HVFA Concrete—An Industry Perspective

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The use of high-volume fly ash (HVFA) concrete fits in very well with sustainable development. HVFA concrete mixtures contain lower quantities of cement, which leads to lesser consumption of energy and natural resources in cement manufacture and lesser carbon dioxide emissions. The increased utilization of fly ash also reduces landfilling of fly ash. Moreover, the use of HVFA concrete may lead to a considerable increase in concrete durability, which directly increases sustainability. Besides the environmental benefits, the use of HVFA concrete can also lead to significant cost savings.

If half of all "portland-cement-only concrete" in the U.S. were to contain fly ash and the average use of fly ash in each batch were to be about 30% of total cementitious content, an additional 10 million tons (9.1 million tonnes) of fly ash could be used in ready-mixed concrete in the United States.[1,2] This fly ash can lead to annual cost savings in the U.S. in excess of $500 million, stemming from the reduced costs of concrete materials and in lessening the need for landfilling fly ash. Improvements in concrete durability, with its resulting lower life-cycle costs of structures, provides further financial benefit.

The use of fly ash in concrete at proportions ranging from 35 to 70% of total cementitious content has been studied extensively over the last 20 years and the properties of this type of blending are well documented.[3-7] Published case studies detail projects that have incorporated so-called HVFA concrete at proportions of 50% or more. In spite of the advantages offered by employing fly ash into concrete, only about 54% of all ready-mixed concrete placed in the U.S. contains fly ash. Even in ready-mixed concrete containing fly ash, the average usage is relatively low—only about 20% by weight of total cementitious content. As a whole, the industry has been reluctant to accept fly ash contents at higher proportions because of perceptions about its effects on constructibility and performance. We offer an attempt to identify and address many of the industry's concerns.

First, it must be established that it is not feasible to use 50%-plus fly ash concrete in all situations. In some applications, perhaps only 15% is acceptable. Various materials, applications, environments, and construction requirements combine to determine pozzolan limitations. The point is to tailor the fly ash content based on the performance requirements for specific applications. Rather than attempt to deal with mixture proportions for every potential concrete application, this work divides discussion into two broad categories. Provided also for each category are recommended fly ash percentages, with suggestions about critical factors of which both engineers and concrete producers should be aware. These suggestions can guide the contractor and ready-mixed concrete producer in maximizing fly ash content in their concrete. In turn, the engineer can follow the approach given to specify higher levels of fly ash in concrete more confidently.

CHALLENGES AND SOLUTIONS

While increased volumes of fly ash make sense theoretically, what about practical issues related to construction processes in the real world? Questions are typically asked about the early strength gain, initial setting time, bleeding, and curing. Because of the lower amount of cement used, a main concern is that the concrete may not gain strength fast enough or may have a very long initial setting time as determined by the ASTM C 403 test procedure.[8]

Early strength

Table 1 summarizes the laboratory test programs conducted. Mixture A attained a compressive strength greater than 3000 psi (21 MPa) by 3 days as required for formwork removal in elevated-slab construction. Fly ash represented 51% of the total cementitious content, and the addition of a standard high-range water reducer (HRWR), polynaphthalene sulfonate-based, decreased the water-cementitious material ratio (*w/cm*) to 0.33. Experience indicates that to achieve higher early strength, the *w/cm* of HVFA concrete should be low. Other options to achieve high early strengths are the use of a Type III portland cement, a highly reactive pozzolan such as silica fume or ultra fine fly ash, a polycarboxylate-based HRWR, or an accelerating admixture. Typically, the reduction of *w/cm* will be the most cost-effective and practical solution. Mixtures B and C, in Table 1, were designed to achieve a compressive strength in excess of 3000 psi (21 MPa) in 28 days—a typical requirement for residential and light commercial applications. Mixture B served as the portland-cement-only control, whereas Mixture C contained 45% fly ash. Because high early strength was not required, Mixture C lacked HRWR and had a *w/cm* of 0.52.

Table 2 summarizes another laboratory test conducted for a precast/prestressed concrete manufacturer in Texas. The concrete strength requirement was 5000 psi (35 MPa) by 16 h. This producer did not use any steam curing unless the weather was quite cool (usually less than 50 °F [10 °C]). Based on past experience, it was determined that cylinders cured in an insulated box within a laboratory matched the strengths of cylinders cured along with the structural element. Table 2 also reveals that the producer can use as high as 21% fly ash and still attain the required early strength. With the addition of a polycarboxylate-based HRWR, the acceptable amount of fly ash increased to almost 30% while still achieving a compressive strength greater than 5000 psi (35 MPa). Note that curing within an insulated box achieved higher strengths than those treated under typical lab conditions.

Depending on the application, the concrete may be proportioned for strength at 56 or 90 days rather than the standard 28 days. However, "target strengths" should be specified at 3 and 7 days, taking into account the slower rate of strength development of HVFA concrete mixtures. This is to permit quality-control decision making if low late age strengths are predicted that will adversely affect the construction schedule. In addition, engineers usually require that the concrete attain 60 to 75% of design strength before formwork removal. This requirement needs to be carefully examined. In situations

TABLE 1:
MIXTURE PROPORTIONS

	Mixture A	Mixture B	Mixture C
Type I portland cement, lb/yd^3 (kg/m^3)	294 (174)	425 (252)	270 (160)
Class F fly ash, lb/yd^3 (kg/m^3)	306 (182)	—	220 (130)
Total cm, lb/yd^3 (kg/m^3)	600 (356)	425 (252)	490 (291)
Fly ash, %	51	0	45
Sand, lb/yd^3 (kg/m^3)	1503 (891)	1469 (871)	1464 (868)
No. 67 crushed limestone, lb/yd^3 (kg/m^3)	1750 (1038)	1700 (1008)	1700 (1008)
Water, lb/yd^3 (kg/m^3)	199 (118)	300 (178)	254 (151)
w/cm	0.33	0.71	0.52
Type A, oz./100 lb (mL/100 kg)	—	3.0 (196)	3.0 (196)
Type F, oz./100 lb (mL/100 kg)	14.4 (940)	—	—
Concrete temperature, °F (°C)	69 (21)	73 (23)	75 (24)
Slump, in. (mm)	9.0 (230)	7.0 (180)	6.75 (170)
Air, %	1.2	3.2	2.5
Unit weight, lb/ft^3 (kg/m^3)	151.4 (2426)	142.2 (2279)	144.1 (2309)
Set time, h:min (initial) (final)	6:20 8:00	4:43 —	5:00 —
Compressive strength, psi (MPa)			
1-day 3-day 4-day 7-day 28-day 56-day 90-day	1790 (12) 3660 (25) 4240 (29) 4980 (34) 7770 (54) 8650 (60) 9290 (64)	— 2260 (16) — 2840 (20) 4080 (28) — 4570 (32)	— 1690 (12) — 2260 (16) 4230 (29) — 5650 (39)

TABLE 2:
MIXTURE PROPORTIONS OF FLY ASH CONCRETE FOR PRESTRESSED APPLICATIONS

Type III cement, lb/yd³ (kg/m³)	658 (390)	600 (356)	550 (326)	475 (282)
Class F fly ash, lb/yd³ (kg/m³)	0	100 (59)	150 (89)	200 (119)
Fly ash, %	0	14.3	21.4	29.6
No. 67 crushed limestone, lb/yd³ (kg/m³)	1774 (1052)	1774 (1052)	1774 (1052)	1774 (1052)
Fine aggregate, lb/yd³ (kg/m³)	1431 (849)	1354 (803)	1355 (804)	1363 (808)
Water, lb/yd³ (kg/m³)	230 (136)	227 (135)	212 (126)	218 (129)
w/cm	0.35	0.32	0.30	0.32
Type F1*, oz./100 lb (mL/100 kg)	22 (1435)	22 (1435)	17 (1109)	0
Type F2†, oz./100 lb (mL/100kg)	0	0	0	7 (457)
Strength-lab, psi (MPa)	4215 (29)	4430 (31)	3820 (26)	3980 (27)
Strength-box, psi (MPa)	5900 (41)	5830 (40)	5350 (37)	5150 (36)
Slump, in. (mm)	7.00 (180)	7.50 (190)	7.50 (190)	8.75 (220)
Box temperature, °F (°C)	102 (39)	102 (39)	98 (37)	98 (37)

*Type F1—an ASTM C 494 Type F naphthalene-based HRWR.
†Type F2—an ASTM C 494 Type F polycarboxylate-based HRWR.

where a structural element is not subjected to early loads, a compressive strength of 750 psi (5.2 MPa) would be adequate to allow form removal operations without damaging the concrete. In addition, when HVFA concretes are proportioned to meet high early strength requirements, their later age strengths tend to be much higher than equivalent portland-cement-only concrete mixtures. Engineers can make use of this higher later age strength in certain design applications.

Initial setting time

As can be seen in Table 1, the initial setting time (as measured by ASTM C 403) of the 51% fly ash concrete (Mixture A) was about 6 h, which is acceptable normally for field conditions. The table also shows that Mixture C, which contains 45% fly ash, had almost the same initial setting time as Mixture B, which had no fly ash. Certain fly ashes may, however, extend initial setting times. An increase in initial setting time can delay the finishing process of a slab, particularly if it requires trowel finishing. In such a case, a contractor must wait until the concrete has gained enough "strength" to support the weight of the finisher and trowel machine.

Even though the time to achieve this "strength" is much less than the initial setting time,[9] a delayed initial setting time most frequently leads to a time delay before which trowel finishing process can be initiated. In contrast, a broom finish can be applied externally and, therefore, delayed initial setting times are of much less concern. Delayed finishing for a trowel-finished slab can result in higher labor costs as well as plastic shrinkage cracking.

Accelerating admixtures, however, can reduce initial setting times. Of course, the increased expense in using chemical accelerators should be weighed against the cost savings offered by the use of fly ash. In most cases, lowering the dosage of water reducer can decrease, to some extent, the initial setting time of the fly ash concrete. Still, delayed setting times may prove to be beneficial in warmer weather and detrimental in cooler weather.

Bleeding and shrinkage

HVFA concrete mixtures designed with a *w/cm* of less than 0.40 may display a reduction in quantity of bleed water and a slower bleed water rate. Coupled with the potential for extended initial setting times, such a condition can make HVFA concrete mixtures vulnerable to plastic shrinkage cracking. Generally, this is only of concern for slab-type structural elements that require finishing and will be exposed to rapid drying conditions such as low relative humidity, high wind speed, and the like. In such situations, the guidelines suggested in ACI 305[10] to protect the concrete from plastic shrinkage cracking should be adopted. These guidelines aim to reduce evaporation on the plastic concrete surface during finishing by such means as wind breaks, fog sprays, evaporation retarders, and impervious sheeting.

If the concrete is not well protected, its top surface may dry out quickly, leaving an undetectable, moist, spongy underlying level that cannot support the weight of the finishers. Finishers should be made aware of the slowed rate of bleed water so that they don't begin their work prematurely. The type and dosage of chemical admixtures, including air-entraining agents as well as combined aggregate gradation and total aggregate volume, can be varied to control bleeding. Another solution can be the use of synthetic fibers, which have been shown to increase the strain capacity of concrete in its plastic condition, thereby reducing the potential for cracking. When the *w/cm* decreases too much below 0.40, autogenous shrinkage increases and effective curing of slabs is mandatory immediately after the conclusion of finishing operations.[11]

Curing

Another common question asked is: will HVFA concrete be more susceptible to adverse curing conditions? Strength and various durability tests conducted with 25 to 58% fly ash concrete reveal that 7 days of moist curing is adequate for both HVFA concrete and portland-cement-only concrete.[12-16] With just 1 day of test curing in its mold, and then given laboratory air curing, fly ash concrete exhibited a lower oxygen permeability and chloride penetration. Compressive strengths, however, also proved to be lower, and carbonation deeper than portland-cement-only concrete. To achieve similar compressive strengths and carbonation levels, it was recommended that fly ash concrete be moist cured for a slightly longer period—for instance, 3 days instead of the 1 or 2 days for portland-cement-only concrete. It was also believed that fly ash concrete's greater sensitivity in concrete strength development during inadequate curing is of practical significance only in thin sections.

Air entrainment

A primary issue associated with some fly ashes in concrete relates to the impact these materials can have on air entrainment. The residual carbon content in some fly ashes can adsorb chemical air-entraining admixture and thus reduce the effective concentration of surfactant available to stabilize an adequate air-void system. Thus, fluctuations in fly ash carbon content can cause variations in air entrainment and in the color consistency of a concrete element's surface. The selection of a consistent, high-quality fly ash is critical to the successful employment of HVFA concrete.

RECOMMENDED FLY ASH CONTENT RELATED TO CONCRETE USE

As noted previously, HVFA concrete can be better suited for certain applications than others. In the following practical approach, various structural applications are identified and appropriate fly ash levels suggested. Table 3 displays recommended fly ash contents compared with concrete use, assuming an average daily ambient temperature of 68 °F (20 °C) and higher during placement and curing. In cooler temperatures, fly ash quantities can be adjusted downwards, depending on the specific properties of the fly ash, the use of accelerating admixtures, temperature control, type of application, performance requirements, and the like.

Engineer and concrete producer should use the stated guidelines as a starting point for testing concrete made with locally available materials. Higher fly ash levels than those indicated in Table 3 have been successfully applied in the field.[6,7,17] For an engineer unaccustomed to fly ash use exceeding 25%, the fly ash levels shown in Table 3 may themselves represent an aggressive approach. The various concrete applications can be divided broadly into two categories:

Category A: no finishing

Cast-in-place columns, walls, beams, precast elements, precast and prestressed elements, some foundations, drilled piers, and mud mats fall under the "no finishing" category of structural elements. The early strength requirements vary as indicated in Table 3. The early strength requirements for columns, walls, beams, and precast elements have to facilitate formwork removal when the elements cast do not carry early loads. Generally, a strength of 750 psi (5.2 MPa) by 14 to 16 h should satisfy these requirements. As noted in Table 3, the recommended fly ash content is 40 to 50%, and a HRWR may be required to lower the *w/cm* to attain the required strength. More specifically for precast and prestressed elements, the fly ash level that is suggested is 20 to 30%, depending on the early strength requirement (3000 to 6000 psi [21 to 41 MPa]), nature of early curing, and type of HRWR.

Some foundations, drilled piers, and mud mats typically do not have any early strength requirement. For such applications, a fly ash content of 40 to 50% can be used without need for an HRWR to reduce the *w/cm*. Since there is no finishing involved for Category A type structures, there is no concern for delayed initial setting time, change in bleed properties, and the like.

Category B: needs finishing

Structural elements such as slabs-on-ground (SOG), certain foundations, concrete pavements, tilt-up walls, suspended slabs, SOGs subject to early age loads and/or traffic, post-tensioned SOGs, slabs on metal deck, and toppings fall into the category of "needs finishing." Generally, a strength of 750 psi (5.2 MPa) by 1 day is sufficient for formwork removal when the element does not carry early loads. A slightly lower strength is acceptable in 14 to 16 h for joint cutting in slabs and pavements. For suspended slabs, SOGs subject to early age loads and/or traffic, post-tensioned SOGs, slabs on metal decks, toppings, and tilt-up walls, a compressive strength of 2500 to 3000 psi (17 to 21 MPa) by 2 to 7 days may be required to avoid impact on the construction schedule in question.

The recommended fly ash content depends on the type of finish that the slabs will receive. If the slabs are to be broom finished then, as was discussed earlier, delayed initial

TABLE 3:
Fly ash content related to concrete use

Classification	Use	Fly ash content, % of cm	Critical factors to watch for:
A. No finishing	Columns, walls, beams, precast (750 psi [5.2 MPa] by 14 to 16 h)	40 to 50%	Early strengths should be met with materials to be used in the job under job site conditions.
	Precast and prestressed (3000 to 6000 psi [21 to 41 MPa] by 16 h)	20 to 30%	
	Some foundations, drilled piers, and mud mats (no early strength)	40 to 50%	
B. Needs finishing	Slabs-on-ground (SOG), foundations, concrete pavements, tilt-up walls, suspended slabs, SOG subject to early loading, SOG post-tensioned, slabs on metal deck, and toppings	40 to 50% (if broom finished)	Cast trial slabs to understand bleed and setting properties of HVFA concrete. May have to use measures to control plastic shrinkage cracking.
		25 to 50% (if trowel finished)	

*Note: 25% fly ash limit for concrete exposed to deicing chemicals.

setting time is of much less concern. So, for broom-finished slabs, the recommended fly ash content is 40 to 50%, and again an HRWR may be required to lower the *w/cm* and attain required early strength. If the slabs are to be trowel finished, then the maximum fly ash percentage that will yield acceptable initial setting time should be used. This can range anywhere from 25 to 50% and would depend on the fly ash source, as well as the use of chemical admixtures such as water reducers and accelerators.

Regardless of the type of finish, if the *w/cm* of HVFA concrete is less than 0.45, the concrete may have less bleed water and a reduced rate of bleeding. The bleeding characteristics of the HVFA concrete should be determined by casting trial slabs prior to project start up. If it is determined from the trials that the HVFA concrete has less bleed water, or if the rate of bleed water is lower than the rate of surface drying, then steps should be undertaken during the project to control plastic shrinkage cracking. If, because of project limitations, trial slabs cannot be constructed, then fly ash contents of 25% for trowel-finished slabs and 50% for broom-finished slabs are recommended, and steps to control plastic shrinkage cracking should be adopted if the *w/cm* is below 0.45.

ACI 318 fly ash limits

ACI 318 limits maximum fly ash content to 25% if the concrete is exposed to deicing chemical. Many engineers mistakenly believe that ACI recommendations limit fly ash content to 25% for all applications, which is not the case. Further, the 25% limit for exposure to deicing chemical is based on data from the ASTM C 672 deicer salt scaling test. It has been suggested that the ASTM C 672 test is too severe and concrete that had failed under laboratory testing conditions had actually performed satisfactorily in the field.[18] Pending further research, the 25% fly ash limit for concrete exposed to deicing chemical should be adopted.

SUMMARY

The increasing use of fly ash as a cementing material in concrete can yield considerable technical and economic benefits and, above all, can contribute significantly to sustainable development. It appears that it is possible to use higher percentages of fly ash in Category A structures barring prestressed applications and in Category B structures that will be broom finished. Even Category B structures that will be trowel finished can contain higher percentages of fly ash, provided the initial setting time of the concrete is acceptable. Some adjustments to the mixture proportion, such as a lower *w/cm* to achieve higher early strengths, are recommended. Based on the specific applications, the engineer and concrete producer who have been using 20% fly ash for all applications can use higher fly ash percentages as outlined by Table 3.

A combined effort is necessary for HVFA concrete to become more readily utilized. Engineers should critically re-examine strength requirements, and should specify only the strength essential for a structural element at the appropriate age and intended service. Material suppliers and concrete producers should regularly test concrete mixtures having varying percentages of fly ash with local materials during different seasons of the year. They also should make the generated data available to engineers so that the latter can more confidently specify HVFA concrete.

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References

1. Copeland, K. D.; Obla, K. H.; and Meyer, K., "Use of High Volume Fly Ash Concrete in the Real World," *Proceedings of 15th International Symposium on Management and Use of Coal Combustion Products (CCPs)*, V. 1, 2003 (available from EPRI, Pleasant Hill, CA).

2. "Survey of Mineral Admixtures and Blended Cements in Ready Mix Concrete," *PCA/NRMCA Survey*, Oct. 2000.

3. Malhotra, V. M., “High-Performance High-Volume Fly Ash Concrete,” *Concrete International*, V. 24, No. 7, July 2002, pp. 30-34.

4. Naik, T. R., and Singh, S. S., “Superplasticized Structural Concrete Containing High Volumes of Class C Fly Ash,” *ASCE Journal of Energy Engineering*, V. 117, No. 2, Aug. 1991, pp. 87-95.

5. Sivasundaram, V.; Carette, G. G.; and Malhotra, V. M., “Properties of Concrete Incorporating Low Quantity of Cement and High Volumes of Low-Calcium Fly Ash,” *Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete—Proceedings, Third International Conference,* SP-114, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, MI, 1989, pp. 45-71.

6. Dunstan, M. R. H.; Thomas, M. D. A.; Cripwell, J. B.; and Harrison, D. J., “Investigation into the Long-Term In Situ Performance of High Fly Ash Content Concrete Used for Structural Applications,” *Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete—Proceedings, Fourth International Conference*, SP-132, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, MI, 1992, pp. 1-20.

7. Naik, T. R.; Ramme, B. W.; Kraus, R. N.; and Siddique, R., “Long-Term Performance of High-Volume Fly Ash Concrete Pavements,” *ACI Materials Journal*, V. 100, No. 2, Mar.-Apr. 2003, pp. 150-155.

8. ASTM, “Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance,” ASTM C 403-99, West Conshohocken, PA, 1999.

9. Dodson, V., “Time of Setting,” *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, Chapter 11, P. Klieger, and J. F. Lamond, eds., ASTM STP 169C, 1994, pp. 77-87.

10. ACI Committee 305, “Hot Weather Concreting (ACI 305R-99),” American Concrete Institute, Farmington Hills, Mich., 1999, 20 pp.

11. Aitcin, P.-C., “Demystifying Autogenous Shrinkage,” *Concrete International*, V. 21, No. 11, Nov. 1999, pp. 54-56.

12. Marusin, S. L., “Influence of Fly Ash and Moist Curing Time on Concrete Permeability,” *Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete—Proceedings, Fourth International Conference*, SP-132, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, MI, 1992, pp. 257-269.

13. Thomas, M. D. A.; Matthews, J. D.; and Haynes, C. A., “The Effect of Curing on the Strength and Permeability of PFA Concrete,” *Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete—Proceedings, Third International Conference*, SP-114, V.M. Malhotra, ed., American Concrete Institute, Farmington Hills, MI, 1989, pp. 191-217.

14. Haque, M. N.; Gopalan, M. K.; and Burnside, D. E., “Strength of Fly ash Concretes in Various Curing Regimes,” *Concrete for the Nineties,* Proceedings of the International Conference on the Use of Fly Ash, Slag, Silica Fume and other Siliceous Materials in Concrete, W. B. Butler, and I. Hinczak, eds., Concrete Institute of Australia and CSIRO, Australia, 1990.

15. Khatri, R. P.; Sirivivatnanon, V.; and Marsh, P., “Importance of Curing on Chloride Induced Corrosion,” *Proceedings of the Fifth International Conference on Durability of Concrete*, SP-192, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, MI, 2000, pp. 487-505.

16. Thomas, M. D. A.; Matthews, J. D.; and Haynes, C. A., “Carbonation of Fly Ash Concrete,” *Proceedings ot the Fifth International Conference on Durability of Concrete*, SP-192, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, MI, 2000, pp. 539-556.

17. Mehta, P. K., and Langley, W. S., “Monolith Foundation: Built to Last a 1000 Years,” *Concrete International*, V. 22, No. 7, July 2000, pp. 27-32.

18. Thomas, M. D. A., “Laboratory and Field Studies of Salt Scaling in Fly Ash Concrete,” *Frost Resistance of Concrete*, M. J. Setzer and R. Auberg, eds., E & FN Spon, London, 1997, pp. 21-30.

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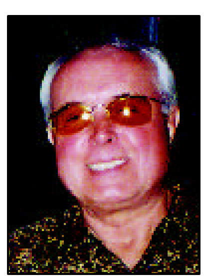

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