ACI Mortar Workability Competition

Objectives

While current ACI competitions focus mainly on strength or hardened concrete performance, this competition will focus on workability and rheological properties of cement-based materials. Teams are challenged to create a mortar mixture with optimum flowability and stability. Students are to mix mortar at the convention competition site and their mixture will be poured into a mold made in the shape of the letters *aci* from the top of the letter "*a*". Both flowability and mixture stability will be evaluated. In creating their mortar mixture, teams will have to pay careful attention to the specified material requirements just as concrete producers must meet specification and project requirements on a daily basis.



Prizes

Flowability, mixture stability, cost of the mixture, and quality of written report will be used to determine the winners of the competition. First-second-and third-place entries will each be awarded a certificate of recognition, will be recognized in *Concrete International* magazine if space allows, and will be recognized on ACI's website. In addition, the first-place team will receive a $750 award, the second-place team will receive $500, and the third-place team will receive $250. Winners will not be announced, and prizes will not be awarded until the student lunch on Monday following the competition.

Rules

1. Eligibility

a. Each team must consist of students in high school, technical school, trade school, or undergraduate students of a college or university at the time of the competition. Undergraduate students on cooperative or internship work assignment are also eligible to compete. All members of a given team must be from the same school.
b. A team is limited to eight individuals. Each school may register only one team.

c. Each team must have a supervising faculty advisor who will see that the student team complies with the rules of the competition.
d. Since this competition involves mixing and pouring of mixture at the convention, it is required that at least two team members be present at the convention to participate in the mixing, pouring, and cleanup during the competition. Participation by additional team members is both permitted and encouraged, though a maximum of 4 students will be allowed to mix mortar in order to maintain a safe working area.
e. Please note that previously for this competition there have been many teams disqualified due to non-compliance with the rules. Please review the rules carefully, taking special note of the allowable materials and requirements for aggregate composition and water content.

2. Material

All material requirements indicated below should be closely followed and all materials and the mix design used in the competition are to be clearly described in the Written Report (see Section 3). The mix design and cost calculation need to be submitted online. The specific details can be found in Appendix A. **Teams failing to do so will be either disqualified from the competition or will have a penalty applied, as determined by the judges**. Special attention should be paid to the aggregate gradation requirements dictated in Section 2e.

a. The mortar must use cementitious materials as binder, as defined in Section 2b below. A maximum of 30% of the binder material may be supplementary cementitious materials (by total mass of cementitious products).
b. The cementitious materials shall be Portland cement meeting ASTM C150. Supplementary cementitious materials (up to 30% of total binder) such as fly ash and natural pozzolans meeting ASTM C618, silica fume meeting ASTM C1240, or slag cement meeting ASTM C989 may also be used. If no pure Portland cement is available in the region of the competing team, a blended cement may be used, provided the amount of SCM in the cement does not exceed the limiting quantity. Product information sheets must be included in the report. If the quantity of SCM is stated to be in a certain range, the maximum value shall be assumed for this competition. The cost of a blended cement is considered to be equal to the cost of a pure Portland cement.
c. Mineral fillers such as kiln dusts and rock dusts are also allowed to be used provided the total substitution for Portland cement does not exceed 30%. Blended cement shall not be used, except if no pure Portland cement is available, as discussed in 2.b.
d. Nano-materials shall only be used in aqueous suspensions. Those materials shall not be used in dry/powder form for safety reasons. A water content of 80% (by mass of the suspension) shall be included in the total water content. The maximum ratio between water and cementitious materials plus mineral fillers is 0.50 (by mass).
e. Chemical admixtures meeting ASTM C494 or C1017 may be used.
f. Aggregate shall be non-metal aggregates meeting fine aggregate requirements described in ASTM C33. In addition, fine aggregate selected shall have 100% passing sieve size 4.75 mm (No. 4). The mixture must contain 60% (by mass of the whole mixture) aggregate as a minimum. See Table 1 for a summary of ASTM C33 fine aggregate requirements. The mix design needs to be reported in SSD conditions.

g. The aggregate needs to be delivered at or below SSD condition at the moment of the competition. **No water shall be added to correct for a moisture condition**, as it is uncertain how much of the water will be absorbed by the aggregate. SSD condition may be verified on site through ASTM C 128. The mass of aggregate (min. 60%) will be considered in its totality on-site for the competition, regardless of its moisture condition.
h. For every liquid chemical admixture, a solid content of 40% will be assumed. The remaining 60%, which is assumed to be water (by volume), will be counted as water content and will influence both w/cm and the total mixture mass (and thus the relative sand content).

Table 1: ASTM C33 fine aggregate requirements

Sieve Size		% Passing
4.75 mm	(No. 4)	95 to 100
2.36 mm	(No. 8)	80 to 100
1.18 mm	(No. 16)	50 to 85
600 µm	(No. 30)	25 to 60
300 µm	(No. 50)	5 to 30
150 µm	(No. 100)	0 to 10

Fineness Modulus: 2.3 to 3.1
No more than 45% passing one sieve and retained on the next.

3. Written Report

Teams shall submit a unique written report meeting the requirements listed below for the judges to review and score. An electronic version of the report in standard PDF format (not in Microsoft Word or similar) shall be submitted as described below and detailed in Appendix A. The electronic report due date is indicated in Section 7. A hard-copy version shall be also submitted at the competition as described below for display during the competition. The hard copy shall be on standard letter size paper (or A4 format) and bound together. Teams failing to submit the hard-copy version of the report shall receive a zero in the report section of the Final Score equation given in Section 5. Failure to submit the electronic report prior to the competition will be considered as a withdrawal from the competition, despite the intention of the team to compete.

The report must consist of the following sections: Cover Page, Abstract, Introduction, Methodology (Materials and Mixture Proportions, Procedures), Results, Discussion, Conclusions, and References. All reports shall be scored between zero and 100%, with 100% being the best. Table 2 shows the point allocation that the judges will use to score the report:

Table 2: Report evaluation criteria rubric

Formatting	3
Cover page	2
Abstract	5
Introduction	15
Methodology: Materials and Mixture Proportions[1] Procedures	 20 10
Results	15
Discussion	20
Conclusions	5
References	5

Additional details about the minimum requirements for the report are provided in Appendix A.

4. Testing/Cost Evaluation

a. Each team is to prepare two sets of raw materials (cementitious materials, filler [if applicable], aggregate(s), chemical admixture(s)). The two sets of raw materials shall be identical and provide 650 ± 100 mL of final mortar mixture. **All materials**, except water and admixtures, **are to be pre-weighed, bagged individually**, and brought to the competition. Admixtures may be measured at the competition site, but must be supplied by the team. All bags shall be clearly labeled with the 5-character Team ID mentioned in Appendix A.2.iii and the type of material. The competition organizer will prepare appropriate measures for water measurement on-site. The chemical admixtures can only be measured by means of a syringe (provided by the team) (by volume) on site. The judges will inspect both sets of raw materials and verify compliance with the rules, including the amount and gradation requirements. Both sets of identical raw materials shall comply with the rules (see Section 8). Note that in order to ensure all raw materials arrive on time, all teams are strongly encouraged to contact their traveling companies regarding regulations of baggage and carry-on allowance, particularly liquid—that is, chemical admixture(s)—prior to their travels.
b. The judges will randomly select one set of the raw materials for mixing.
c. Mixing
    i. If necessary, a judge will verify the water content of the sand by means of the procedure described in ASTM C-128. If the judges deem that the aggregate is above SSD condition (the sand does not slump), the team will be disqualified.
    ii. All bagged materials will be weighed by a judge prior to mixing. The entire quantity of each bag containing solid materials must be added to the mixer. **In**

[1] Failure to include the material properties (density or relative density, absorption for the aggregate, and data sheets for all chemical admixtures and any alternative binder/powder) shall lead to disqualification of the team. Failure to include a correct mix design sheet shall also result in disqualification (Hint: the relative density of a standard mortar should be around 2.2-2.3, unless valid assumptions can be made to have a lower relative density based on the materials added).

other words, teams are required to provide all solid materials, pre-weighed in separate bags for each material, and no adjustment to the quantity of (solid) materials can be made on-site. Teams should consider that the moisture content of the sand may vary during transportation and on-site, and should ensure that regardless of the moisture content, 60% of the mixture mass is composed of aggregates.

iii. The teams have 5 minutes to prepare the water and admixture quantities on-site. Rules section 4.a will be strictly enforced concerning the measurement of chemical admixtures.

iv. A standard 5 qt laboratory mixer provided by the competition organizer, is to be used for mixing. Each team will be responsible to mix their own mixture on-site. It is recommended to follow ASTM C305; however, a team can decide their own mixing procedure, based on the selected mixing procedure as described in the written report. The maximum mixing speed on the mixer is not allowed to be used. A maximum of 10 min is allowed for each team to have their mixtures prepared and handed to the judges. The 10 min period starts either when turning on the mixer or when adding the mixing water to the mixer bowl.

v. Should the team determine that the workability of their mixture does not meet their expectation, the team will be allowed to adjust the quantity of 1 (one) chemical admixture, employed in the reported mortar mixture, relative to the mix design reported by the team. Multiple additions of the same chemical admixture are allowed, as long as the total mixing time does not exceed the maximum of 10 (ten) min as specified in section 4.c.iv. Each addition should be reported to the judge. Failure to report each addition, exceed the maximum of 10 min allowed mixture preparation time, the adjustment with multiple chemical admixtures (on site), or the use of a chemical admixture which is not incorporated in the reported mortar mix design will lead to disqualification of the team. It should be noted that when adding chemical admixture on-site, 60% of its volume will be counted towards w/cm and may also affect the relative sand content. Exceeding the maximum w/cm by the on-site addition of extra chemical admixture, even when the design w/cm in the report was below 0.50, will result in disqualification. As a consequence, designing the mixture at the maximum w/cm prescribed in the rules will not permit the inclusion of any “extra” liquid chemical admixture on-site. Upon completion of mixing, the bowl with the mixture shall be weighted. The mass of the bowl (determined before the competition) will be subtracted. The volume of the mortar will be derived from the mass based on the density or relative density (specific gravity) of the mixture, which will be taken from the submitted report. If the volume of the mixture is out of the allowable limits: between 550 and 750 mL, the team will be disqualified.

vi. Upon the completion of mixing, the judges will collect the mixing bowl and pour mixtures into two standard 250 mL containers, with each container filled with 250 ± 10 mL of mortar mixture. The latter container of mixture is to be used for the flowability test (see Section 4.d) and the first filled container of mixture is to be used for the stability testing (see Section 4.e).

vii. Each team is then to deposit the surplus mixture into the designated cleanup area. The team is responsible for cleaning the mixing bowl, paddles, and any other

tools used in mixing appropriately. An additional 10 min is allowed for cleanup time. Teams failing to properly cleanup will be disqualified from the competition.

d. Flowability Testing
    i. Mixture from the second filled container as prepared in Section 4.c.vii will be used for flowability testing.
    ii. Within 3 min after the mixture is delivered to the judges, judges will pour the mixture into the *aci* mold through a funnel with an opening of approximately 12 mm. During the process of the mixture being poured into the funnel, the judge will be filling the funnel while holding his/her finger over the end of funnel until all materials from Section 4.d.i are poured into the funnel. The judge will then place the opening of the funnel right above the opening of letter "a" and release the mortar mixture into the mold flowing under the force of gravity alone. A detailed drawing of the mold can be found in Appendix B. Molds will be provided at the competition site. Students may use the drawing to fabricate their own mold for testing at their own school, although the competition molds may not behave exactly similar to school training molds. Time for the mixture to fill the mold—that is, from mixture poured into top of letter "a" to the time for mixture to come out from top of letter "i"—will be recorded. No vibration and/or consolidation will be permitted during the pouring process. A maximum of 3 min will be allowed for the mixture to flow through the mold.
    iii. If the mixture is not able to fully fill the mold, the degree of mixture filling the mold will be recorded. The degree of mixture filling the mold will be recorded when there is no obvious flow continuing. This will be no later than 3 min from the initial filling.
    iv. The judges will score the flowability test from each entry using the following scoring percentage (based on a total of 100%):
        a. Mold filling time – 40%
        b. Mold filling percentage – 60%

        Notes: "Mold filling time" category only applies to teams with mortar mixture completely filling the *aci* molds—that is, if the mortar does not completely fill up the mold, 0 points will be awarded in the category. The final score for the flowability testing is, $F = 0.6 \times F_p + 40 \times (30 - F_t) / 30$. Where Fp = filling percentage (in %) and Ft = filling time (in s). A filling time larger than 30 s will lead to zero score for the filling time part. No negative score for the filling time will be allocated. The scores are based on the performance of each mixture, not on the ranking of teams.
        For example:
        Team 1 fills the mold in 6 s. Total score = 0.6 x 100 (perfect filling) + 40 (30 – 6) / 30 = 60 + 32 = 92.
        Team 2 fills the mold in 24 s. Total score = 0.6 x 100 + 40 (30 – 24) / 30 = 60 + 8 = 68.
        Team 3 fills the mold in 45 seconds. The total score = 60, as the filling is 100%, but the time is larger than 30 s.
        Team 4 fills the mold to 75%. The total score = 0.6 x 75 + 0 = 45.

e. Stability Testing
    i. Mixture from the first container as prepared in Section 4.c.vii will be used for stability testing.
    ii. Within 3 min after the mixture is delivered to the judges, judges will pour the mortar mixture into a 250 mL graduated cylinder. The cylinder will be filled for a minimum of 230 mL and a maximum of 250 mL. The exact volume (to the nearest 2 mL) will be determined by a judge on site. A photograph will also be taken.
    iii. After letting the cylinder rest for 30 min, a reading of the solid-liquid separation line in the cylinder, to the nearest 2 mL, will be made by a judge. A photograph will also be taken.
    iv. The teams will be scored over the ratio of the solid-liquid line after 30 min of rest, relative to the initial volume, called R_s, expressed in %. At least two other judges will determine both readings of 4.e.ii and 4.e.iii from the taken pictures. The average of at least three measurements will be used to calculate the stability score as: $4 \times (R_s - 75)$. Stability scores cannot be negative. R_s values lower than 75% will lead to a zero score on the stability test. For example:
        a. Team 1: initial filling height = 250 mL. No sedimentation is observed after 30 min, reading = 250 mL. R_s = 100%. Score is $4 \times (100 - 75) = 100$.
        b. Team 2: initial filling height = 250 mL. After 30 min, the sedimentation reading = 200 mL. R_s = 80%. Score is $4 \times (80 - 75) = 20$.
        c. Team 3: initial filling height = 250 mL. After 30 min, the sedimentation reading = 125 mL. R_s = 50%. The score: $4 \times (50 - 75)$ is negative. Allocated score = 0.
f. Mixture Cost
    i. The Final Cost will be calculated as the sum of the material cost for the individual materials per unit volume (one cubic yard) of fresh mortar used for the competition, as specified in the Official Mix and Cost Worksheet.
    ii. Students are responsible to provide a complete and accurate mix design and cost calculation. Should they fail to provide such information, all points associated with the cost category are to be forfeited.
    iii. It is strongly encouraged that the team includes a material data sheet for all supplemental cementitious materials, chemical materials and filler materials in the appendix of the report. Any material classified as Other Filler Materials or Other Chemical Admixture on the Official Mix and Cost Worksheet is required to have a material data sheet for the mixture cost calculation.
    iv. If students use materials other than those on the cost sheet, they need to provide a cost estimate for any material not included in the cost sheet, as well as a cost estimate for ordinary Portland cement. The cost of the non-included material shall be calculated relative to the cost of the cement.
    v. Due to the potential misinterpretation of classes of chemical admixtures and other materials, judge(s) will have the final right to adjust the type and unit cost of materials used.
    vi. Should onsite adjustments be made (see section 4.c.v), the cost associated with the additional chemical admixture added is to be included to the unit cost calculation by the judge(s).

vii. The teams should refer to the detailed cost scoring sheet found in Appendix C.

5. Scoring

Two competition categories are considered: the overall efficiency category and the economical design category:

a. The **overall efficiency** score will be calculated as described below. The team that achieves a score with a value closest to 100 will receive the prize of first place. The teams with the next values in descending order will receive the prize of second and third place. In the case of a tie, the winner shall be the team with the better flowability testing score.
Overall Efficiency Score = (0.50)(F) + (0.20)(S) + (0.25)(R) + (0.05)(C)

where

F is Overall score from flowability test
S is Overall score from stability test
R is Overall score from the written report section
C is Overall score from the cost category

b. The **economical design** category considers the cost of mortars which pass the flowability and stability tests. It only applies to teams which have a 100% mold filling percentage and a stability value (R_s) of at least 95%. These values are determined according to the procedures in 4.d and 4.e, respectively. Report score (as long as the report is submitted on time electronically, and a hard copy is brought on site), and mold filling time are not considered in this category. Teams which either:

- are disqualified,
- had a point deduction of any kind for non-compliance with the rules,
- did not fill the mold entirely
- showed stability values lower than 95%

will not be considered for this prize category. The remaining teams will be ranked from lowest to highest cost. The team with the lowest cost of the mixture wins the economical design prize. Second and third place will be awarded with increasing cost of the mixture. It should be noted that the on-site cost is taken into consideration, including any adjustments of chemical admixture during the mixing process.

c. Considerations: Competing teams should be aware of the consequences of some of the rules. Judgments on the compliance of the mix design and materials with the rules will be made twice: once before the competition by means of the report and once during the competition based on the batch weights of each material. The following should be kept in mind:

- In the report, the mass of the sand should be expressed in SSD condition, and needs to fulfill the minimum mass requirement of 60%. However, on-site there is no possibility for the judges to determine the moisture content, apart from the distinction between above and below SSD. **No water shall be added to compensate for absorption.** The recorded mass of the sand on-site, regardless of its moisture condition, will be used to re-evaluate the mass of the sand relative to the mass of the mixture. If a team decides to design the mortar with a sand content exactly at 60% in SSD condition, this would induce a large risk, as the team needs to deliver the sand in SSD condition. Above SSD would mean disqualification and a sand content below SSD condition would lead to a slight (but non-negligible) reduction in the mass of the sand, which will no longer satisfy the "mass sand $\geq$ 60% mass mixture" rule.
- As the water content in the admixtures is taken into consideration for w/cm, any adjustment on-site, especially an increase, will result in more water being added to the mortar. This extra water can push the w/cm ratio (even slightly) above 0.50, especially if the mortar is designed right at w/cm = 0.50. Also the mass of the sand relative to the (recorded) mass of the mixture may be influenced.
- These requirements will be verified on-site, and judges will be very strict in evaluating compliance with the rules. Teams should take these considerations into account when designing their mortar mixtures.

6. Judging

a. The judges will be appointed by the Chair of ACI Committee 238-0A. Judges may be different for each testing category.
b. The lead judge along with the Chairs of ACI Committee S-801 and ACI 238-0A will make the final determination on compliance with the rules and penalties for rules violations under advisement from the other judges. Disqualified entries shall not be included in the scoring or considered for awards. See Section 8.
c. The decision of the judges will be final, and appeals will not be considered.

   Suggestions for improvement may be submitted to the Chair of ACI Committee 238-0A or Committee S-801.

7. Registration and Material Submission

a. Advance registration is required. Teams shall submit the online advance registration form for their entry. This form shall be submitted to ACI by February 1st, 2019, 11:59 pm EST. It indicates the team's intent to enter the competition.
b. The electronic report, as described in Section 3, shall be submitted via e-mail no later than 11:59 pm Eastern Standard Time on February 27th, 2019, to the official contact listed below.
c. The following link must be used for the submission of the mix design and cost evaluation. This online form must be submitted in addition to the report, and this

form does not exempt a team from including the mix design in the report. The link allows the teams to enter the properties of the constituent materials, their mix design, and to calculate the cost of the mix design. **The form cannot be submitted if the mix design is incorrect (the website will prevent you to submit)**, so teams are advised to enter data ahead of the deadline and verify whether the total mortar volume is correct. The form calculates the total volume of the mortar based on the mentioned masses (in kg/m^3) and relative densities. If the sum of the volumes does not deliver 1m^3 (1000 liter), the mix design is incorrect. Students can use the online form to design their mixtures, but they need to be aware that **only 1 form can be submitted.** Note, the form does not save your data. If you enter data and do not submit, you will need to start over from page 1.
https://www.cognitoforms.com/ACI238A/ACIMortarWorkabilityCompetitionSpring2019

d. The hard copy of the report for each entry along with the bags of materials shall be submitted at the competition site in person at competition registration. Competition registration will open at several times on the day of the competition. Registered teams will be divided into groups for registration and competition scheduling. These group times will be posted at the competition area and sent to registered teams prior to the competition. Teams checking in past their check-in deadlines will not be accepted for entry into the competition.
e. The competition will begin at 9:00 a.m. local time on March 24, 2019.

8. Compliance with ACI-Workability Competition rules

ACI reserves the right to perform a detailed examination and check all entries for compliance with the competition rules. Due to the complexity of this task, the examination may be done after the competition. If the examination shows that a team did not follow the rules, the team, their advisor, and all of his/her teams will be disqualified. ACI Committee S801 will further document recommendations to disallow the team, their advisor, and/or school/university from participation in future competitions.

Contact Information:
Sharon Schuman
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Farmington Hills, MI 48331
248-848-3188
E-mail: students@concrete.org

Appendix A Report Guideline

A.1 Formatting:

i. Typed pages consisting of single spacing. Use 12 pt font size. Allowable font type is Times New Roman. Captions and fonts in figures and tables are also 12 pt.
ii. Margins: 1 inch all around.
iii. Number all pages except the cover sheet (the first page of your submission). The page following the cover sheet should be numbered as "1". The remaining pages must be numbered sequentially.
iv. Label figures with a number and title below the figure.
v. Label tables with a number and title above the table.

A.2 Cover page:

i. School name and department
ii. Team members and faculty advisor names (provide first and last names)
iii. 5-Character Team ID – this same ID shall be used to label all mix materials

A.3 Abstract:

The abstract must be no longer than 300 words. The purpose of this abstract is to provide a brief description of the goal and constraints of the competition, present the materials and mixture proportions of the final mortar used to achieve the competition's goal. In addition, the overall cost of the mixture should be included in the abstract.

A.4 Introduction:

The introduction section must have a maximum of one page. The purpose of this section is to provide the reader with insight about the concrete workability and why this competition is important to the concrete industry. This section must include the following:

i. Clear definitions of concrete workability and rheology.
ii. Brief summary of major factors affecting the mixture performance of fresh concrete—that is, how will factors such as cement, cementitious materials, water content, aggregate, chemical admixtures, mixing procedures, temperature, and time affect concrete workability?
iii. Brief description of importance of concrete workability during construction—that is, how does concrete workability affect constructability?
iv. Brief description of one of the major challenges limiting widespread adoption of rheological methods in concrete construction (note there are several, however the students must only focus on one of these challenges).

A.5 Materials and Mixture Proportions:

i. Provide the mixture design (saturated surface-dry (SSD) masses) and final batch mass to be used in the competition, all units in kg/m^3.
ii. Provide the relative density (specific gravity) of the individual materials in the mixture, as well as the relative density of the mixture. Failure to do so will result in disqualification of the team according to section 4.c.iii.
iii. Identify the cementitious materials and chemical admixtures (if applicable) used in the mixture. Identify the chemical admixtures by their commercial trade names and types.

iv. Identify the aggregate(s) used in the mixture(s), including gradation curve(s) and absorption of aggregate(s).

v. Submit the mix design and cost calculation using the following link: *insert link.* The mix design still needs to be included in the report. The online form will solely be used for mix design compliance evaluation with the rules.

A.6 Procedures:

The procedures section is a maximum of two pages. The procedures section will provide the important details about how the mortar was or will be prepared. This section must include the following:

i. Numbered list describing the mixing process. Include information about the type of mixer used during any trials (e.g. hand mixed, mechanical, etc.). If mechanical, state the model and manufacturer of the equipment.

Include details about the mixing time, sequence and any special precautions taken to ensure quality control.

ii. Describe testing of flowability and stability performed, if any.

A.7 Results: Maximum of 3 pages The team will present the data obtained of flowability and stability with graphs, figures, and tables of the final mix to be used in the competition as well as prior trials that lead to the selection of the final mix.

A.8 Discussion. This section must have a maximum of 3 pages. The students must discuss their approach and decision-making process to achieving the goal of this project while taking into account the constraints. For example, did the team opt to focus on flow and then stability, or stability and then flow? Similarly, if the team decided to minimize a certain material or use a particular mixing method to optimize flow and stability this should be discussed as well as the reason for it. Feel free to include graphs or flowcharts, illustrating the team's decision-making process in selecting the final mixture components. Include trial mixes and how they were modified in order to achieve the desired results.

This section of the report focuses on the broader implications of this work.

i. Discuss the key challenges to conducting this project.

ii. Discuss the specific contribution to sustainability for the mixture design used.

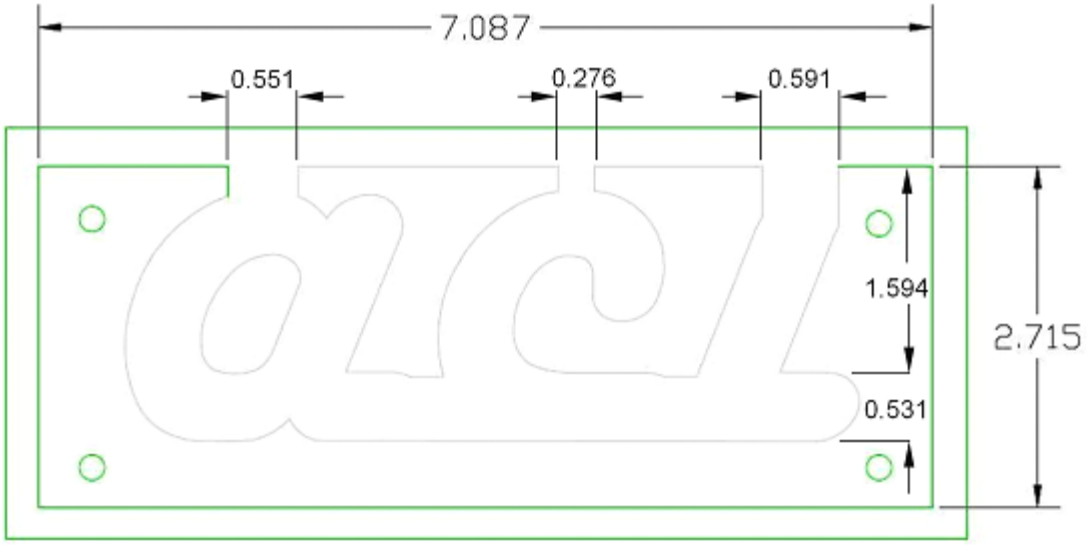
iii. Include composition and cost analysis of the final mixtures. Cost is to be calculated using the information provided in Appendix D, the Official Mix and Cost Worksheet, a copy of which is submitted in section 5, Materials and Mixture Proportions.

A.9 Conclusion. The conclusion has a 1 page limit. The purpose of the conclusion is to summarize the key findings regarding what the student found to be the best approach (with respect to materials, mixture proportioning, cost, etc.) to achieve the goal of the competition. In addition, lessons/insights that the students learned from participating in this competition should also be described.

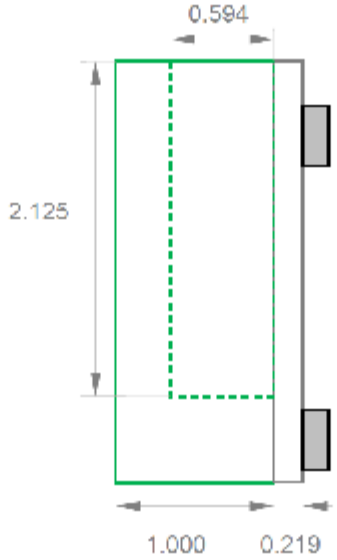
A.10 References:

i. Cite all references using a standard reference format (e.g., MLA, APA, etc.).
ii. If values other than the unit cost values provided are used for the cost analysis, provide a reference for that source and if possible include a copy of that reference in an appendix section. Note, personal communications with a manufacturer is a valid reference.
iii. If no references are used, state “NONE” in this section.

Appendix B: Drawing of Mold



Front view (all units in inches)



Side view (all units in inches)

Also see .DWG file for precise dimensions

Appendix C. Detailed Scoring Sheet for Cost Category

Unit Cost (/m^3)	Score
<$74.99	100
$75.00-$99.99	87.5
$100-$124.99	75.0
$125-$149.99	62.5
$150-$174.99	50.0
$175-$199.99	37.5
$200-$224.99	25.0
$225-$249.99	12.5
>$250	0

Appendix D. Cost for Each Constituent Material Used

Material	($/metric ton)
Natural Sand	$10
Manufactured Sand	$30
Water	$2.5
Portland Cement	$105
Fly Ash	$50
Slag Cement	$105
Silica Fume	$600
Metakaolin	$300
Limestone Powder	$40
Glass Powder	$300
Nanomaterials	$900
Others*	

*to be provided by the teams in combination with the cost of a ton of cement at the same location as the team

Material	$/liter
Air-entraining Agent	$1.00
Normal Water-Reducing Agent	$1.10
Mid-Range Water-Reducing Agent	$1.95
High-Range Water-Reducing Agent (Non-PCE)	$2.15
High-Range Water-Reducing Agent (PCE)	$3.75
Viscosity-Modifying Agent	$2.50
Set Retarder	$2.10
Accelerator	$1.95
Others*	

*to be provided by the teams in combination with the cost of a ton of cement at the same location as the team