

# **Development of Self-Compacting Lightweight Concrete For RFP Reinforced Floating Concrete Structures**

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## **Abstract**

The economic production of self-compacting, high strength lightweight concrete was successfully demonstrated with large-scale precast production. It is found that the workability of such mixes are inherently more sensitive to various production variables than conventional concrete mixes. Therefore, successful implementation of self-compacting lightweight concrete on full-scale project will require both trial batching with actual production equipment and materials, and good quality control of the production/placement operations.

## **1. Applications**

Lightweight aggregate concrete is an excellent construction material for long-span structures and marine structures for its durability, high strength-to-weight ratio, high fire resistance and fatigue strength. A research program is currently underway for development of self-compacting lightweight concrete. The concrete is intended for use in constructing of floating concrete structures with carbon fiber reinforced plastic (CFRP) meshes and post-tensioning tendons. The CFRP meshes are mainly used for crack control and impact resistance, while the post-tensioning will provide adequate structural strength. In precasting the floating concrete structures, internal vibration will be difficult in some cases. Hand held vibrators could easily damage the CF mesh. Form vibration is impractical for construction of base plating and some closure pour joints between precast panels. A vibratory screed could be used, but may not be able to ensure full consolidation. Self-compacting lightweight concrete is most appropriate for these applications. This paper describes the researches on the concrete mix and test results conducted so far.

## **2. Performance Requirements of Self-Compacting Lightweight Concrete**

Development of self-compacting lightweight concrete is technically challenging in that the concrete workability has to attain an optimum balance between good flowability and adequate cohesion. The specific performance requirements for the concrete mixture are as follows:

1. The concrete should be able to flow around CFRP meshes and post-tensioning duct by the gravitational force and achieve full compaction,

2. The concrete mix must be cohesive enough to prevent appreciable segregation and bleeding.
3. The concrete should retain adequate flowability for 60 minutes,
4. The concrete should develop 50-60 MPa compressive strength in 56 days,
5. Unit weight of the concrete should be less than 1950 kg/m<sup>3</sup>,
6. Shrinkage and creep of the concrete should be acceptable.

### 3. The basis of concrete mix design

The behavior of fresh concrete is closely linked to many concrete mixture variables. The influences of various concrete mixture variables on the rheological behavior of concrete have been investigated in many studies (Gerwick 1981, Khayat 1996, and Yao 1999). The conclusions from these studies are summarized in the following four aspects:

1. The free water content of the concrete: The water content in a mixture can be classified into free water and the bound water. Free water is the interstitial water existing between fines and aggregates. It disperses and lubricates the solid particles in concrete to create fluidity and plasticity of concrete. Therefore, it is the quantity and quality of free water that determines much of the rheological behavior of fresh concrete. On the other hand, flowable concrete, especially flowable lightweight concrete, requires rich fine content to achieve adequate cohesion. The fines content in concrete basically determines the amount of the bound water. It has been found that the appropriate water-to-fines ratio in self-compacting lightweight concrete ranges from 0.85 to 1.0 by volume.
2. Dispersion characteristics of solid particles in concrete: Water-reducing admixtures are dispersion agents that reduce cement flocculation and release bound water in concrete. On the other hand, a cohesive agent “thickens” the interstitial free water in concrete, making it more cohesive and thixotropic. Only when the cohesive agent is properly used together with water reducing admixtures, the desirable self-compacting property can be achieved.
3. Particle packing characteristics have significant effects on the concrete workability. Self-compacting concrete typically contains fine aggregates in the range of 45-50% of total aggregates by volume. The shape and size of coarse aggregates also have a influence on concrete workability. As concrete flows, the aggregates will contact each other to impose friction force in resistance. Thus, concrete containing large and angular aggregates tends to be less workable.
4. Composition of cementitious materials is also an important parameter. Replacing a portion of the portland cement with fly ash may remarkably improve the concrete workability. Cement containing high C<sub>3</sub>A content usually causes rapid hydration of cement and consumption of free water in the paste, resulting in loss of slump with time. Type II Portland cement is typically used.

On the basis of the previous studies, a number of concrete proportions were developed for trial batch tests. In essence, the concrete mixtures had water-to-cement ratios in the range of 0.3 to 0.34. The total cementitious materials content was

approximately  $550 \text{ kg/m}^3$ , which includes 9 percent silica fume and 25 percent fly ash. The high fines content was intended to develop adequate cohesive consistency in concrete. The material cost of the self-compacting lightweight concrete was approximately 20-30 percent higher than the conventional lightweight concrete. A basic mix design developed in the trial batch test is shown in Table 1.

Chemical admixtures used in the test include a self-placing admixture designed for self-compacting normal weight concrete. In the initial trial batching, it was found that use of the self-placing admixture alone did not consistently produce the required workability for lightweight concrete. The problem is that lightweight aggregates tend to float up during placement because they are lighter than cement paste. Additional adjustment of concrete workability with a cohesive agent and Superplasticizer provided good results.

### **3. Trial Batch Tests**

Fifteen trial batches and two small-scale constructibility tests were conducted in two independent testing laboratories. Various cement content and chemical admixtures were tested to achieve the desired workability. It was found that use of cementitious materials in the range of  $530 \text{ kg/m}^3$  and  $600 \text{ kg/m}^3$  stabilized the rheological behavior of the concrete and minimized use of chemical admixtures.

The trial batch tests show that lightweight concrete with a slump flow below 430 mm is not likely to have full compacting performance. Lightweight concrete with a slump flow over 660 mm often leads to severe segregation. A slump flow in the range of 460 mm to 560 mm has been found to provide the required workability (Figure 1).

Two small-scale constructibility tests were conducted. The tests entailed placement of flowable concrete into several 0.6 m by 0.9 m form without compaction. Carbon fiber meshes stood 38 mm above the base and were supported at the corners (Figure 2). Lightweight concrete was able to flow around and fully encase the carbon fiber mesh. After the concrete hardened, it was cut to observe its quality. As shown in Figure 3, the concrete is uniformly distributed through the specimens. Neither concrete segregation nor voids were observed in the specimens.

The 56-day compressive strength of the concrete mixtures ranged from 52 MPa to 74 MPa. The concrete strength largely depends on the type of lightweight aggregates used. Two types of aggregates were used in the tests - extruded and crushed aggregates. The extruded lightweight aggregates, as typically manufactured in West Coast of United States, have smooth, rounded particle shape. Crushed aggregates, as produced in East Coast and Midwest of United States, have angular shape and typically are denser than the extruded aggregates. The denser aggregates typically produce higher concrete strength. Unit weight of concrete mixtures were measured as  $1913\text{-}1970 \text{ kg/m}^3$ . Again, weight of the concrete largely depends on the density of the aggregates used. Drying shrinkage tests were conducted in accordance with ASTM C 157. The measured shrinkage was in the range of 0.021 to 0.024 percent. The low water-to-cementitious materials ratio in the concrete was probably the cause of the low shrinkage observed in the tests.

#### **4. Field Trial Tests**

Constructibility tests were conducted in a precast concrete plant. The constructibility test consists of precasting two 3-m by 1-m by 0.2-m constructibility specimens. The first constructibility test specimen experienced segregation, as lightweight aggregates floated up. The segregation was caused by overdosing the concrete with superplasticizer. There are significant differences in the mixing efficiencies between the central mixer at the precast plant and small mixers in the laboratories where the trial batch tests were conducted. The central mixer is capable of dispersing cementitious material particles in a highly efficient manner. Therefore, it does not need as much superplasticizer as the laboratory mixers

For the second test, the concrete mixture proportions were adjusted by increasing its cohesive agent dosage and reducing the amount of superplasticizer. It was found that as much as 50% superplasticizer can be eliminated with use of the high efficiency central mixer. The subsequent concrete placement shows a substantial improvement in workability and cohesion. The constructibility specimens were cut open after one day curing to examine the concrete quality. Figure 4 shows a comparison between segregated and non-segregated concrete specimens. Subsequently, eleven test specimens, 6-m by 0.6-m by 0.2-m in size, were successfully fabricated for load testing of their strength, failure mode, cracking characteristics, and deflection.

#### **5. Summary**

Self-compacting lightweight concrete was successfully produced in full-scale precast concrete production. Rheological behavior of the fresh concrete is critical to production implementation. The key parameters in the concrete mixture design include the water-to-fines ratio, the dispersion characteristics of solid, the rate of early hydration of cement, the size, shape and specific weight of aggregates. It was found that lightweight concrete with a slump flow less than 430 mm is not likely to have the self-compacting property. Lightweight concrete with a slump flow over 660 mm leads to severe segregation. A slump flow in the range of 460 mm to 560 mm provides the desirable workability in this application. Both small-scale and large-scale constructibility tests show that the lightweight concrete mixtures flew around and fully encased the CFRP meshes under their own weight and without segregation. production of high quality, self-compacting lightweight concrete is not only technically feasible, but also cost-competitive

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Table 1. Basic Mix Proportions for Trial Batch Test (1 cubic meter)

Mix Components	Mix Proportions
Type II Cement	360 kg
Fly Ash Class F	140 kg
Silica Fume	50 kg
Lightweight Coarse Aggregates	526 kg
Fine Aggregate	677 kg
Water (Total Mix)	200 kg
Self-placing admixture	377 (oz.)
Cohesive agent	35 (oz.)
Superplasticizer	97 (oz.)



Figure 1. Concrete slump flow in the range of 460 mm to 560 mm



Figure 2. A Small-scale constructibility test of self-compacting concrete



Figure 3. Specimens were cut to show uniform aggregates distribution



Figure 4. Lightweight concrete specimens from large-scale precast constructibility test were saw-cut. The upper specimen showing segregation due to overdosing of chemical admixtures, the lower specimen showing uniform distribution of aggregates when concrete is properly mixed.