Options for Productivity Improvements- The next step in SCC Technology

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ABSTRACT

Self-consolidating concrete (SCC) has been gaining more widespread acceptance in recent times. The features associated with SCC focus attention on the plastic properties of the concrete mixture. With the advent of new polycarboxylate (PC) dispersant technology the productivity benefits of SCC can be enhanced beyond just the plastic properties. With a newer generation of these PC dispersants faster strength development occurs. Using these products, sometimes in combination with other strength accelerating materials, can result in achieving release strengths while reducing production costs. Some of the ways this system can be used is by reducing or eliminating the need for steam curing, reducing the time required to achieve release strengths or by using normal Type I cements instead of Type III cements.

Keywords: Self-Consolidating Concrete, Hardened Properties, Energy Requirements, Savings

INTRODUCTION

Labor savings, both in placement and consolidation, as well as in rubbing or finishing costs are two of the main reasons why many precast concrete producers have either experimented with or implemented Self-Consolidating Concrete (SCC). SCC is highly workable concrete that can flow through densely reinforced or geometrically complex structural elements under its own weight and adequately fill voids without segregation or excessive bleeding without the need for vibration to consolidate it[1]. The benefits of using SCC have been well documented through the multiple international symposiums and conferences held in recent years [2,3,4]. Most of the published papers have described these benefits only as they result from the fresh properties of SCC.

The rising costs in fuel and its affect on the public as well as the business sector have been reported extensively [5, 6]. To some degree the impact of these rising energy costs to the concrete producer have been offset by the benefits arising from SCC fresh properties. However, to maximize the benefits of SCC and truly offset these energy costs, one needs to look beyond just the high fluidity levels and envision how the hardened properties, particularly the compressive strength gaining characteristics, can be optimized. It has been previously reported that certain admixture combinations provide options for precast producers to reduce costs by optimizing strength gaining characteristics [7]. These systems have been implemented at several precast concrete facilities resulting in savings not experienced when only relying on the fresh properties of SCC. This paper will describe the potential methods for reducing costs by optimizing the strength gaining characteristics of SCC, present data to substantiate these options, and present case studies of actual producers demonstrating how the system was used to their advantage.

PROGRAM

The program for taking advantage of the strength gaining characteristics of SCC takes multiple variables into consideration. Some precast producers may require 3500-psi compressive strength to permit the stripping of forms. The typical time for stripping of forms is between 12 and 24 hours depending upon the facility and the pieces being cast. To achieve these strength levels at earlier ages several variables can be manipulated to produce the desired results. These variables include concrete mixture proportions, cementitious composition, including cement type and pozzolans, and the inclusion of heat curing and curing time. Since all facilities are different, the purpose of this program is to optimize combinations of the above mentioned variables to fit the cost structure of each individual plant.

The following sections will provide laboratory data as well as a case history in outlining the affect of the three variables on strength development. In developing this data, concrete mixtures were run using a rotary drum mixer. All mixtures were non air-entrained and the materials used included both ASTM Types I and III cements, a naturally-mined glacial deposit for the fine aggregate and a crushed dolomitic limestone for the coarse aggregate.

The admixtures used include two polycarboxylate-based high-range water reducers, a normal strength developer (PC NS) and a high early strength developer (PC HES), a viscosity modifying admixture (VMA) and a non-chloride accelerator (NCA).

Table 1 contains the basic mixture proportioning data from the laboratory mixtures. Mixture 1 was proportioned to simulate a typical precast concrete mixture run to a slump of 7-8 inches. Mixtures 2-6 were designed to be SCC and therefore the cementitious contents were increased and w/c ratios were reduced. Based on these two adjustments to produce SCC one can see immediately that the strength of the SCC mixtures will be higher. It is for this reason that some attention should be given to optimizing this benefit of SCC.

	1	**2**	**3**	**4**	**5**	**6**
Type III cement. lb/yd3	658	812	803	641		
Type I Cement, lb/yd3					721	799
Fly Ash, lb/yd3	0	0	0	160	80	0
W/cm	0.37	0.34	0.34	0.34	0.34	0.34
NCA, oz/cwt		24	48	24	24	48
PC-NS, oz/cwt	14					
PC-HES, oz/cwt		13	13	13	11	11
VMA, oz/cwt		6	6	6	6	6
Slump, in.	7.5					
Slump Flow, in.		28.0	28	28.0	28.0	27.75
Compressive Strength, psi						
Heated						
4-hour	460	3680	3850	1880	2150	3040
8-hour	3490	5570	5920	4640	4590	4430
12-hour	5060	6660	7310	5480	5350	6390
Lab Cured						
4-hour	0	170	520	120	230	630
8-hour	300	2790	3710	2110	2250	2880
12-hour	2670	4940	5400	3640	3470	4310

Table 1. Mixture proportions and performance data for concrete mixtures

Samples for compressive strength testing were cast from each mixture in 4 x 8 inch cylinders. Multiple cylinders were cast from each batch and tested at 4, 8 and 12 hours. For each of the ages tested, one set was left in a standard laboratory environment at 70 degrees F until the time of testing and another set was cured in an accelerated manner according to the temperature ramping sequences outlined in Figure 1.

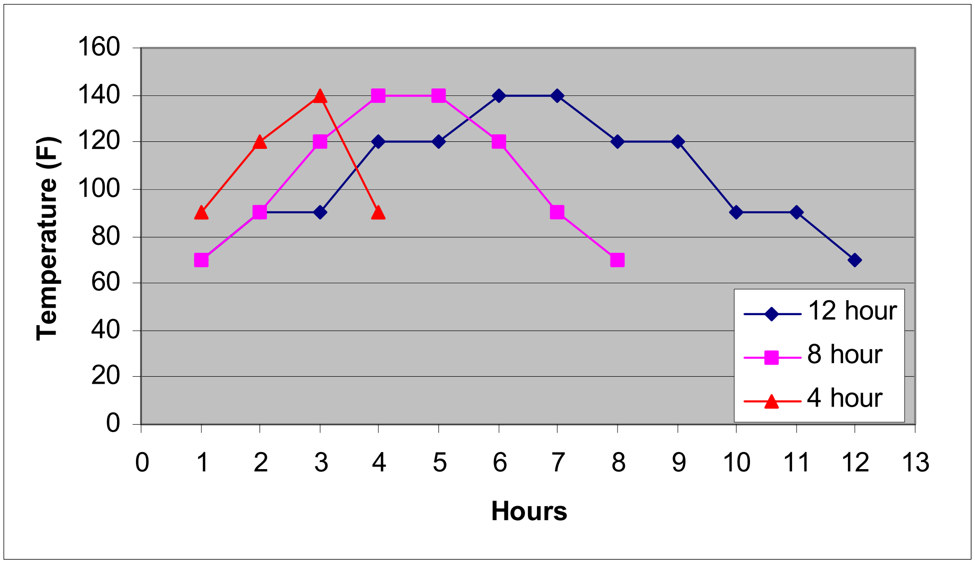

Figure 1. Accelerated curing temperature ramping sequences for 4, 8 and 12 hour testing

RESULTS AND CASE STUDIES

The following sections will provide laboratory developed strength data and a case study for the various options available to optimize production costs by controlling strength development. The options include controlling the cementitious composition (with cement type and pozzolan addition), the curing time and the curing temperature (steam versus no steam).

CEMENTITIOUS COMPOSITION

The influence of the various types of cement and pozzolans on strength development is widely known. In some areas of the country type III cements are difficult to obtain. In addition, fly ash is available in some areas of the country and can be a good addition to SCC mixtures because it increases the overall fine material content at a cost lower than straight cement. Most producers will know the characteristics as well as cost of materials in their local area. Therefore, the inclusion of fly ash, in some cases, may be more economically viable than replacing type III with a type I cement. Figure 2 shows data indicating both of these options are viable for controlling cementitious composition costs. This figure shows the heat cured strength developing characteristics of mixtures 4 and 5 versus mixture 1 (the reference mixture) through twelve hours. Mixture 4 uses a SCC mixture with a 20% fly ash replacement and mixture 5 uses a type I cement with a 10% fly ash replacement. These two mixtures performed almost identically through twelve hours and surpassed both the reference mixture strength as well as the target of 3500 psi.

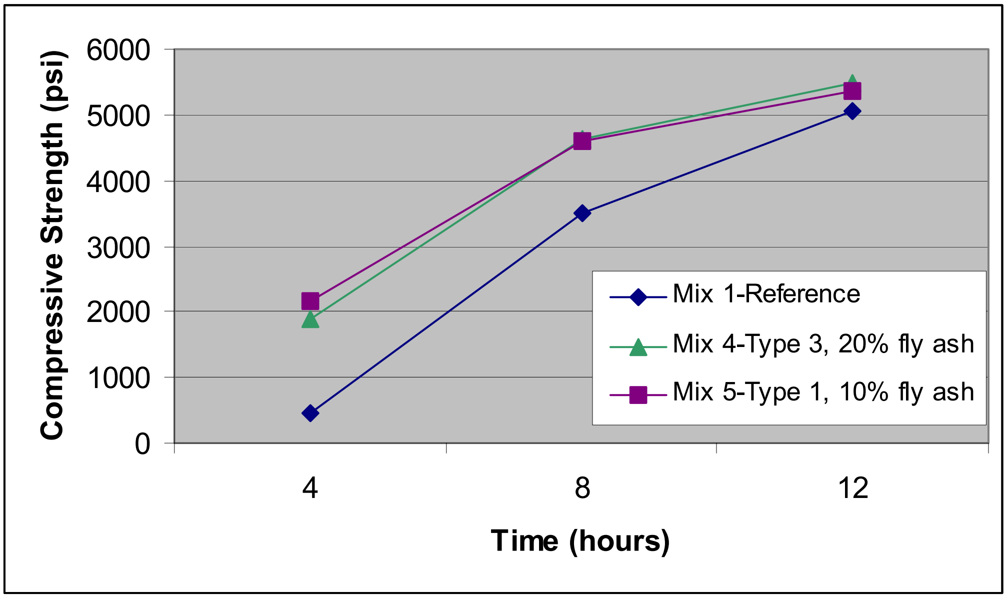

Figure 2. Cementitious composition and strength development

Case Study – Pozzolan Replacement

The first case study involves an early innovator of SCC technology. For over 3 years, this precast producer experimented with numerous SCC mix designs and their experience offers great insight to the full advantages that can be experienced with this new technology. They have gained advantages in terms of labor savings, energy savings, and material savings while progressively improving not only the fluidity properties of the concrete but the hardened properties as well. The SCC mixture was originally developed to minimize bugholes, reduce their total labor costs, and improve worker safety. A subsequent mix incorporated the use of a non-chloride accelerator (NCA) to accelerate early age strength gain and minimize, by nearly 50%, the amount of steam required to achieve their stripping strength requirements. Their latest SCC mixture developments, which is the subject of this case study, allowed the precast producer to replace up to 20% fly ash in the mix and reduce the cost of each cubic yard of concrete by 10%, while still maintaining the stringent engineering properties of the hardened concrete product.

The use of pozzolanic materials, such as fly ash, in combination with HRWRs and VMAs can yield a performance-enhanced and cost-effective SCC mixture. Fly ash introduces additional fines into the mixture which helps improve the flowability and stability of the SCC mixture. Since fly ash is typically one-half the cost of cement, this can yield significant cost savings. However, the early-age strength of a SCC mixture containing fly ash must be monitored.

Due to early age strength development concerns when using fly ash, the precast producer developed a testing program to determine the optimal combination of cement, fly ash and admixtures for the SCC mixture. The test program consisted of 3 steps:

1) Determine the best cement / fly ash combination.
2) Determine the best admixture combination to work with the chosen cement and fly ash combinations
3) Final evaluations of the mix produced in the batch plant and utilization in daily production

Step 1 only varied the water, brand of cement, type of cement and fly ash source to determine the best performing and most economical materials. The same admixtures and dosages were used in every batch. Water was adjusted in an attempt to achieve a consistent spread in an effort to determine water demand for different cement / fly ash combinations. The two best combinations of cement and fly ash were determined.

In step 2, various HRWRs in combination with several VMAs, non-chloride accelerators, and air entrainers were evaluated. An optimal mix design from small lab batch testing was determined based on a combination of cementitious content, aggregate type and gradation, and admixture performance. In step 3, the best mix design was implemented in full batch quantities to insure the SCC mix would work properly and consistently on a daily basis.

The optimized mix resulted in a 20% fly ash replacement and an increase in the amount of admixture used in every batch of concrete. Even with the increased use of admixture, the pozzolan replacement in the mix yielded significant cost savings. Material costs dropped nearly 12% per cubic yard of concrete. Though the precast producer had to install a silo to hold the newly incorporated fly ash, the capital expense of installing the silo was returned in less than 12 months.

Precast producers have been on the forefront in implementing SCC technology for over 3 years. They have fully benefited from the use of SCC through labor savings, energy savings, and material savings while progressively improving the plastic fluidity properties and the ultimate hardened properties of the concrete.

CURING TIME

An additional option for improving productivity and reducing costs is to shorten the curing cycle. By shortening the heat curing cycle two benefits could be realized. The first benefit is the ability to produce more units in a given day or in a given week. The second benefit is a reduction in steaming costs because of the shorter curing cycle. Both of these benefits will reduce the cost per piece produced. Figure 3 shows the heat cured, strength gaining characteristics of mixtures 2 and 6 versus the reference mixture. The difference between the mixtures was the cement type and accelerator dosage. As a type I was substituted for a type III cement, the accelerator dosage is increased. In this case the use of high performance SCC mixtures decreased the time to reach 3500 psi by 50%.

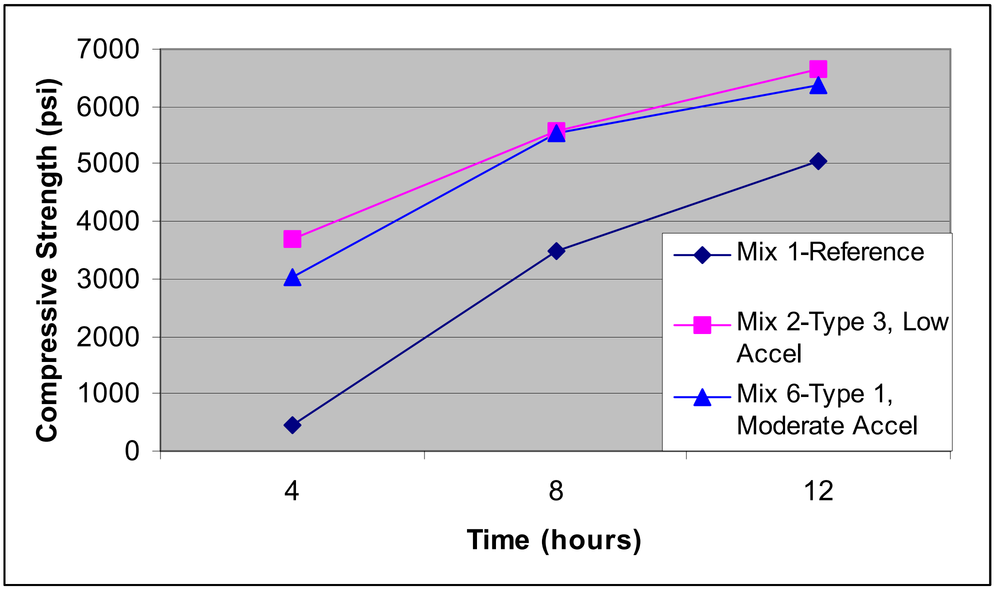

Figure 3. Reduced curing time

Case Study – Accelerated Curing and Increased Form Turnover

In high volume production environments, the ability to turn over forms for the next production run is critical. Precast producers face two options as the demand for their product increases. They can expand their operations by either 1) adding more capacity to an existing plant or 2) constructing a new plant. Or they can implement productivity improvements to their operation in order to manufacture more product with existing equipment. The first option requires capital expenditures, a sometime risky proposition in uncertain times. The second requires re-examining current operations from materials selection to personnel distribution and may require an increase to operational expenses to achieve productivity benefits.

A residential basement wall producer supplies precast walls for one of the largest single family homebuilders in the country. Their precast process is designed to produce enough concrete panels for 2-3 houses per day, 300 days per year. To do this efficiently and economically, they use a self-consolidating concrete mixture that achieves 3500 psi in 8 hours and allows them to run a second full production shift. The performance achieved from this concrete mix enabled them to redirect resources to set up forms and pour a second set of panels in the same day. Overall, this precast producer improved their productivity, decreased their overall production costs, and produced a high-quality precast product by utilizing SCC.

When this precast wall producer started their operation 3 years ago, they immediately implemented a self consolidating concrete program because they recognized the value SCC could provide in terms of the pouring efficiency, labor savings, and material optimization.

After 18 months, the demand for their products was exceeding the capacity of their plant, which was based on one production run per day. Their production capacity was nearly maximized and the ability to expand was limited due to their environmental surroundings. As a result, the precast producer adjusted their SCC mix design to accelerate their concrete production and allow them to produce twice the amount of panels by adding a second shift.

Two changes occurred to the mix design to facilitate this increased production. First they switched from a Type III to a Type I cement. This switch lowered their water cement ratio by lowering the water demand of the mix and still allowed them to maintain the ultimate specified compressive strength of the concrete, 5000 psi. The switch from Type III cement to Type I required an, additional 100 pounds of cement. Even with this cement increase, the total cement cost was unchanged.

The other change was in the amount and type of admixtures used in the mix. A combination of a HRWR (PC), non-chloride accelerator (NCA) and a viscosity modifying admixture (VMA) was used to provide a stable, 25” spread self-consolidating concrete mix. Though all of these admixtures were part of the initial mix, the new SCC mix design required an increase in HRWR and NCA. It was this combination and amount of admixture that allowed the switch from a Type III to a Type I cement and enabled them to achieve significantly higher strengths in a shorter time period.

The precast producer is currently achieving 3500 psi in 8 hours without the need for steam curing. Their design strength of 5000 psi is easily reached within 7 days. Their forms can be poured and stripped twice in 2 – 8 hour shifts. The ability to do this came at a cost to their operational expenses, both in the increase in mix design costs and the operational costs associated with running a 2nd shift. The increased production and raw materials costs were minimal compared to the productivity improvements and efficiencies associated with the high performance, SCC mix.

Today, this precast producer has the flexibility to meet their production requirements based not only on their operational capacity but also based on the SCC mix design developed for their operation. They are able to meet the increasing demand for their product in a way that provides flexibility in case the demand ever decreases. The flexibility is achieved with the onset of new admixture technologies designed to optimize concrete performance.

CURING TEMPERATURE (STEAM VERSUS NO STEAM)

The third option for improving productivity is to completely eliminate the need for steam in the curing process while still obtaining the required compressive strength in the same amount of time. Figure 4 demonstrates that this can be achieved by using the appropriate mixture proportions. To achieve high early strengths without using steam, a type III cement and accelerator combination will most likely be needed. The steam-cured, reference mixture compressive strengths are plotted versus the unheated compressive strengths of two high performance SCC mixtures both using type III cement and two different accelerator dosages.

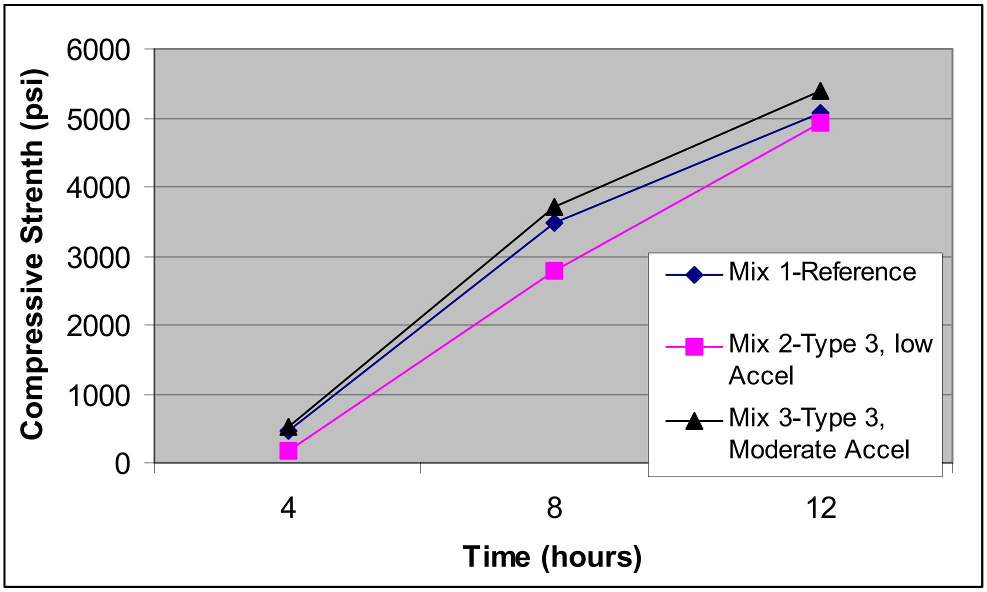

Figure 4. Compressive strength of non-heated versus heated reference

It should be noted as a point of interest that the lab cured specimens, being 4 x 8-inch cylinders, do not have the benefit of the mass effect that would be experienced when casting full sized pieces in a production facility. Therefore, these compressive strength values can be considered conservative estimates.

Case Study – Reduction in Steam Curing

Steam curing is currently the most widely adopted method of developing high early strength concrete in precast production. Effective steam curing is both a time consuming and an expensive task for a precast operation. A structural precast producer in Utah offers an excellent example of how total energy costs, specifically steam costs, can be minimized or even eliminated with the implementation of SCC. The precast producer was able to significantly minimize, and at times, eliminate the need for steam curing for their structural girders, Bulb T's, and beams. In addition to minimizing the need for steam, they also witnessed a significant improvement in their pouring time and the overall finished aesthetics of the precast elements.

The optimal design and use of SCC was investigated for their precast operation in late 2002. The intent was to minimize the total "in-place" cost of their concrete by decreasing the amount of time to pour each piece, improve the finished look, and minimize the total energy costs to make each piece. Prior to implementing SCC, structural elements produced on a daily basis typically used 4 hours of steam curing. After implementing a SCC mix program in their operation, steam requirements dropped to a maximum of 30 minutes in order to obtain their stripping strengths of 6000 psi or more.

In designing the appropriate SCC mix, the most well-graded aggregates available in their area were incorporated into the mix. The mix design was able to contain the same amount of Type III cement as was contained in their original 8-9 inch slump mix. The challenge was to find the right combination of HRWRs, VMAs, and water to obtain the proper flow characteristics and ultimate strength requirements without the need for steam. The right combination yielded a flowable, yet highly stable, SCC mix measuring 24-27 inches in spread.

The benefits of this mix were noticed immediately. The precast elements on average could be poured 25% faster with the SCC mix. In addition, the grouting process to repair bugholes and other surface imperfections were minimized by 25% as well. On architectural pieces, SCC eliminated the need for all surface repairs and removed the shadows appearing on the concrete caused by the vibration equipment.

In terms of energy consumption, the amount of steam curing energy was reduced by 88%. Though precise dollar figures are difficult to determine for steam curing costs associated with a yard of concrete, estimates can be calculated by adding up the total costs to run the boiler (including fuel, maintenance and chemicals), as well as the actual money invested in lines, fittings and valves on yearly basis. Based on these numbers, the typical costs associated with steam averages between $4 -$6 per cubic yard. These estimates suggest a precast producer can save a significant amount of money if they are able to eliminate or significantly reduce the amount of steam required to achieve the ultimate hardened properties of their concrete.

This precast producer invested significant time in developing the optimal SCC mixture for their operation. Though they experienced a slight increase in their concrete mix design cost, the monetary benefits far exceed the investment. Today, they have significantly improved their profitability by pouring concrete elements faster and reducing their patching requirements. Most impressively, they are able to achieve 7000 psi stripping strengths without the need for steam while still using the same amount and type of cement and other raw materials. The new generation of high range water reducers and viscosity modifying admixtures enable precast producers to produce fresh concrete to flow easily without segregation providing a high rate of production, smooth concrete surfaces and a finished product with improved durability.

CONCLUSIONS

Self-consolidating concrete is gaining wide use because of the benefits derived from its fresh properties. Additional benefits can be obtained by controlling the hardened properties of SCC mixtures. These benefits include;

1. Reduction in cementitious materials cost by substituting fly ash for cement or using a type I instead of a type III cement.
2. Reduction in curing time resulting in production of more pieces in the same amount of time and reducing steaming time/cost.

3. Reduction in steam costs by eliminating the need for heat curing.

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