Admixtures and Aggregates:

Key Elements in "Athletic Concrete" Revisited

BY WILLIAM S. PHELAN

This article revisits "athletic concrete" commented on by this author in a previous edition of *Concrete International* (April 2000). At that time, usage of this type of concrete was just emerging. Athletic concrete today is being employed on an increasing basis as a high-performance concrete. It is proportioned with a high content of maximum-size coarse aggregate, a combined aggregate gradation meeting ACI guidelines for maximum density, and a low water content. Supplementary cementitious materials such as fly ash, slag, and silica fume enhance its durability, impermeability, and long-term strength. High-range and mid-range water-reducing admixtures lower its water content and increase its slump and cement efficiency.

Athletic concrete is built on a robust frame of coarse aggregate (Fig. 1). It is molded into a lean, muscular frame having high-quality paste, minimal fat (low mortar content), and low water content, and is proportioned to achieve the appropriate water-cementitious materials ratio (*w/cm*) while providing two-tiered high performance. That is, initially, the concrete must have the proper workability, pumpability, finishability, and setting times needed to successfully place, consolidate, and, where required, finish the concrete in a building or other structure. Also, the mixture is most importantly high performance in its hardened state where the required long-term durability, minimal cracking and curling, proper finish, and adequate compressive and flexural strengths are achieved.

SELECTION CRITERIA

During the last 4 years, many concrete mixture proportions have been prepared based on the key requirements mentioned previously. With athletic concrete, however, the traditional method of preparing a mixture based on compressive strength—employing the field experience method or trial mixture test data from a laboratory—plays a secondary role. Instead, athletic concrete is prepared in accordance with the following principles:

1. Using the largest coarse aggregate size and amount suitable for the slab, member, or structure;
2. Choosing the proper water content for mixture usage. Floors with steel trowel finishing require a water content that provides sufficient lubricity for proper results. (Mixtures for formed members may have a lower water content.);
3. Using a high-range or mid-range water-reducing

Fig. 1: Athletic concrete is built on a robust frame of coarse aggregate

Fig. 2: Microwave unit for testing water content per AASHTO requirements

admixture to increase the water slump to the target slump for the selected placing method;

4. Selecting a *w/cm* based on project specifications, or on ACI standards or guidelines;
5. Targeting a combined aggregate gradation that meets ACI 302 guidelines of 8 to 18% retained on each sieve below the top size and above No. 100 (150 µm). (These combined aggregate gradations usually have one or more sieves falling outside the envelope noted.);
6. Successfully pretesting the proposed mixture proportions by placing concrete on site to verify proper workability, pumpability, finishability, and setting characteristics that will enable the concrete contractor to successfully achieve the specified qualities in the resulting hardened concrete;
7. Ensuring that the preplacement conference will devote sufficient time to discussing the mixture proportioning as well as the modifications required for climatic changes, and to reaching agreement on the proper quality control procedures at the plant and in the quality assurance program on site; and
8. Verifying on site that all high-performance concrete mixtures have water contents (Fig. 2, the microwave test) and air contents (air meter test and unit weight) within tolerance. (These field verifications are critical for concrete where durability, low shrinkage, and minimal cracking and curling are long-term goals.)

The procedures noted are designed to optimize mixture performance and ensure low water content and high quality paste—but not too much of it—in all batches. As described, such mixtures always reduce shrinkage compared to traditional mixture proportions of the same ingredients. This is a beneficial result in all high-performance concretes.

However, athletic concrete performance has proven that a lower *w/cm* is not beneficial in cases where it can only be achieved with a higher cementitious content. An excellent example is that of a high-performance industrial floor. These floors require a uniformly burnished steel-trowel finish, equal to or exceeding specified F_F/F_L values, and having minimal long-term cracking and curling. Such floors are increasingly being measured on the basis of a 12-month walk-through in addition to measurement immediately after installation.

EXCEEDING MAXIMUM w/cm

As aggregate size is increased and combined aggregate gradation is improved, both water and paste content requirements have been lowered. These mixtures generally require a 2 ± 1/2 in. (50 ± 10 mm) water slump to provide sufficient lubricity for proper finishing. As the paste content decreases, a higher *w/cm* is needed to reach the target slump. Thus, many owners and engineers have been distressed initially in finding that the maximum *w/cm*s of 0.45, 0.48, and 0.50 in their current specifications are now being exceeded because of the decreased cementitious content. However, after mixture proportioning is discussed with them they soon come to understand that the higher *w/cm* is appropriate.

In such discussions, it is pointed out that the coarse aggregate content is at the maximum and the water content at the minimum. The only approach left for reducing the *w/cm* is increasing the cementitious content. However, this increase would result in removing an equal volume of aggregate. Upon reflection, the correct decision normally made is to use a *w/cm* of 0.53 or 0.54 for optimum long-term performance.

AN SCC?

Can athletic concrete be used as self-consolidating concrete (SCC)? The answer is: not to the fullest extent. SCC with a slump flow of 20 to 30 in. (500 to 750 mm) places a limit on the coarse aggregate size. Also for SCC, proper aggregate gradation is very important. Nevertheless, viscosity-modifying admixtures (VMA) in athletic concrete can help provide a robust mixture that offers the desired SCC qualities. However, a certain mortar content will be required to ensure consistent SCC-type performance.

Supplementary cementitious materials make SCC more workable and help to produce a more homogenous mortar system. Still, if its coarse aggregate content

Fig. 3: Coarse aggregate used for the distribution center concrete (No. 467 stone [37.5 to 4.75 mm])

TABLE 1: Mixture proportions for distribution center floor

Cement	325 lb/yd³
Slag	175 lb/yd³
Fine aggregate	1431 lb/yd³
Coarse aggregate	2000 lb/yd³ (No. 467 [5 to 40 mm]) 12.12 ft³*
Water content	265 lb/yd³
Air content (entrapped)	1.8%
High-range water-reducing admixture (HRWRA)	72 oz/yd³
w/cm	0.53
Initial slump (water)	2 ± ½ in.
Final slump	4 to 6 in.

*Combined aggregate gradation conformed to ACI 302 requirements with slight deviations on several sizes.

Note: 1 ft³ = 0.03 m³; 1 in. = 25.4 mm; 1 lb/yd³ = 0.6 kg/m³; 1 fl oz/yd³ = 39 mL/m³. No. 467 stone properties in ASTM C 33.

TABLE 2: Mixture proportions for an elevated airport roadway

Cement	455 lb/yd³
Slag	210 lb/yd³
Microsilica	40 lb/yd³
Fine aggregate	969 lb/yd³
Coarse aggregate	1800 lb/yd³ (No. 57 [5 to 25 mm]) 200 lb/yd³ (No. 8 [2 to 10 mm]) 11.80 ft³
Air-entraining admixture	16.5 oz/yd³
Corrosion inhibitor	512 oz/yd³
HRWRA	85 oz/yd³
Water-reducing retarding admixture	21 oz/yd³
Water	251 lb/yd³
Air content	8% ± 1.5%
Slump (water)	1 to 3 in.
Slump (final)	5 to 7 in.
w/cm	0.37

Note: 1 ft³ = 0.03 m³; 1 in. = 25.4 mm; 1 lb/yd³ = 0.6 kg/m³; 1 fl oz/yd³ = 39 mL/m³. No. 57 and No. 8 stone properties in ASTM C 33.

TABLE 3: Six-ft-thick (2 m) mat mixture proportions and measured values

	Initial mixture (2/3 of project)	Final mixture (1/3 of project)
Cement	100 lb/yd³	80 lb/yd³
Ground granulated blast-furnace slag	400 lb/yd³	320 lb/yd³
Fine aggregate	1100 lb/yd³	1160 lb/yd³
Coarse aggregate	2150 lb/yd³	2250 lb/yd³
Mid-range water-reducing admixture	40 oz/yd³	45 oz/yd³
Water	250 lb/yd³	200 lb/yd³
Air	5.5%	5.5%
w/cm	0.50	0.50
Slump	5 to 6 in.	4 to 5 in.
Measured 7-day strength	3889 psi	3135 psi
Measured 28-day strength	5910 psi	5030 psi
Measured % air	5.5	5.2
Measured *w/cm*	0.52	0.56
Measured slump	5.18 in.	5.07 in.
Measured unit weight	146.9 lb/yd³	150.0 lb/yd³

Note: 1 in. = 25.4 mm; 1 psi = 6.89 kPa; 1 lb/yd³ = 0.6 kg/m³; 1 fl oz/yd³ = 39 mL/m³ exceeds 10.5 ft^3/yd^3 (0.4 m^3/m^3), SCC could be classified as an athletic concrete "light." Athletic concrete generally has a paste content of 25 to 36%.

SOME PROJECTS USING ATHLETIC CONCRETE

A distribution center with 1.4 million ft^2 (0.13 million m^2) of industrial floor was completed in late 2003. On this project, the floor achieved all of the client's requirements—a burnished steel-troweled floor (Fig. 3); excellent abrasion resistance (verified by usage and Chaplin Abrasion tests); observed minimal cracking and curling; and minimal splitting of semi-rigid joint filler (Table 1).

Table 2 provides the proportions used in pumped concrete for an airport roadway. On another job, a 5000-psi (35 MPa) concrete was employed for the placement of a 6-ft-thick (2 m) mat (Table 3 and Fig. 1). The structure fiber, industrial floor mixture optimized the coarse aggregate content (12.06 ft^3 [0.4 m^3] GFC) and low water content. (Table 4 and Fig. 2).

DAY-TO-DAY USE

Athletic concrete is being successfully used on a daily basis by knowledgeable owners, engineers, contractors, and ready mixed concrete producers. The result is significantly increased hardened concrete quality at reduced cost. Cost savings with athletic concrete versus conventional concrete achieving similar 28-day compressive strengths average about \$1.00/yd^3 (\$1.30/m^3). The use of supplementary cementitious materials, fly ash, slag, and silica fume has also had a positive effect on the environment, enabling the user to conform to the Leadership in Energy and Environmental Design (LEED) program.

TABLE 4:
PROPORTIONS FOR MIXTURE CONTAINING STRUCTURAL FIBERS

Cementitious materials	520 lb/yd^3
Fine aggregate	1202 lb/yd^3
Coarse aggregate	1700 lb/yd^3 (No. 467 [5 to 40 mm]) 350 lb/yd^3 (3/8 in. [9.5 mm]) 12.06 ft^3
Water	275 lb/yd^3
Air content	1.5%
Admixtures: high-range water reducer, Type F	54 oz/yd^3
Structural fibers	4 lb/yd^3
w/cm	0.52
Initial slump (water)	2 ± 1/2 in.
Final slump (high-range water reducer)	5 to 6.5 in.

Note: 1 in. = 25.4 mm; 1 lb/yd^3 = 0.6 kg/m^3; 1 ft^3 = 0.03 m^3; 1 fl oz/yd^3 = 39 mL/m^3

Selected for reader interest by the editors.

William S. Phelan, FACI, is Senior Vice President of Marketing and Technical Services for The Euclid Chemical Co. He regularly conducts seminars and presentations on various aspects of the concrete industry throughout the Americas and Europe. Phelan is a civil engineering graduate of the University of Detroit and has been in the concrete specialty business for over 30 years. He is Chair of ACI Committee 212,Chemical Admixtures, and a member of ACI Committees 117, Tolerances; 302, Construction of Concrete Floors (Chair, 1980-1988); and 308, Curing Concrete. He is also a member of the ACI Strategic Development Council Executive Committee.