Who Will Be Making High Performance Concrete?

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ABSTRACT

There is an increasing demand for high performance concrete all around the world. Self-compacting concrete is growing in popularity, especially in precast factories; ultra high strength concrete attracts the interest of architects and designers, other high performance cement-based materials such as strain hardening composites, textile reinforced concrete and others are gaining their acceptance in the structural repairs and new product development sectors. Production and supply of high performance concrete is very technologically specific as it is highly sensitive to external influences, such as quality and uniformity of raw materials, batching (weighing) accuracy, mixing, personnel qualifications and capabilities, formwork quality, and many others.

The main medium for production and delivery of concrete in mass volumes these days is readymix (or pre-mixed) concrete, which originated in the 1920-30s. Concrete mixing technological advances enable to manufacture concrete even quicker and of better quality and uniformity, but the main objective of any readymix (RMC) organization – the fast production of a large volume of concrete - hasn't changed. RMC plants achieve this goal through the production of plain concrete.

Self-compacting concrete (SCC) is one of the most used types of high-performance concretes. Despite the intensive effort of commercializing self-compacting concrete (SCC) in concrete construction industry in the last 15 years, globally SCC makes up approximately only 7% of total concrete produced (this excludes precast concrete). One the main reasons for this is that RMC industry, by the nature of the business organization, does not have enough incentive to be attracted to supply high performance concrete, as requirements for HPC production go beyond the routine daily operation. This paper discusses the problem in more detail and looks at whether the RMC industry can become the prime vehicle for the manufacture and delivery of high performance concrete.

The purpose of this paper is to simply bring up an awareness of the potential issues and in no way to criticize ready mix concrete and concrete construction industries.

1. DEFINING HIGH PERFORMANCE CONCRETE

High performance concrete (HPC) is concrete that possesses high workability, high strength and high durability. It has also been defined as concrete in which certain characteristics are developed for a specific application and environment, concrete that is designed to exceed the performance of ordinary concrete.

HPC is a complex composite material with enhanced mechanical properties. In addition to Portland cement, aggregates and water HPC also includes high performance admixtures, pozzolanic (or supplementary cementing) materials and different types of fibre. Some promising new technologies, such as self-compacting concrete, fibre composites, textile reinforced concrete, have recently been developed that should make HPC an attractive alternative to conventional concrete from both economical and sustainability perspectives [1].

The properties of HPC most certainly make it the first choice as an economical, durable and sustainable material for repairs of concrete structures. This is because HPC can be specifically formulated to achieve extremely high deformability and required mechanical and durability characteristics. Due to the high interest in HPC and especially self-compacting concrete (SCC), new research has emerged focusing on fresh properties (rheology, flow modeling, etc.), durability, and sustainability (service life prediction and modeling, ultra-high strength, structure weight reduction, CO_2 emission reduction, etc.). The relationship between concrete mix design and hardened and fresh concrete properties is a significant part of this research.

It has become evident that the quantitative precision and consistency in properties of HPC mix design is much higher than it would be for conventional vibrated concrete (CVC). The importance of precise dispersion of all the ingredients by means of mixing adds to the complexity of manufacturing HPC. This poses several challenges for the concrete industry – the first and foremost being the maintenance of the homogeneity of HPC right through the production, delivery and placement of concrete. Although this is a challenge it is also a prime goal for the manufacturers of HPC: most are designed for high flowability. The main most appropriate way to address this challenge is to employ the science of rheology to provide necessary tools.

2. SELF-COMPACTING CONCRETE

Self-Compacting Concrete (SCC) is the most well-known, used and researched type of High Performance Concrete. Its use has become widespread from the mid-1990s, and since then the percentage of total SCC supplied to the in-situ concrete construction has stayed at only approximately 7%. This figure is an average across the world, however in some countries it is less. Conversely, precast concrete factories in many countries, like the Netherlands, Denmark, Germany, USA and others convert all their concrete to SCC. This section will examine in greater detail the enormous differences in SCC production between RMC and Precast Concrete

Self compacting concrete technology brings a new set of rules into the conventional concrete construction sites. By its very nature SCC, during casting, does not require much effort to place, which means the contractor's role and expertise in placing SCC is minimal. The quality of concrete structures depends much more on the fresh concrete properties, placing more responsibility onto concrete supplier. Although it is still the contractor's responsibility, of course, to make sure that formwork systems are suitable for SCC, i.e. formwork material, release agent and formwork bracing are properly selected for SCC, and after placing curing of concrete is in place. Traditionally, the responsibility of a concrete supplier stops when a truck load of concrete is formally accepted by the concrete contractor, but with SCC, the boundaries of responsibility are becoming unclear, as workability check is now the supplier's internal quality assurance procedure and contractor becomes an observer rather than an active participant in placing concrete. Because of this responsibility shift, both concrete supplier and concrete contractor may not be fully comfortable, and may try to avoid wherever possible the supply and use SCC. And here is the paradox: a contractor is reluctant to use SCC while a concrete manufacturer is not very enthusiastic about supplying it. Because of this, both are losing opportunities to learn about SCC technology and to take economical advantage offered by the technology despite facing unavoidable responsibility change.

SCC is a prime example of the current challenge facing the conceret industry: neither RMC nor the concrete construction industry in their current organisational state are quite prepared to take up challenges presented by new technological advancements. Nevertheless, there is a large number of examples where architectually appealing and complex concrete structures were built with SCC and collaboration between designer, supplier and user has been clearly demonstrated. But it is clear that SCC is not replacing CVC yet.

There might be some arguments that one of the main reasons for SCC not taking off is the high cost involved. It is true that often the cost of SCC is more than CVC, but the final structures made of SCC can be much more economical [2]. If it was not true, the precast concrete industry would not be at the highest level of aceptance of SCC technology [3]. The ultimate goal of a precast operation is the quality and the economical value of finished product, that is precast (pre-fabricated) elements. In order to achieve desired quality and value of precast products, a precaster invests into SCC technology, which also includes upgrades of concrete batching plants. The precaster owns and controls the whole process from the quality of raw materials to the quality and the cost of finished products. The precaster is fully and solely responsible for every stage of the process where production of self-compacting concrete is just one part of it. There is no responsibility transfer in a precast factory.

3. CONCRETE CONSTRUCTION INDUSTRY TODAY

Globalization, advances in technology, environmental factors and changes in the structure of the economy are presenting new and serious challenges to the construction industry. To capture new opportunities, the industry must respond positively. New challenges require new approaches.

Construction industry worldwide is largely made up of small firms, and is fragmented, with low profit margins, low-bid tendering, inequitable risk sharing, and poor investment in technology. The industry fragmentation is associated with the fact that many involved disciplines (design, production, construction, specialist contractors and consultants) are separated and, therefore, damage innovation perspectives. Supply chain is long and complex, which makes it extremely difficult to bring all the parties together. The fragmented structure of the industry is a major problem to change or adaption of new technologies [4].

Innovative technologies demand innovative business organizations. There have been recent examples of the construction industry’s attempts to solidify its fragmented management and procurement structures and create new innovative business organizations such as design-and-build. This certainly allows for an easier implementation of innovations and the use of advanced technologies. This also tolerates the use of more advanced project specifications, like performance based, rather than obsolete prescriptive types, which have been in place for the last 30-40 years or more in some instances. Performance based specifications are free of process limitations and construction methods, which opens the doors to innovations in construction processes, like self-compacting and high performance concretes.

The responsibility transition on the concrete construction site offers new opportunities and challenges for both concrete supplier and the contractor. For example, the contractor can reduce the amount of work needed for casting, as concrete supplier may start taking responsibility to deliver SCC directly into the formwork which ensures more control over fresh concrete properties. This in return offers the supplier a number of benefits. For example, an opportunity to optimise the truck fleet utilization. This might progress further and also include subcontracting to the readymix concrete supplier more of the sub-processes such as formwork construction, finishing, curing, demoulding, and so on. This may sound absurd, but it has its positive moments. Maintaining required fresh properties of concrete is critical for the quality of the complete structure. The timing issue is very sensitive as far as acceptance of concrete workability is concerned. And, in reality, the workability testing and acceptance is more linked to the responsibility rather than quality. One single business unit would be responsible for the complete process including concrete mix design, concrete manufacture, concrete delivery, casting and curing. The product delivered to the next business unit would be a complete concrete structure, similar to an independent precast operation [5]. Now we have concrete mix design, concrete manufacture, concrete delivery, concrete placement and curing are all under one roof. The main focus of such operation is on efficiency and the quality of the final product – precast elements.

4. MAKING CONVENTIONAL CONCRETE AT READY MIXED CONCRETE PLANT

Production of conventional vibrated concrete (CVC) is a worldwide-established practice. Concrete is premixed at a specialized concrete batching plant, batched using reasonably accurate weighing equipment and mixed either in stationary or transit mixers. An average batching plant has limited aggregate storage facility that permits for only restricted number of aggregates available for making concrete. Luckily, the huge variety of different types of concrete are made using the same base materials. Acceptable material weighing tolerances are usually in the vicinity of ±1÷5% depending on the type of the material and local code of practice. All modern mixers can be grouped into two main mixing action types: shear and gravity mixers. Mixing action of former is based on high shear forces generated by rotating mixing arms and blades, while the latter relies on solid particles of different size that would have different energy when falling while rotating in a mixing bowl. The varieties mostly range from very fast twin horizontal shafts and planetary mixers to rotating bowls. Most modern concrete batching plants are fitted with the batching computers that control weighing accuracy and mixing time. Batching and mixing processes are aiming to achieve the required (target) workability, expressed in slump values. Raw material moisture parameters either manually entered into batching computers or instantly transmitted from moisture probes. Some computer programs enable for cement content adjustments to maintain the design w/c when higher or lower than design slump is required. Some concrete mixer manufacturers offer moisture probes fitted into the mixers for water evaluation in the mixture that allows for accurate w/c calculation. Any deviations form the quality of concrete constituents, e.g. minor changes in particle size distribution of aggregates that can change from batch to batch, that affect the workability (slump) are usually compensated with added water or superplasticiser.

With the basic quality control and quality assurance in place, the required quality of CVC is achieved. Serving solely the construction industry, RMC suffers the same problems: in order to be profitable it has to survive in a highly competitive market, the products have to have low margins, and the operation must be low cost. The latter, of course, is the main concern. RMC industry is driven by production of large volume of concrete and this is the RMC's biggest driver and reason for its existence. Production of plain concrete is a commercially viable option for many concrete readymix plants, because they don't have to control most of the influencing factors necessary for production of HPC.

All the above confirms the sentiment that the RMC's greatest incentive is fast production of large volume of concrete with minimum quality compliance at lowest possible costs. But the question still remains, that is if RMC, main vehicle for making bulk CVC concrete, have enough motivation to produce bulk HPC when required.

5. CONCLUSION: WHO WILL BE MAKING HIGH PERFORMANCE CONCRETE?

There are no doubts that RMC is very capable of supplying quality high performance concrete. The concrete mixing technology has advanced quickly and offers highly efficient machinery which is able to reliably produce homogenous concrete. However, and this has been shown by the history of SCC evolution, it requires extra knowledge, specific staff training, much higher quality control at all stages of the production and placement of concrete, more accurate weighing and advanced mixing equipment, and an additional storage capacity for a number of extra special constituents. RMC industry is doing its very best to upgrade itself, but the process is very slow. The main reason, but not the only one, is that the bulk revenue is coming from selling conventional concrete.

At this point of development, demand on HPC, including SCC, is small, and, when it occurs, RMC delivers good quality products. But it comes at cost, as every HPC (SCC) supply project requires special management and high concentration of resources from RMC. The question is that if RMC will be able to supply consistent quality HPC when demand is high, whenever it is going to happen.

Manufacture and delivery of HPC is only one a link in a chain of concrete construction. The construction industry that uses HPC is the larger barrier as it generates demand and, hence, the question may need to be extended to Who will be making HPC structures? But the prime focus of this paper is on HPC manufacturing issues.

Two quite distinct approaches to future HPC manufacture and supply are envisaged: (a) upgraded RMC batch plant, and (b) a mobile unit solely specialized on production of HPC (this can be either part of RMC set up, or construction company). The former will only work efficiently when two problems are resolved:

Problem 1: Reasonable demand on HPC is necessary to justify investment into RMC upgrade (machinery, knowledge, training, etc.), and;

Problem 2: On site responsibility transfer from concrete supplier to concrete user.

It seems that the first problem will be sorted out naturally when the second problem is resolved. However, in order to resolve the second problem, some serious organizational changes are necessary.

The main attraction to the specialized HPC production units is that such units can be fully integrated into the construction process and the whole high performance concrete construction process would be similar to a concrete precast factory where concrete production and concrete placement are under one management roof. However, if such specialized unit is part or extension of RMC operation, the responsibility transfer issue can still be presented.

Quality and serviceability of structures made of HPC is entirely determined by the quality of fresh HPC. Approaches to the manufacturing processes of CVC and HPC are distinctly different in the sense that manufacturing of quality HPC is by far more complex. Therefore, there is a concern that at its current state RMC industry would not be able to adequately supply high volumes quality HPC of different kind when demand grows.

The purpose of this paper was not to provide solutions but rather bring up an awareness of the potential issue and in no way to criticize ready mix concrete and concrete construction industries, but rather bring up an awareness of the potential issue.

6. REFERENCES

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