ACI Sub-Committee 544-C

Testing of Fiber Reinforced Concrete

Agenda

Tuesday, October 26, 2010

2:00 PM – 3:30 PM

Room: C-315

David L. Lawrence Convention Center

1. CALL TO ORDER

2. INTRODUCTIONS

3. APPROVAL OF AGENDA

4. REVIEW SUB-COMMITTEE ACTIVITIES SINCE 2006 (ATTACHED)

5. TESTING DOCUMENT BALLOT RESULTS (FEB 2010)

6. PROPOSED RESOLUTION TO FEB 2010 BALLOT (ATTACHED)

7. PROPOSED FUTURE WORK OF ACI 544C

8. ASTM, RILEM, FIB LIAISON REPORTS?

9. NEW ITEMS

10. ADJOURNMENT

List of Activities 2006-Present

ACI 544-C THE MEASUREMENT OF PROPERTIES OF FIBER REINFORCED CONCRETE

Sub-Committee Chair: Dr. Dean Forgeron

Summary

The subcommittee has been working on an update to the ACI 544.2R-89: Measurement of Properties of Fiber Reinforced Concrete document since before 2005. I began as acting chairman of ACI 544-C for Dr. Trottier during the Charlotte convention in the spring of 2006. From 2006 to 2007 many members contributed to the document and all contributions were compiled and formed into a ballot document that was submitted in Oct 2007. The results of the ballot were discussed in Puerto Rico in the fall of 2007. Based on discussion of comments and negatives during subsequent sub-committee meetings a second draft of the document was submitted in Oct 2009 that focused on testing procedures only. During the spring 2010 meeting in Chicago, the results of a third ballot of the document were discussed and the vision of the new Committee chairman was incorporated into a plan to further refine the document and re-ballot a new version as soon as possible. The refinements include complimenting the description of the recently balloted testing procedures with additional information that will help the reader interpret the testing results more accurately and apply them more effectively.

<u>Detailed Sub-Committee Activities Since 2006</u>

- **ACI 544 C Testing Document** balloted to the entire committee for the first time in **October 2007**. Results of the ballot are shown below:

-Affirmative	= 36	-Affirmative with comments	= 10
-Negative	= 7	-Abstain	= 2
-Not retuned	=12		

-**Re-approval 2009 of ACI 544.2R-89**: Measurement of Properties of Fiber Reinforced Concrete. This was required while continuing to work on the current document.

- **ACI 544 C Testing Document** balloted to the entire committee for the second time in **October 2009**. Results of the ballot are shown below:

-Affirmative	= 34	-Affirmative with comments	= 6
-Negative	= 4	-Abstain	= 5
-Not retuned	=18		

- **ACI 544 C Testing Document** (select sections) balloted to the entire committee in **February 2010**. One negative vote was cast on the proposed changes.

Barzin

I am voting negative at this stage since I believe that a ballot on addressing only the "negative votes" does not completely address all areas of potential improvement for this document.

1) We need to make sure to include all the points of concern during the ballot process before we move forward. The ballot in the present stage has only addressed the negative votes, and the positive with comment votes have not been addressed. Some of these comments in the previous ballot process were quite valid and must be addressed by the committee at the same time as the negatives. Ignoring the contributions of committee members will result in people getting discouraged from participation, or voting a strong negative on the next stage of balloting.

Proposed Resolution

2) Are the literature search and the discussion of available test methods complete and up-to-date? 4-5 pages on shotcrete may be too much compared to the limited discussion on the test methods on plastic shrinkage, or tensile and flexural properties. This document has to be sent to TAC after committee approves it, and we have to anticipate what type of primary questions we'll get from TAC. (Contribution attached)

Proposed Resolution attached

3) There are too many old references and not enough recent references and discussion of activities in the past 10-15 years. The main document may look outdated by reporting tests that were developed 20+ years ago such as the impact section.

Proposed Resolution

4) The document has treated several important areas such as flexural tests and toughness with very limited discussion of the available collective knowledge.

Proposed Resolution

5) How does this document correlate with other documents the committee has been working on, i.e. mechanical properties, design, etc. Can the methods specified here complement the work that other sub-committees are doing?

Proposed Resolution

6) Does this report elaborate and communicate the test methods used and discussed in other committee reports such as the recently published report on durability and physical properties? There may be a duplication of discussions on topics such as the section on creep.

Proposed Resolution

7) The report should discuss (at least to a limited extent) strengths and weaknesses and in addition the pro vs. cons, of the test methods proposed. Listing and describing ASTM tests without discussing their pitfalls and strengths is not sufficient. Fundamental technical concerns about ASTM test methods should be addressed. ACI users must be cautioned against the use of ASTM C1399 Residual Strength Method for design purposes for reasons that have been discussed several times during the committee meetings. When we rush to put documents forward, we may end up setting the industry back. Case and point is the ASTM C-1018 which took many years to rectify.

Proposed Resolution

Proposed Resolution of Feb 2010 Ballot Negative

Inclusion of the following to the existing document.

4.2 Tensile Strength and Toughness
Open loop methods of control do not always yield accurate results for direct tensile tests since the deformation of concrete increases homogeneously at first, but near the peak load it localizes within a planar region that develops as a crack. The region outside the crack unloads while the crack continues to open. Therefore, the total load-displacement response normally exhibits snap-back behavior due to the large unloading region. Use of notched sections or "dog-bone" specimens ensures that the crack occurs within the zone of reduced section. When the displacement over this zone is measured, the corresponding load-displacement curve is often free from snap-back and provides stability at the postpeak (Mobasher and Shah 1989; Gettu et al. 1996; Peres-Pena and Mobasher 1994).

4.3 Flexural Strength and Toughness
For flexural testing of fiber reinforced concrete, the location of the crack is not predetermined if the sample is not notched. The response is dominated by the cracking along the centerline of the specimen and grows along the depth of the beam. As the deformation localizes at the main crack the response is dominated by crack propagation. Since the critical deformations are those of the crack itself, the best-controlled variable in flexure tests is the crack opening or a similar displacement. Deflection of the specimen can also be measured to compute the toughness throughout the test. To measure the fracture parameters, loading/unloading tests can be performed. The test may begin under load control and switches to the extensometer during the crack opening mode. The unloading cycle can be done under load control up to a few percentage of the maximum load level. The control mode is switched for each loading cycle. The envelope of the cyclic loading/unloading response can be obtained and used for comparison purposes (Mobasher and Li 1996).

In page 21, line 13, a reference can be added for the Laser Holographic Interferometry (Mobasher et al. 1990).

4.4 Fracture Resistance
Closed-loop control (CLC) can be defined simply as the process by which a desired response is continuously obtained from a system by adequately modifying its input. The use of CLC significantly increases the scope of testing systems and their accuracy. It provides the operator with the ability to use any quantifiable aspect of the specimen response as the controlled variable. CLC is beneficial in both material and structural testing; especially when the stable postpeak response has to be obtained or when cyclic and sustained loading have to be applied (Gettu et al. 1996).

Fracture tests are performed on specimens with notches or initial cracks, where the behavior is governed exclusively by cracking. As such a test progresses, the deformation localizes at the notch and is followed by crack propagation. Since the critical deformations are those of the crack itself, the best controlled variable in fracture tests is the crack opening or a similar displacement. Fracture tests are conducted under several loading configurations. Those tests that involve only opening or tensile displacements along the crack are called mode I tests. Fracture tests that also involve crack sliding or shear displacements are called mixed mode tests. It is generally easier to perform mode I tests and to interpret their results. Moreover, since the tensile strength of concrete is relatively low, the mode I response is most important. The ideal mode I configuration is the notched panel under pure tension, but this is a difficult test to design and to conduct (Hillerborg 1989).

Gopalaratnam and Shah (1985) performed tension tests on double-edge notched plates where the controlled variable was the average of the two notch (or crack) mouth opening displacements. The most popular mode I test configuration for concrete is the notched beam loaded at midspan. The test is best performed under CLC with crack mouth opening as the controlled variable. A similar procedure was used by Li and Mobasher (1996) for determining the fracture response of fiber reinforced concrete under cyclic flexural loading.

4.5 Impact Resistance

The Instrumented Pendulum

The instrument developed by Gopalaratnam et al. (1984) was modified and utilized to characterize the properties of GFRC specimens (Mobasher and Shah 1989). It was indicated that the first-cracking load as determined from deflection measurements was higher than that determined from the extreme fiber-tensile strain of the centerline measurements. Also, it was found that the accelerated aging environment reduces toughness more severely than the corresponding values of modulus of rupture.

The Instrumented Drop-Weight Tests

Properties of these composite systems were investigated under three point bending conditions using an instrumented drop weight impact system (Zhu et al. 2009). AR glass cement composites samples were studied from the viewpoint of the variations of impact load, deflection response, acceleration and absorbed energy. It was concluded that maximum flexural stress and absorbed energy of composites increase with drop height. In beam specimens, complete fracture did not take place as cracks form and close due to rebound and significant microcracking in the form of radial fan cracking was observed, whereas interlaminar shear was the dominant failure mode in the plate specimens.

5.2 Autogenous and Drying Shrinkage

Restrained Shrinkage

If the prismatic specimen is restrained on the length direction, uniaxial tensile stresses are produced which is similar to a uniaxial tensile test. The linear specimens have the advantage of the relatively straight-forward data interpretation; however, it is difficult to provide sufficient restraint to produce cracking with linear specimens, especially when cross sectional dimensions are large (Grzybowski and Shah 1990). Unfortunately due to difficulties associated with providing sufficient end restraint, these test methods are generally not used for quality control procedures (Weiss and Shah 1997).

Other investigators have used different types of specimens such as plate-type specimens to simulate cracking due to restrained shrinkage (Padron and Zollo 1990). When restraint to shrinkage is provided in two directions, a biaxial state of stress is produced. Consequently, the results obtained from plate-type specimens may depend on specimen geometry in addition to the material properties (Grzybowski and Shah 1990).

A restrained shrinkage test using a steel ring was done as early as 1939 to 1942 by Carlson and Reading (Carlson and Reading 1988). As a result of drying, concrete ring would tend to shrink, but the steel ring would prevent this and cracking occurs. More recently, to better quantify early-age cracking tendency of cementitious material, instrumented rings have been used by researchers to measure the magnitude of tensile stresses that develop inside the material (Shah et al. 1992; Hossain and Weiss 2004, Mane et al. 2002; Soranakom et al. 2008). Due to its simplicity and economy, the ring test has been developed into both AASHTO PP-34 and ASTM C-1581 standards. The main difference between these standards is the relative ratio of the concrete to steel ring thickness which influences the degree of restraint provided to the concrete.

5 HARDENED CONCRETE – LONG TERM PROPERTIES AND DURABILITY

Suggested subcategory:

5.10 Aging and weathering

The primary concern for glass fiber reinforced cement composites (GFRC) is the durability of glass fibers in the alkaline environment of cement. Despite the use of improved alkaline-resistant glass fibers (AR-glass) and pozzolanic materials such as silica fume and fly ash, durability concerns still exist (Shah et al. 1988). Marikunte et al. (1997) and Shah et al. (1988) immersed cured GFRC specimens in a hot water bath at 50°C for a long period of time and then tested the samples in flexure and tension. The concept behind the accelerated aging test is that the strength loss at high temperatures can be used to predict strength loss at lower temperatures expected to occur over a long period of time. The results indicated that the blended cement consisting of pozzolanic materials significantly improves the durability of GFRC composite.

References

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