Concrete Canoe Project

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Executive Summary :

Michigan Technological University (Michigan Tech) was established in 1885 as the Michigan School of Mines to train mining engineers in response to the copper mining boom of the mid-1800's. Since its creation, the school has evolved into a *U.S. News & World Report* "Top 50 Public University." Located in Houghton at the southern edge of the scenic Keweenaw Peninsula, Michigan Tech is home to approximately 6,000 undergraduate and graduate students. Individuals in the Keweenaw Peninsula are not only proud of the University, but also their rich hockey heritage. Since the formation of the first professional hockey team, the Portage Lake Professional Hockey Team in 1904, the Keweenaw Peninsula and Michigan Tech has had a continued tradition of hockey excellence.

The Michigan Tech Concrete Canoe Team is proud to present their 2005 canoe, **The MacInnes,** named after the legendary Michigan Tech hockey coach John MacInnes (555-295-39) who clinched three NCAA Division I Championships. Like MacInnes' legendary hockey teams, the success of the Michigan Tech Concrete Canoe Team relies on dedication, teamwork, and perseverance. Although participating in concrete canoe competitions since the mid-1970's, Michigan Tech was not a strong competitor until the mid-1990's. At the national competition, the Michigan Tech Concrete Canoe Team has represented the North Central Region six times, with a team best 7th place in 2003. The 2005 team hopes to again proudly represent the North Central Region at the national competition.

The MacInnes was completed on time and within its budget through the use of a hierarchal management system. The mix entitled **Slapshot** was used to form **The MacInnes** into a 20 foot long, 200 pound canoe with a maximum depth of 14 inches and maximum beam of 29.5 inches. **Slapshot** possesses a 28-day compressive strength of 2500 psi and unit weight of 58 pcf. Loose-strand carbon fiber dispersed throughout the mix acts as a secondary reinforcement. The primary reinforcement consists of two layers of carbon fiber reinforcement mesh which assisted in reducing the nominal thickness of the canoe to ½ inch. White cement enhanced the use of concrete pigments giving **The MacInnes** a black exterior and yellow interior ribs. The remainder of the interior was not pigmented and maintained its natural white color. Inlaid graphics contrasting against the black hull were an additional aesthetic innovation. Basic design analysis was augmented through the use of finite element analysis under multiple loading conditions to ensure structural integrity. With these key innovations, Michigan Tech is confident that **The MacInnes** is the superior canoe at the 2005 National Concrete Canoe Competition.

1.0 Hull Design

Previous experience in the National Concrete Canoe Competition (NCCC) has proven that success in the races require speed, stability, maneuverability, and straight-line tracking. Therefore, these characteristics were essential in **The MacInnes**' design. As in last year's canoe, **Boomrun**, the properties of a Hassel® design professional marathon racing canoe were emulated. This design offers an optimal balance of speed, stability, maneuverability, and straight-line tracking in addition to utilizing tumblehome for increased paddling efficiency. Because **Boomrun** possessed sufficient tracking and stability, maneuverability and velocity were the focus of this year's hull design.

During the design process, an estimated boat weight of 200 pounds in addition to paddler weights and locations were entered into Vacanti Prolines 98 Pro® design software. This analysis enabled drag forces, maneuverability, stability, and freeboard characteristics to be evaluated through simulation. Table 1.1 displays the results calculated for **The MacInnes**, **Boomrun**, and the Hassel® design.

Table 1.1: Canoe Characteristics

Canoe	Race	Length to Width Ratio	TDF[1], lbs	Moment to Trim 1", ft-lbs	Initial Stability, ft-lbs/deg
The MacInnes	Male	9.158	16.25	195.10	0.00324
The MacInnes	Coed	8.893	17.60	206.82	0.00264
Boomrun	Male	8.812	18.50	207.03	0.00432
Hassel	Male	8.594	15.75	165.72	0.00205

[1]Drag calculations were based upon boat velocity of 5 knots

The amount of total drag force (TDF) acting on the hull determines the maximum attainable velocity of a canoe. TDF is the sum of the skin drag, defined as the friction between the water and wetted surface of the hull, and wavemaking drag, the amount of force required to separate and return water around the hull. To reduce each of these factors of TDF, **The MacInnes** features a larger length-to-width ratio than **Boomrun**. Increasing this ratio reduced the wavemaking drag by producing less water disturbance around the hull and decreased skin drag by minimizing the wetted surface area. Incorporating a flatter hull also decreased the wetted area and consequently the skin drag.

Simulation results showed that an increased length-to-width ratio decreases stabilityand maneuverability. The flatter hull helps to offset these adverse effects. It creates more initial stability, or heeling tendency immediately felt by the paddlers, and aids maneuverability, as measured by moment to trim. Maneuverability was also increased with an additional ½ inch of rocker as compared to **Boomrun**. The final design characteristics of **The MacInnes** can be seen in Table 1.2.

Table 1.2: MacInnes' Design Characteristics

Length	20 ft.
Beam	28.5 in.
Bow Depth	14 in.
Stern Depth	12 in.
Rocker	1.5 in.
Angle of Entry	15°

The MacInnes possesses several other important hull design characteristics incorporated from the Hassel® design. Tapered gunwales permit a more efficient forward stroke. The narrow bow and low angle of entry significantly reduce the wavemaking drag and allows the bow to sink deeper into the water than the stern. Furthermore, the stern is slightly flatter than the bow, allowing it to increase water displacement producing a lower waterline and enhancing maneuverability. Collectively these properties cause the center of action to shift forward of amidship, allowing for greater maneuverability. Two inches of freeboard was also added to the bow to prevent submergence. This analysis proved that **The MacInnes** possesses the best hull design ever produced by Michigan Tech.

2.0 Analysis

Once the hull design was completed, the design loads and stresses were analyzed using finite element analysis. The hull design was imported from Vacanti Prolines 98 Pro® into IDEAS® finite element analysis (FEA) software. A finite element model (FEM) identical to **The MacInnes** was constructed using 1.5 square-inch elements. Maximum load scenarios created during the two-person male and co-ed races were then analyzed. These results provided composite specifications that would ensure that **The MacInnes** would sustain the rigors of competition.

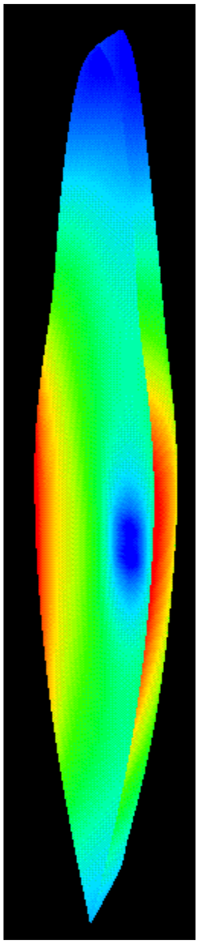


Figure 2.1: Maximum Stresses

Forces applied to the FEM included the weight of the canoe, dynamic weight of the paddlers, and a buoyant force. The canoe weight was assumed to be 200 pounds distributed along its length. Preliminary tests measured the actual forces exerted by paddlers on the canoe during race conditions. This allowed development of a dynamic ratio of 1.25 to account for dynamic forces in a static model. In the two person analysis, factored male paddler weights of 280 pounds were located 42 and 204 inches from the bow. The coed loading case assumed the 280 pound male paddler loads to be at the forward and aft positions while the factored 190 pound female paddlers were located 84 and 162 inches from the bow. Each paddler's weight was considered as a point load to maximize stresses on the canoe. Lastly, a buoyant force was applied to the hull below the calculated water line. This force was equal to the sum of paddler and canoe weights.

Because the FEA was completed before the final mix design was determined, values for the Modulus of Elasticity, Poisson's Ratio, Shear Modulus, unit weight, and strength were approximated for the initial design. Using a unit weight of 60 pounds per cubic foot and ultimate concrete strength of 2500 psi, ACI 318 Code Section 8.5.1 yielded an elastic modulus of 766,850 psi. A typical value for Poisson's Ratio of .2 was used to determine a shear modulus of 319,520 psi.

To complete the FEA, minimal translational and rotational restraints were specified as three dimensional pin and roller connections at 42 and 204 inches from the bow, respectively. Results from the FEA proved the maximum moment of 100 inch-pounds/inch occurs during the two person race. The locations of these maximum stresses can be seen in Figure 2.1.

Once a mix design was finalized, values for the Modulus of Elasticity, Poisson's Ratio, Shear Modulus, unit weight, and strength were determined. The FEA was then re-evaluated with the new material parameters to ensure that the assumed values were sufficient.

3.0 Development and Testing

3.1 Mix Design

The mix design for **The MacInnes** was based upon the 2004 mix **Crosscut** which had limited cracking due to adequate concrete strength (190 psi tensile, 2600 psi compressive). Because this strength met the minimum material design specifications determined by the FEA, the 2004 mix was chosen as the baseline mix. However, deficiencies in this mix dictated additional design specifications to increase workability and minimize shrinkage effects during curing.

The baseline mix consisted of 71.9 % Type I portland cement, 20.5 % Class C fly ash, 5.1 % silica fume, and 2.5 % latex. This mix possessed a binder to aggregate ratio of 1 to 3. Aggregate consisted of a dense graded blend of Siscor ® glass spheres. Admixtures to the baseline mix include Master Builders Glenium 3400® superplasticizer to increase workability and Micro Air® air entrainer to reduce unit weight.

A two level design process was used to incorporate the desired changes to the baseline mix. In the first level, over 45 trial batches were mixed in a 5-liter Hobart® mixer. In each batch, specific types and amounts of aggregate, binding materials, and admixtures were incorporated independently into the baseline mix to analyze their effects. Six, two-inch diameter by four-inch tall test cylinders were procured from each batch and wet-cured for seven days. After curing, the samples were tested for compressive (ASTM C 39) and splitting tensile (ASTM C 496) strengths on a digitally controlled MTS® servo-hydraulic testing system. Using the level one test results, five second level mixes were created incorporating varying amounts of several desired components. The results of these mixes were used to determine the specific composition of the final mix, **Slapshot**.

Rice Husk Ash (RHA), a natural silica, was tested as an alternative to silica fume. Similar to silica fume, RHA possesses a small particle size which lowers the porosity of concrete and is a highly reactive pozzolan. However, previous experience has shown that silica fume decreases the initial set time of concrete and increases the amount of shrinkage in the mix. RHA does not possess these undesired characteristics. Furthermore, RHA has a greater amount of surface area per unit weight than silica fume, helping to increase the overall strength of the mix. Therefore it was chosen to replace silica fume.

Type S hydrated lime in the form of lime putty was added to increase workability of the mix. Lime putty is composed of minute, round particles of water saturated lime. These particles act as lubrication between larger particles throughout the mix. The lime putty also retains free water throughout the mixing process. This free water can be worked out when trowelled allowing for better finish.

The aggregate composition of **Slapshot** is primarily composed of Siscor ® glass spheres. These spheres were selected because they possessed a low specific gravity of 0.4-0.9, provided adequate strength, and increased workability. A dense gradation was chosen to reduce the amount of space between the particles reducing the volume of binder material required. This helped reduced the unit weight of the concrete as the binding constituents possess much higher specific gravities than the Siscor ® glass spheres. The binder to aggregate ratio of **Slapshot** was decreased from the baseline mix to 1:3.33. The gradation of the aggregate was also designed to the ASTM C 33 fineness limitation to help reduce the minimum concrete layer thickness and concrete porosity. The final gradation can be found in Appendix C.

The binder composition by mass of the final mix, **Slapshot,** can be seen in Figure 3.1. Type I portland cement was chosen because it provided a favorable compromise between high early and overall strength. Latex provided additional compressive and tensile strength by filling voids and forming bonds between solid binding material. Class C fly ash was chosen for its cementitious properties, which allow **Slapshot** to achieve full strength weeks sooner than Class F fly ash. The final mix design can be found in Appendix B.

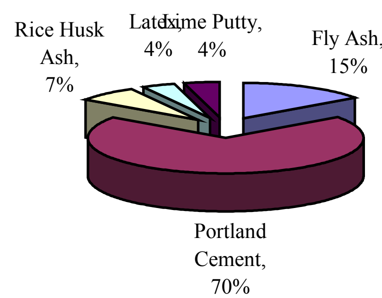


Figure 3.1:
Slapshot Binder Composition

The actual material properties of **Slapshot** were checked against the approximations used for the FEA. The Modulus of Elasticity and Poisson's Ratio were determined to be 765,000 psi and .2, respectively, using the procedure outlined in ASTM C469 and a suitable combined compressometer-extensometer. The Shear Modulus which resulted from this new data was 318,750 psi. These experimental values did not vary considerably from the approximated values used to run the FEA. However, the FEA was rerun with the final properties and no noticeable change occurred.

3.2 Reinforcement Design

Emphasis was placed on determining the final concrete and reinforcement composite after finalizing the concrete mix. Lightweight reinforcing materials with both a high modulus of elasticity and a high strain to failure ratio were researched. This research produced three potential reinforcements to be tested: polypropylene, epoxy impregnated fiberglass, and epoxy impregnated carbon fiber meshes. Each mesh was cast into a 17 inch by 17 inch, ½ inch thick composite consisting of two layers of reinforcement and three layers of concrete. This composite structure was determined using previous years' experience. After being wet cured for 14 days, the plates were cut into 4 inch by 16 inch sections. These samples were loaded to flexural failure in accordance with ASTM C 78. Each type of reinforcement was evaluated based upon its overall strength, nature of failure, and ease of handling.

The final composite structure chosen for **The MacInnes** consists of two layers of epoxy impregnated carbon fiber mesh between three layers of concrete. The mesh is composed of carbon fiber strands spaced at one inch on center with a weight of three ounces per square yard and a grid openness of 80%. This spacing allows for adequate shear strength through the plane of reinforcement while also maintaining enough reinforcement to limit cracking. This reinforcement design proved favorable over the other specimens which failed at lower bending moments.

The maximum aggregate size dictated that the exterior concrete layers would have to provide a minimum of $^1/_8$ inch of cover. A $^1/_4$ inch core layer was chosen to help increase the overall rigidity, moment of inertia, and puncture resistance of the hull. The final composite has a unit weight of 58 pcf, and can withstand a bending moment of 130 inch-pounds/inch, satisfying the design requirements specified during the analysis process.

4.0 Project Management

The MacInnes was constructed using a design-build system with hierarchal management structure (page 6). The design-build system utilized veteran team member experience and increased efficiency by allowing design and construction to occur simultaneously. The hierarchal system further increased construction efficiency by distributing responsibility throughout the team. Management was headed by the project manager who oversaw the entire project. Project engineers directed specific tasks and reported directly to the project manager while a safety director oversaw all activities.

Table 4.1: Project Milestones

Critical Path Activities	Major Milestones	Variance	Labor Hours To Complete
Hull Design	Hull Design Finalized	None	85
Composite Design	Composite Finalized	None	142
Mold Construction	Mold Completed	None	153
Casting	Casting Day	None	163
Finishing	**The MacInnes** Completed	None	280
		Total Labor Hours:	823

A schedule to complete **The MacInnes** was created using the Critical Path Method before the construction process began. Emphasis was placed on the timely completion of each activity as not to affect the final product. Critical Path Activities and Major Milestones along with the time to complete each are shown in Table 4.1. A full detailed schedule of the construction of **The MacInnes** can be seen on page 7.

5.0 Construction

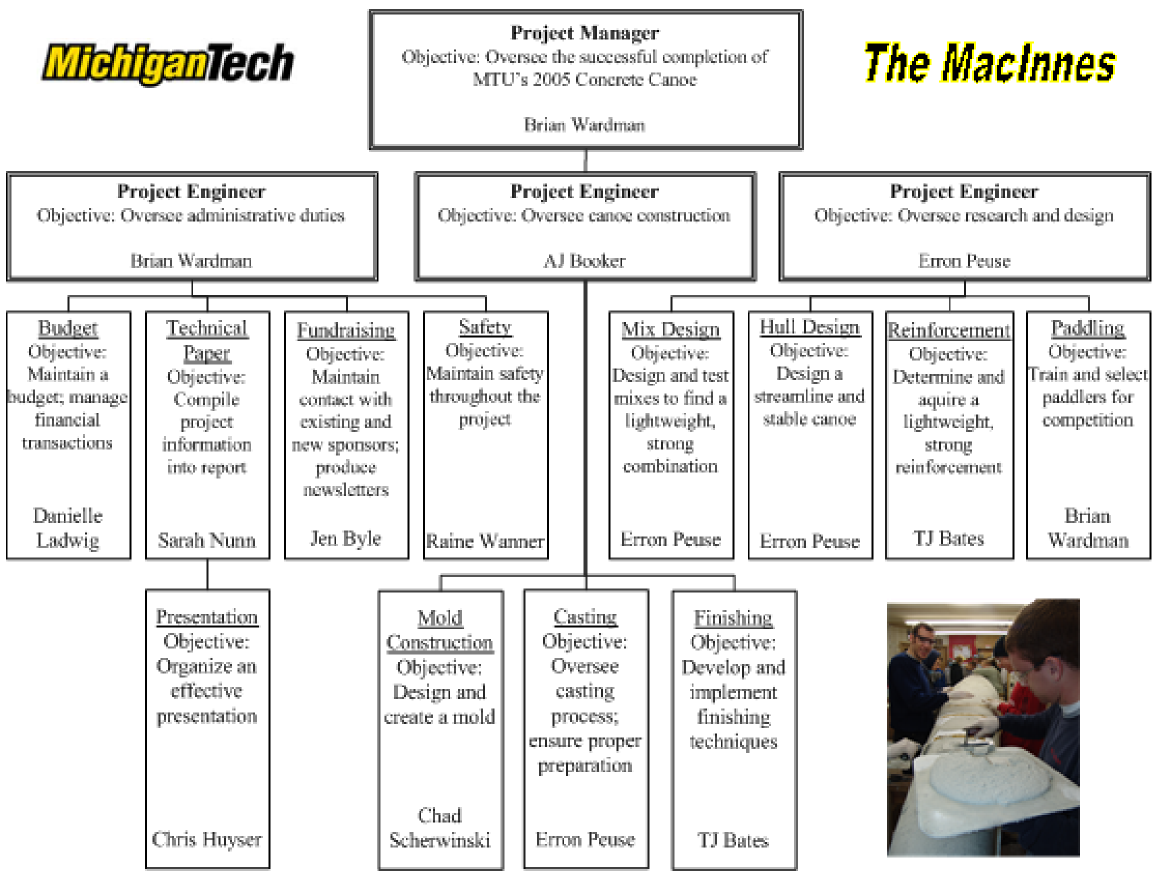
Construction of the mold began upon completion of the hull design. Foam, as opposed to the cedar strip used previously, was used to create a male mold for two reasons: (1) ability to monolithically cast a canoe with ribs and (2) less structural damage is created by mold fluctuation during curing.

Cross sections were plotted at 2 inch, 4 inch, and 6 inch intervals and cut out of ¼ inch hardboard. Extruded polystyrene was placed between the hardboard templates, cut to shape using a hotwire, and attached to a strong back. Ribs were carved into the mold at specified locations and 1/16 inch vinyl flooring templates were attached to create voids for inlays on the interior of the canoe. Drywall compound was placed onto the mold and faired to smooth imperfections. The mold was then coated with a textured drywall compound to aid in troweling. Lastly, the mold was coated with an oil-based paint to facilitate easy removal.

Prior to the placement of concrete, the temperature of the cure room was lowered and the humidity raised to delay the initial set time of **Slapshot.** The concrete was trowelled onto the mold using steel trowels for better compaction and magnesium floats to help prevent interlayer delamination. Small batches of concrete were mixed and placed under strict quality control specifications. After the initial set of the concrete, **The MacInnes** was wet cured under burlap curing blankets in a steam tent for fourteen days at an average temperature of 85 F with 100 percent relative humidity.

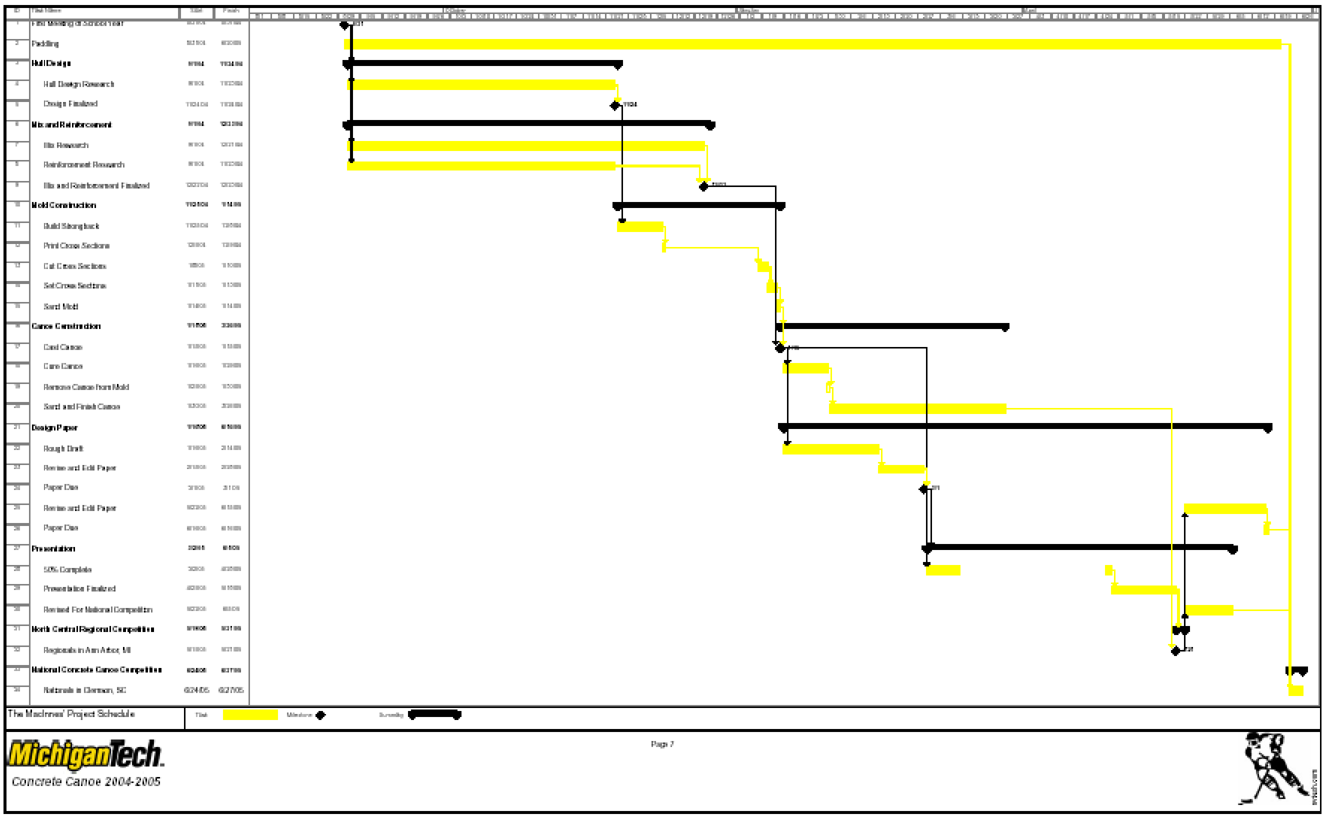
The final construction step began with the removal of the mold. Inlaid graphics were filled, and a slurry coat was applied to rough areas. Final finishing of the boat was performed using a Flex water cooled angle grinder/polisher and 60 through 3000 grit diamond impregnated polishing pads. Concrete stain was rolled on to give the desired effects and then sealed by rolling on a concrete sealer. **The MacInnes** was completed when vinyl graphics were applied to the exterior.

6.0 Organization Chart :



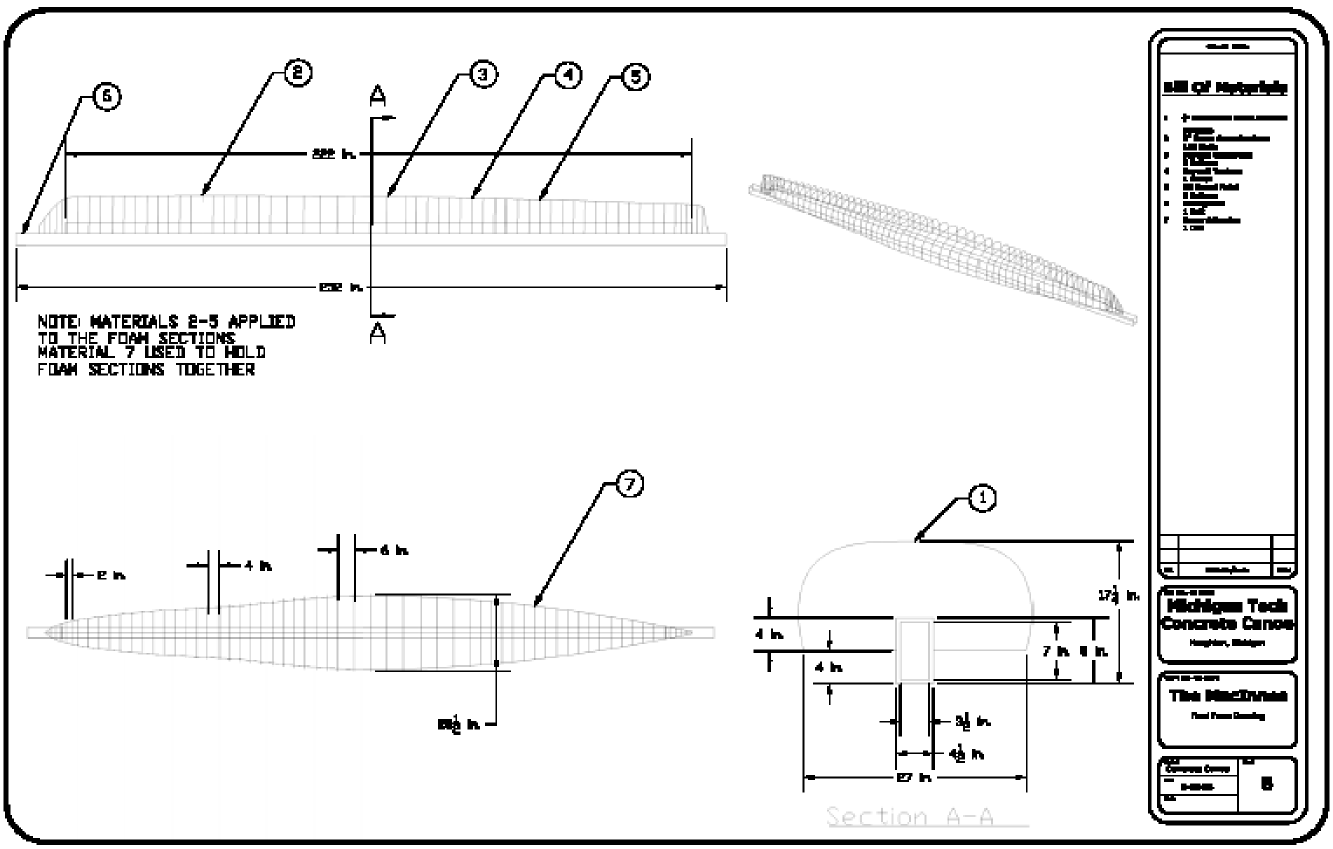
MichiganTech-Organization Chart

7.0 Project Schedule :



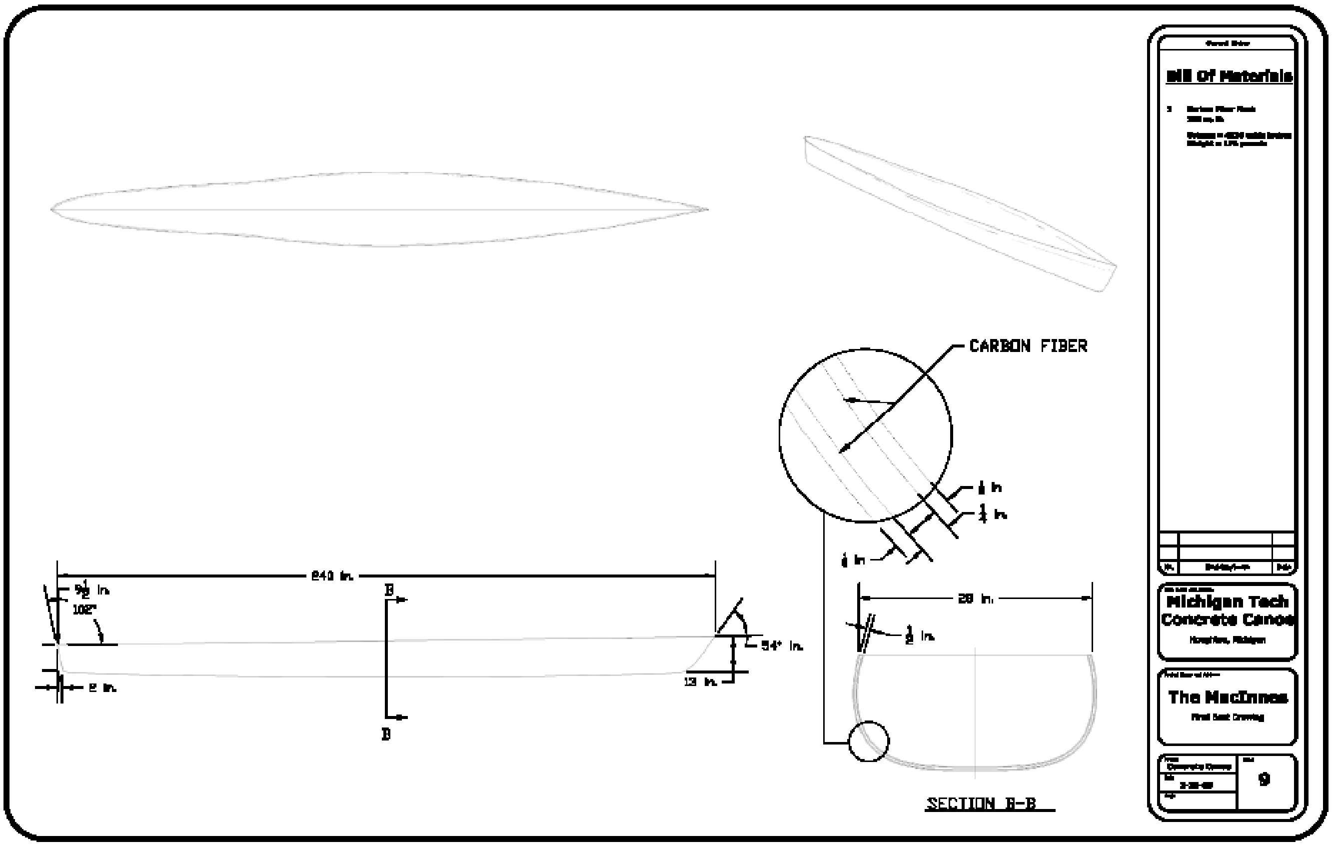
Project Schedule - MacInnes

8.0 Drawings : Form



BC 2-hander meshing-Form-No-Center-Line

9.0 Drawing : Canoe



BC 2-Hander MeshingTWO-Weight

Photograph : MacInnes

MichiganTech-The MacInnes

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Appendix B – Mixture Proportions

Table 3.1 – Summary of Mixture Proportions   Mixture Designation: Slapshot – Exterior

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete	Amount: 9.6 (%)	Volume: 0.096 (m^3)		
Cementitious Material	Specific Gravity	Amount (kg/m^3)	Volume (m^3)	
ASTM C 150 Cement Type:	3.15	296.8	0.0942	
2*: Class C Fly Ash (ASTM C 618)	2.40	63.6	0.0265	
3*: Lime Putty	2.20	17.0*	0.0077	
4*: Rice Husk Ash	2.10	29.7	0.0141	
5*: Latex	1.00	17.0*	0.0170	
Σ(all cementitious materials)		*cm*: 424.1	Vol_{cm}: 0.1595	(1)
Cement-to-cementitious materials ratio		*c/cm*: 0.700		

AGGREGATES					
Aggregate #	Amount (kg/m^3)	ASTM C 127/128 *BSG (SSD)*	Volume (m^3)	Batch Weight (kg/m^3)	
1.Siscor Ret. #16	$W_{SSD,1}$: 111.7	0.48	0.2328	$W_{stk,1}$: 111.7	
2.Siscor Ret. #30, #50	$W_{SSD,2}$: 127.4	0.64	0.1991	$W_{stk,2}$: 127.4	
3.Siscor Ret. #100	$W_{SSD,3}$: 47.7	0.88	0.0542	$W_{stk,3}$: 47.7	
4.3M S32	$W_{SSD,4}$: 15.1	0.32	0.0472	$W_{stk,4}$: 15.1	
Combined	$W_{SSD,agg}$: 301.9	0.57	0.5333	$W_{stk,agg}$: 301.9	(2)

FIBERS					
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m^3)	Batch Weight (kg/m^3)	
1. Loose Strand Carbon Fiber	0.20	1.8	0.0020	3.6	
2.					
Σ(all fibers)	0.20		0.0020	3.6	(3)

WATER				
Water †	*W*: 200.3	w_{batch}: 185.0	kg/m^3	
vol. of admixture #1 Superplasticizer	x_1: 3575		mL/m^3	
vol. of admixture #2 Air Entrainer	x_2: 295		mL/m^3	
vol. of admixture #3 Pigment	x_3: 16377		mL/m^3	
water from admixture #1		$w_{admx,1}$: 3.3	kg/m^3	
water from admixture #2		$w_{admx,2}$: 0.3	kg/m^3	
water from admixture #3		$w_{admx,3}$: 11.7	kg/m^3	
total of free (surplus) water from all aggregates		$\sum w_{free}$: 0	kg/m^3	
Total Water	*w*: 200.3	*w*: ‡ 200.3	kg/m^3	(4)
concrete density §	929.9		kg/m^3	
water-to-cement ratio	*w/c*: 0.675			
water-to-cementitious materials ratio	*w/cm*: 0.472			

.*Denotes mass of solids in slurry that were added to mix. The free water in the slurry was included in the wbatch number.

Table 3.2 – Summary of Mixture Proportions   Mixture Designation: Slapshot - Interior

AIR AND CEMENTITIOUS MATERIALS				
Air Content of Concrete	Amount: 11.1 (%)	Volume: 0.889	(m^3)	
Cementitious Material	Specific Gravity	Amount (kg/m^3)	Volume (m^3)	
ASTM C 150 Cement Type:	3.15	329.6	0.1046	
2*: Class C Fly Ash (ASTM C 618)	2.40	64.2	0.0268	
3*: Lime Putty	2.20	17.1*	0.0078	
4*: Rice Husk Ash	2.10	0	0	
5*: Latex	1.00	17.1*	0.0171	
Σ(all cementitious materials)		*cm*: 428.0	Vol_{cm}: 0.1563	(1)
Cement-to-cementitious materials ratio		*c/cm*: 0.770		

AGGREGATES					
Aggregate #	Amount (kg/m^3)	ASTM C 127/128 *BSG (SSD)*	Volume (m^3)	Batch Weight (kg/m^3)	
1.Siscor Ret. #16	$W_{SSD,1}$: 109.9	0.48	0.2289	$W_{stk,1}$: 109.9	
2.Siscor Ret. #30, #50	$W_{SSD,2}$: 125.3	0.64	0.1958	$W_{stk,2}$: 125.3	
3.Siscor Ret. #100	$W_{SSD,3}$: 46.9	0.88	0.0533	$W_{stk,3}$: 46.9	
4.3M S32	$W_{SSD,4}$: 14.9	0.32	0.0464	$W_{stk,4}$: 14.9	
Combined	$W_{SSD,agg}$: 297.0	0.57	0.5244	$W_{stk,agg}$: 297.0	(2)

FIBERS					
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m^3)	Batch Weight (kg/m^3)	
1. Loose Strand Carbon Fiber	0.20	1.8	0.0020	3.6	
2.					
Σ(all fibers)	0.20		0.0020	3.6	(3)

WATER				
Water †	*W*: 201.6	w_{batch}: 198.0	kg/m^3	
vol. of admixture #1 Superplasticizer	x_1: 3575		mL/m^3	
vol. of admixture #2 Air Entrainer	x_2: 295		mL/m^3	
vol. of admixture #3	x_3:		mL/m^3	
water from admixture #1		$w_{admx,1}$: 3.3	kg/m^3	
water from admixture #2		$w_{admx,2}$: 0.3	kg/m^3	
water from admixture #3		$w_{admx,3}$:	kg/m^3	
total of free (surplus) water from all aggregates		$\sum w_{free}$: 0	kg/m^3	
Total Water	*w*: 201.6	*w*: ‡ 201.6	kg/m^3	(4)
concrete density §	930.2		kg/m^3	
water-to-cement ratio	*w/c*: 0.612			
water-to-cementitious materials ratio	*w/cm*: 0.471			

*Denotes amount of solids in slurry that were added to the mix. The free water from the slurry was included in the wbatch.

Table 3.3 – Summary of Mixture Proportions   Mixture Designation: Slapshot - Slurry

Air and Cementitious Materials				
Air Content of Concrete	Amount: 3.5 (%)	Volume: 0.0035 (m^3)		
Cementitious Material	Specific Gravity	Amount (kg/m^3)	Volume (m^3)	
ASTM C 150 Cement Type:	3.15	444.5	0.1411	
2*: Class C Fly Ash (ASTM C 618)	2.40	95.3	0.0397	
3*: Lime Putty	2.20	25.4*	0.0115	
4*: Rice Husk Ash	2.10	44.5	0.0212	
5*: Latex	1.00	25.4*	0.0254	
Σ(all cementitious materials)		*cm*: 635.1	Vol$_{cm}$: 0.2389	(1)
Cement-to-cementitious materials ratio		*c/cm*: 0.700		

Aggregates					
Aggregate #	Amount (kg/m^3)	ASTM C 127/128 *BSG (SSD)*	Volume (m^3)	Batch Weight (kg/m^3)	
1.Siscor Ret. #16	$W_{SSD,1}$: 86.6	0.48	0.1804	$W_{stk,1}$: 86.6	
2.Siscor Ret. #30, #50	$W_{SSD,2}$: 98.7	0.64	0.1543	$W_{stk,2}$: 98.7	
3.Siscor Ret. #100	$W_{SSD,3}$: 40.0	0.88	0.0420	$W_{stk,3}$: 40.0	
4.3M S32	$W_{SSD,4}$: 11.7	0.32	0.0366	$W_{stk,4}$: 11.7	
Combined	$W_{SSD,agg}$: 237.0	0.57	0.4133	$W_{stk,agg}$: 237.0	(2)

Fibers					
Fiber #	Volume Fraction (%)	Specific Gravity	Volume (m^3)	Batch Weight (kg/m^3)	
1. Loose Strand Carbon Fiber	0	1.8	0	0	
2.					
Σ(all fibers)	0		0	0	(3)

Water				
Water †	W: 309.6	w_{batch}: 293.0	kg/m^3	
vol. of admixture #1 Superplasticizer	x_1: 3153		mL/m^3	
vol. of admixture #2 Air Entrainer	x_2: 265		mL/m^3	
vol. of admixture #3 Pigment	x_3: 18653		mL/m^3	
water from admixture #1		$w_{admx,1}$: 2.9	kg/m^3	
water from admixture #2		$w_{admx,2}$: 0.3	kg/m^3	
water from admixture #3		$w_{admx,3}$: 13.4	kg/m^3	
total of free (surplus) water from all aggregates		$\sum w_{free}$: 0	kg/m^3	
Total Water	w:	w: ‡ 362.9	kg/m^3	(4)
concrete density §	1178.5		kg/m^3	
water-to-cement ratio	*w/c*: 0.700			
water-to-cementitious materials ratio	*w/cm*: 0.487			

*Denotes mass of solids in slurry that were added to the mix. The free water in the slurry was included in the wbatch number.

Appendix C – Gradation Curves and Tables

Figure 3.2: 3M S 32 Gradation Curve

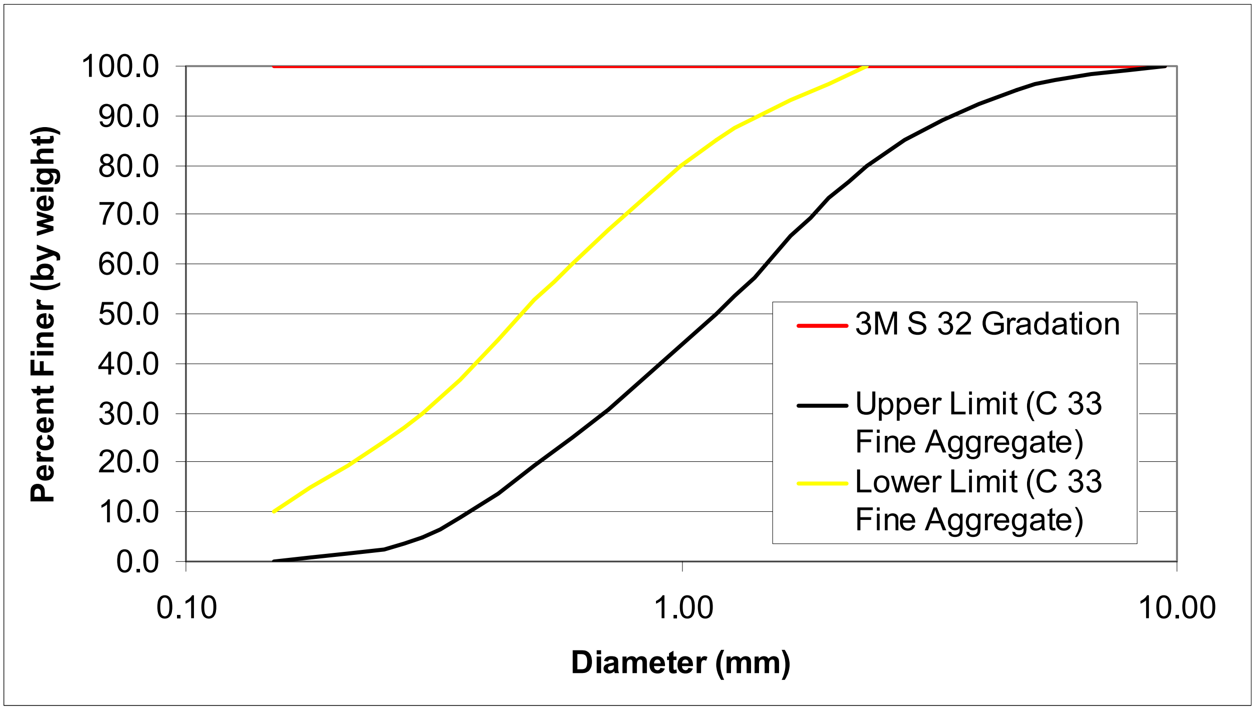

Table 3.4: 3M S 32 Gradation

Concrete Aggregate: 3M S 32 Glass Microspheres
Sample Weight: 1000 grams
Specific Gravity (G_s): 0.32
Finess Modulus: 0

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	0.0	0.0	100.0
No. 30	0.60	0.0	0.0	100.0
No. 50	0.30	0.0	0.0	100.0
No. 100	0.15	0.0	0.0	100.0

Figure 3.3: Siscor Gradation Curve

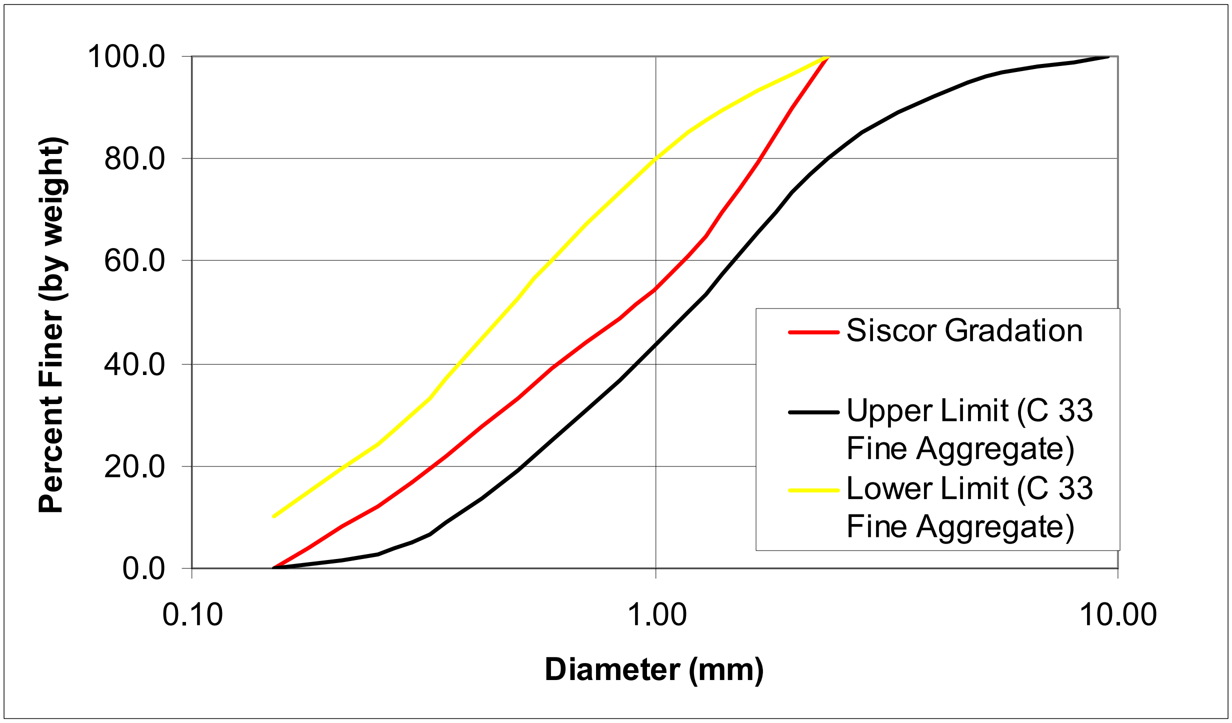

Table 3.5: Siscor Gradation

Concrete Aggregate: Siscor Spheres
Sample Weight: 1000 grams
Specific Gravity (G_s): 0.59
Finess Modulus: 2.53

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	388.9	388.9	61.1
No. 30	0.60	222.2	611.1	38.9
No. 50	0.30	222.2	833.3	16.7
No. 100	0.15	166.7	1000.0	0.0

Figure 3.4: Slapshot Gradation Curve

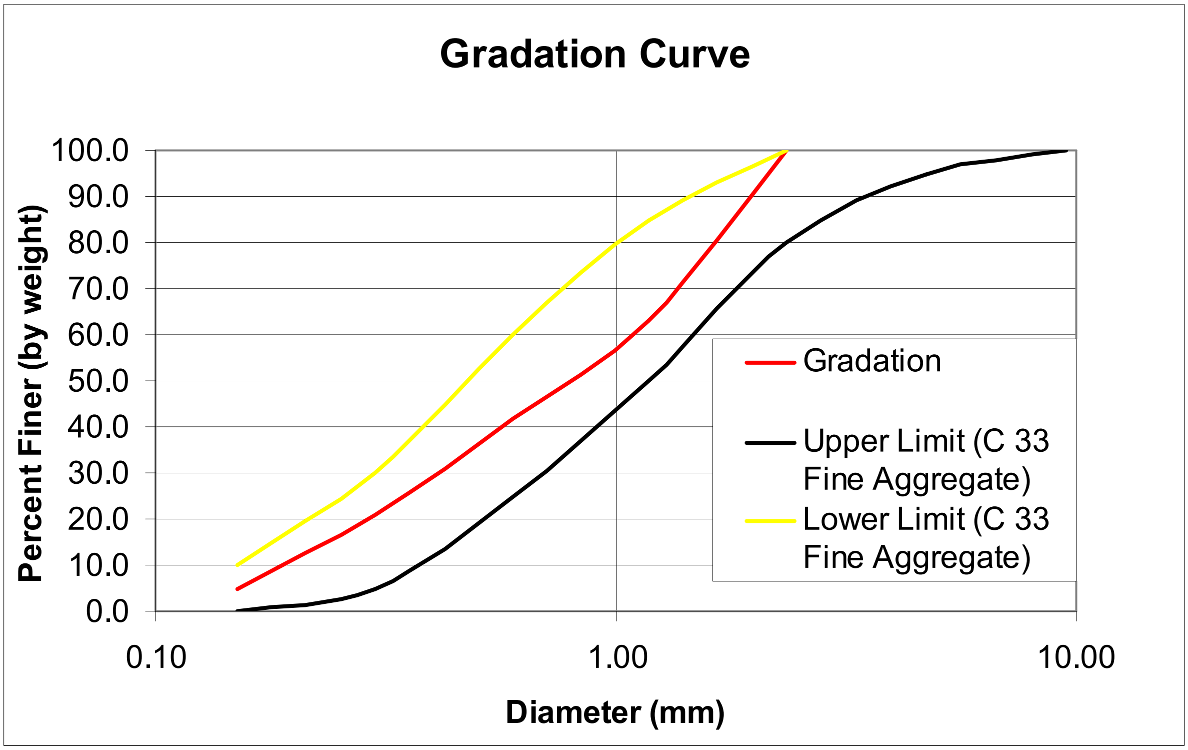

Table 3.6: Slapshot Gradation

Concrete Aggregate: **Slapshot** Composite
Sample Weight: 1000 grams
Specific Gravity (G_s): 0.57
Finess Modulus: 2.69

Sieve	Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Percent Finer (%)
3/8 inch	9.50	0.0	0.0	100.0
No. 4	4.75	0.0	0.0	100.0
No. 8	2.36	0.0	0.0	100.0
No. 16	1.18	370.0	370.0	63.0
No. 30	0.60	211.0	581.0	41.9
No. 50	0.30	211.0	792.0	20.8
No. 100	0.15	158.0	950.0	5.0

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Compliance Certification

Michigan Tech University's 2004-2005 Concrete Canoe team hereby certifies that the construction and finishing of **The MacInnes** has been completed in compliance with the rules and regulations set forth by the National Concrete Canoe Competition. Additionally, the canoe has been completely built within the current academic year of the competition. The nine (9) registered participants are qualified student members and National Student Members of ASCE as specified in the rules and regulations of the National Competition.

Registered Members of the 2004-2005 Michigan Tech Concrete Canoe Team

Danielle Ladwig	424944	Erron Peuse	407636
Sarah Nunn	416350	Brian Wardman	410471
Raine Wanner	425456	Craig Morehouse	391300
Kimberly Zehler	437185	Tim Rank	444582
		Timothy Bates	444263

Property	Dimension/Parameter
Maximum Length	20 ft 0 in (6.1 m)
Maximum Width	2 ft 5.5 in (0.75 m)
Maximum Depth	14 in (0.36 m)
Average Thickness	0.5 in (13 mm)
Overall Weight	175 lbs (79.4 kg)
Slapshot Mixture	
Density	58 pcf (929 kg/m^3)
28-Day Compressive Strength	2500 psi (17.2 Mpa)
28-Day Tensile Strength	190 psi (1.3 Mpa)
28-Day Flexural Strength	120 in-lbs/in (13.6 N-m/m)

We certify that the aforementioned information is valid.

____________________________ Date

Brian Wardman
Concrete Canoe Captain
(906)370-2475
bgwardma@mtu.edu

____________________________ Date

L. Bogue Sandberg
Michigan Tech ASCE Advisor
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Making of Concrete Canoe

MichiganTech-The MacInnes Team

THE TEAM
MICHIGAN TECH - MACINNES