HIGH EARLY STRENGTH CONCRETE WITH 51% FLY ASH REPLACEMENT

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ABSTRACT

While there has been a lot said lately regarding the use of high volume fly ash (HVFA) concrete and its relationship to green building and sustainable design, most of the information showcases construction projects that have the luxury of time. The project is willing to wait 3 days for initial set, or 10 days for stripping strength. In most cases, specifications call for 56-day strength instead of the standard 28-day strength. Many of the case examples only serve to support the myth of what can and cannot be done with HVFA. The increasing demand for green construction and sustainable design projects, compounded by LEED® programs will only drive the demand for this type of material higher. The myth and misconception surrounding HVFA will be explored, and demystified, and in most cases outright shown as incorrect through both laboratory and field results.

Keywords: High Early Strength, fly ash, HVFA

INTRODUCTION

The use of fly ash as a supplementary pozzolanic material has been well documented for the last 30 years. Its improvement to strength, permeability, and the durability of structures has been well established over that same time period. However, among concrete technologists, there is an apparent limit to the amount of fly ash that can be used before certain performance properties are sacrificed. Using too much class C fly ash dramatically increases the setting. Use too much class F fly ash and the strength gain dramatically drops. Producers over a wide range of replacement programs and methods have determined various upper limits to ash replacement based on environmental conditions (ambient temperature, humidity, and wind speed) and construction needs (form stripping, partial stressing, curing and finishing requirements). While blending the two ash types together to generate the benefits of both, is both impractical for production methods, and does not yield the theoretical performance that may seem apparent on the surface. This translates into a practical upper limit for fly ash replacement that has been determined through field experience and laboratory trials. For most producers, that limit is around 30% to 35% replacement by weight (in a 1:1 replacement). Beyond this limit, the above listed performance properties begin to decline. But does that mean that the performance goals of high early strength, standard set times, higher compressive strengths, and improved durability cannot be attained with high volume fly ash replacement? The results prove that it can be done.

DISCUSSON

In the Summer of 2002, a large commercial project (80,000+ cubic yards) was bidding in Ft. Worth, Texas. The project was seeking LEED® certification. The owners and engineers wanted to use fly ash as a replacement material in an effort to produce “green” concrete. To accomplish this goal and comply with the laborious LEED® process, a 51% fly ash replacement was suggested. This was not unheard of. In fact, a project has just been completed in Houston, Texas that utilized HVFA, with a replacement percentage upwards of 60%. However, there was a large difference between the project in Houston and the project in Ft. Worth. The project in Houston was on a “patient” construction schedule. HVFA pours would begin and conclude on the same day, however finishing would be delayed for several days while the concrete reached initial set. Form stripping was pushed to 7 days while the concrete generated the minimum of 1000 psi necessary for form stripping. Curing operations were accomplished by flood coating the slab surfaces with 2” or more of water for over 72 hours. This was a patient general contractor and owner. Normal construction schedules would dictate form stripping within 48 hours, initial set times between 5 to 7 hours in all temperature conditions, and a workability range that would allow the concrete to be pumped or placed directly from the truck. The project in Ft. Worth has these types of requirements along with the requirement that the mix design use 51% ash replacement for the cement content.

Conventional wisdom would think this might not be an issue if the mix design were to use a 10+ sack (940lb+ total cementious material) design to get the strength and set time results.

The real challenge would be to generate those results using standard cementious contents of 5.0 sk to 7.0 sk (470lb to 658lb of total cemetious material) with a 51% ash replacement.

Research into the arena of HVFA replacement revealed that while numerous projects have been done with high replacement, no one project had ever documented standard construction results that were a requirement on this project. In an effort to generate consistent results and accomplish the goal, an extensive research and development program was initiated. The program involved three phases:

Phase 1: Lab testing for development of 3000psi in 3 days, 5 hr set time, and 9 inch slump.

Phase 2: Truck testing. Verify lab results with $4yd^3$ mixes in actual ready-mix trucks

Phase 3: Field testing. $80yd^3$+ supply to 20ft x 20ft, 20 x 40ft, and 20ft x 80ft panels on grades.

For all three phases, compressive strength cylinders, set times through penetration testing, and cores when applicable were taken. To move from Phase 1 to Phase 2 at least 2 verifiable results were required. A move to Phase 3 required Phase 2 and Phase 1 results were consistent.

During the scooping of the project, the specification for the concrete was discussed, as was as follows:

- 5000 psi in 28 days
- Maximum slump of 5 inches, minimum slump of 3 inches
- Restricted use of fly ash in elevated slabs, maximum fly ash replacement of 40%
- A combined gradation specification

A conventional construction specification would more than likely include all of the following. However, there is not real direction in terms of realistic performance. After discussion with the architect, engineer, and contractor an realists performance specification was developed. The revised specification for the concrete contained no prescriptive guidelines for total cemetious content. In actual fact, it was a true performance specification:

- 3000psi in 3 days, 5000psi in 28 days
- 5 to 7 hour initial set time
- Point of delivery slump of 9”

Due to the cutting edge nature of the concrete and the performance requirements, it was decided that the mix design and proportions would remain proprietary, and not be shown to anyone outside the concrete producer's research and development team. The engineers, contractors, nor testing lab were allowed to see the mix design. The engineers and contractors would only be allowed to see performance mix design data and total cementious content. Other suppliers followed suit, by holding their mix design proprietary, and only submitting performance results. In addition to the performance requirements for the HVFA, holding the mix designs and proportions proprietary was another move forward for performance concrete. The producers were allowed to use any available technology to accomplish the performance criteria. The only guideline was that the results must be reproducible both in the lab, and more importantly, in the field, where it counts.

Phase 1 began with a comprehensive matrix of tests involving the following materials:

Material	Types
Cement (1)	ASTM C150 Type I
Fly Ash (4)	ASTM C618 Class C and Class F from 2 different suppliers
Admixtures (8)	ASTM C494 Type A, Type D, Type E, and Type F
Coarse Aggregate (1)	ASTM C33 #57
Fine Aggregate (1)	ASTM C33 per 6.1

Before moving to Phase II testing, over 64 mix design combinations were tested. Once the mix designs were verified in Phase II, Phase III testing was scheduled. There were three goals during Phase III:

- Verify field performance of the concrete, both fresh properties and hardened properties.
- Test various curing methods (moist curing vs. chemical curing)
- Evaluate changes in techniques for placing, finishing, and curing by allowing numerous finishing contractors to place and finish the concrete.

Fig. 1 gives a large overview of the various panels that were used during three test pours. Panels were of various sizes including 20ft x 20ft, 20ft x 40ft, and 20ft x 80ft. Panels were 4" thick and poured on polyethylene sheeting on top of cushion sand.

Fig. 1. Photo of tests slabs for Phase III

During laboratory and truck testing it was observed that the concrete produced no bleed water. Normal construction practice expects and uses bleed water to aid in finishing. The HVFA concrete has no bleed water at all. Additionally, it was observed that the finished surfaces began to dry and form a crust almost as soon as the stikeoff operation was complete. As a solution to this, an evaporation retarder and curing compound were used to form a "chemical curing" approach. The chemical curing approach used during field testing is as follows:

1. Complete initial Strike off
2. Apply evaporation retarder with sprayer
3. Complete bullfloat
4. Apply evaporation retarder with sprayer
5. Complete final finishing
6. Apply curing compound with sprayer

To test some of the assumptions, regarding the use of the evaporation retarder, several areas, were not sprayed with the evaporation retarder. Fig. 2 shows the skin on the surface with small "tears" that lead to cracking. In fact, anytime that the surface of the concrete was disturbed by a finishing operation, if the evaporation retarder was not reapplied, the tearing and cracking would start. The use of an evaporation retarder, in addition to reapplication after each operation, represented a dramatic change for the finishing contractor.

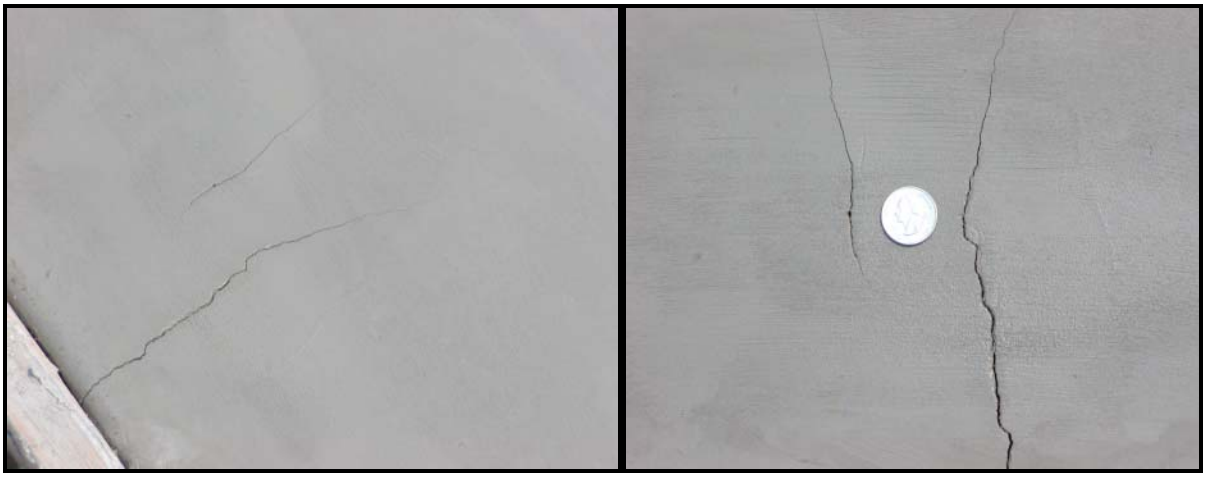

Fig. 2. Area where no evaporation retarder was used.

Because moist curing methods had been used on other HVFA projects, it was investigated for benefits with the Ft. Worth project. Fig. 3 shows how each panel was moist cured on one side, while the other side used an curing compound. The moist cure utilized saturated burlap, covered by polyethylene sheeting, which was anchored to the ground. The moist cure was applied for 7 days.

Fig. 3. Moist cure vs. chemical cure.

The results from the comparison between field cylinders and the two curing methods are in Fig. 4. From a practical standpoint, there is a large cost difference between chemical curing and moist curing. The moist curing can be as much a three times the price, not including the project delay for 7 days of saturated curing. While the results of the cores taken from the moist cured side of the test panel did show a strength increase, both curing methods exceeded the design strength. Therefore, it was unnecessary to incur the expense of moist curing for the project. The chemical curing approach was proven to be the most cost effective, and still assisted the concrete exceeding design strength.

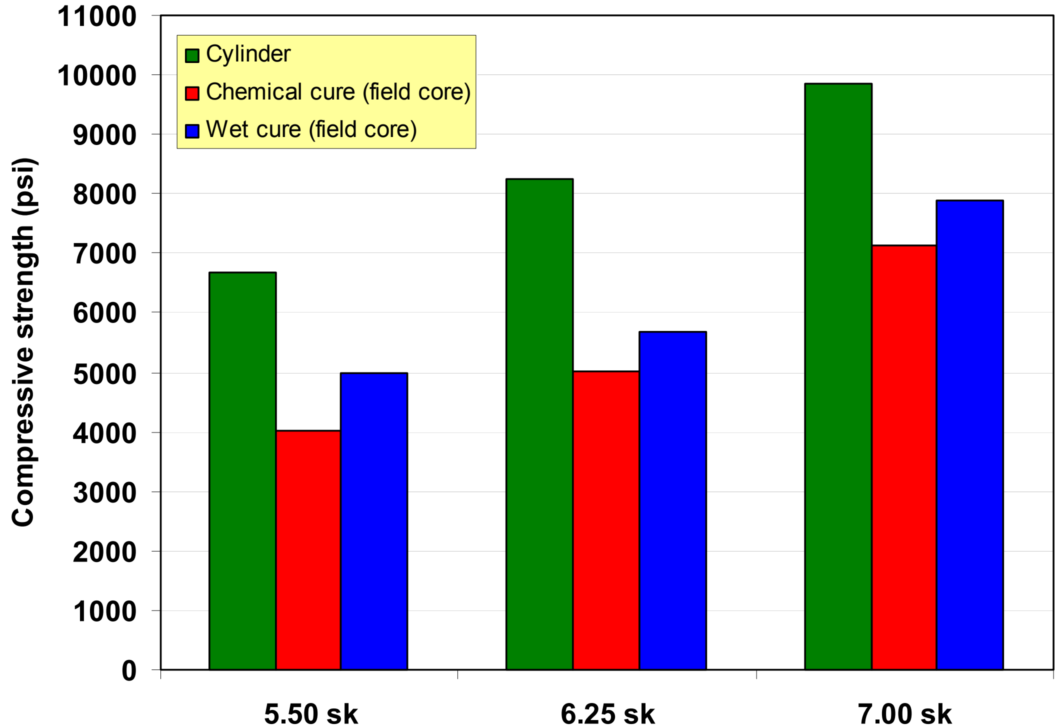

Fig. 4. Comparison of curing methods and field cylinders.

Another question that developed during Phase III was the workability and pumpability of the concrete. The slump life of the concrete was tested in Phase I, Phase II, and Phase III. The Phase three results from the actual truck are presented in Fig. 5. It should be noted, that while not the intent for workability, the concrete behaved in manner similar to self-compacting concrete, and needed little to no vibration for placement. Because 90% of placement was going to use a pump, additional field-testing had to be done using a pump. Initial testing revealed that pumping pressures where higher than normal, even though, the output was acceptable. It was thought that the large amounts of fly ash generated more friction. To evaluate pumping pressure and output, an additional test was run under extreme boom angles and hose constrictions, Fig. 6. The multiple right angles and length of hose were specifically chosen as the worst-case scenario. The results from the field test indicated that the concrete would still meet a point of discharge slump of 6” to 8”, and would meet the required output rate.

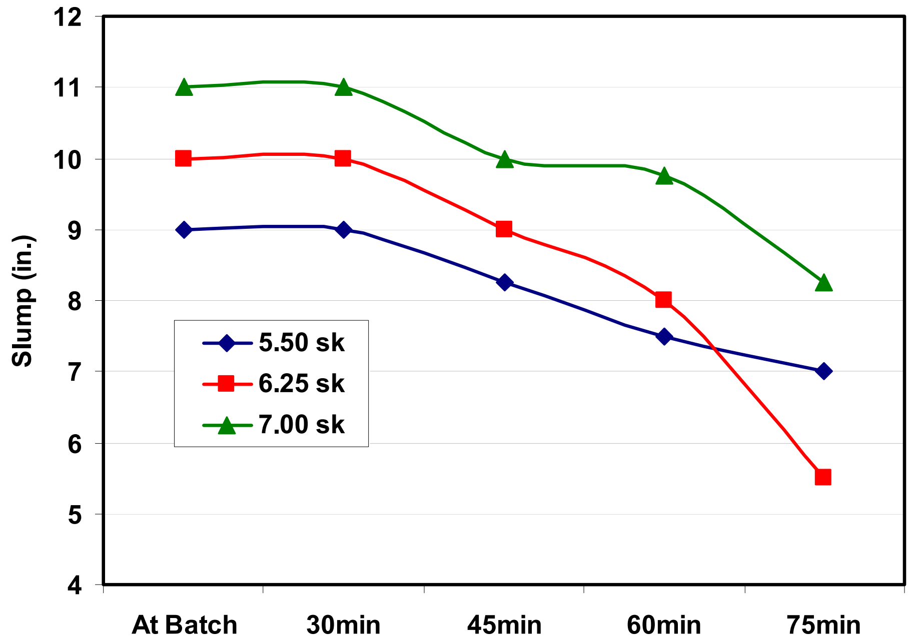

Fig. 5. Slump life of HVFA

Fig. 6. Phase II pumpability testing

The final and most critical element for evaluation was the design strength requirements. As shown in Fig. 6 the 28 day strength is exceptional, and does in fact exceed the design requirement. However, the form stripping strength at 3 days and the initial set are equally, if not more critical for the success of the project. Fig. 7 and 8 show both the 3 day and 28 day compressive strength. In the same two Fig.s is an overlay of the initial set times. These results demonstrate the possibility to generate high early strength, traditional initial set times, and standard cementious content with HVFA replacement.

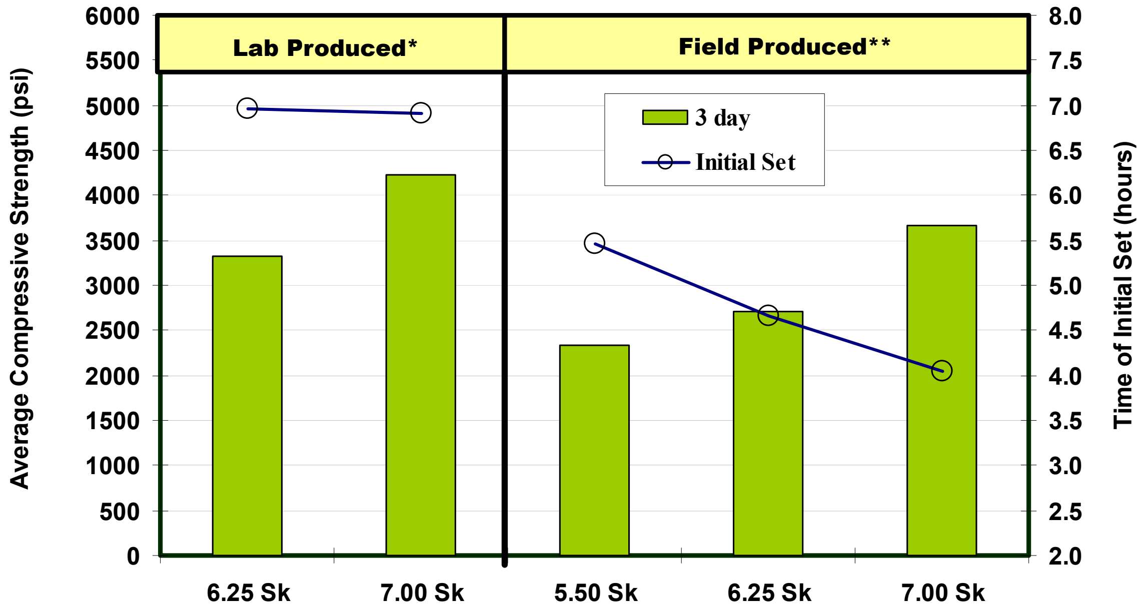

Fig**. 7.** 3 day compressive strength (based on concrete cylinders) from concrete made with 51% fly ash replacement (by weight of total cementious material).

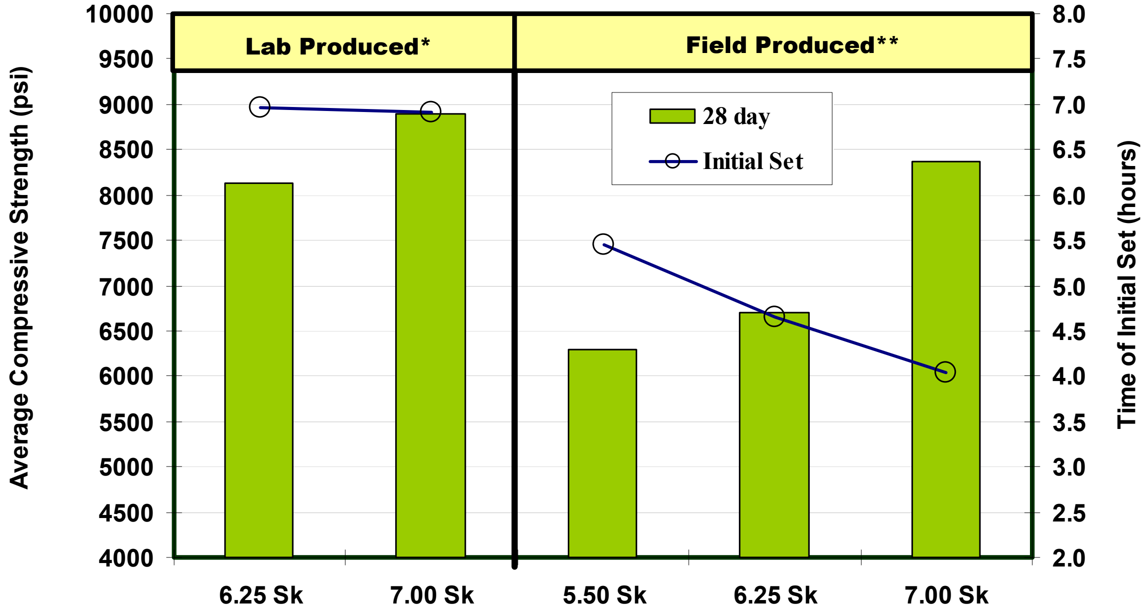

Fig. 8. 28 day compressive strength (based on concrete cylinders) for concrete made with 51% fly ash replacement (by weight of total cementious material).

CONCLUSIONS

With the advent of new technologies, the concrete industry must let go of traditional paradigms of what concrete can and cannot do. The use of HVFA is at the forefront of this type of discussion. The majority of industry professional will state that a high volume of fly ash replacement will result in longer set time and slower strength gains. The performance specifications from a LEED project tin Ft. Worth, Texas, wanted something more than the industry believed was possible. The results from that project, clearly show, that it is possible to produce concrete with HVFA concrete that is highly workable, has standard set times, high early strength, and exceptional ultimate strength, all while using standard cementious contents. The key to accomplishing this goal involves three key items: 1.) Performing the necessary laboratory and field evolutions to show reproducible and consistent performance; 2.) Focusing on actual performance requirements, and not on the assumptions of archaic tables for prescriptive amounts of materials are thought to be necessary to achieve the desired performance; 3.) Making use of the best available technology. Development of cutting edge concrete technology requires something more than the average approach within our industry. It is not just a matter of "thinking outside the box." It is an innovation process that must be applied to all links in the chain. The owners, engineers, contractors, and testing labs, all have vested interest the project. When a new concrete technology is develop, it impacts all parties. The use and development of HVFA concrete demands that all parties be aware of the changes to their own discrete operations, and what those changes mean to the whole project. Failing to do this, will generate resistance, and ultimately result in a new technology going unused.