Robust Methods for UHPC Early-Strength Determination and Quality Control For ABC

Quarterly Progress Report
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1. PROJECT ABSTRACT

It is a well-known fact now that UHPC is one of the most commonly used or desired solution for ABC connections nowadays. With large initiatives for developing non-proprietary UHPC mixes (e.g. ABC-UTC ongoing imitative), the applications and use of UHPC for ABC will only continue to increase. Given the ABC nature, many projects considering UHPC for connections and early bridge opening for traffic or following construction phases are hinging on reaching a desired early age strength. For example, bridge owners have recently specified Ductal JS1212 for projects requiring that 12 ksi strength is achieved at 12 hours. While robust mixes can accomplish this requirement, a reliable quality control method to verify such requirement on-site is still lacking. In remote sites, it becomes harder to verify the UHPC early age strength using the current state-of-practice, i.e. preparing cylinders by cutting and grinding the ends then testing them within 10-12 hours. To help address this issue, this project will extend two methods that have been well-established and used for conventional concrete strength characterization to use for UHPC. These are using cubes as opposed to cylinders for compression tests and utilizing previously-developed strength maturity curves for quality control. No documented efforts have yet showed the feasibility of such methods for early strength determination of UHPC. Thus, a comprehensive experimental program that considers 3 different UHPC mixes with wide range of mechanical properties will be conducted in this study to develop guidance for UHPC quality control and early strength characterization.

2. RESEARCH PLAN

2.1. STATEMENT OF PROBLEM

UHPC is one of the most commonly used or desired solution for ABC connections nowadays. With large initiatives for developing non-proprietary UHPC mixes (e.g. ABC-UTC ongoing imitative), the applications and use of UHPC for ABC are further expanding in the US and international markets. Given the ABC nature, many projects considering UHPC for connections and early bridge opening for traffic or following construction phases are hinging on reaching a desired early age strength. For example, bridge owners have recently specified Ductal JS1212 for projects requiring that 12 ksi strength is achieved at 12 hours. While robust mixes can accomplish this requirement, a reliable quality control method to verify such requirement on-site is still lacking. In remote sites, it becomes harder to verify the UHPC early age strength using the current state-of-practice, i.e. preparing cylinders by cutting and grinding the ends then testing them within 10-12 hours. In consultation with Caltrans among UHPC vendors and experts in relevant ACI committees, there is big interest in using two of the well-established methods for conventional concrete strength characterization for UHPC. These are using cubes as opposed to cylinders, and relying on strength maturity for quality control. No documented efforts have yet showed the feasibility of such methods for early strength determination of UHPC, which is the motivation of this project.

2.2. RESEARCH APPROACH AND OBJECTIVES

Proper cylinder preparation (e.g. surface grinding) is crucial for UHPC strength evaluation, but could be hard to apply especially for early age testing at 10-, 12-, 14-hour age, etc. when heat curing is desired or in case of remote sites and lack of near-by well-equipped testing facilities. Meanwhile, other methods such as the strength maturity method (SMM) and using cubes instead

of cylinders for strength evaluation are well established but never explored specifically for early age strength of UHPC. Using brass or steel molds for the cubes will likely lead to the desired planeness and orthogonally of cube sides for compression testing. Accordingly, either SMM or the use of cubes, if properly specified and validated using laboratory testing, would eliminate the need for UHPC cylinder grinding and reduce the variability commonly observed in early-strength UHPC cylinder testing.

The **objectives** of this project are to: (1) conduct comparative compression tests for various UHPC mixes and types using cubes and cylinders at early ages (as early as 10 hours); (2) develop strength maturity curves for various UHPC mixes and assess the reliability of using such curves for estimating UHPC early strength; (3) collect data from UHPC vendors (e.g. Steelike Inc.) on UHPC maturity to assemble a larger database; and (4) develop guidelines for UHPC quality control and assurance as pertains to early compression strength characterization. It is worth noting that the PI was recently involved in a pilot study through Caltrans (see Figure 1 for some illustrations) to explore feasibility of SMM for UHPC 12-hour strength characterization. Figure 1 shows pictures of sampling and heat curing of UHPC cylinders along with a strength maturity sensor that is embedded in selected cylinders to measure the strength maturity index. The very preliminary results obtained from that effort were very promising in terms of results consistency and such results are presented later in the work plan as a sample of what can be generalized and comprehensively established through this project.

Figure 1. UHPC cylinders sampling, heat curing, and application of strength maturity sensors at a contractor's site in Sparks, NV for characterizing Ductal JS1212

2.2.1. Summary of Project Activities

An experimental approach will be used and several research activities will be executed to accomplish the objective of this study. A summary of the proposed research tasks is as follows:

- Task 1 – Conduct literature search on maturity method for concrete strength evaluation
- Task 2 – Comparative assessment of cubes and cylinders for UHPC early strength
- Task 3 – Establishing strength maturity datasets using experimental testing
- Task 4 – Develop quality control guidelines for UHPC early strength characterization
- Task 5 – Summarize the results in a final report

2.2.2. Progress of Research Tasks

An overview of each research task and progress-to-date is presented in this section.

Task 1 – Conduct a literature search on strength maturity

For the cube vs. cylinder, (Graybeal & Davis, 2008) and (Kusumawardaningsih et al., 2015) presented the conversion factors for different UHPC specimen sizes; they presented only one conversion factor between all two different sizes.
On the other hand, the strength maturity method, its procedures, and the equations for developing the strength-maturity relation for UHPC are the same for normal concrete and are mentioned in (ASTM C1856, 2017); however, later in this report, guidelines are added to estimate the UHPC strength using the strength maturity method with minimal errors.

Task 2 – Comparative assessment of cubes and cylinders for UHPC early strength

The objective of this task is to conduct a large number of UHPC cube and cylinder tests with various sizes that range from 2 to 4 inches in diameter or cube side length and at different ages (14-, 18-, and 24-hours, as well as 3-, 7-, 14-, and 28-days). Eight UHPC mixtures were cast and tested. The eight UHPC mixtures were cast through different seasons of the year, from hot temperature and dry conditions to freeing temperature and humid conditions. the conversion factors are still under processing and will be presented in the following report.

Task 3 – Establishing strength maturity of large datasets using experimental testing.

The eight UHPC mixtures were divided into two groups: one group was used for the parametric study. The parametric study aimed to determine the maturity constants and procedures that could lead to accurate predictions. The second group of mixtures was aimed at verifying the parametric study conclusions. The concluded maturity constants were -2 C for t_0 and 5000 K for Q., where t_0 is the maturity constant for the Nurse-Saul function and Q is for the Arrhenius function.

Furthermore, one of the parametric study aimes was to figure out the age configuration of the lab breaking points that could be used to develop the strength maturity relationship. It was found that the best configuration that leads to the best predictions was to develop the strength maturity relationship at ages near the site ages that the strength is meant to be predicted. Thus based on this conclusion, a developed fitting was established: the piecewise linear method. The method is concluded based on the observation that the strength maturity curve changes slope four times, as shown in figure 2. it was found that the maturity index values where the slope changes are approximately 18, 60, and 300 hours. So, we recommend breaking the lab specimens at maturity index values equal to a point before 18 hours (i.e., 10 hours), then 18, 60,300, and 600 hours.

There will be no one equation that will be used to predict the strength of all ages. Instead, four equations will be developed according to the maturity index values. Each equation will be constructed using two points out of the five points. The equation used for every two points is a logarithmic equation. the four equations are:

- Equitation using the two breaking points at 10 and 18 equivalent age hours
- Equitation using the two breaking points at 18 and 60 equivalent age hours
- Equitation using the two breaking points at 60 and 300 equivalent age hours
- Equitation using the two breaking points at 300 and 600 equivalent age hours

So, the choice of the maturity equation out of the four will be used based on the site equalent age value.

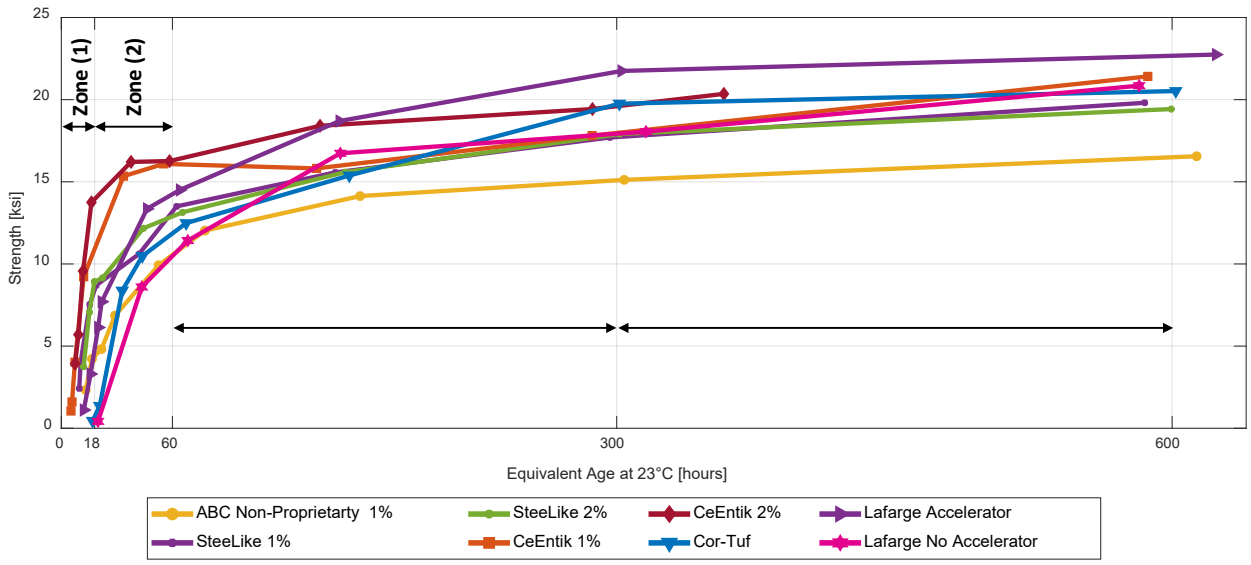

Figure 2: Strength-Maturity curves for the eight UHPC mixtures

TASK 4 – Develop quality control guidelines for UHPC early strength characterization

Based on the parametric study, the best maturity constants were -2 C for t_0 and 5000 K for Q. furthermore, for establishing the strength maturity relationship using the piecewise linear method, we recommend breaking the lab specimens at maturity index values equal to a point before 18 hours (i.e., 10 hours), then 18, 60, 300, and 600 hours. Then, develop the four strength maturity equations demonstrated in the previous section.

TASK 5 – Results dissemination and Final report

A final report will be prepared and submitted first to the advisory panel for review and comments then a revised version will be widely disseminated through the ABC-UTC. The report will be complemented with ABC-UTC guide for the quality control guidelines. Two journal papers and one conference paper are also expected to be produced from this project and will be submitted for potential publication in peer-reviewed journals.

2.3. ANTICIPATED RESEARCH RESULTS AND DELIVERABLES

- Final Report and ABC-UTC guide on early strength characterization and quality control for UHPC
- Two comprehensive manuscripts that assess the use of cubes versus cylinders for early strength characterization of UHPC and establishing strength maturity methods for UHPC
- Five-minute video summarizing research study and findings

2.4. APPLICABILITY OF RESULTS TO PRACTICE

The results from this project are expected to immediately benefit different states DOTs that have already implemented UHPC for ABC field joints and other applications.

3. TIME REQUIREMENTS (GANT CHART)

To allow for the completion of all the project tasks, the study will be conducted over a period of 15 months (5 quarters) following the schedule in Table 1.

Table 1 – Gantt schedule of major project tasks

Task	2021										2022				
	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1. Literature search															
2. Comparative UHPC cubes vs. cylinders															
3. Establish maturity curves															
4. Quality control guide															
5. Final report & dissemination															

Completed or work in progress | Remaining

Percentage of completed work: 85%

Percentage of remaining work: 15%

4. REFERENCES

ASTM C1856. (2017). Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete. *ASTM International*, *i*, 4. https://doi.org/10.1520/C1856

Graybeal, B., & Davis, M. (2008). Cylinder or cube: Strength testing of 80 to 200 MPa (11.6 to 29 ksi) ultra-high-performance fiber-reinforced concrete. *ACI Materials Journal*, *105*(6), 603–609. https://doi.org/10.14359/20202

Kusumawardaningsih, Y., Fehling, E., & Ismail, M. (2015). UHPC compressive strength test specimens: Cylinder or cube? *Procedia Engineering*, *125*, 1076–1080. https://doi.org/10.1016/j.proeng.2015.11.165