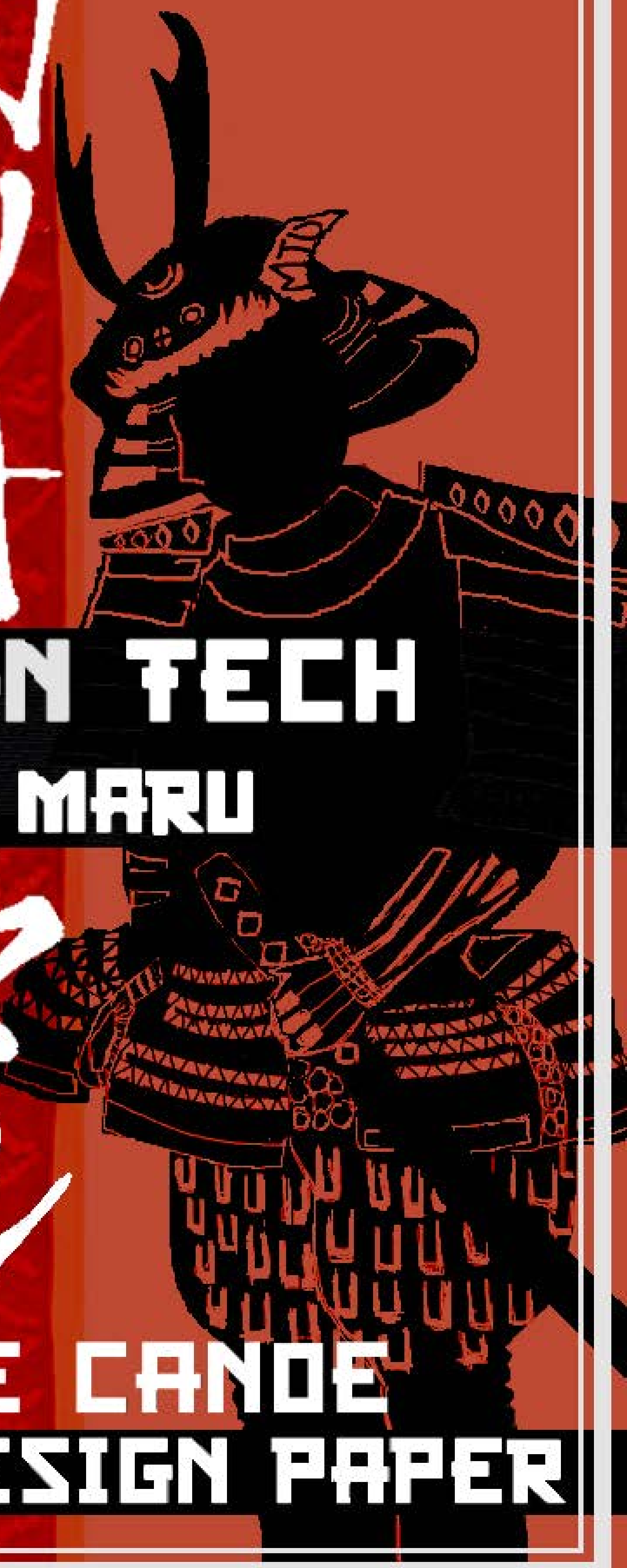
カツオマル

MICHIGAN TECH

KATSUO MARU



2013-2014

CONCRETE CANOE DESIGN PAPER

Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

In early Japan, samurai were fearsome warriors, selfless servants, and dedicated scholars who followed the Way of the Warrior, or bushido. This code of honor governed their lives and demanded from them loyalty, justice, and courage. Their way of life made the samurai not only the protectors of Japan, but leaders within their communities. A samurai was able to face the most formidable opponent, yet maintain a modest, creative, and intellectual life. Their lives consisted of a balance between honor and serenity. The culture surrounding the samurai livelihood is instilled today in icons such as swords, armor, poetry, art, and beliefs. Inspired by the culture of Japan that stemmed from the dedication and determination of these warriors, the Michigan Tech Concrete Canoe team chose this as its theme for the 2014 concrete canoe competition.

Michigan Technological University (Michigan Tech), established in 1885, is located in the western region of Michigan's Upper Peninsula. The Michigan Tech Concrete Canoe team is a member of the North Central Conference and has placed first overall for the past four years. The team has proudly represented the conference at the national level fourteen times, placing sixth, third, and seventh during 2011, 2012 and 2013, respectively. Striving to continue its success, the team optimized a hull design that reduced wave drag while retaining displacement and maneuverability. The turning ability of 2008's *Gambler* and the semi-displacement bulge introduced in 2012's *Genoa* were incorporated into an innovative V-bottom hull design. In addition to these design elements, a workable mix was developed, achieving the highest tensile strength in recent years while maintaining a low unit weight. Hayate, meaning "smooth," was chosen as the name of this final mix. The team also experimented with the possible implementation of recycled water into the mix design. Safety was emphasized throughout development and construction. With this in mind, duct work was added to dramatically improve the air filtration system that was installed last year.

Much like the samurai's loyalty and responsibilities are rewarded for a job well done, the team hopes its past experience and current innovations will be rewarded in this year's competition with its 2013-2014 canoe, *Katsuo Maru.* Properties for this year's canoe can be found in Tables 1, 2, and 3 below.

Table 1: 2014 Concrete properties.

2014 Concrete Properties			
	Unit Weight (pcf)	**Compressive Strength (psi)**	**Tensile Strength (psi)**
Structural	54.4 Wet, 53.1 Dry	1700	400
Finishing	89.6 Wet, 83.4 Dry	1417	235
Inlay/Outlay	71.3 Wet, 65.5 Dry	890	261

Table 2: 2014 Canoe properties.

2014 Canoe Properties	
Weight	170 pounds
Length	20 feet
Width	31.9 inches
Depth	15.4 inches
Nominal Thickness	0.375 inches
Main Color	White
Complimentary Colors	Black, Blue, and Red

Table 3: 2014 Reinforcement properties.

2014 Reinforcement Properties	
Continuous Reinforcement	Kevlar® Fabric 4009-1, 24K Carbon Tow, 0.014 Kevlar Thread
Fiber Reinforcement	Nycon-PVA RF4000, Nycon-PVA RECS15, FORTA® ECONO-NET®

Project Management

The Michigan Tech Concrete Canoe team prides itself on strong leadership, teamwork, and communication. The team is led by two captains. One captain is selected each year to serve a two-year term beginning their third year on the team. This provides for a smooth transition and consistent leadership. A safety chairperson was selected to oversee and ensure proper safety practices during all construction tasks and paddling practices. Experienced members on the team held leadership positions and worked with new members to guarantee that knowledge would be passed along. Additionally, education sessions were conducted to expose new members to concrete canoe project objectives, methods, and concrete basics. The organization chart can be seen on page 2.

The team placed an emphasis on safety throughout the year. In October, a general safety course was held in conjunction with Michigan Tech's Civil and Environmental Engineering Department safety coordinator. This course familiarized all team members with safety procedures and equipment, material safety data sheets, fire extinguishers, exit routes, and emergency contact information. The team's safety chair also demonstrated proper power tool equipment use and care. The use of personal protective equipment was required when preforming any work within the team's facilities.

Milestones were selected from the previous year's project schedule and are indicated by the black dots on the project schedule on page 9. The critical path was based on any project objective that, if not completed by its scheduled date, would postpone completion of the entire project. These activities can be seen on the project schedule in red.

This year, final casting was set back over a month. The most significant delay resulted from minor hull design modifications, which were implemented following prototype construction. Additional delays stemmed from procurement of the mold and reinforcement. Anticipating the possibility of project setbacks, the team incorporated a buffer of two weeks within the project schedule. Through hard work, the setbacks were overcome and all critical project objectives will be completed in time for the Regional Competition.

Figure 1 illustrates how the team members allocated their time throughout the year. In order to create *Katsuo Maru*, the team spent 370 man-hours on hull design, 360 man-hours on structural analysis, 145 man-hours on construction, and expects to devote nearly 630 man-hours to the final aesthetics of *Katsuo Maru*.

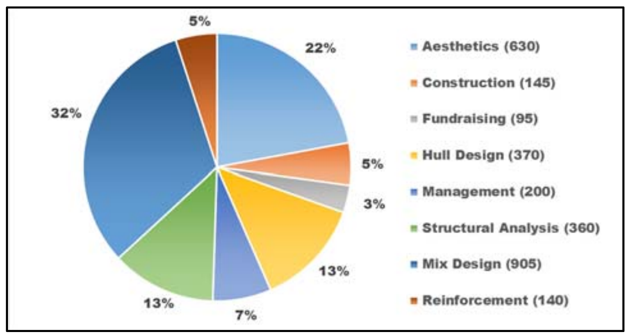


Figure 1: Man-hour allocation chart.

In order to construct *Katsuo Maru*, the team had to procure resources. The team received $3,050 in donations and fundraised over $800. The total cost to the team was about $10400 for all project expenses and travel costs to attend the Regional Competition in Detroit. Figure 2 depicts the financial recourse allocation.

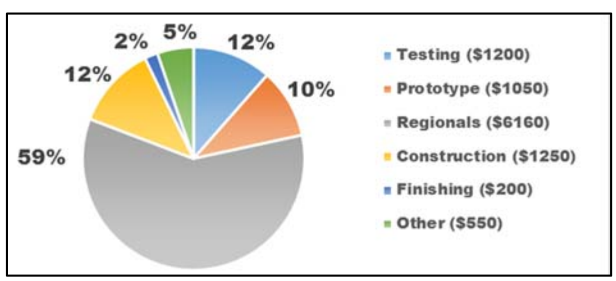


Figure 2: Breakdown of team costs.

Organization Chart

Hull Design and Structural Analysis

Hull design has provided an opportunity for Michigan Tech to showcase its ingenuity in previous competitions. This year, the tradition continued by combining aspects of the 2008 canoe, *Gambler*, and the 2012 canoe, *Genoa*. *Gambler* was utilized for its semi-displacement hull design and excellent turning ability; *Genoa's* bulge was incorporated to optimize displacement and reduce total drag.

After analyzing the 2013 paddling performance, goals for the new canoe design were established: improve straight line tracking performance and decrease drag. Using PROLINES software for design and analysis, a canoe length of 20 feet was chosen to balance turning capability with straight line speed. From previous years' experience, it was apparent that ample freeboard is necessary for effective paddling. Freeboard was set at a minimum of 6 inches for all racing scenarios to increase paddler comfort, safety, and leaning ability in a buoy turn.

This year a V-bottom hull was developed to slice through the water, providing greater lift and lower drag. *Katsuo Maru* achieved the lowest total drag of any past Michigan Tech canoe, beating its predecessor, *Mesektet*, by 7%. Similarly, block coefficient decreased from 0.36 to 0.31. The progression of block coefficients over the last five Michigan Tech hulls are shown in Figure 3. Block coefficient is a strong indicator of a canoe's performance in the water, representing the ratio of the submerged volume of the canoe to the volume of the smallest box that still encases the wetted surface area of the canoe.

To increase turning ability with the V-bottom hull design, rocker was set at 6.1 inches in the bow and 2.15 inches in the stern. Combining this rocker and the bulge allows *Katsuo Maru* to pivot with both ends of the canoe out of the water, reducing waterplane area, thus improving maneuverability.

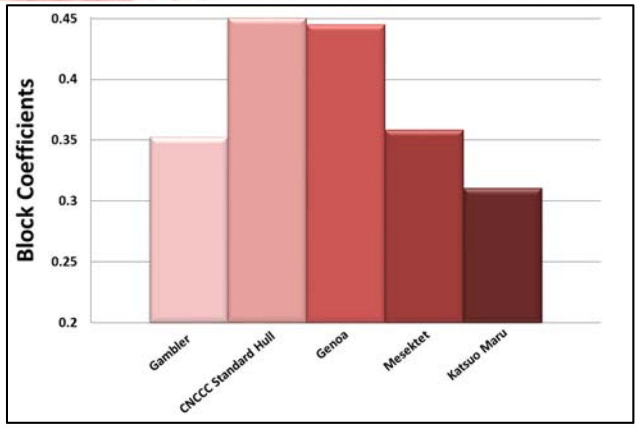


Figure 3: Block Coefficients comparison: 2008 to 2014

To practice with the design, a prototype was constructed of low-cost luan wood as shown in Figure 4. To better capture the complex hull geometry, luan strips were cut to a width of ½ inch rather than ¾ inch as used in previous years. After testing paddler ergonomics, the final design was modified to decrease the severity of the V-bottom hull. This modification improved paddler comfort and stability.

Figure 4: Testing of the constructed prototype, Kanu

Achieving this year's goals optimized paddler efficiency, reduced drag, and ultimately increased maximum velocity. These accomplishments resulted in the finest design yet created by Michigan Tech displayed in Figure 5.

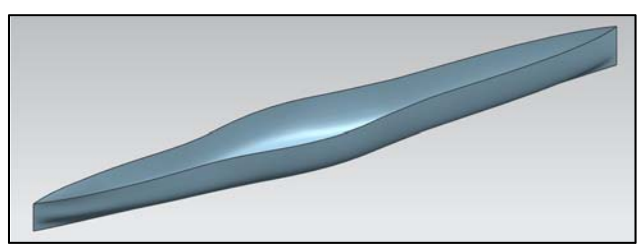


Figure 5: Michigan Tech's final hull design

In order to determine the survivability of *Katsuo Maru*, hand calculations, iterated in MATLAB and Excel, were performed to compare the maximum principal stresses during five different load cases. The principal stresses in each of the paddling load cases were found by combining the normal stresses from flexural bending and shear stresses from torsion developed during a buoy turn. Each race was modeled using four possible combinations of paddlers sitting and kneeling. Pure bending was also considered during transportation and display of *Katsuo Maru*. Allowable stress design was used to determine *Katsuo Maru's* safety factor.

In order to perform these calculations, a few assumptions needed to be made. First, the bending stresses were calculated assuming straight-line dynamic loading conditions. Male and female paddlers' weights, 200 pounds and 170 pounds, respectively, were increased by 20% to account for additional loading during a paddle stroke. Each paddler was represented by two linear distributive loads. Seated paddlers were found to transfer 83% of their weight, whereas kneeling paddlers transferred 41% of their weight through the rear contact length. *Katsuo Maru* was modeled with a nominal thickness of 3/8 inch and a self-weight of 160 pounds. For this analysis, the canoe and the water were assumed to be in equilibrium.

Width and height dimensions were taken at one inch increments along the length of *Katsuo Maru* to develop shallow V-bottom cross-sections, see figure 6, at each of these locations.

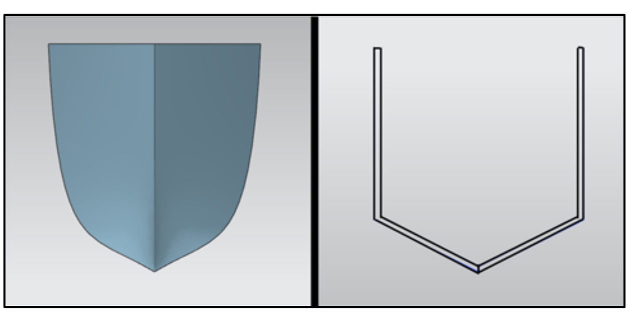


Figure 6: Developed cross sections of *Katsuo Maru's* V-bottom hull

The volume of each one inch segment was calculated to accurately model the varying buoyancy force pushing upward on the canoe.

The maximum normal stress in the gunwales, chines, and keel of each cross-section was calculated and can be seen in Table 4. Shear stresses in the chines developed from torsional forces during a buoy turn were then calculated using shear flow analysis for open cross-sections (*Journal*.) The load case with two kneeling male paddlers yielded the maximum principal tensile stress of 270 psi, located in the gunwale, 7.5 feet from the stern of the canoe. This is located at the center of *Katsuo Maru's* bulge. The maximum compressive stress of 539 psi was located one foot from the stern along the keel during the coed race.

Table 4: Principle stresses found from structural analysis.

Load Case	**Critical Stresses**	
	Compressive (psi)	Tensile (psi)
2 Males	216	270
2 Females	188	234
2 Males & 2 Females	240	258
Stands	25	35
Transport	24	31

The tensile and compressive strengths of Hayate are 400 psi and 1700 psi, respectively. This means that the gunwales of *Katsuo Maru* would have a factor of safety of 1.48 for tensile failure, and the keel has a factor of safety of 7.08 for compressive failure without reinforcement. However, the team chose to design for a safety factor of 3.0, which required one layer of reinforcement to increase the tensile strength of the canoe and ensure *Katsuo Maru* will survive the rigors of competition. With these concerns in mind, the team considered additional testing to determine an appropriate reinforcement scheme.

Development and Testing

The team had several goals in mind throughout the mix development process. A structural mix with high tensile strength and low unit weight was crucial. Aesthetics were also a priority, as an all-white mix was needed to complement *Katsuo Maru*'s design. Last year's structural mix, Musa, was used as a baseline because it met initial strength, weight, and color criteria. However, it was difficult to cast due to low workability. Data comparing Hayate to last year's mix is shown in Table 5 below.

The team conducted three tiers of testing to examine the effects of binders, aggregates, and fibers. The water-to-cementitious material ratio (w/cm ratio) decreased from 0.40, as seen in Musa, to 0.38. In addition, the aggregate-to-binder ratio decreased from 4.5 to 4.25. Both of these adjustments contributed to an overall increase in strength.

This year, white Portland cement, ground granulated blast furnace slag (GGBFS), and VCAS 160 were all re-examined from last year's mix design. After discussion with the supplier, VCAS 140 was incorporated into testing. Two mechanically ground pumice pozzolans, Hess Pozz and Hess Ultra Pozz, were also tested for the first time.

Poraver glass microspheres of 1-2 mm, 0.5-1 mm, and 0.25-0.5 mm, the same grades used in Musa, were utilized during testing. Similarly, 3M™ K1 glass microspheres were carried over as an aggregate. A new material, Elemix, composed of lightweight, synthetic particles, was included in the aggregate tier. Poraver 0.1-0.3 mm spheres were also used in the finishing mix to produce a finer gradation.

During *Mesektet*'s casting, many trowelers found it difficult to create 1/8 inch layers with Musa. One of these reasons was believed to be the blend of secondary fibers used in the mix as shown in Table 6. In order to determine if this truly was the case, mixes from the fiber tier were used for troweling practices prior to casting. It was found that by limiting the amount of FORTA® PE-2 and GRT Polymesh, workability would increase without having a substantial impact on strength. In addition, FORTA® ECONO-NET®, a fibrillated polypropylene fiber, was utilized.

Table 6: Comparison of Secondary Reinforcement Used

Fiber Type	Composition	Musa	Hayate
(PVA) Fibers	Polyvinyl Alcohol	✓	✓
PE-2	Polyethylene	✓	
Polymesh	Polypropylene	✓	
ECONO-NET	Polypropylene		✓

The final structural mix incorporates the best qualities of the previously tested batches. Hayate's binders include white Portland cement, GGBFS, and VCAS 140 and160. Aggregates included Poraver 1-2 mm, 0.5-1 mm, and 0.25-0.5 mm, 3M K1, and Elemix. A finishing mix and inlay/outlay mix were adapted from Hayate using the same binders, while omitting the fibers and incorporating a blend of aggregates suitable for each mixes intended purpose. While there was a slight increase in unit weight and a decrease in compressive strength, the team was satisfied with the 27% increase in tensile strength from Musa. Final mix components have been included in Appendix B.

Tensile and compression testing were performed at 7 and 14 days in accordance with ASTM standards. For each batch, four 3" by 6" cylinders were cast for split tensile tests, while only two 3" by 6" cylinders were cast for uniaxial compression tests.

Table 5: Engineering properties 2013-2014

Year	Mix Name	Unit Weight (pcf)	14-Day Compressive Strength (psi)	14- Day Tensile Strength (psi)
2013	Musa	53.5	1915	314
2014	Hayate	53.9	1700	400

In addition to efforts concerning strength, weight, and workability, the team investigated ways to increase the sustainability of this year's mix. Previously, a water filtration system was installed in the team's facility with the intent of recycling water for use in mixing. Prior to this year, it had only been used to wash equipment. To determine if this water was adequate for use in the mix, two batches of the same mix were made, one with control water and one with recycled water. However, the batch containing recycled water failed to meet the 90% minimum compressive strength of the control water required by ASTM C1602. Therefore, the recycled water could not be used and the water filtration system must be refined before the water can be implemented in mixes.

Previously used reinforcements, Chromarat C-Grid® CT275 Carbon Fiber Grid and Kevlar® 4009-1, were used as baselines for researching new materials. This year, reinforcement with larger grid spacing and no epoxy coating was desired to promote bonding between the layers of concrete. However, prefabricated reinforcements which featured large grids were typically epoxy coated during production. The team decided to engineer a reinforcement when research failed to find a manufactured material that met the set requirements.

To begin the development of a woven, engineered grid, 24K Carbon Tow was procured for testing. Percent open area (POA) calculations were generated to determine the spacing for grids of forty, fifty, sixty, and seventy POA. A square foot grid was woven by interlacing 24K Carbon Tow with 0.014 inch diameter Kevlar® thread for each potential POA. Plates were then cast using Musa to provide comparable results for previous punching shear tests.

Punching shear tests were conducted assuming an isotropic composite, where both in-plane and out-of-plane yield stress values were the same. Plates were supported by a wooden frame as a uniform 1.5 inch diameter force was applied at a steady rate of 2.5 pound-mass per second. The data was used to develop stress-strain curves for analysis. The smaller POA obtained a higher yield strength, as shown in Table 7. However, 50% open area was chosen to provide a balance between material cost, yield strength, and bonding properties between concrete layers.

Table 7: Initial woven, engineered grid testing results

Percent Open Area	Yield Stress (ksi)
40	5063
50	4425
60	3781
70	2625

To create the reinforcement grids used in *Katsuo Maru*, the construction process was modified to increase efficiency and ensure proper POA. Instead of weaving Kevlar® thread throughout the grid, knots were tied along the border and at alternating intersections between the carbon fiber strands as shown in Figure 7. The reinforcement scheme in the canoe consists of a single woven sheet in the bottom of the canoe and eleven panels in the side walls. In the bottom of the canoe, a second layer of reinforcement was added to account for punching shear. However, due to time and space constraints, a sheet of Kevlar® 4009-1 was used for this second layer instead of the woven, engineered grid.

Figure 7: Construction of the woven, engineering grid

The Rule of Mixtures was used to find the maximum tensile strength, which occurs at the top of the gunwales. A 3/8 inch layer of Hayate containing one layer of the woven, engineered grid was used to simulate this composite and yielded a composite flexural strength of 1390 psi. This allowed *Katsuo Maru*'s safety factor to be increased from 1.48 to 11.0.

Construction

This year, the team aimed to trowel *Katsuo Maru* to a nominal thickness of 3/8 inch. A female mold was necessary to accurately capture the complex geometry of the hull.

The team ordered a CNC-milled mold made from 10% pre-consumer recycled high-density polystyrene foam. The mold was received in six sections, cut in half through the keel and into thirds along the length of the canoe. The sections were put together and fastened by aligning the edges and attaching the mold to a rigid frame. This can be seen in the design drawing located on page 10.

Two layers of epoxy were applied to the mold to provide a stiff surface for concrete placement and a barrier to prevent water loss through the foam. Thirty minutes prior to casting, Huron Technologies Release Coating 7572 was applied to the mold; manufacturer specifications state that the release agent is designed for use between concrete and epoxy surfaces for an aesthetically-appealing result.

On casting day, the team was divided into specific assignments. Eight trowelers and four quality control (QC) monitors were selected to construct the canoe and ensure proper thickness. The remaining members were assigned either to the reinforcement team, which guaranteed proper placement of the reinforcement, or the mix crew, which ensured consistent concrete throughout the casting process. The team captains served as runners between two separate rooms for casting and mixing to facilitate communication throughout the day.

Fewer QC monitors were utilized compared to previous years to reduce the number of personnel within the casting area. As a result, casting was completed using a section approach, where each troweler was assigned a specific section to cast, rather than casting each layer through an assembly line style.

Team members assigned to QC used premeasured depth gauges to determine the thickness of the canoe throughout construction. The team has had problems with QC in the past, so a new style of depth gauge was created this year. The new gauges were designed using Unigraphics software and then 3D printed. Each gauge consisted of a measured cylinder extending from a circular disk. A longer handle was also added to ease grip when wearing gloves. Gauge depths of 1/8 inch, 1/4 inch, and 3/8 inch were made for successive concrete layers. The gauge diameter was also modified to ensure that the gauge could pass through the concrete without compromising the surface of the mold or the Kevlar® reinforcement. Figure 7 shows the depth gauges used this year compared to those used in construction of *Mesektet.*

Figure 8: Comparison of 2013 and 2014 QC depth gauges

Katsuo Maru was cast with three 1/8 inch layers of structural concrete, two layers of reinforcement, and one layer of finishing mix.

According to analysis and previous years' experience, the team was able to determine that one layer of reinforcement throughout the walls would be sufficient. Eleven panels of the woven, engineered grid were placed within the walls. Previous testing has shown that two layers of reinforcement are necessary along the bottom of the canoe to prevent failure from punching sheer. The bottom consisted of one layer of the custom grid reinforcement and one layer of Kevlar® reinforcement. The final reinforcement scheme is shown in Figure 9.

Figure 9: Reinforcement arrangement within *Katsuo Maru*

Having successfully cast a gunwale cap with a female mold in years past, the team implemented the same process for *Katsuo Maru.* Extruded polystyrene foam was used as a placement guide for the gunwale caps on casting day. One layer of epoxy and one layer of release aid were applied to the polystyrene form. This prevented the concrete from sticking while still allowing the foam to shape to the curves of the gunwale. On casting day, these forms were clamped to the mold after the main body of the canoe was completed. The foam molds were filled partially with a concrete layer. After a strip of Kevlar reinforcement was placed throughout the cap, the molds were filled and leveled. The completed gunwale caps are shown in Figure 10.

Figure 10: Gunwale caps were cast following the completion of *Katsuo Maru's* hull

The final thickness of the canoe was measured to be 3/8 inch, which met the team's casting goal for *Katsuo Maru.*

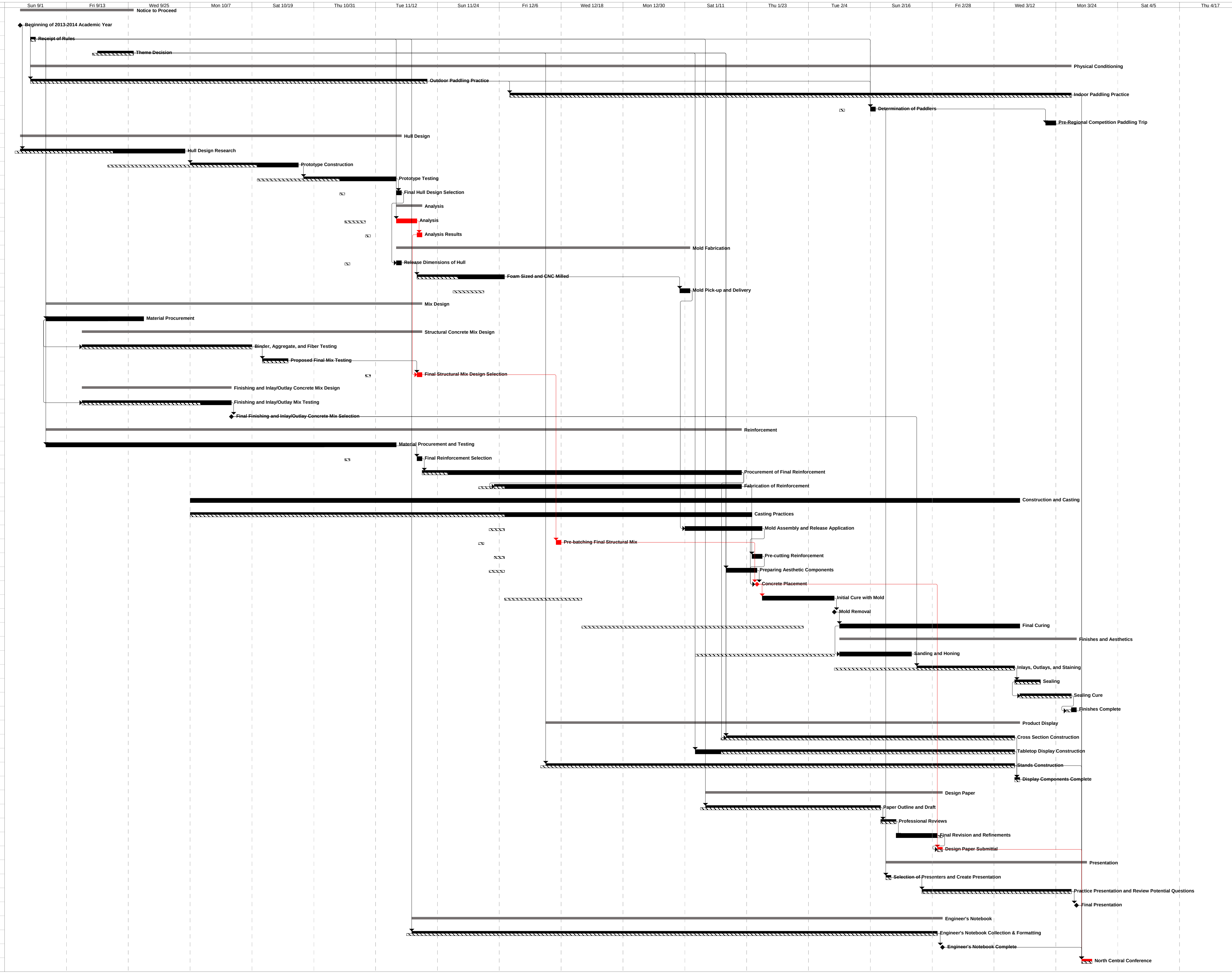
After two weeks of curing, the mold was removed from the canoe. A week of initial sanding commenced. Finishing mix was then applied, followed by five weeks of extensive sanding. This year, the air filtration system in the finishing area was improved to provide safer conditions for team members during sanding. Duct work was extended to provide more efficient dust removal. Flexible hoses were also added to deliver spot-specific vacuuming as needed.

The air compressor within the facilities will be utilized for airbrush staining. The team has found that this method guarantees uniform covering for base coats and large details. Compared to previous methods which required the use of aerosol cans, the air compressor reduces material consumption and costs. Remaining intricate details will be painted by hand in order to express the character of *Katsuo Maru.*

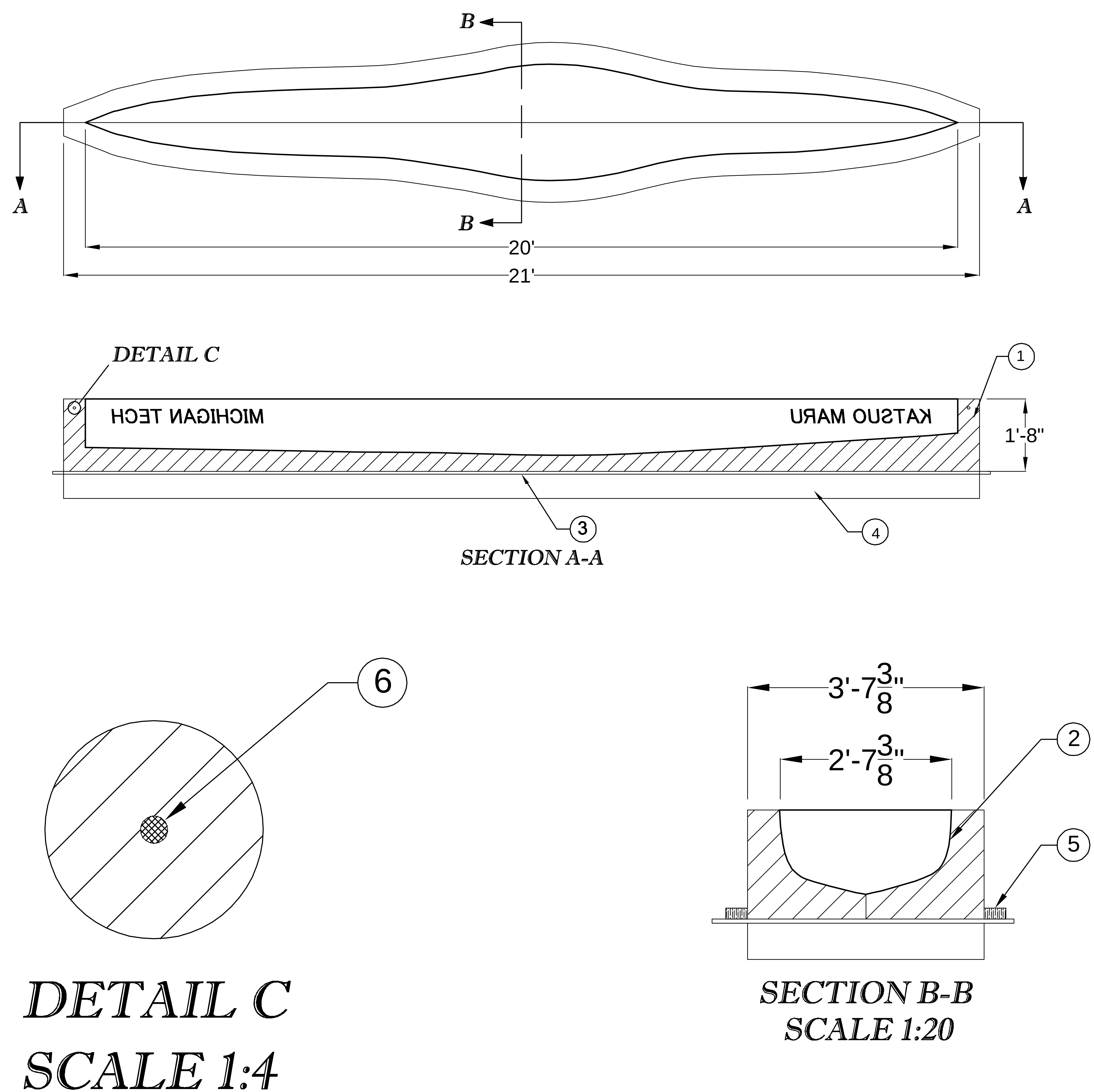
After staining is completed, two layers of ChemMasters® Crystal Clear-A will be applied. This sealant is used to protect and enhance the finished aesthetics. One week is required for the sealant to set.

Katsuo Maru's innovative hull design combined with Hayate's impressive tensile strength result in the greatest concrete canoe designed by Michigan Tech. The team is excited to demonstrate what it has learned this year and hopes that *Katsuo Maru* will bring another honorable and rewarding year.

ID	Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish
1	**Notice to Proceed**	**Tue 9/3/13**	**Wed 9/25/13**	**Tue 9/3/13**	**Wed 9/25/13**
2	Beginning of 2013-2014 Academic Year	Tue 9/3/13	Tue 9/3/13	Tue 9/3/13	Tue 9/3/13
3	Receipt of Rules	Fri 9/6/13	Fri 9/6/13	Fri 9/6/13	Fri 9/6/13
4	Theme Decision	Wed 9/18/13	Wed 9/25/13	Wed 9/18/13	Wed 9/25/13
5	**Physical Conditioning**	**Fri 9/6/13**	**Wed 3/26/14**	**Fri 9/6/13**	**Wed 3/26/14**
6	Outdoor Paddling Practice	Fri 9/6/13	Thu 11/21/13	Fri 9/6/13	Thu 11/21/13
7	Indoor Paddling Practice	Sun 12/8/13	Wed 3/26/14	Sun 12/8/13	Wed 3/26/14
8	Determination of Paddlers	Mon 2/10/14	Mon 2/10/14	Sun 2/16/14	Sun 2/16/14
9	Pre-Regional Competition Paddling Trip	Sat 3/22/14	Sun 3/23/14	Sat 3/22/14	Sun 3/23/14
10	**Hull Design**	**Tue 9/3/13**	**Tue 11/5/13**	**Tue 9/3/13**	**Sat 11/16/13**
11	Hull Design Research	Tue 9/3/13	Sat 9/21/13	Tue 9/3/13	Sat 10/5/13
12	Prototype Construction	Sat 9/21/13	Sat 10/19/13	Sun 10/6/13	Sun 10/27/13
13	Prototype Testing	Sun 10/20/13	Mon 11/4/13	Mon 10/28/13	Fri 11/15/13
14	Final Hull Design Selection	Tue 11/5/13	Tue 11/5/13	Sat 11/16/13	Sat 11/16/13
15	**Analysis**	**Wed 11/6/13**	**Sun 11/10/13**	**Sat 11/16/13**	**Wed 11/20/13**
16	Analysis	Wed 11/6/13	Sat 11/9/13	Sat 11/16/13	Tue 11/19/13
17	Analysis Results	Sun 11/10/13	Sun 11/10/13	Wed 11/20/13	Wed 11/20/13
18	**Mold Fabrication**	**Mon 11/18/13**	**Sat 1/11/14**	**Sat 11/16/13**	**Sat 1/11/14**
19	Release Dimensions of Hull	Wed 11/6/13	Wed 11/6/13	Sat 11/16/13	Sat 11/16/13
20	Foam Sized and CNC Milled	Wed 11/20/13	Wed 11/27/13	Wed 11/20/13	Fri 12/6/13
21	Mold Pick-up and Delivery	Wed 11/27/13	Mon 12/2/13	Fri 1/10/14	Sat 1/11/14
22	**Mix Design**	**Mon 9/9/13**	**Fri 11/8/13**	**Mon 9/9/13**	**Wed 11/20/13**
23	Material Procurement	Mon 9/9/13	Fri 9/20/13	Mon 9/9/13	Fri 9/27/13
24	**Structural Concrete Mix Design**	**Mon 9/16/13**	**Fri 11/8/13**	**Mon 9/16/13**	**Wed 11/20/13**
25	Binder, Aggregate, and Fiber Testing	Mon 9/16/13	Fri 10/18/13	Mon 9/16/13	Fri 10/18/13
26	Proposed Final Mix Testing	Mon 10/21/13	Fri 10/25/13	Mon 10/21/13	Fri 10/25/13
27	Final Structural Mix Design Selection	Sun 11/10/13	Sun 11/10/13	Wed 11/20/13	Wed 11/20/13
28	**Finishing and Inlay/Outlay Concrete Mix Design**	**Tue 9/10/13**	**Wed 10/9/13**	**Mon 9/16/13**	**Tue 10/15/13**
29	Finishing and Inlay/Outlay Mix Testing	Mon 9/16/13	Tue 10/8/13	Mon 9/16/13	Mon 10/14/13
30	Final Finishing and Inlay/Outlay Concrete Mix Selection	Wed 10/9/13	Wed 10/9/13	Tue 10/15/13	Tue 10/15/13
31	**Reinforcement**	**Mon 9/9/13**	**Fri 12/6/13**	**Mon 9/9/13**	**Tue 1/21/14**
32	Material Procurement and Testing	Mon 9/9/13	Fri 11/1/13	Mon 9/9/13	Fri 11/15/13
33	Final Reinforcement Selection	Wed 11/6/13	Wed 11/6/13	Wed 11/20/13	Wed 11/20/13
34	Procurement of Final Reinforcement	Thu 11/21/13	Mon 11/25/13	Thu 11/21/13	Tue 1/21/14
35	Fabrication of Reinforcement	Mon 12/2/13	Fri 12/6/13	Wed 12/4/13	Tue 1/21/14
36	**Construction and Casting**	**Mon 10/7/13**	**Sun 3/16/14**	**Mon 10/7/13**	**Sun 3/16/14**
37	Casting Practices	Mon 10/7/13	Fri 12/6/13	Mon 10/7/13	Thu 1/23/14
38	Mold Assembly and Release Application	Wed 12/4/13	Fri 12/6/13	Sat 1/11/14	Sat 1/25/14
39	Pre-batching Final Structural Mix	Mon 12/2/13	Mon 12/2/13	Tue 12/17/13	Tue 12/17/13
40	Pre-cutting Reinforcement	Thu 12/5/13	Fri 12/6/13	Thu 1/23/14	Sat 1/25/14
41	Preparing Aesthetic Components	Wed 12/4/13	Fri 12/6/13	Sat 1/18/14	Fri 1/24/14
42	Concrete Placement	Sat 12/7/13	Sat 12/7/13	Sat 1/25/14	Sat 1/25/14
43	Initial Cure with Mold	Sat 12/7/13	Sat 12/21/13	Sat 1/25/14	Sat 2/8/14
44	Mold Removal	Sat 12/21/13	Sat 12/21/13	Sat 2/8/14	Sat 2/8/14
45	Final Curing	Sun 12/22/13	Sun 2/2/14	Sun 2/9/14	Sun 3/16/14
46	**Finishes and Aesthetics**	**Mon 1/13/14**	**Wed 3/26/14**	**Sun 2/9/14**	**Thu 3/27/14**
47	Sanding and Honing	Mon 1/13/14	Sat 2/8/14	Sun 2/9/14	Sun 2/23/14
48	Inlays, Outlays, and Staining	Sun 2/9/14	Sat 3/15/14	Mon 2/24/14	Sat 3/15/14
49	Sealing	Sun 3/16/14	Thu 3/20/14	Sun 3/16/14	Thu 3/20/14
50	Sealing Cure	Mon 3/17/14	Wed 3/26/14	Mon 3/17/14	Wed 3/26/14
51	Finishes Complete	Wed 3/26/14	Wed 3/26/14	Thu 3/27/14	Thu 3/27/14
52	**Product Display**	**Sat 12/14/13**	**Sun 3/16/14**	**Sat 12/14/13**	**Sun 3/16/14**
53	Cross Section Construction	Sat 1/18/14	Sat 3/15/14	Sat 1/18/14	Sat 3/15/14
54	Tabletop Display Construction	Sat 1/18/14	Sat 3/15/14	Mon 1/13/14	Sat 3/15/14
55	Stands Construction	Sat 12/14/13	Sat 3/15/14	Sat 12/14/13	Sat 3/15/14
56	Display Components Complete	Sun 3/16/14	Sun 3/16/14	Sun 3/16/14	Sun 3/16/14
57	**Design Paper**	**Mon 1/13/14**	**Sat 3/1/14**	**Tue 1/14/14**	**Sat 3/1/14**
58	Paper Outline and Draft	Tue 1/14/14	Mon 2/17/14	Tue 1/14/14	Mon 2/17/14
59	Professional Reviews	Tue 2/18/14	Thu 2/20/14	Tue 2/18/14	Thu 2/20/14
60	Final Revision and Refinements	Fri 2/21/14	Sat 3/1/14	Fri 2/21/14	Fri 2/28/14
61	Design Paper Submittal	Sat 3/1/14	Sat 3/1/14	Sat 3/1/14	Sat 3/1/14
62	**Presentation**	**Tue 1/28/14**	**Sat 3/29/14**	**Wed 2/19/14**	**Sat 3/29/14**
63	Selection of Presenters and Create Presentation	Wed 2/19/14	Wed 2/19/14	Wed 2/19/14	Wed 2/19/14
64	Practice Presentation and Review Potential Questions	Wed 2/26/14	Wed 3/26/14	Wed 2/26/14	Wed 3/26/14
65	Final Presentation	Fri 3/28/14	Fri 3/28/14	Fri 3/28/14	Sat 3/29/14
66	**Engineer's Notebook**	**Mon 11/18/13**	**Sat 3/1/14**	**Mon 11/18/13**	**Sat 3/1/14**
67	Engineer's Notebook Collection & Formatting	Mon 11/18/13	Fri 2/28/14	Mon 11/18/13	Fri 2/28/14
68	Engineer's Notebook Complete	Sat 3/1/14	Sat 3/1/14	Sat 3/1/14	Sat 3/1/14
69	North Central Conference	Sat 3/29/14	Sun 3/30/14	Sat 3/29/14	Sun 3/30/14



Critical Path | Task | Milestone ◆ | Summary | Critical | Critical Split | Baseline



Katsuo Maru

MichiganTech

Michigan Technological Universit

1400 Townsend Dr.
Concrete Canoe
Houghton MI, 49931

Bill of Materials

No.	Qty.	Descriptior
1	6 Parts	Polystyrene Foam
2	1 gal	Epoxy
3	48 ft²	3/4" OSB
4	56 LFT	2x6 Lumber
5	56 LFT	2x4 Lumber
6	2 ea.	3/8"x8" Bolt Assembl

Drawing Name: Mold Desigr

Boat Name: Katsuo Maru

Drawn By: Philip Doederlein

Checked By: Mike Larson

Date: 14 Feb. 2014

Scale: 1:30 Sheet: 1

Appendix A – References

ASTM. (2009). “Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate.” *C29/C29M-09,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Practice for Making and Curing Concrete Test Specimens in the Field.”*C31/C31M-12,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.”*C39/C39M-12a,* West Conshohocken, Pennsylvania.

ASTM. (2013). “Standard Terminology Relating to Concrete and Concrete Aggregates.” *C125-13a,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate.” *C127-12,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate.” *C128-12,* West Conshohocken, Pennsylvania.

ASTM. (2006). “Standard Test Method for Sieve Analysis of Fine and Course Aggregates.” *C136-06,* West Conshohocken, Pennsylvania.

ASTM. (2013). “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.” *C138 /C138M-13,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Test Method for Slump of Hydraulic-Cement Concrete.” *C143 / C143M - 12,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Specification for Portland Cement.” *C150 / C150M-12,* West Conshohocken, Pennsylvania.

ASTM. (2010). “Standard Practice for Sampling Freshly Mixed Concrete.” *C172-10,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.” *C173 / C173M - 12,* West Conshohocken, Pennsylvania.

ASTM. (2010). “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.” *C231 / C231M -10,* West Conshohocken, Pennsylvania.

ASTM. (2010). “Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.” *C469 / C469M-10,* West Conshohocken, Pennsylvania.

ASTM. (2013). “Standard Specification for Chemical Admixtures for Concrete.” *C494/C494M-13,* West Conshohocken, Pennsylvania.

ASTM. (2011). “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.” *C496/C496M-11,* West Conshohocken, Pennsylvania.

ASTM. (2011). “Standard Test Method for Determining Density of Structural Lightweight Concrete.”*C567-11,* West Conshohocken, Pennsylvania.

ASTM. (2010). “Standard Specification for Pigments for Integrally Colored Concrete.” *C979-10,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Specification for Ground Granulated Blast-Furnace Slag for use in Concrete and Mortars.” *C989-12a,* Conshohocken, Pennsylvania.

ASTM. (2010). “Standard Specification for Fiber Reinforced Concrete.” *C1116/C1116M-10a,* West Conshohocken, Pennsylvania.

ASTM. (2011). “Standard Specification for Latex and Powder Polymer Modifiers for Hydraulic Cement Concrete and Mortar.” *C1438-11a,* West Conshohocken, Pennsylvania.

ASTM. (2012). “Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.” *C1602 / C1602M - 12, West Conshohocken, Pennsylvania.*

Chu, Kuang-Han, and Anatole Longinow. "Torsion in Sections with Open and Closed Parts."*Journal of the Structural Division* 93.AUG (1967): 213-27. Print.

Gluckman, Dale Carolyn and Sharon Sadako Takeda et al. When Art Became Fashion: Kosode in Edo-Period Japan. Los Angeles: Los Angeles County Museum of Art. Web. 28 February 2014.

Mamlouk, Michael S., and John P. Zaniewski. “*Materials for Civil and Construction Engineers*.” Upper Saddle River: Prentice Hall, 2011. Print

Michigan Tech Concrete Canoe. (2005). “The MacInnes.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

Michigan Tech Concrete Canoe. (2008). “Gambler.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

Michigan Tech Concrete Canoe. (2011). “Frontier.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

Michigan Tech Concrete Canoe. (2012). “Genoa.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

Michigan Tech Concrete Canoe. (2013). “Mesektet.” NCCC Design Paper, Michigan Technological University, Houghton, Michigan.

NCCC Rules. (2014). “2014 American Society of Civil Engineers National Concrete Canoe Competition Rules and Regulations,” online at: http://www.asce.org/uploadedFiles/Concrete_Canoe/Rules_and_Regulations/2014%20ASCE%20NCCC%20Rules%20and%20Regulations.pdf

KATSUO MARU
MICHIGAN TECHNOLOGICAL UNIVERSITY

Appendix B- Mixture Proportions

	Mixture ID: Hayate		Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3): 0.195							
Cementitious Materials		SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Federal White Type I Portland Cement	3.15	394.22	2.006	2.84	0.014	403.50	2.053
CM2	Lafarge NewCem®GGBFS	2.99	149.68	0.802	1.08	0.006	153.20	0.821
CM3	VCAS™ 140	2.60	65.09	0.401	0.47	0.003	66.62	0.411
CM4	VCAS™ 160	2.60	130.15	0.802	0.94	0.006	133.22	0.821
	Total Cementitious Materials:		739.14	4.011	5.33	0.029	756.54	4.106
Fibers								
F1	Nycon-PVA RF4000	1.30	6.72	0.083	0.05	0.001	6.88	0.085
F2	Nycon-PVA RECS15	1.30	5.50	0.068	0.04	0.000	5.63	0.069
F3	FORTA® ECONO-NET®	0.91	0.46	0.008	0.00	0.000	0.47	0.008
	Total Fibers:		12.68	0.159	0.09	0.001	12.98	0.162
Aggregates								
A1	Poraver 1-2 mm Abs: 0.2	0.39	124.47	5.115	0.90	0.037	127.40	5.235
A2	Poraver 0.5-1.0 mm Abs: 0.25	0.47	74.99	2.557	0.54	0.018	76.76	2.617
A3	Poraver 0.25-0.5 mm Abs: 0.3	0.59	62.77	1.705	0.45	0.012	64.25	1.745
A4	3M™ K-1 Abs: 0.22	0.13	48.41	5.967	0.35	0.043	49.55	6.108
A5	Elemix Abs: 0.055	0.04	4.46	1.702	0.03	0.012	4.57	1.742
	Total Aggregates:		315.10	17.046	2.27	0.123	322.52	17.448
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	280.87	4.501	2.03	0.032	287.49	4.607
	W1a. Water from Admixtures		6.07		0.32		6.22	
	W1b. Additional Water		274.80		1.70		281.27	
W2	Water for Aggregates, SSD	1.00	73.37		0.53		75.09	
	Total Water *(W1 + W2)*:		354.24	4.501	2.56	0.032	362.58	4.607
Solids Content of Latex, Dyes and Admixtures in Powder Form								
S1	Xypex Xycrylic	1.05	13.85	0.211	0.10	0.002	14.18	0.216
	Total Solids of Admixtures:		13.85	0.211	0.10	0.002	14.18	0.216
Admixtures (including Pigments in Liquid Form)		% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)
Ad1	Xypex Xycrilic *8.8 lb/gal*	28.02	38.05	5.39	2.03	0.29	38.95	5.52
Ad2	BASF Glenium® 3030NS *9.2 lb/gal*	20.27	6.34	0.68	0.34	0.04	6.49	0.70
	Water from Admixtures *(W1a)*:			6.07		0.32		6.22
	Cement-Cementitious Materials Ratio		0.53		0.53		0.53	
	Water-Cementitious Materials Ratio		0.38		0.38		0.38	
	Slump, Slump Flow, *in*.		1 in ± 0.5 in		0.5 in		0.5 in	
M	Mass of Concrete. *lbs*		1435.02		10.35		1468.80	
V	Absolute Volume of Concrete, ft^3		25.93		0.19		26.54	
T	Theorectical Density, lb/ft^3 = *(M / V)*		55.3		55.3		55.3	
D	Design Density, lb/ft^3 = *(M / 27)*		53.1					
D	Measured Density, lb/ft^3				54.4		54.4	
A	Air Content, % = *[(T - D) / T x 100%]*		3.97		1.71		1.71	
Y	Yield, ft^3 = *(M / D)*		**27**		0.19		**27**	
Ry	Relative Yield = *(Y / Y_D)*				0.977			

Appendix C – Bill of Materials

Material	Units	Quantity	Unit Price	Total
Federal White Type I White Portland Cement	lb	67.75	$0.27	$18.29
Lafarge NewCem® GGBFS	lb	25.72	$0.05	$1.29
VCAS™ 140	lb	11.18	$0.35	$3.91
VCAS™ 160	lb	22.37	$0.35	$7.83
Poraver® 1.0-2.0mm	lb	18.98	$0.85	$16.13
Poraver® 0.5-1.0mm	lb	11.45	$0.85	$9.73
Poraver® 0.25-0.5mm	lb	9.53	$0.85	$8.10
Poraver® 0.1-0.3mm	lb	1.51	$0.85	$1.28
3M™ K-1	lb	7.66	$11.03	$84.49
Elemix	lb	0.64	$2.50	$1.60
Nycon Kuralon™ RECS15 (8mm) PVA	lb	0.97	$6.60	$6.40
Nycon Kuralon™ RF4000 (30mm) PVA	lb	0.79	$6.90	$5.45
FORTA® ECONO-NET®	lb	0.13	$5.30	$0.69
Xypex Xycrylic-Admix	gal	0.50	$5.10	$2.55
BASF Glenium® 3030 NS	gal	0.10	$15.00	$1.50
Textile Products Kevlar® 4009-1	sq ft.	40.00	$7.69	$307.60
Fibre Glast 24K Carbon Tow	yd	750.00	$0.19	$142.50
CS Hyde 69 Kevlar Thread	yd	1200.00	$0.06	$72.00
Butterfield Color Elements™ Transparent Concrete Stain – Assorted Colors	oz	36.00	$1.85	$66.60
Quikrete Liquid Cement Color – Charcoal	oz	2.00	$0.70	$1.40
Huron Technologies Release Coating 7572	gal	1.00	$22.50	$22.50
ChemMasters Crystal Clear - A	gal	1.00	$22.00	$22.00
10% Post-Consumer Recycled Foam Mold	LS	1.00	$1,702.02	$1,702.02
Canoe Finishing	LS	1.00	$112.00	$112.00
Design Stencil	LS	1.00	$50.00	$50.00
Total Production Cost				**$2,667.87**