SUPER SLUMP RETAINING PCE BASED ADMIXTURES FOR SELF-CONSOLIDATING CONCRETE APPLICATIONS IN THE PRE-CAST CONCRETE INDUSTRY

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Abstract

Ever since the first prototype of Self-consolidating Concrete (SCC) was developed in Japan (1988), this type of concrete has come a big way across the globe. Notably, the world’s largest ready mix SCC pour was witnessed recently in the Middle East.

SCC, however, still has practical issues in the pre-cast industry under hot ambient conditions in respective parts of the world, since there has to be a trade-off in achieving the right balance between high early strength and flowability retention for a reasonable period of time. Advancement in the Polycarboxylate ether (PCE) technology has now broken such application barriers and made it possible in practice to achieve equally both.

By a skilful use of a building block methodology in PCE development, admixtures can help in reduction / elimination of both rapid loss of workability, as well as achieving desired strengths at early ages and minimizing autoclave / steam curing processes. This paper is useful for application engineers and pre-cast manufacturers for analyzing new generation PCE based admixtures in SCC applications for pre-cast and for understanding the improvements possible in pre-cast operations under hot climate conditions.

1. INTRODUCTION

There has been a great transition in concrete technology over the last hundred years. The early 1900s saw the beginning of the industrial revolution; through the mid 1950s concrete technologists started making breakthroughs in application in large projects; and as we trundled into y2k era pre cast concrete evolved into quite a bit of perfection in form of Self-Consolidating Concrete (SCC) with minimized or elimination of heat curing, process automatization (laser measurement, robotized storage), more simplified delivery and modules / systems in place.

Admixtures have long been recognized as important components of SCC in pre cast concrete applications to improve its performance. With evolution of new concepts / technologies in admixtures, the markets are moving from pure performance to balanced products.
2. REQUIREMENTS FOR PRE CAST SCC

The need for admixtures to contribute to high performance pre cast concrete industry using SCC is underlined in the following:

- Fluidity & workability retention
- Setting with mixes rich in SCMs, i.e. supplementary cementitious materials (slag / fly ash)
- Early Strengths (8 – 10 hrs, 1 day) & final 28 days strengths
- “Low stickiness” of the fresh concrete
- Robustness with cement compatibility

Traditional superplasticizers (high range water reducer) have become a quite common practice - Originally developed in Japan and Germany in the early 1960s; they were introduced in the United States in the mid-1970s. Depending upon the ambient conditions, most of the commercial and conventional admixture formulations belong to any of the three families[1]:

1. β-naphthalene sulphonates (BNS) or
2. β-melamine sulphonates (BMS) or
3. Basic Polycarboxylate ether (PCE) chemistry

The basic idea for using superplasticizers SCC was for:

1. flowing, self-consolidating concrete without increasing water, without reducing cement and without sacrificing early strength;
2. producing workable, high-strength concrete by reducing the water and thus the water-cement ratio; or,
3. While the first two types are not suitable for SCC applications the third type – PCE – has been extensively used in SCC applications in the pre cast industry.

3. PCE CHEMISTRY – TRENDSETTER FOR TODAY’S PRE CAST MARKET

The problems associated with BNS / BMS in terms of workability retention, early strength development (Fig 1) and robustness were always present. While PCE chemistry attempted to close the gaps, and provided a great boost to the fluidity and early strength; other parameters like the robustness, workability retention, “low stickiness”, and adaptability in both winter / summer temperatures were still left to be addressed.

While water reduction capability of BNS / BMS has limitations, the latest arrival in the block is the much improved polycarboxylate ether (PCE) technology around the mid eighties [2]. With the advent of newer ideas, as technology evolved further, it was reported recently that a record breaking 130 MPa designed concrete was actually applied in high-rise construction in Japan, using the latest PCE technology [3].
Keeping in view today’s precast trends, the basic objective is to strike a balance between performance (e.g. strength, setting, fluidity) and comfort (cement compatibility, robustness, workability retention, etc) so that the precast manufacturer is able to execute to meet their requirements with maximum efficiency.

A number of factors impact precast concrete producers:
1. Customer’s requirements – architectural, civil engineering, functional
2. Raw material issues – cement consistency (esp. with use of alternative fuels), use of SCMs, recycled aggregates, etc
3. Environmental & social issues – reduction in noise, ergonomic, reliability
4. Technology drive – higher performance, new materials (“nanotechnology”)
5. Globalization – availability of resources, cycle times and overload of information

Based on the above and understanding the precast process – from raw materials, fresh technology issues, early strength requirements, hardening process, durability / serviceability issues – it became essential that the admixture technology based on PCEs achieved the maximum level in terms of water reduction and not much further development shall occur in this particular aspect of admixture performance [4].

However, to achieve other core properties of both fresh and hardened SCC – slump flow retention, early & final strengths, viscosity, robustness, low stickiness, permeability, freeze-thaw resistance, durability, elasticity and others parameters, admixtures have to be assessed thoroughly for their influence on the ultimate quality of precast concrete [5].

Among various parameters, it is generally accepted that workability retention (i.e. slump retention) and early strength are opposed to each other, and workability retention is often achieved by retardation of the hydration process of cement. Various sugar based combinations work as retarders / slump retainers for a concrete plasticized by BNS /BMS under hot ambient
conditions. By default, the delay of hydration causes delayed strength development, which in pre cast concrete applications, is an unacceptable issue. Precast concrete producers, utilizing SCC, require a short cycle time to maximize utilization of the equipment and space, and also contractors of bigger projects who prefer an acceleration of the early strength development to speed up the overall construction process [6].

The dependency of properties becomes even more complex if the ultimate strength of the concrete is taken into account. It is described that certain hydration accelerating admixtures, typically based on calcium salts, provide an improved early strength, but due to incomplete hydration of the cement, the final strength of the respective concrete might be reduced [7].

4. A NEW TOOLBOX TO FORMULATE A NEW FAMILY OF PCE ADMIXTURES

In this paper, we present data of concrete performance when using a new family of admixtures. The results show that despite the dependency of the properties “workability retention”, “early strength” and “final strength”, all three properties can be optimized, and even be controlled independently to a certain degree.

The admixtures used in this test series are based on a modified PCE technology. In principle, the admixtures consist of basic modular blocks taken out of a typical toolbox (Fig.1, left half),

- $S$ for water reduction of concrete
- $W$ is responsible for workability retention
- $E$ for early strength
- $A$ for better cement affinity
- $V$ for lower “stickiness” of the mix

The modular blocks are combined into a polymer structures, or in certain cases, can also be formulated to achieve the desired performance. In brief, to mention about the working mechanism, block $W$ controls the adsorption speed of the PCE to the cement surface [8, 9], while it is not retarding. Modular block $E$ is enhancing the natural hydration process, without influencing the hydration products. Block $V$ contributes to lower “stickiness” of the mix and lowers the viscosity of the mix (thus easing pumping or placement, esp. with ternary / binary blends of concrete, and at the same time maintaining the segregation resistance of concrete) [7]. Block $A$ controls the absorption of the polymer into the $C_3A$ / $SO_4^{2-}$ phases and improves the cement compatibility over cement variation. Block $S$ is a conventional water reducing component for a PCE [10].

Using this modular approach, a seemingly unlimited number of combinations of PCE polymers is thinkable (Fig.1, right half). E.g. by using multiple modular blocks of type $S$, the respective concrete would show good workability after elapsed time, without retardation of the hydration process. Depending on the specific application and the requirement of the pre cast concrete producer, polymers and admixtures can be tailored to the specific needs.

In this paper we discuss one admixture PRECAD-1, which were designed for precast , respectively[8, 9].
• PRECAD-1 is formulated with proportions of all five blocks mentioned above as follows:
  
  - more of early strength and water reduction blocks \((E & S)\) since Self-consolidating Concrete applications require more fluidity and at the same time this formulation requires to contribute to higher early strengths,
  
  - lesser content of workability retention block \((W)\) because of pre cast application where workability retention upto 1 hour is fine,
  
  - optimum content of cement affinity block \((A)\) and lower stickiness \((V)\)

4.1 Admixture tailored to precast application

The composition of PRECAD-1 indicates that the performance would be useful in SCC precast applications where workability retention requirement is often required for less than 1 hour only, owing to the batching plant being in close proximity to the precast yard.

![Comparison of flow retention over 1 hr in pre cast SCC, T = 38 deg C](image)

**Figure 2: Flow retention performance of PRECAD-1 in comparison to BNS & PRECAD-2 in precast SCC Mix**

In fact, PRECAD-1 provided sufficient slump retention in the actual application in a hot climate condition. Mix design and slump flow retention are depicted in Table 1 & Fig 2, where PRECAD-1 is benchmarked against PRECAD-2 (a conventional PCE based precast admixture) and a BNS formulation (typical for pre-cast). The application of PRECAD-1 in a high slump flow concrete (SCC) offered the following benefits:

- Applying PRECAD-1 in a typical pre cast SCC high slump flow concrete, leads to a flow loss not bigger than 8 – 9 cm in one hour, even at 36 - 38°C ambient temperature. The flow of PRECAD-2, on the contrary, is only acceptable for approximately 20 - 30 minutes.
Early strength @ 8 hrs with PRECAD-1 is also marginally higher in comparison to conventional PCE admixture, PRECAD-2; and significantly higher than a BNS based one., as shown also in Fig 3.

$T_{500}$ is lower in case of SCC with PRECAD-1 in comparison to PRECAD-2 (the BNS was not compared in this case).

Table 1: Mix details for pre cast SCC to compare performance of PRECAD-1 in comparison to PRECAD-2 and BNS in precast mix-design

<table>
<thead>
<tr>
<th>mix-design</th>
<th>w/c</th>
<th>OPC + FLY ASH</th>
<th>Air</th>
<th>BNS</th>
<th>PRECAD-1</th>
<th>PRECAD-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/m$^3$</td>
<td>0.33</td>
<td>460</td>
<td>2.0%</td>
<td>2.0%</td>
<td>0.8%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

With the life of slump flow extended, one would expect a significant drop in early strength of PRECAD-1. Table 2 shows this contrary to the belief, instead PRECAD-1 shows not only early strength marginally more than PRECAD-2, but after 28 days at standard curing conditions the strength exceeds the benchmark by 7%.

Figure 3: Cement compatibility - Strength increase at selected ages upon use of PRECAD-1 in percent compared to use of PRECAD-2

It is noteworthy, that due to the chemical nature of the mechanism of the admixtures based on this tool box, its effect is quite dependent on the cement composition. A brief study was done to check its robustness in terms of cement compatibility across the Asia Pacific region. Fig. 3 shows comparison data of several regional cements. Apparently, even though the early
strength development can differ significantly, it is always improved, and differences are leveled out at later ages, where a strength increase between 5 – 15% can be expected, compared to conventional admixture PRECAD-2. The mechanism behind the difference in strength development, which is dependent upon the cement composition, is currently under investigation and remains unclear at this point of time.

Table 2: Early and late strength development \textit{PRECAD-1, PRECAD-2, BNS; SCC Mix} proportion same as in Table 1

<table>
<thead>
<tr>
<th>Spread of Flow (mm)</th>
<th>Strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>\textit{BNS}</td>
<td>530 x 550</td>
</tr>
<tr>
<td>\textit{PRECAD -1}</td>
<td>640 x 620</td>
</tr>
<tr>
<td>\textit{PRECAD -2}</td>
<td>600 x 610</td>
</tr>
</tbody>
</table>

4.2 Performance of PRECAD-1 under fine sand condition (FM of sand < 1.8)

Many parts of Asia are moving towards using crushed rock fines / “manufactured sand” in structural precast concrete owing to paucity of the same. A typical experience has been encountered in Vietnam where extremely fine sand of F.M.(fineness modulus) lower than 1.8 has to be used. As a result, the pre cast concrete producer struggles with the very quick slump loss.

The successful new technology of PRECAD-3 prompted us to compare conventional, slump retaining, PCE based admixture PRECAD-4 with PRECAD-3 under fine sand conditions (FM = 1.8).
Flow Retention of PRECAD-3 over 2 hours under fine sand condition

![Graph showing flow retention of PRECAD-3 and PRECAD-4](image)

Figure 4: Flow retention of PRECAD-3 in a 40 MPa SCC precast concrete at T = 37°C.

Table 2: Mix proportions (for Fig. 4)

<table>
<thead>
<tr>
<th>Mix -design</th>
<th>water</th>
<th>OPC</th>
<th>Sand</th>
<th>Stone</th>
<th>Air</th>
<th>PRECAD-3</th>
<th>PRECAD-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/m³</td>
<td>180</td>
<td>450</td>
<td>885</td>
<td>885</td>
<td>2.30%</td>
<td>1.2%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

Figure 4 reveals the superior spread of flow retention performance of PRECAD-3, providing consistent workability even under hot climate condition for nearly 2 hrs, while PRECAD-4 does not meet expectation.

5. CONCLUSIONS

New PCE based polymers PRECAD-1 and PRECAD-3 represent a new family of concrete admixtures, which allow simultaneous control of water reduction, longer flow retention (as in SCC applications), better robustness (fine sand, wider cement range), lower stickiness and early & final strength. PRECAD-1 and PRECAD-3 were identified precast admixtures exhibiting unrivalled flow retention for in pre cast concrete applications, far exceeding current admixture technology. Thus, a new path for achievement of High Performance Concrete is paved. Such a concept paves way to eliminate / minimize steam / autoclave curing processes and can contribute immensely to pre cast concrete savings (labour / productivity / materials) [11].
REFERENCES


