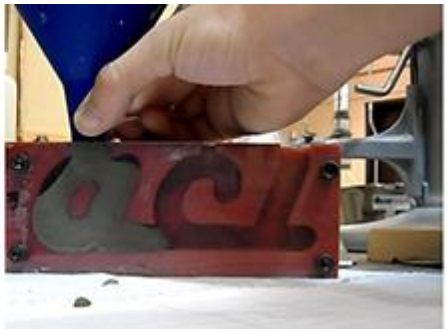
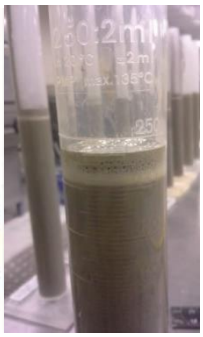
# ACI Mortar Workability Competition

## Objectives

While other ACI competitions focus mainly on strength or hardened concrete performance, this competition will focus on workability and rheological properties of cement-based materials. Also, as sustainability is an important topic in concrete design and construction, this aspect also needs to be considered. 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

Flowablity, mixture stability, cost of the mixture, global warming potential (GWP) related to $CO_2$ emissions from the production of the constituent materials and quality of the 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, for each prize category. Winners will not be announced, and prizes will not be awarded until the Student Awards Program on Monday following the competition. A feedback session will be provided by the competition organizers following the Student Awards Program.

## 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. Each team must consist of at least two and not more than eight students. Each school may register only one team.
c. Each team must have a supervising teacher or faculty advisor who will see that the student team complies with the rules of the competition.
d. Since this competition involves mixing the mixture at the convention, it is required that at least two team members be present at the convention to participate in the mixing, and cleanup during the competition. Participation by additional team members for interaction and support is both permitted and encouraged, though a maximum of 2 students will be allowed to mix mortar in order to maintain a safe working area. Other members of the team are requested to remain outside of the competition working area, but can be consulted by the mixing team.
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, GWP and cost calculation need to be submitted online through the ACI portal. 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 2i.

a. The mortar must use cementitious materials as binder, as defined in Section 2b below. A minimum of 50% by mass of the powder materials (identified as the sum of cement, cementitious materials, mineral fillers and nanomaterials) must be Portland cement or the Portland cement component of a blended cement.
b. The cementitious materials shall be Portland cement meeting ASTM C150 or blended cement according to ASTM C595. If a blended cement is used (e.g. Type I-P, Type I-L, etc.), a mill certificate from the cement plant is recommended to be provided indicating the amount of blended materials in the cement. If the quantity of SCM or limestone powder in the cement is listed to be in a certain range, the maximum value shall be assumed for this competition. If no mill certificate is provided, the maximum amount of allowable SCM or filler to the cement according to the applicable standard shall be assumed. Entries without mill certificates for blended cements will not be considered for the ecological design category.
c. Supplementary cementitious materials and mineral fillers such as fly ash and natural pozzolans meeting ASTM C618, silica fume meeting ASTM C1240, or slag cement meeting ASTM C989, kiln dust, rock dust or limestone powder may also be used. The total amount of Portland cement shall be at least 50% of the total powder content (cement

+ SCMs + mineral fillers, including nanomaterials). The portions of SCMs and mineral fillers in blended cements do NOT count towards the total Portland cement content.

d. For example:
   A team using 60% Type I Portland cement and 40% slag cement is allowed to compete.
   A team using 45% Type III Portland cement, 40% fly ash, 14% limestone filler and 1% nanoclay will be disqualified. Despite the quantity of Portland cement being more than 50% of the total binder (Cement + SCMs), the limestone filler and nanoclay will count towards the total powder content.
   A team using 50% Type I-P blended cement, for which the mill certificate shows 20% fly ash, and adding 50% fly ash themselves will be disqualified, as the total amount of Portland cement is 40% (50% x 0.8) and the amount of fly ash is 60%.
   A team using 62.5% Type I-P blended cement, for which the mill certificate shows 20% fly ash, and adding 37.5% fly ash themselves will be allowed to compete (although borderline), as the total amount of Portland cement is 50% (62.5% x 0.8) and the amount of fly ash is 50%.
   A team using 55% Type I-L cement, without providing a mill certificate, and 45% slag cement is not allowed to compete, as due to the absence of the mill certificate, the maximum allowed quantity of limestone powder in a Type I-L cement (15%) is considered. Total Portland cement content was 46.75%.
e. 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 assumed for the total water content. The solid portion of nanomaterials will be included in the total powder content.
f. The maximum ratio between water and powder (w/p) is 0.50 (by mass).
g. Chemical admixtures meeting ASTM C494 or C1017 may be used.
h. 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. The percentage of fine aggregate passing the #200 sieve shall be counted towards the sand content, but shall not be counted towards the powder content.
i. The aggregate needs to be delivered 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 will be verified on site through ASTM C128. The mass of aggregate (min. 60%) will be considered in its totality on-site for the competition, regardless of its moisture condition.
j. 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/p and the total mixture mass (and thus the relative sand content).

| 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.

Table 1: ASTM C33 fine aggregate requirements

## 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: | 20<br>10 |

| | |
|---|---|
| Materials and Mixture Proportions[1] Procedures | |
| Results | 15 |
| Discussion | 20 |
| Conclusions | 5 |
| References | 5 |

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

The mix design shall be included in the report, and submitted separately by means of the template excel file.

## 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 C128. 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 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**

[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).

**(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 first material 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/p and may also affect the relative sand content. Exceeding the maximum w/p by the on-site addition of extra chemical admixture, even when the design w/p in the report was below 0.50, will result in disqualification. As a consequence, designing the mixture at the maximum w/p 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 density of the mixture, which will be taken from the sedimentation test. 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 split the mixture, approximately equally into two containers. 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.vi 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 closing the end of the 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 estimated and 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 $F_p$ = filling percentage (in %) and $F_t$ = 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.vi 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 220 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. After this second reading, the judge will weigh the graduated cylinder with the material. The mass of an empty cylinder will be subtracted. Based on this recorded mass, and the initially recorded volume in 4.e.ii, the density of the material will be calculated. This density will be used to determine the volume of sample delivered (4.c.v), which needs to be between 550 and 750 mL.

v. 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 and Global Warming Potential

i. The Final Cost and Global Warming Potential will be calculated as the sum of the material cost and GWP for the individual materials per unit volume (one cubic meter) of fresh mortar used for the competition, as specified in the Official Mix and Cost and Carbon Worksheet.

ii. Students are responsible to provide a complete and accurate mix design, cost and GWP calculation. Should they fail to provide such information, all points associated with the cost and GWP categories are to be forfeited.

iii. It is strongly encouraged that the team includes a material data sheet for all supplemental cementitious materials, chemical admixtures 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 and GWP calculation.

iv. If students use materials other than those on the cost and GWP sheet, they need to provide a cost and GWP estimate for any material not included in the cost and GWP, as well as a cost and GWP for ordinary Portland cement. The cost and GWP of the non-included material shall be calculated relative to the cost and GWP 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, unit cost and GWP of materials used.
vi. Judges also have the right to adjust cost and GWP emissions of non-included materials after submission of the report. Any changes to cost and GWP made by the judges will be announced before the competition starts. Previous allocations of cost and GWP of non-included materials by any judge, the chair of S801 or the competition committee does not guarantee the allocation of the same values for the intended competition.
vii. Cost and GWP will be recalculated on-site based on the true masses and volumes of materials added. This includes additional costs and GWP associated with extra dosages of chemical admixtures during the mixing process on-site.
viii. The cost score will be calculated according to the following equation: $C = 100 - (\$/m^3 - 100)/1.5$
ix. The GWP score will be calculated according to the following equation: $GWP = 100 - (CO_2/m^3 - 200)/3$
x. The cost and GWP scores cannot exceed 100 and cannot be lower than zero.
xi. Detailed cost and GWP scoring tables can be found in Appendix C.

## 5. Scoring

Three competition categories are considered: the overall efficiency category, the ecological design category (sponsored by ACI's center of excellence for carbon neutral concrete: NEU) 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) + (0.15)(R) + (0.10)(GWP) + (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
GWP is Overall score from the GWP category
C is Overall score from the cost category

b. The **ecological design** category considers the GWP 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 are 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 GWP. The team with the lowest GWP mixture wins the ecological design prize. Second and third place will be awarded with increasing GWP of the mixture. It should be noted that the on-site GWP is taken into consideration, including any adjustments of chemical admixture during the mixing process.

c. 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.

**d. 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, leading to disqualification as well. Note that SSD is very rarely reached for samples in the concrete industry and that transport may affect moisture contents. Designing at exactly 60% sand content in SSD is not recommended. Note that in the previous competition, 25% of the teams were disqualified because of low sand contents.

- As the water content in the admixtures is taken into consideration for w/p, any adjustment with chemical admixtures on-site, especially an increase, will result in more water being added to the mortar. This extra water can push the w/p ratio (even slightly) above 0.50, especially if the mortar is designed right at w/p = 0.50. Also, the mass of the sand relative to the (recorded) mass of the mixture may be influenced. 9% of the teams were disqualified because of too high w/p in the previous competition.
- The volume of the delivered mixture will be determined by dividing the mass of the mortar in the bowl after mixing by the density determined from the sedimentation test. The judges will calculate your volume based on these values, regardless of what is provided in the report. 22% percent of teams were disqualified last competition because of inadequate volume.
- Teams should also be aware of a series of factors which affect workability in different conditions: mixer type, mixing energy, mixing duration, addition sequence of materials, temperature, and relative humidity can all affect workability and the response of the mixture on-site. As such, the mixture properties on-site may not be identical to the mixture properties prepared by the students. One risky strategy is the use of a large amount of air-entraining agent. Last competition, one team followed that strategy, but the air-entraining agent acted differently, disqualifying the team because of volume requirements. Entraining an exact amount of air is a significant challenge during concrete production.
- 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 and will change throughout the competition day.
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 formulated through the survey you can complete after the student awards program, or during the office hours after said program.

## 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, 2024, 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 no later than 11:59 pm Eastern Standard Time on February 29th, 2024 through the ACI submission portal.
c. The template excel file with the materials' properties, mix design, GWP and cost calculation must be submitted in conjunction with the report through the ACI online portal.
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 24th, 2024.

## 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:
Rachel Belcher
American Concrete Institute
38800 Country Club Drive
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 at least 10 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. The maximum number of pages in the report is 7, excluding the References and Appendix. The cover sheet is included in the page limit.
v. The Appendix can only contain pictures, and supporting documents (such as materials data), but it should not contain mix designs, discussions, ore results.
vi. Label figures with a number and title below the figure.
vii. 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 150 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 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.
ii. Brief summary of major factors affecting the mixture performance of fresh concrete—that is, how will selected 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. A brief description of the benefits and/or challenges associated with fulfilling requirements for sustainability and workability simultaneously.

## 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 and GWP calculation using the template excel file. The mix design still needs to be included in the report. The excel file will solely be used for mix design compliance evaluation with the rules.

**A.6 Procedures:**

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:** The team will present the data obtained of flowability and stability 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**. 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.

**A.9 Conclusion.** 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:**

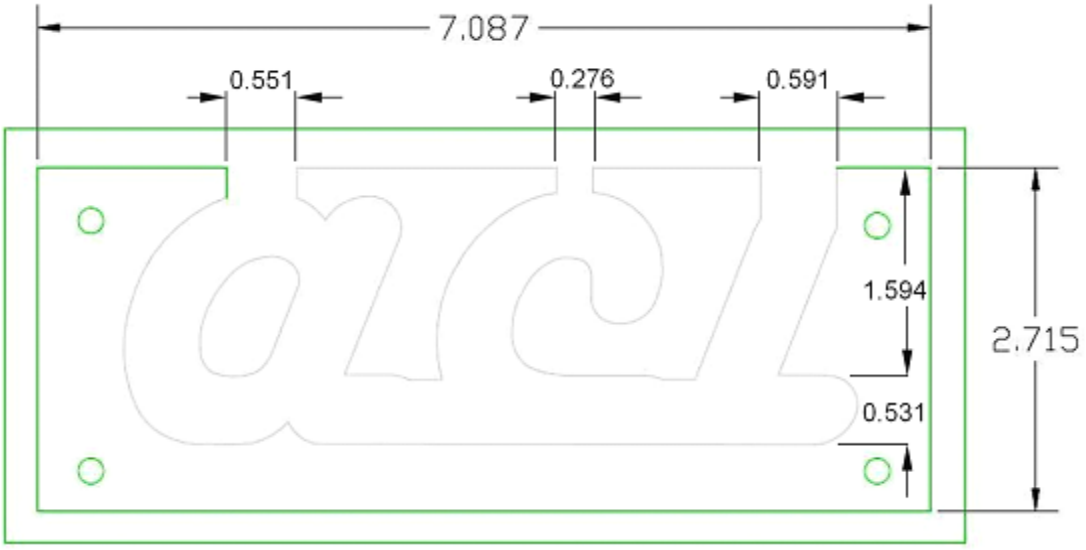
i. Cite all references using a standard reference format (e.g., MLA, APA, etc.).

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.
iv. The reference section does not count towards the page limit of the report.

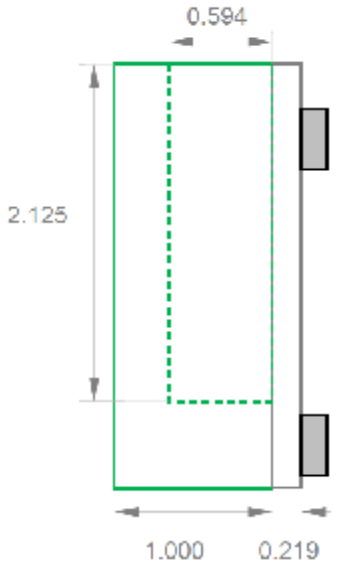
### A.11 Appendix:

In the Appendix, include relevant documents for the materials, including material data sheets for SCMs, fillers, admixtures, mill certificates for the cement (if desired), etc. Pictures of tests are also allowed in the Appendix, but the Appendix shall not be used to circumvent the report page limit: all relevant information shall be included in the report. The Appendix does not count towards the report page limit.

## Appendix B: Drawing of Mold




Front view (all units in inches)




Side view (all units in inches)

**Appendix C. Cost and GWP for Each Constituent Material Used**

| Material | ($/metric ton) | $kgCO_2eq/kg$ |
|---|---|---|
| Natural Sand | $15 | 0.010 |
| Manufactured Sand | $35 | 0.012 |
| Water | $2.5 | 0 |
| Portland Cement | $175 | 0.90 |
| Fly Ash | $150 | 0.04 |
| Slag Cement | $125 | 0.24 |
| Silica Fume | $700 | 0.30 |
| Metakaolin | $300 | 0.06 |
| Limestone Powder | $40 | 0.06 |
| Glass Powder | $300 | 0.17 |
| Nanomaterials | $900 | 1.69 |
| Other materials | | |

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

| Material | $/liter | $kgCO_2eq/liter$ |
|---|---|---|
| Air-entraining Agent | $1.00 | 0.7 |
| Normal Water-Reducing Agent | $1.10 | 2.1 |
| Mid-Range Water-Reducing Agent | $1.95 | 2.1 |
| High-Range Water-Reducing Agent (Non-PCE) | $2.15 | 2.1 |
| High-Range Water-Reducing Agent (PCE) | $3.75 | 2.1 |

| | | |
|---|---|---|
| Viscosity-Modifying Agent | $2.50 | 2.8 |
| Set Retarder | $2.10 | 1.1 |
| Accelerator | $1.95 | 1.1 |
| Others* | | |

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