# The Clemson Concrete Canoe Team
# is ready to
# "TAKE IT FOR GRANITE"

## ASCE National Concrete Canoe Competition
## June 15 – 17, 2006
## Stillwater, Oklahoma

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## Executive Summary:

Following nine months of research, testing, construction, and training, the Clemson Concrete Canoe Team (3CT) returns to the ASCE National Concrete Canoe Competition ready to introduce and compete with TAKE IT FOR GRANITE (Table 1). Founded in 1889, Clemson University is a public, land grant university with 14,000 undergraduate and 3,000 graduate students. The team is comprised of 17 civil engineering students and a faculty advisor. 3CT has successfully competed in and won the Carolina's Conference concrete canoe competition every year since 1993. These regional titles have led to 12 top ten finishes, including three national titles at the National Concrete Canoe Competition ('99, '01, '02).

| Table 1: Canoe Dimensions |
|---|
| Length: 18.8 ft (5.73 m) |
| Weight: 151 lb (68.49 kg) |
| Thickness: 0.4 in (1.02 cm) |
| Depth: 9.5 in (24.13 cm) |
| Beam at Waterline: 32 in (81.28 cm) |
| Color: Brown Granite |

TAKE IT FOR GRANITE is a swift, maneuverable, and stable canoe constructed of ultra thin, lightweight concrete and reinforced with nanotubes, polypropylene mesh and pre-tensioned tendons. The canoe is the product of new innovations, extensive research, economical construction, and continuous attention to detail. Parameters such as turning speed, decreased weight, and stability led 3CT to develop a dramatically different hull design compared to previous years' canoes. Detailed structural and finite element analysis techniques set concrete and composite standards to ensure durability and prevent failure under race conditions.

Through the combination of lightweight aggregates, dispersed fibers, nanotechnology, and reinforcement, TAKE IT FOR GRANITE is lightweight, innovative, and strong (Table 2). The placement of nanotubes in the inner layers of TAKE IT FOR GRANITE created a stress absorbing interlay, providing increased flexural strength and limiting the propagation of cracks.

| Table 2: Concrete Properties | | |
|---|---|---|
| Composite First Crack Strength | 950 psi (6.55 MPa) | C1018 28 Day |
| Composite Ultimate Strength | 1210 psi (8.34 MPa) | C1018 28 Day |
| **Final Mix** | | |
| Unit Weight | 63.1 lb/ft$^3$ (1011 kg/m$^3$) | C138 28 Day |
| Compressive Strength | 980 psi (6.76 MPa) | C109 28 Day |
| Flexural Strength | 416 psi (2.87 MPa) | C78 28 Day |
| **Nanotube Mix** | | |
| Unit Weight | 62.7 lb/ft$^3$ (1004 kg/m$^3$) | C138 28 Day |
| Compressive Strength | 974 psi (6.72 MPa) | C109 28 Day |
| Flexural Strength | 443 psi (3.05 MPa) | C78 28 Day |
| **Finishing Mix** | | |
| Unit Weight | 63.4 lb/ft$^3$ (1016 kg/m$^3$) | C138 28 Day |
| Compressive Strength | 988 psi (6.81 MPa) | C109 28 Day |
| Flexural Strength | 262 psi (1.81 MPa) | C78 28 Day |

Quality control methods such as mechanical mixing, thermal imagery, and time-lapse photography during placement allowed for consistency in the final product; innovative additions such as fiber optics and acid staining techniques created an aesthetically pleasing canoe. Each of these analytical and construction techniques has allowed 3CT to leave nothing to chance with TAKE IT FOR GRANITE.

## Hull Design:

High performance racing canoes require a delicate balance of speed, maneuverability and stability. Successful sprint and endurance races require straight line speed while the slalom requires exceptional maneuverability and stability. In previous years, 3CT focused on maximizing straight line speed. However, last year's canoe, ACES WILD, was slow during turns due to the heavy weight of the canoe. For this reason, maximizing turning speed and reducing canoe weight were the main goals of hull design. The hull design also focused on increasing stability due to the instability a third paddler creates in the endurance race.

3CT utilized a new software program, Prolines 7, in the hull design development. In addition to minimizing drag forces, Prolines 7 emphasizes laminar flow over turbulent flow around the hull. In previous years, the hull analysis software only focused on minimizing the drag forces. Therefore, the use of Prolines 7 gave 3CT the opportunity to create a substantially different hull design based on the goals set forth for this year.

Using Prolines 7, 3CT created several preliminary designs with varied length, width, rocker, and beam proportions (Table 3). Watermark, a local kayak company, critiqued the designs and suggested several improvements for a racing canoe including an optimal range for the prismatic coefficient. The prismatic coefficient, an indicator of fineness of ends for a canoe in relation to midsection width, was optimal between 0.59 and 0.65.

**Table 3: Final Hull Design Summary**

| Design | Length (ft) | Width (ft) | Prismatic Coefficient |
|---|---|---|---|
| **Aces Wild** | **21.4** | **2.45** | **0.532** |
| Design 1 | 21.5 | 1.72 | 0.599 |
| Design 2 | 21.5 | 2.72 | 0.477 |
| Design 3 | 18.8 | 3.16 | 0.530 |
| Design 4 | 18.8 | 3.13 | 0.558 |
| **Final Design** | **18.8** | **3.13** | **0.604** |

Using the professional suggestions from Watermark, 3CT finalized the hull design of TAKE IT FOR GRANITE. The canoe is eight inches wider and 31 inches shorter than ACES WILD. The wider and shorter hull allows the canoe to sit higher in the water and reduces surface area. These parameters increase its maneuverability and decrease total weight, thereby achieving team goals. Additionally, the design removed rocker to counteract the unbalanced bow and stern during endurance races and reduced the freeboard to eliminate surface area and increase paddling efficiency.

After finalizing the hull design, 3CT constructed a prototype and conducted tests to experimentally determine the straight line speed and turning ability of TAKE IT FOR GRANITE. Although straight line speed was not a priority for the hull design, 3CT wanted to ensure that the design changes did not reduce this speed in comparison to previous canoes. Testing indicated that TAKE IT FOR GRANITE encountered comparable straight line drag forces to those of other designs.

To test the turning ability of TAKE IT FOR GRANITE against ACES WILD, 3CT applied varying forces to the bow of each canoe while securing the stern as a pivot point. The angle of rotation was recorded (Figure 1) and converted to the theoretical time to complete a 180 degree turn. Test results demonstrated that TAKE IT FOR GRANITE had a turning time of 2.7 seconds less than ACES WILD, creating a significant advantage in slalom and sprint turns.

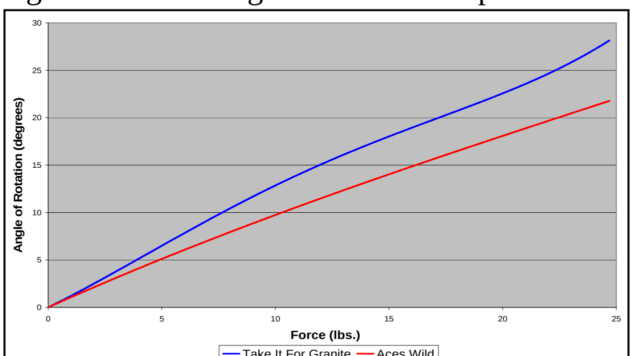



**Figure 1: Turning Speed**

Once testing confirmed that TAKE IT FOR GRANITE was an improvement over previous canoes, the hull design was complete. Though the hull design was a dramatic change from previous years, consideration of race changes and paddling needs ensured TAKE IT FOR GRANITE would provide success at the highest level.

## Analysis:

Upon completion of the hull design, 3CT used both theoretical and experimental analysis techniques to establish the minimum structural requirements needed to ensure TAKE IT FOR GRANITE can withstand the maximum stresses experienced during competition.

The initial step in theoretical analysis was to create a model of the hull to determine the maximum shear and moment experienced by TAKE IT FOR GRANITE and the location of these maximum forces. Paddlers were treated as 180 lb (81.65 kg) point loads in the two and three person loadings and two 140 lb (63.50 kg) and two 180 lb (81.65 kg) point loads in the four person loading. Preliminary mix design results estimated the canoe weight at 160 lb (72.57 kg). The model determined the three person loading would control both the maximum shear and moment (Figure 2). The model then calculated the contributions to the moment and shear from the self-weight of the canoe as well as the paddlers in order to accurately apply a factor of safety (FS) of 1.57, based upon the combination of dead and live loads. The contribution of each load established a final maximum shear of 342.0 lb (155.13 kg) located under the middle paddler, while the maximum moment was 575.9 ft-lb (780.8 N-m) located near the canoe center.

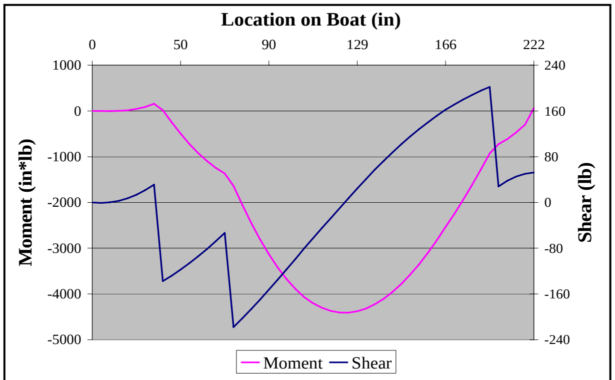



Figure 2: Shear-Moment Diagram

The design program CONCAD used the maximum shear and moment to determine both the necessary compressive concrete strength and the required modulus of elasticity of reinforcement to be used. The program treated the sides of the canoe as reinforced beams with reinforcement strength equal to the smallest modulus of elasticity determined in preliminary reinforcement testing. Results determined the concrete needed a minimum compressive strength of 725 psi (5.00 MPa) in conjunction with a minimum reinforcement modulus of elasticity of 4,000 ksi (27.58 GPa). Based on prior years' experience, 3CT set the minimum flexural concrete strength at 350 psi (2.41 MPa) to minimize flexural cracking.

The next step in theoretical analysis was to determine the necessary composite strength by conducting a Finite Element Analysis (FEA) (Figure 3). 3CT modeled the canoe in SAP 2000 using 300 shell elements, each 0.4 in (10.2 mm) thick, with a concrete compressive strength of 725 psi (5.00 MPa). Eight roller supports and two pin supports were placed along the canoe to provide stability. The FEA ignored the possible effects of bulkheads to increase the maximum stresses calculated by the program. The FEA determined that a maximum tensile stress of 560 psi (3.86 MPa) occurred along the chines near the paddlers' knees. After applying the same FS as before, 3CT set the minimum composite strength at 880 psi (6.07 MPa).

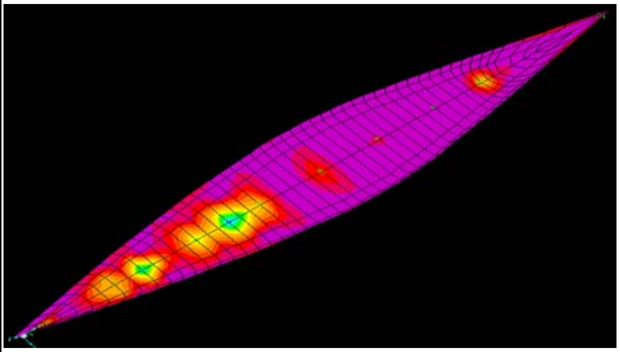


Figure 3: Finite Element Analysis

3CT also conducted experimental analysis to determine the required pre-tensioned tendon force necessary to keep the sides of the canoe in constant compression. 3CT outfitted a previous canoe with a deflection measuring device that recorded the maximum outward deflection of the gunwales during racing conditions. By converting the deflection to an equivalent force and multiplying by a FS, 3CT determined that 12 pre-tensioned tendons tensioned to 46 lb (20.87 kg) each would allow the gunwales of TAKE IT FOR GRANITE to stay in compression. 3CT was now ready to begin the development and testing process.

## Development and Testing:

Upon completion of the structural analysis, 3CT began the development and testing process. Although cracking along the chines due to applied forces on the gunwales in races is always a main concern of 3CT, analysis of ACES WILD indicated that higher canoe weight was more problematic than minimal cracking. Therefore, 3CT focused on minimizing concrete unit weight while maximizing workability and maintaining the standards established in structural analysis.

The goals for mix design included a unit weight less than 62.4 lb/ft$^3$ (1,000 kg/m$^3$) as well as the minimum compressive and flexural strengths determined in structural analysis. After establishing these parameters, 3CT divided research into six phases: aggregate, lightweight aggregate, cementitious material, latex, admixture, and fiber and nanotube testing. Compressive strengths were determined in accordance with ASTM C109, while flexural strengths were calculated using third point bending in accordance with ASTM C78.

Phase one involved determining the amount of each aggregate size needed to comply with ASTM C33. 3CT tested Perlite, Stalite, and Ottawa Sand to determine the base aggregate for construction of TAKE IT FOR GRANITE. Inconsistent weight and strength results from Perlite led to its elimination as a possible aggregate source. While Ottawa Sand had 11% higher strength results, 3CT chose Stalite due to its acceptable strength and 27% lower unit weight. Because preliminary mixes with Stalite remained above the target weight, 3CT tested ceramic microspheres retained on a number 100 sieve and found that this aggregate replacement significantly decreased weight with minimal strength reduction (Figure 4).

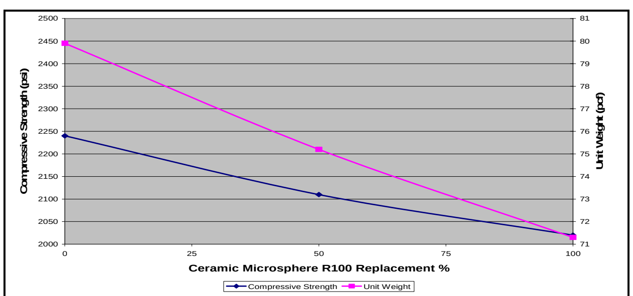



Figure 4: Microsphere Replacement Testing

Phase two tested light weight aggregate mix designs to continue unit weight reduction. The results of phase one provided the baseline mix to test six individual and twelve blended glass bubble aggregates. Test results concluded that K15 and K25 glass bubbles each added at 5% by weight of total aggregate provided the optimal combination of weight reduction and compressive strength maximization.

Phase three tested cementitious materials including Class C Fly Ash, Micron 3, and Silica Fume. The results indicated that Silica Fume and Micron 3 failed to increase concrete strength and decreased the concrete workability. Therefore, Option I, a minimum of 70% Portland Cement and 15% Fly Ash by weight, provided the optimal combination of cementitious materials. More testing of various combinations indicated that the addition of Class C Fly Ash at 20% and Type I Portland Cement at 80% provided the greatest combination of strength and weight.

Phase four tested latex to determine its effectiveness in decreasing the unit weight. 3CT added latex to the mix at increasing percentages up to the maximum allowed by the water-to-cement ratio. Test results indicated that as percent latex increased both unit weight and strength decreased. The final mix design incorporated latex at 10% by weight of cementitious material, the highest percentage that remained above the minimum required strength (Figure 5).

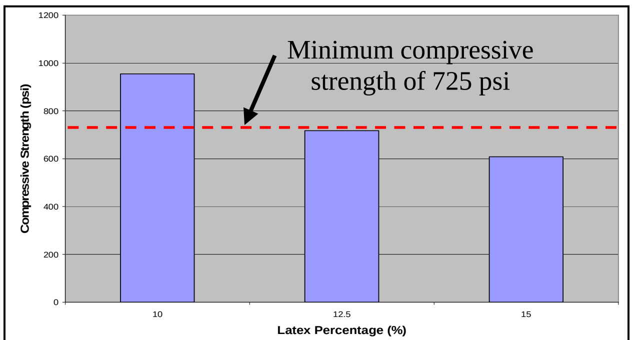



Figure 5: Latex Testing

Phase five tested air entraining admixtures. 3CT examined manufacturer requirements to determine the range of dosages added to the mix. Due to the recommendation of the latex manufacturer to remove air from the mix with a defoaming agent, 3CT used the minimum recommended dosage of 0.25 fl. oz. per 100 lbs of cementitious material. While the admixture decreased mix strength by approximately 10%, the strength remained above the set parameters.

Phase six tested fibers and nanotubes to improve the flexural strength of the concrete. Fiber testing showed that synthetic fibers increased the post peak strength while the use of carbon fibers resulted in an increase in peak flexural strength. 3CT added synthetic fibers at varying percentages by weight of cementitious material to determine the optimal combination of strength and workability in the mix. As fiber addition increased, flexural strength increased and workability decreased. The percentage with the optimal combination of post peak strength and workability was determined to be 1%. Carbon fiber testing determined the best ratio between fiber types. 3CT tested carbon fibers at varying ratios of 1:10 up to 1:3.57. A ratio of 1:5 was the optimal ratio of carbon to synthetic fibers, corresponding to 0.2% by weight of cementitious material (Figure 6).

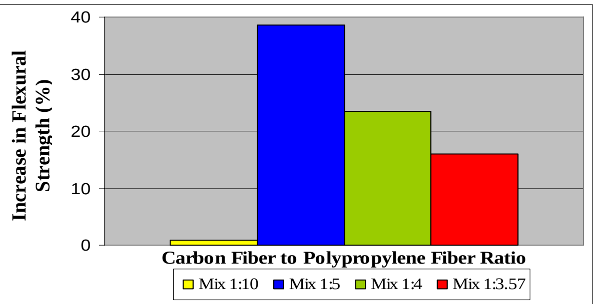



**Figure 6: Flexural Strength of Fibers Ratio**

3CT tested carbon nanotubes due to their ability to increase peak and post-peak flexural strength. Nanotubes increase flexural strength due to their ability to elastically buckle under deformation. Because nanotubes are essentially one-dimensional objects, each well defined along their principle axis, dispersion into a mix creates a grid of increased flexural strength. Beams and cubes containing nanotubes at one, two and three percent by weight of cementitious materials were tested to determine compressive and peak and post-peak flexural strengths. After conducting the testing as well as an extensive literature review, 3CT added nanotubes at 2%, as it increased both peak and post-peak flexural strengths while maintaining compressive strength (Table 4).

**Table 4: Nanotube Testing Summary**

| Strength Type | Regular Mix | Nano Mix | % Increase |
|---|---|---|---|
| **Compressive** | 980 psi | 974 psi | -0.61% |
| **Peak Flexural** | 416 psi | 443 psi | 6.49% |
| **Initial Post-Peak** | 223 psi | 264 psi | 18.39% |

After completion of each testing phase, the final properties of the mixes were set. The final concrete mixture without nanotubes had a unit weight of 63.1 lb/ft$^3$ (1,011 kg/m$^3$), compressive strength of 980 psi (6.76 MPa), and a flexural strength of 416 psi (2.87 MPa). The final mix containing nanotubes had a unit weight of 62.7 lb/ft$^3$ (1,004 kg/m$^3$), compressive strength of 974 psi (6.72 MPa), and a flexural strength of 443 psi (3.05 MPa).

During concrete testing, primary reinforcement testing was also performed. 3CT tested multiple carbon fiber, polypropylene, Eglass, and fiberglass meshes for axial tensile strength and puncture strength. After analyzing the results, 3CT eliminated the fiberglass meshes due to brittle failures during each type of testing and the carbon fiber meshes due to lack of workability. Eglass was eliminated after failing to pass the sand test when stacked in three layers. Therefore, with a maximum tensile strength of 831 psi (5.73 MPa) and puncture strength of 110 psi (0.76 MPa), 3CT chose the stronger of the two polypropylene meshes for the primary reinforcement design.

Reinforcement testing also examined the effects of pre-tensioned tendons placed at the gunwales above the neutral axis. 3CT added six tendons pre-tensioned to 46 lbs (20.87 kg) and spaced 0.5 in (12.7 mm) apart in alternating layers within the inner two layers. Beams were tested in accordance with ASTM C293. With a first crack strength of 950 psi (6.55 MPa) and an ultimate composite strength of 1,210 psi (8.34 MPa), the final composite met all minimum requirements. At this point, 3CT completed the design of the project and was ready to begin the construction of TAKE IT FOR GRANITE.

## Project Management and Construction:

Completing a project of great magnitude on time and under budget constraints requires detailed planning and constant communication.

3CT first selected two project managers based on their previous canoe experience to oversee all aspects of the project. Project managers then selected leaders for each project task based on their specific interest areas and created an organizational breakdown structure. New recruits worked with leaders in different areas based on their interests. Project managers and key leaders established a work breakdown structure based on time tables of previous years to set individual and team deadlines. The work breakdown structure determined critical path activities to include hull design, analysis, mix design, composite testing, placement, finishing, and writing of the technical paper. Intermediate milestones of final mix design, final composite design, placement, technical paper submissions, the regional competition, and the national competition were also determined.

After 3CT established the schedule, project managers and leaders held weekly meetings to discuss progress in individual areas, to inform about upcoming deadlines, and to modify the schedule due to unforeseen circumstances. Leaders held meetings within their specific areas and assigned duties to increase individual involvement. In addition, the leaders created sign-in and sign-out sheets to document the number of person-hours spent on each section of the project. 3CT spent approximately 1,750 person-hours completing the project from start to finish.

Because many team members graduated in May and December 2005 graduations and more were anticipated to graduate in May 2006, recruitment was a major concern for 3CT. Thus, 3CT recruited students throughout the year to ensure adequate team numbers and participation both this year and in subsequent years. At the beginning of the fall semester, project managers organized a general interest meeting which included video footage and pictures from the previous year to introduce the concrete canoe competition to young undergraduates. Paddling trainers arranged paddling demonstrations to show new recruits the correct paddling form and to begin the yearlong training schedule. The team held subsequent recruitment meetings mid-fall semester and at the beginning of the spring semester. The Clemson chapter of ASCE also worked closely with 3CT to ensure that undergraduates had the opportunity to learn about the concrete canoe competition. 3CT utilized ASCE meetings to share information and make announcements, and the team arranged meetings following ASCE for efficient use of recruits' and members' time.

Once 3CT finished recruiting and completed all aspects of analysis and design, the construction phase of the project began. The construction of a concrete canoe requires careful planning, long hours of labor, and knowledge of techniques and processes dealing with construction. Before beginning construction, 3CT divided the construction process into four phases: form construction, prototype placement, canoe placement, and finishing.

3CT began construction of the form by researching time and cost effective methods while utilizing readily available materials. The team then created an AutoCAD drawing of the hull design which instructed a milling machine to cut wooden ribs at 12 inch intervals. After bolting the wooden ribs to a table, high density foam was placed between each rib, cut and shaped with a hot wire, and sanded to the desired dimensions. 3CT covered the composite form with drywall joint compound and sanded it to the correct shape to ensure a smooth and even outer surface. Form construction took approximately 300 person-hours and cost $950.

Phase two involved the placement of the prototype canoe. 3CT built a full-scale fiberglass canoe using fiberglass mesh and resin. The canoe required insulation foam in the bulk heads to ensure flotation and needed wooden slats along the gunwales to provide stability and safety. The team also added a wooden frame in the center for extra support. The prototype allowed both testing and paddling practice in a canoe identical to TAKE IT FOR GRANITE.

The third phase of construction was canoe placement. In preparation for placement, the team pre-batched aggregates, fibers, nanotubes, and cementitious materials to reduce construction time on placement day. 3CT also applied and heated 0.4 mil plastic to the form to provide for an easy and smooth release of the canoe from the form.

On placement day, 3CT placed alternating layers of concrete and reinforcement with six tendons pre-tensioned to 46 lbs (20.87 kg) placed in each of the two middle layers of concrete along the gunwales (Figure 7). The team chose a concrete mix with nanotubes on the inner two layers in order to minimize cracking as well as to limit the expansion of cracks that do form.

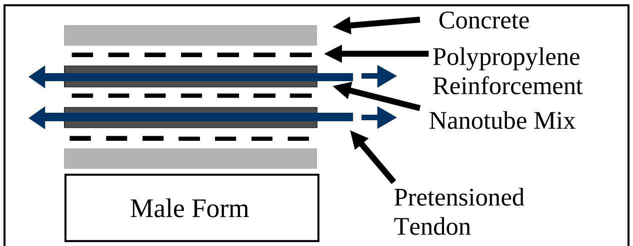



Figure 7: Construction Method

To ensure quality control in both concrete production and concrete placement, 3CT used mechanical mixers, thermal imagery, and time lapse photography. Mechanical mixers ensured consistency between batches of concrete and also decreased time between placement of layers on the canoe. The average placement time for past canoes was approximately three hours, whereas the placement for TAKE IT FOR GRANITE was two hours and ten minutes. This substantial reduction in placement time ensured a consistent bond between each layer of concrete, creating a much higher quality final product. The thermal imagery ensured that a consistent heat of hydration occurred both within a single layer and throughout different layers of concrete (Figure 8). Time lapse photography was conducted in order to assist future teams in organization of placement day.

To provide a smooth finish to the canoe and reduce sanding time, 3CT applied a thin patch mix immediately following placement. By using long, flexible trowels that smoothed around the chines, 3CT was able to evenly fill in many uneven areas, greatly reducing the hours spent on sanding and patching.

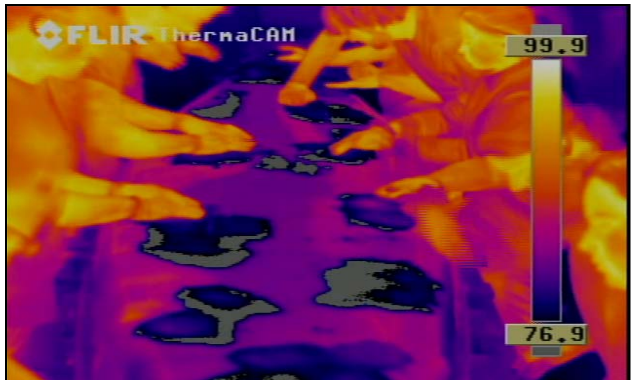



**Figure 8: Thermal Image of the Canoe**

Finishing was the final phase of construction. The canoe cured for 14 days in a temperature controlled environment under plastic sheeting to provide an enclosed, moist environment. Team members (Figure 9) sprayed TAKE IT FOR GRANITE twice daily with water to prevent shrinkage cracking. After 14 days, 3CT broke cubes and beams to ensure the mix had reached an acceptable strength for removal and sanding purposes. Sanding began on the exterior of the canoe using 100 to 180 grit sandpaper. Due to the plastic sheeting placed between the form and the canoe during placement, the interior of the canoe needed minimal sanding to create a smooth surface.

3CT completed construction by adding fiber optics, end caps, decals, acid staining, and sealer to increase the aesthetic qualities of the canoe. The placement of the fiber optics was incorporated into the end cap placement by running each fiber along the bottom of the canoe in depressed channels created during placement. The fibers then went through each end cap into a non-structural section above the end cap where the light source for each fiber optic was located. Acid staining included the innovative use of varying concentrations of two different stains to create a textured granite look. Finally, two coats of sealer were applied in accordance with the manufacturer's recommendations. With the canoe properly managed and successfully completed on schedule (Figure 10), 3CT was ready to hit the water with TAKE IT FOR GRANITE.

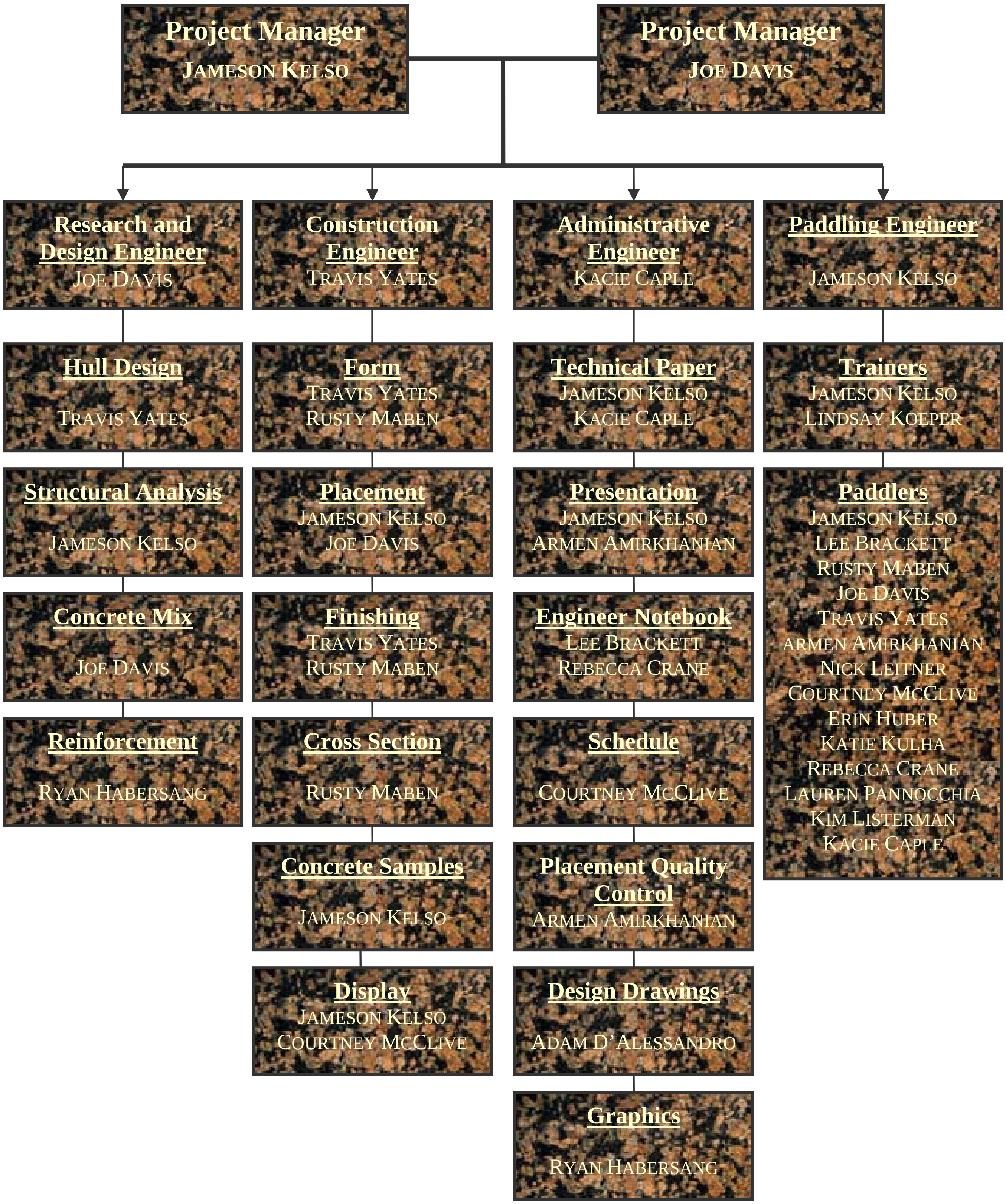
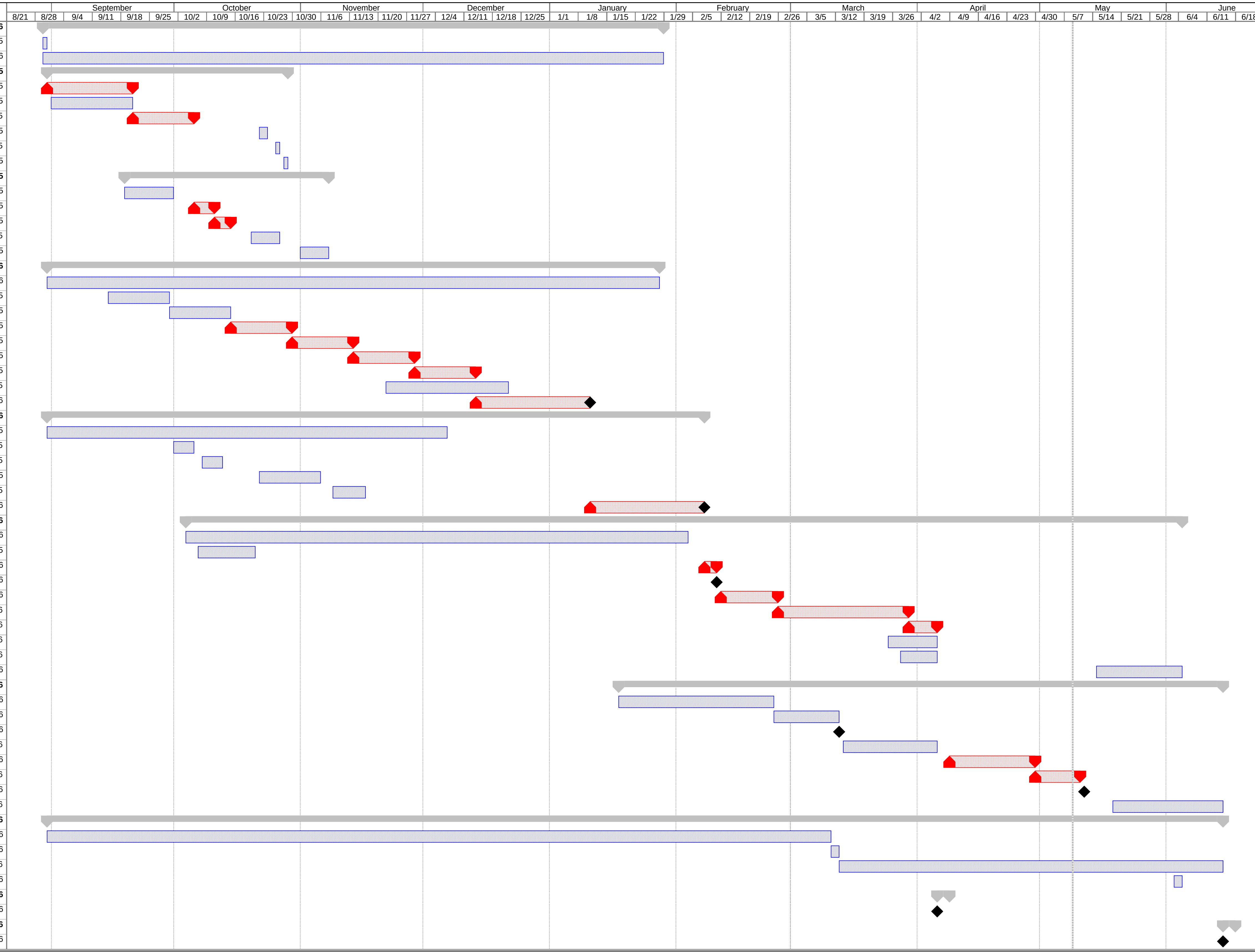


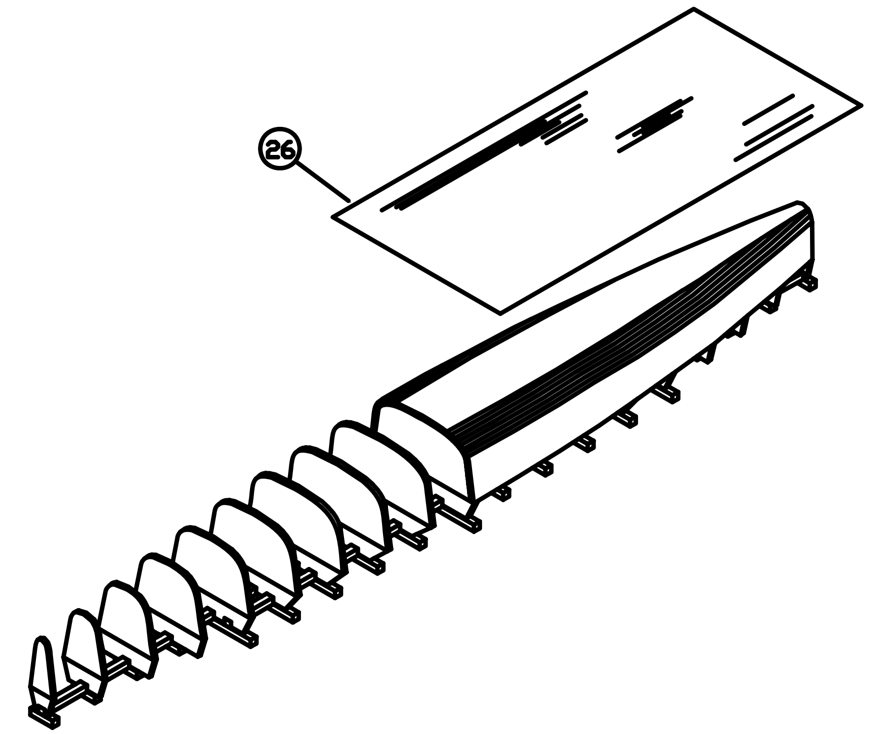

**Figure 9: 3CT Organizational Breakdown Structure**

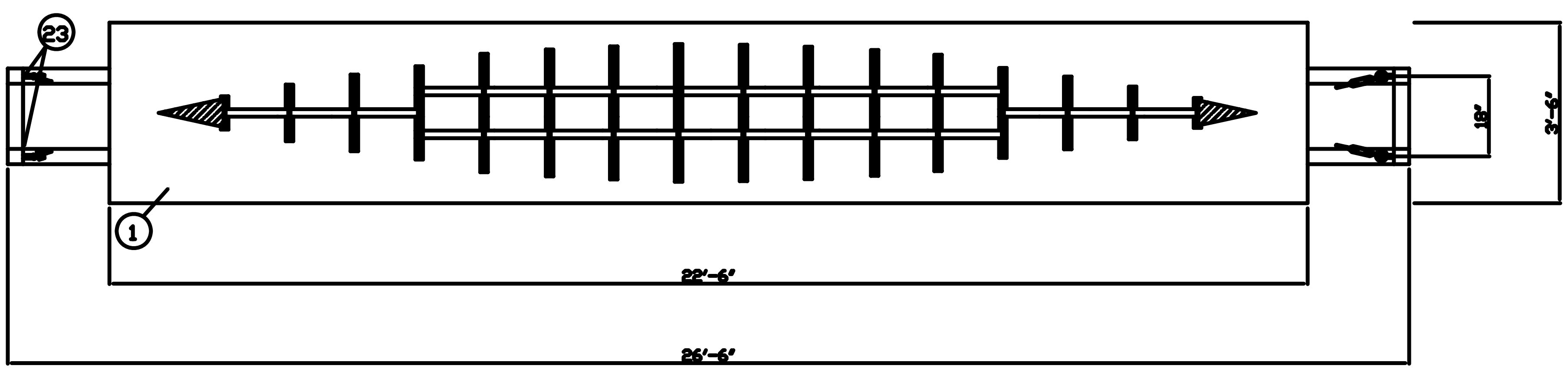
| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **Recruitment** | **152 days** | **Tue 8/30/05** | **Sat 1/28/06** |
| 2 | First Team Meeting | 1 day | Tue 8/30/05 | Tue 8/30/05 |
| 3 | Recruitment | 152 days | Tue 8/30/05 | Sat 1/28/06 |
| 4 | **Hull Design** | **59 days** | **Wed 8/31/05** | **Fri 10/28/05** |
| 5 | Research | 21 days | Wed 8/31/05 | Tue 9/20/05 |
| 6 | Learn Software | 20 days | Thu 9/1/05 | Tue 9/20/05 |
| 7 | Develop Design | 15 days | Wed 9/21/05 | Wed 10/5/05 |
| 8 | Prototype Construction | 2 days | Sat 10/22/05 | Sun 10/23/05 |
| 9 | Straight Line Forces Testing | 1 day | Wed 10/26/05 | Wed 10/26/05 |
| 10 | Turning Speed Testing | 1 day | Fri 10/28/05 | Fri 10/28/05 |
| 11 | **Structural Analysis** | **50 days** | **Mon 9/19/05** | **Mon 11/7/05** |
| 12 | Research | 12 days | Mon 9/19/05 | Fri 9/30/05 |
| 13 | Structural Analysis | 5 days | Thu 10/6/05 | Mon 10/10/05 |
| 14 | Concrete Analysis | 4 days | Tue 10/11/05 | Fri 10/14/05 |
| 15 | Finite Element Analysis | 7 days | Thu 10/20/05 | Wed 10/26/05 |
| 16 | Pretensioned Tendons Testing | 7 days | Tue 11/1/05 | Mon 11/7/05 |
| 17 | **Concrete Design** | **150 days** | **Wed 8/31/05** | **Fri 1/27/06** |
| 18 | Material Acquisition | 150 days | Wed 8/31/05 | Fri 1/27/06 |
| 19 | Aggregate Testing | 15 days | Thu 9/15/05 | Thu 9/29/05 |
| 20 | Glass Bubble Testing | 15 days | Fri 9/30/05 | Fri 10/14/05 |
| 21 | Blended Aggregate Testing | 15 days | Sat 10/15/05 | Sat 10/29/05 |
| 22 | Cementitious Material Testing | 15 days | Sun 10/30/05 | Sun 11/13/05 |
| 23 | Latex Testing | 15 days | Mon 11/14/05 | Mon 11/28/05 |
| 24 | Admixture Testing | 15 days | Tue 11/29/05 | Tue 12/13/05 |
| 25 | Fiber Testing | 30 days | Tue 11/22/05 | Wed 12/21/05 |
| 26 | Final Concrete Mix Testing | 28 days | Wed 12/14/05 | Tue 1/10/06 |
| 27 | **Reinforcement Design** | **161 days** | **Wed 8/31/05** | **Tue 2/7/06** |
| 28 | Material Acquisition | 98 days | Wed 8/31/05 | Tue 12/6/05 |
| 29 | Axial Tensile Testing | 5 days | Sat 10/1/05 | Wed 10/5/05 |
| 30 | Puncture Testing | 5 days | Sat 10/8/05 | Wed 10/12/05 |
| 31 | Workability Determination | 15 days | Sat 10/22/05 | Sat 11/5/05 |
| 32 | Compliance Testing | 8 days | Wed 11/9/05 | Wed 11/16/05 |
| 33 | Composite Testing | 28 days | Wed 1/11/06 | Tue 2/7/06 |
| 34 | **Canoe Construction** | **244 days** | **Tue 10/4/05** | **Sun 6/4/06** |
| 35 | Material Acquisition | 123 days | Tue 10/4/05 | Fri 2/3/06 |
| 36 | Form Construction | 14 days | Fri 10/7/05 | Thu 10/20/05 |
| 37 | Placement Preparation | 3 days | Wed 2/8/06 | Fri 2/10/06 |
| 38 | Placement | 1 day | Sat 2/11/06 | Sat 2/11/06 |
| 39 | Curing | 14 days | Sun 2/12/06 | Sat 2/25/06 |
| 40 | Sanding and Patching | 32 days | Sun 2/26/06 | Wed 3/29/06 |
| 41 | Finishing | 7 days | Thu 3/30/06 | Wed 4/5/06 |
| 42 | Cross Section | 12 days | Sat 3/25/06 | Wed 4/5/06 |
| 43 | Regional Display | 9 days | Tue 3/28/06 | Wed 4/5/06 |
| 44 | National Display | 21 days | Mon 5/15/06 | Sun 6/4/06 |
| 45 | **Documentation** | **148 days** | **Wed 1/18/06** | **Wed 6/14/06** |
| 46 | Regional Paper Draft | 38 days | Wed 1/18/06 | Fri 2/24/06 |
| 47 | Regional Paper Final | 16 days | Sat 2/25/06 | Sun 3/12/06 |
| 48 | Regional Paper Submission | 1 day | Mon 3/13/06 | Mon 3/13/06 |
| 49 | Regional Presentation | 23 days | Tue 3/14/06 | Wed 4/5/06 |
| 50 | National Paper Draft | 21 days | Sun 4/9/06 | Sat 4/29/06 |
| 51 | National Paper Final | 11 days | Sun 4/30/06 | Wed 5/10/06 |
| 52 | National Paper Submission | 1 day | Thu 5/11/06 | Thu 5/11/06 |
| 53 | National Presentation | 27 days | Fri 5/19/06 | Wed 6/14/06 |
| 54 | **Paddling** | **288 days** | **Wed 8/31/05** | **Wed 6/14/06** |
| 55 | Training | 192 days | Wed 8/31/05 | Fri 3/10/06 |
| 56 | Regional Timetrials | 2 days | Sat 3/11/06 | Sun 3/12/06 |
| 57 | Practice | 94 days | Mon 3/13/06 | Wed 6/14/06 |
| 58 | National Timetrials | 2 days | Sat 6/3/06 | Sun 6/4/06 |
| 59 | **Regionals** | **3 days** | **Thu 4/6/06** | **Sat 4/8/06** |
| 60 | Carolina's Conference | 3 days | Thu 4/6/06 | Sat 4/8/06 |
| 61 | **Nationals** | **3 days** | **Thu 6/15/06** | **Sat 6/17/06** |
| 62 | National Competition | 3 days | Thu 6/15/06 | Sat 6/17/06 |

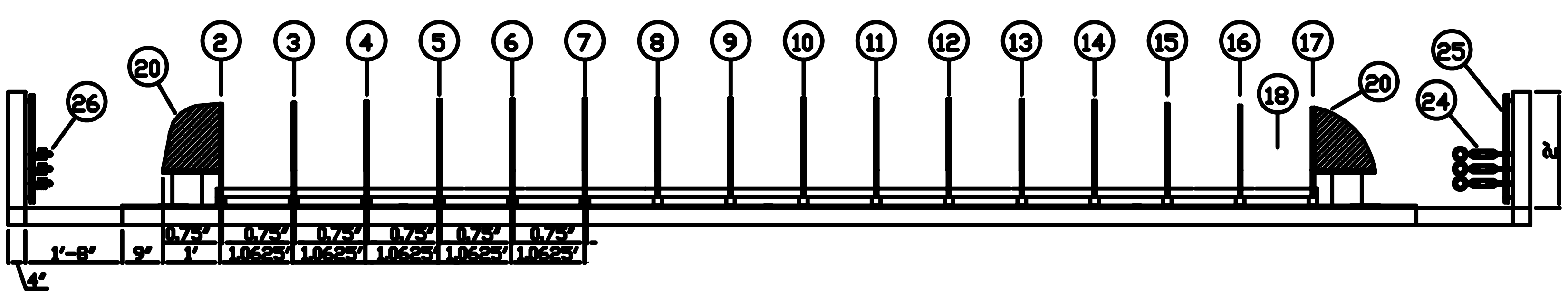


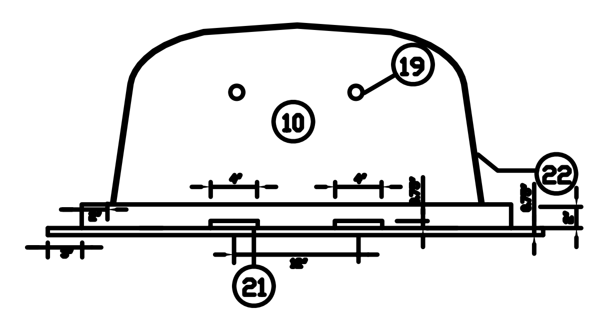

Project: 3CT schedule
Date: Tue 5/9/06

Task | Critical Task | Milestone | Summary




# THE CLEMSON CONCRETE CANOE TEAM

| ITEM NO | QTY | PART | DESCRIPTION |
|---|---|---|---|
| 1 | 1 | TABLE | 3/4" PLYWOOD |
| 2 | 1 | XC-1 | 3/4" PLYWOOD |
| 3 | 1 | XC-2 | 3/4" PLYWOOD |
| 4 | 1 | XC-3 | 3/4" PLYWOOD |
| 5 | 1 | XC-4 | 3/4" PLYWOOD |
| 6 | 1 | XC-5 | 3/4" PLYWOOD |
| 7 | 1 | XC-6 | 3/4" PLYWOOD |
| 8 | 1 | XC-7 | 3/4" PLYWOOD |
| 9 | 1 | XC-8 | 3/4" PLYWOOD |
| 10 | 1 | XC-9 | 3/4" PLYWOOD |
| 11 | 1 | XC-10 | 3/4" PLYWOOD |
| 12 | 1 | XC-11 | 3/4" PLYWOOD |
| 13 | 1 | XC-12 | 3/4" PLYWOOD |
| 14 | 1 | XC-13 | 3/4" PLYWOOD |
| 15 | 1 | XC-14 | 3/4" PLYWOOD |
| 16 | 1 | XC-15 | 3/4" PLYWOOD |
| 17 | 1 | XC-16 | 3/4" PLYWOOD |
| 18 | 15 | FOAM | POLYSTYRENE FOAM |
| 19 | 2 | ROD | 3/8" THREADED STEEL ROD |
| 20 | 2 | END | STYROFOAM END FORM |
| 21 | 3 | XC-BASE | 3/4"x4' BIRCH PLYWOOD |
| 22 | 1 | FORM | DRYWALL JOINT COMPOUND |
| 23 | 12 | SPRING | CALIBRATION SPRINGS |
| 24 | 12 | TURN | TURNBUCKLES |
| 25 | 4 | ROD | 3/8" STEEL ROD |
| 26 | 1 | PLASTIC | 0.4 MIL PLASTIC |

| REV. DATE | REV | DESCRIPTION |
|---|---|---|
| 5/7/06 | 1 | FORMATTING |

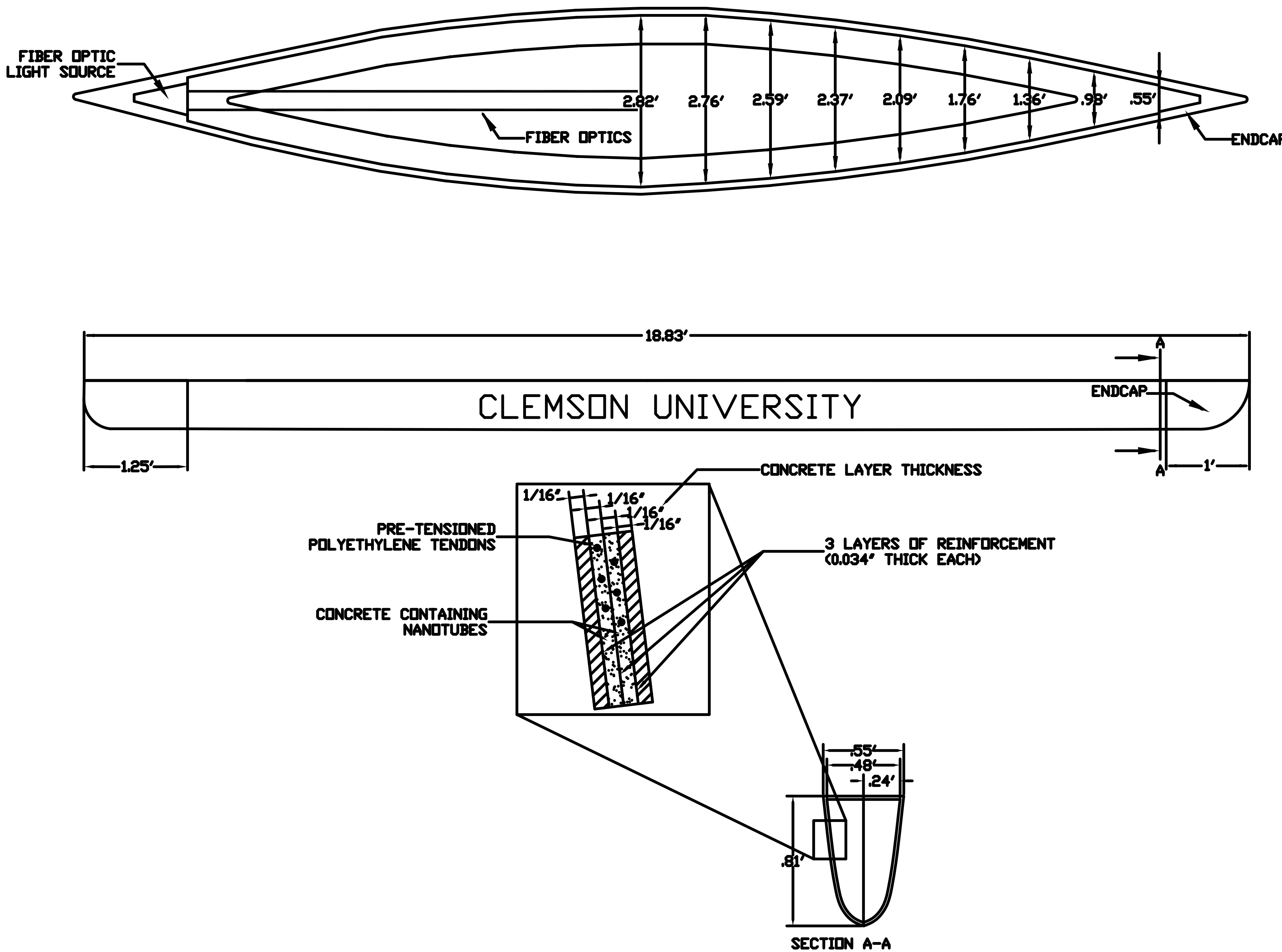
ENGINEER: ADAM D'ALESSANDRO

DRAWN BY: AAD DATE: 3/12/06

CHECKED BY: TMY DATE: 3/12/06

PROJECT: GRANITE

SHEET NO: 9 OF 10




# THE CLEMSON CONCRETE CANOE TEAM

| ITEM NO | QTY | UNIT | DESCRIPTION |
|---|---|---|---|
| 1 | 2.3 | CF | CONCRETE |
| 2 | 169 | SF | POLYPROPYLENE MESH |
| 3 | 225 | LF | POLYETHYLENE TENDONS |
| 4 | 0.89 | CF | POLYSTYRENE FOAM |
| 5 | 1025 | LF | FIBER OPTICS |
| 6 | 4 | | AA BATTERIES |
| 7 | 6 | | LED LIGHTS |

| REV. DATE | REV | DESCRIPTION |
|---|---|---|
| 5/6/06 | 1 | FORMATTING |

ENGINEER: ADAM D'ALESSANDRO

DRAWN BY: AAD DATE: 3/12/06

CHECKED BY: JSK DATE: 3/12/06

PROJECT: GRANITE

SHEET NO: 10 OF 10

## Appendix A - References: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# Appendix B - Summary of Mixture Proportions

**Table B-1: Summary of Final Mixture Proportions**

**Mixture: Final Mixture**

**Batch Size ($ft^3$): 0.03641 $ft^3$**

| | | Proportions as Designed | | Batched Proportions | | Yielded Proportions | |
|---|---|---|---|---|---|---|---|
| **Cementitious Materials** | Specific* Gravity | Amount ($lb/yd^3$) | Volume ($ft^3$) | Amount (lb) | Volume ($ft^3$) | Amount ($lb/yd^3$) | Volume ($ft^3$) |
| 1. ASTM C150 Portland Cement Type I | 3.15 | 536.63 | 2.73 | 0.70 | 0.0036 | 522.74 | 2.66 |
| 2. Class C Fly Ash | 2.20 | 134.16 | 0.97 | 0.18 | 0.0013 | 130.69 | 0.95 |
| Total of All Cementitious Materials | | 670.79 | 3.71 | 0.88 | 0.0049 | 653.43 | 3.61 |
| **Fibers** | | | | | | | |
| 1. Carbon Fibers | 2.90 | 1.34 | 0.0074 | 0.0018 | 0.00001 | 1.31 | 0.0072 |
| 2. Synthetic Fibers | 0.91 | 6.71 | 0.1181 | 0.0088 | 0.000155 | 6.54 | 0.1151 |
| **Aggregates** | | | | | | | |
| 1. Stalite R16<br>Absorption = 2.3%<br>Batched Moisture Content = 0% | 1.93 | 100.62 | 0.84 | 0.132 | 0.0011 | 98.02 | 0.81 |
| 2. Stalite R30<br>Absorption = 2.3 %<br>Batched Moisture Content = 0% | 1.93 | 167.70 | 1.39 | 0.220 | 0.0018 | 163.36 | 1.36 |
| 3. Stalite R50<br>Absorption = 2.3%<br>Batched Moisture Content = 0% | 1.93 | 201.24 | 1.67 | 0.264 | 0.0022 | 196.03 | 1.63 |
| 4. G-3500 Ceramic Microspheres R100<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.70 | 134.16 | 3.07 | 0.176 | 0.0040 | 130.69 | 2.99 |
| 5. K25 Glass Microspheres<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.25 | 33.54 | 2.15 | 0.044 | 0.0028 | 32.67 | 2.09 |
| 6. K15 Glass Microspheres<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.15 | 33.54 | 3.58 | 0.044 | 0.0047 | 32.67 | 3.49 |
| Total of All Aggregates | | 670.79 | 12.70 | 0.881 | 0.0167 | 653.43 | 12.37 |
| **Water** | | | | | | | |
| Batched Water | 1.00 | 268.32 | 4.30 | 0.352 | 0.0056 | 261.37 | 4.19 |
| Total Free Water from All Aggregates | 1.00 | -10.80 | -0.17 | -0.014 | -0.0002 | -10.52 | -0.17 |
| Total Water from All Admixtures | 1.00 | 75.43 | 1.20 | 0.099 | 0.0016 | 73.48 | 1.18 |
| Total Water | | 332.95 | 5.33 | 0.437 | 0.0070 | 324.33 | 5.20 |
| **Admixtures** | % Solids | Amount (fl oz/cwt) | Water in Admixture ($lb/yd^3$) | Amount (fl oz) | Water in Admixture (lb) | Amount (fl oz/cwt) | Water in Admixture ($lb/yd^3$) |
| 1. Master Builders AE90 | - | 0.25 | | 0.0022 | | 0.25 | |
| 2. Rohm and Haas MC-76 Latex | 47 | 304.88 | 75.43 | 2.686 | 0.0992 | 296.99 | 73.48 |
| Cement-Cementitious Materials Ratio | | 0.8 | | 0.8 | | | 0.8 |
| Water-Cementitious Materials Ratio | | 0.496 | | 0.496 | | | 0.496 |
| Slump, in. | | 4 | | 4 | | | 4 |
| Air Content, % | | 15 | | 17.5 | | | 17.2 |
| Density (Unit Weight), $lb/ft^3$ | | 64.8 | | 63.1 | | | 63.1 |
| Gravimetric Air Content, % | | | | 17.2 | | | |
| Yield, $ft^3$ | | 27 | | 0.03641 | | | 27 |

**Table B-2: Summary of Nanotube Mixture Proportions**

**Mixture: Nanotube Mixture**

**Batch Size (ft$^3$): 0.03693 ft$^3$**

| | | Proportions as Designed | | Batched Proportions | | Yielded Proportions | |
|---|---|---|---|---|---|---|---|
| **Cementitious Materials** | Specific* Gravity | Amount (lb/yd$^3$) | Volume (ft$^3$) | Amount (lb) | Volume (ft$^3$) | Amount (lb/yd$^3$) | Volume (ft$^3$) |
| 1. ASTM C150 Portland Cement Type I | 3.15 | 527.99 | 2.69 | 0.70 | 0.0036 | 515.42 | 2.62 |
| 2. Class C Fly Ash | 2.20 | 132.00 | 0.96 | 0.18 | 0.0013 | 128.86 | 0.94 |
| Total of All Cementitious Materials | | 659.99 | 3.65 | 0.88 | 0.0049 | 644.28 | 3.56 |
| **Fibers** | | | | | | | |
| 1. Carbon Fibers | 2.90 | 1.32 | 0.0073 | 0.0018 | 0.00001 | 1.29 | 0.0071 |
| 2. Synthetic Fibers | 0.91 | 6.60 | 0.1162 | 0.0088 | 0.000155 | 6.44 | 0.1135 |
| 3. Carbon Nanotubes | 2.13 | 13.20 | 0.0993 | 0.0176 | 0.000133 | 12.89 | 0.0969 |
| **Aggregates** | | | | | | | |
| 1. Stalite R16<br>Absorption = 2.3%<br>Batched Moisture Content = 0% | 1.93 | 99.00 | 0.82 | 0.132 | 0.0011 | 96.64 | 0.80 |
| 2. Stalite R30<br>Absorption = 2.3 %<br>Batched Moisture Content = 0% | 1.93 | 165.00 | 1.37 | 0.220 | 0.0018 | 161.07 | 1.34 |
| 3. Stalite R50<br>Absorption = 2.3%<br>Batched Moisture Content = 0% | 1.93 | 198.00 | 1.64 | 0.264 | 0.0022 | 193.29 | 1.60 |
| 4. G-3500 Ceramic Microspheres R100<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.70 | 132.00 | 3.02 | 0.176 | 0.0040 | 128.86 | 2.95 |
| 5. K25 Glass Microspheres<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.25 | 33.00 | 2.12 | 0.044 | 0.0028 | 32.21 | 2.07 |
| 6. K15 Glass Microspheres<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.15 | 33.00 | 3.53 | 0.044 | 0.0047 | 32.21 | 3.44 |
| Total of All Aggregates | | 659.99 | 12.49 | 0.881 | 0.0167 | 644.28 | 12.19 |
| **Water** | | | | | | | |
| Batched Water | 1.00 | 263.99 | 4.23 | 0.352 | 0.0056 | 257.70 | 4.13 |
| Total Free Water from All Aggregates | 1.00 | -10.70 | -0.17 | -0.014 | -0.0002 | -10.45 | -0.17 |
| Total Water from All Admixtures | 1.00 | 74.28 | 1.20 | 0.099 | 0.0016 | 72.51 | 1.16 |
| Total Water | | 327.57 | 5.25 | 0.437 | 0.0070 | 319.76 | 5.12 |
| | | | | | | | |
| **Admixtures** | % Solids | Amount (fl oz/cwt) | Water in Admixture (lb/yd$^3$) | Amount (fl oz) | Water in Admixture (lb) | Amount (fl oz/cwt) | Water in Admixture (lb/yd$^3$) |
| 1. Air Entrainment | - | 0.25 | | 0.0022 | | 0.25 | |
| 2. Rohm and Haas MC-76 Latex | 47 | 304.88 | 74.28 | 2.686 | 0.0992 | 295.74 | 72.51 |
| | | | | | | | |
| Cement-Cementitious Materials Ratio | | 0.8 | | 0.8 | | | 0.8 |
| Water-Cementitious Materials Ratio | | 0.496 | | 0.496 | | | 0.496 |
| Slump, in. | | 4 | | 4 | | | 4 |
| Air Content, % | | 16 | | 17.7 | | | 18.0 |
| Density (Unit Weight), lb/ft$^3$ | | 64.3 | | 62.7 | | | 62.7 |
| Gravimetric Air Content, % | | | | 18.0 | | | |
| Yield, ft$^3$ | | 27 | | 0.03693 | | | 27 |

**Table B-3: Summary of Finishing Mixture Proportions**

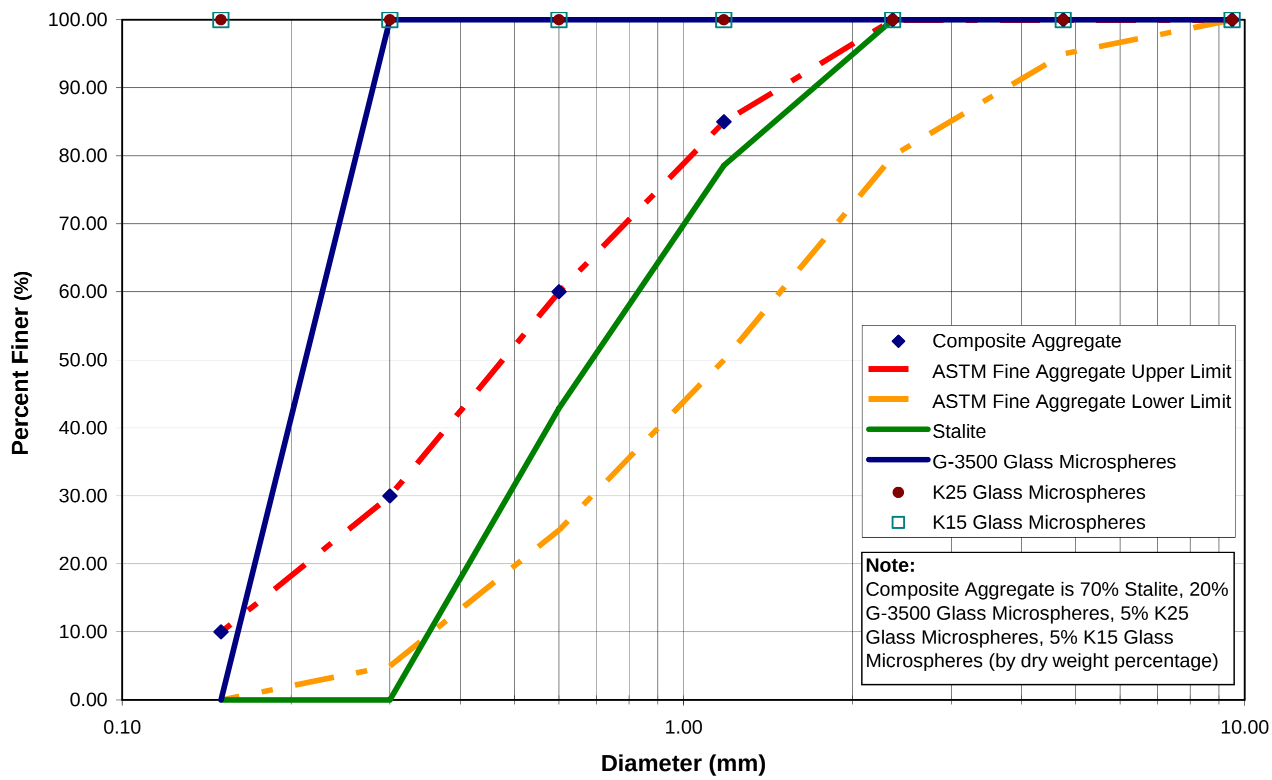
**Mixture: Finishing Mixture**

**Batch Size ($ft^3$): 0.03607 $ft^3$**

| | | Proportions as Designed | | Batched Proportions | | Yielded Proportions | |
|---|---|---|---|---|---|---|---|
| **Cementitious Materials** | Specific* Gravity | Amount ($lb/yd^3$) | Volume ($ft^3$) | Amount (lb) | Volume ($ft^3$) | Amount (lb/yd3) | Volume ($ft^3$) |
| 1. ASTM C150 Portland Cement Type I | 3.15 | 545.93 | 2.78 | 0.70 | 0.0036 | 527.52 | 2.68 |
| 2. Class C Fly Ash | 2.20 | 136.48 | 0.99 | 0.18 | 0.0013 | 131.88 | 0.96 |
| Total of All Cementitious Materials | | 682.42 | 3.77 | 0.88 | 0.0049 | 659.41 | 3.64 |
| **Fibers** | | | | | | | |
| 1. | | | | | | | |
| 2. | | | | | | | |
| **Aggregates** | | | | | | | |
| 1. Stalite R16<br>Absorption = 2.3%<br>Batched Moisture Content = 0% | 1.93 | 102.24 | 0.85 | 0.132 | 0.0011 | 98.79 | 0.82 |
| 2. Stalite R30<br>Absorption = 2.3 %<br>Batched Moisture Content = 0% | 1.93 | 170.60 | 1.42 | 0.220 | 0.0018 | 164.85 | 1.37 |
| 3. Stalite R50<br>Absorption = 2.3%<br>Batched Moisture Content = 0% | 1.93 | 204.72 | 1.70 | 0.264 | 0.0022 | 197.82 | 1.64 |
| 4. G-3500 Ceramic Microspheres R100<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.70 | 136.48 | 3.12 | 0.176 | 0.0040 | 131.88 | 3.02 |
| 5. K25 Glass Microspheres<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.25 | 34.12 | 2.19 | 0.044 | 0.0028 | 32.97 | 2.11 |
| 6. K15 Glass Microspheres<br>Absorption = 0%<br>Batched Moisture Content = 0% | 0.15 | 34.12 | 3.65 | 0.044 | 0.0047 | 32.97 | 3.52 |
| Total of All Aggregates | | 682.42 | 12.92 | 0.881 | 0.0167 | 659.41 | 12.48 |
| **Water** | | | | | | | |
| Batched Water | 1.00 | 272.97 | 4.37 | 0.352 | 0.0056 | 263.76 | 4.23 |
| Total Free Water from All Aggregates | 1.00 | -10.94 | -0.17 | -0.014 | -0.0002 | -10.57 | -0.17 |
| Total Water from All Admixtures | 1.00 | 76.68 | 1.23 | 0.099 | 0.0016 | 74.09 | 1.19 |
| Total Water | | 338.70 | 5.43 | 0.437 | 0.0070 | 327.28 | 5.25 |
| | | | | | | | |
| **Admixtures** | % Solids | Amount (fl oz/cwt) | Water in Admixture ($lb/yd^3$) | Amount (fl oz) | Water in Admixture (lb) | Amount (fl oz/cwt) | Water in Admixture ($lb/yd^3$) |
| 1. Master Builders AE90 | - | 0.25 | | 0.0022 | | 0.25 | |
| 2. Rohm and Haas MC-76 Latex | 47 | 304.88 | 76.68 | 2.686 | 0.0992 | 294.60 | 74.09 |
| | | | | | | | |
| Cement-Cementitious Materials Ratio | | 0.8 | | 0.8 | | | 0.8 |
| Water-Cementitious Materials Ratio | | 0.496 | | 0.496 | | | 0.496 |
| Slump, in. | | 4 | | 4 | | | 4 |
| Air Content, % | | 14 | | 16.5 | | | 16.9 |
| Density (Unit Weight), $lb/ft^3$ | | 65.6 | | 63.4 | | | 63.4 |
| Gravimetric Air Content, % | | | | 16.9 | | | |
| Yield, $ft^3$ | | 27 | | 0.03607 | | | 27 |

# Appendix C - Gradation Curves and Charts

## Figure C-1: Composite and Individual Gradation Curves




## Table C-1: Composite Gradation Chart

Concrete Aggregate: Composite Aggregate
Sample Weight: 800 grams
Specific Gravity ($G_s$): 0.846
Fineness Modulus: 2.15

| Sieve | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|---|---|---|---|---|
| 3/8 inch | 9.50 | 0.00 | 0.00 | 100.00 |
| No. 4 | 4.75 | 0.00 | 0.00 | 100.00 |
| No. 8 | 2.36 | 0.00 | 0.00 | 100.00 |
| No. 16 | 1.18 | 120.00 | 120.00 | 85.00 |
| No. 30 | 0.60 | 200.00 | 320.00 | 60.00 |
| No. 50 | 0.30 | 240.00 | 560.00 | 30.00 |
| No. 100 | 0.15 | 160.00 | 720.00 | 10.00 |
| Pass 100 | - | 80.00 | 800.00 | 0.00 |

### Table C-2: Stalite Gradation Chart

Concrete Aggregate: Stalite
Sample Weight: 560 grams
Specific Gravity ($G_s$): 1.93
Fineness Modulus: 2.79

| Sieve | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|---|---|---|---|---|
| 3/8 inch | 9.50 | 0.00 | 0.00 | 100.00 |
| No. 4 | 4.75 | 0.00 | 0.00 | 100.00 |
| No. 8 | 2.36 | 0.00 | 0.00 | 100.00 |
| No. 16 | 1.18 | 120.00 | 120.00 | 78.57 |
| No. 30 | 0.60 | 200.00 | 320.00 | 42.86 |
| No. 50 | 0.30 | 240.00 | 560.00 | 0.00 |
| No. 100 | 0.15 | 0.00 | 560.00 | 0.00 |

### Table C-3: G-3500 Glass Microspheres Gradation Chart

Concrete Aggregate: G-3500 Glass Microspheres
Sample Weight: 160 grams
Specific Gravity (Gs): 0.70
Fineness Modulus: 1.00

| Sieve | Diameter (mm) | Weight Retained (g) | Cumulative Weight Retained (g) | Percent Finer (%) |
|---|---|---|---|---|
| 3/8 inch | 9.50 | 0.00 | 0.00 | 100.00 |
| No. 4 | 4.75 | 0.00 | 0.00 | 100.00 |
| No. 8 | 2.36 | 0.00 | 0.00 | 100.00 |
| No.16 | 1.18 | 0.00 | 0.00 | 100.00 |
| No. 30 | 0.60 | 0.00 | 0.00 | 100.00 |
| No. 50 | 0.30 | 0.00 | 0.00 | 100.00 |
| No. 100 | 0.15 | 160.00 | 160.00 | 0.00 |

**Figure C-2: K15 Glass Bubbles Gradation Curve**

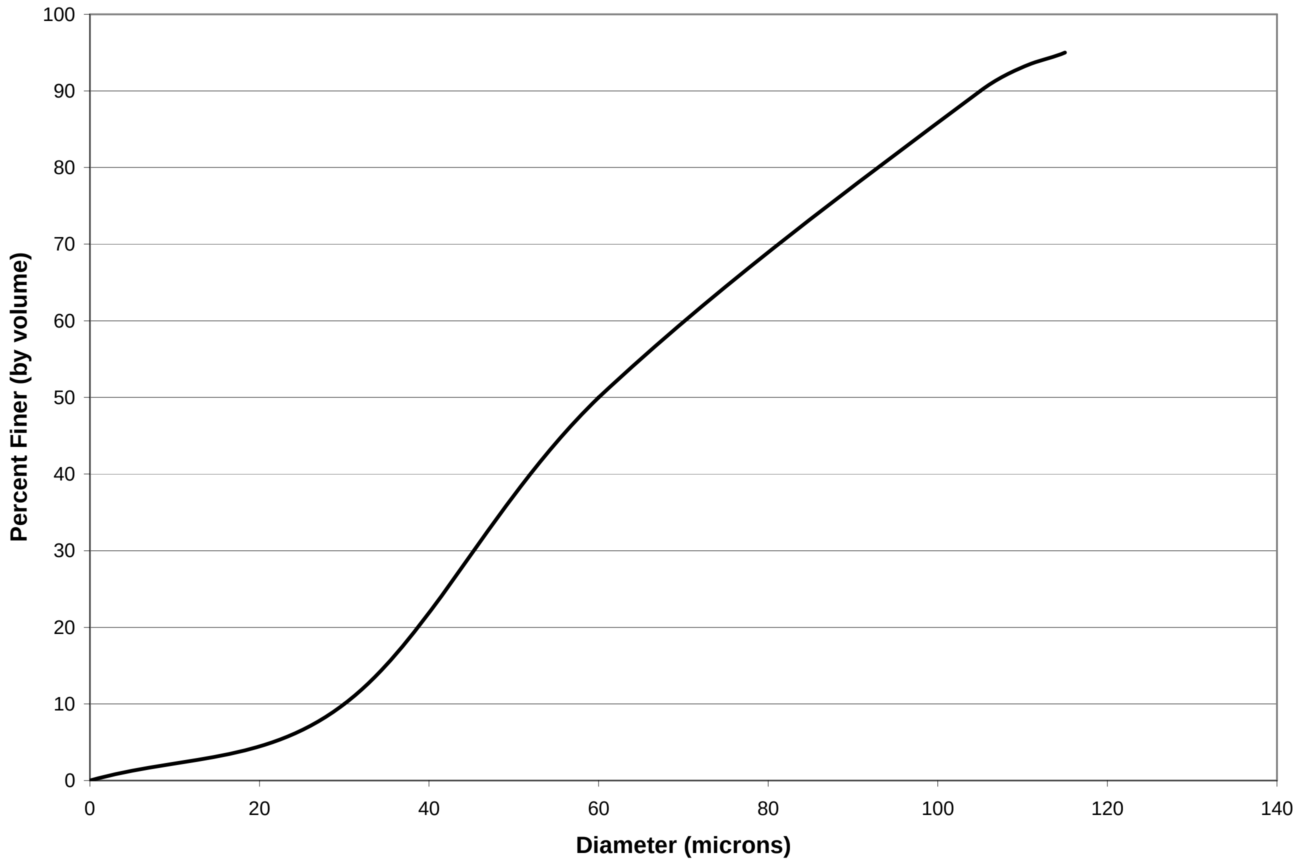


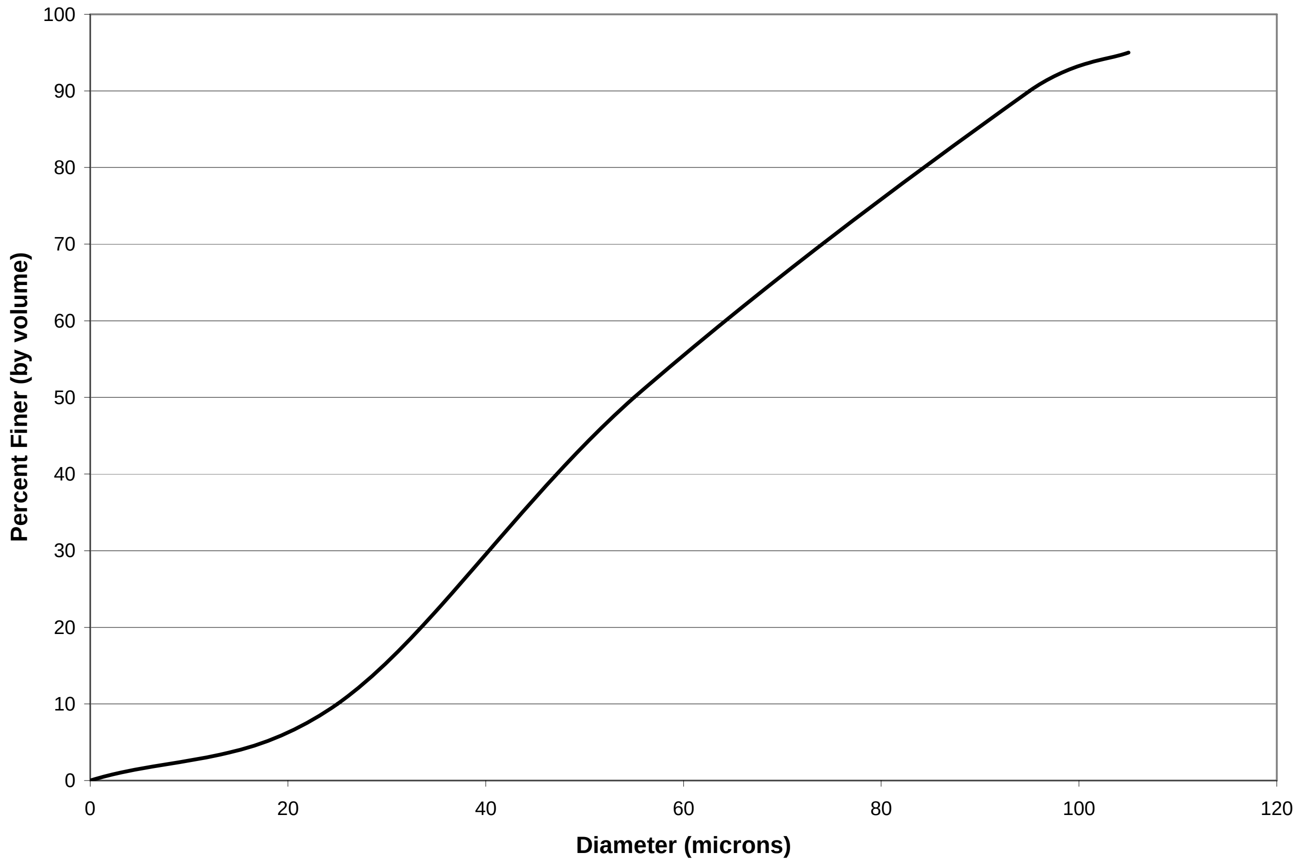

**Table C-4: K15 Bubbles Gradation Chart**

Concrete Aggregate: K15 Glass Bubbles
Sample Weight: 500 grams
Specific Gravity ($G_s$): 0.15
Fineness Modulus: 0.00

| Diameter (mm) | Cumulative Percent Finer (%) |
|---|---|
| 0 | 0 |
| 0.03 | 10 |
| 0.06 | 50 |
| 0.105 | 90 |
| 0.115 | 95 |

*Data based on 3M Scotchlite Glass Bubbles Product Information Sheet

## Figure C-3: K25 Glass Bubbles Gradation Curve




## Table C-5: K25 Bubbles Gradation Chart

Concrete Aggregate:  K25 Glass Bubbles
Sample Weight:  500 grams
Specific Gravity ($G_s$):  0.25
Fineness Modulus: 0.00

| Diameter (mm) | Cumulative Percent Finer (%) |
|---|---|
| 0 | 0 |
| 0.025 | 10 |
| 0.055 | 50 |
| 0.095 | 90 |
| 0.105 | 95 |

*Data based on 3M Scotchlite Glass Bubbles Product Information Sheet