THE HOLISTIC APPROACH TO SELF-CONSOLIDATING CONCRETE

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INTRODUCTION

The acceptance and application of new technologies within any industry is a process. Depending upon the industry and the technology being introduced this process may be relatively short and easy or it may require very deliberate and methodical steps to ensure that the technology is applied correctly. Self-consolidating concrete (SCC) is such a new and emerging technology for the concrete construction industry. The acceptance and application process for SCC is one that is requiring a methodical and deliberate approach.

The reason for this type of approach is that in general, concrete mixtures must satisfy a broad and diverse range of people who are concerned with a particular aspect of the concrete's performance. Owners are concerned with in-service value and construction timetables, engineers and architects are concerned with hardened concrete properties such as compressive creep and aesthetics while contractors and precast producers are concerned with mixture cost versus constructability. Therefore, in an effort to facilitate the acceptance of SCC, the desires of all interested parties must be addressed. This requires that a broad, holistic approach be used in describing and evaluating SCC as a technology. This paper examines SCC from this viewpoint, considering the many variables involved in applying SCC as well as determining the value of the technology in the marketplace. The variables shown will be expanded upon and the ways that they interact will be discussed.

VALUE OF SCC

What is the value of this new technology? Can this technology revolutionize production processes? Is this technology economically feasible? These are the types of questions the concrete industry in North America is asking itself regarding SCC. The use of SCC is certainly attractive to many producers. When the concrete is first demonstrated to a prospective user, the benefits are immediately qualifiable. This technology could indeed be quite valuable and could completely revolutionize construction practices. The real question, which requires quantification, is whether or not it is economically viable. There is an initial qualitatively perceived value in SCC; however, one must go through the process of actually quantifying this value. And as will be seen, this process requires a willingness to view SCC as a technology and not as a prescribed set of test values or mixture proportions. Once through this process, one then can quantify the value of SCC and determine if the perceived and actual values are the same. It may actually be that they are not, but that SCC is economically viable just the same.

Material suppliers, contractors, structural designers, architects, owners, and end users might have different sets of interests that would constitute commercial and technical drivers for adopting this technology. Cost savings and/or performance enhancement can be the driving forces behind the realization of the added value of SCC. Some of the main benefits of using SCC are presented below.

Generic Advantages of SCC

The use of SCC enables the casting of highly flowable concrete that develops mechanical properties without the need for vibration or consolidation. With increased requirements for both productivity and comfort on the job site as well as the performance of the hardened concrete, the use of SCC can reduce costly labor, accelerate construction timetables, enable more flexibility in placement operations and scheduling, as well as provide greater flexibility in using and procuring the required resources, resulting in both time and resource savings.

The use of SCC enables the reduction of noise discomfort on the job site that is especially critical in urban areas. This permits the scheduling of some construction activities in otherwise curfew periods. The reduction of noise pollution is also critical at precast and prestressing plants as it leads to a more pleasant working environment, and in some countries decreases insurance premiums for precast plants. The use of SCC results in superior quality finish that is critical in architectural concrete, precast construction, as well as cast-in-place construction. This reduces the need for surface remedy (patching) and the absence of vibration leads to an increase of the life cycle of the molds.

Further Benefits of Using Highly Stable SCC

The stability of the fresh concrete can further be enhanced by incorporating a viscosity-modifying admixture (VMA). This new class of admixtures is incorporated along with a in high-range water reducer (HRWR) in order to secure highly flowable, yet viscous concrete that can flow into place under its own self-weight with minimum risk of segregation and bleeding.

The production of highly stable SCC can offer further advantages compared to the generic value-added attributes of SCC. The use of highly flowable, yet cohesive SCC enables greater flexibility in selecting locally available materials, including sand, coarse aggregate, cementitious materials and fillers. In mixtures prepared without any VMA, greater care must be given to the selection of raw materials, including aggregate gradation. SCC made with small concentrations of VMA have been found to exhibit better robustness which translates into less sensitivity to changes in the characteristics of primary mixture constituents, including sand fineness and moisture content (1). A more robust SCC can enable the concrete supplier to provide better consistency in delivering concrete, thus reducing the need for interventions at the plant or at the job site.

A highly stable SCC can allow more flexibility in casting such as lower risk of segregation, higher pumping rate, longer pumping distances, greater free fall distances compared to regular SCC, and higher construction lifts possible when the mix is highly stable.

Highly flowable, yet stable SCC can be placed at very low yield value to achieve self-leveling consistency. It is important to note that some of the VMA products on the market promote greater rate of increase in viscosity and cohesiveness. This can have marked effect on segregation resistance and formwork pressure. From an engineering point of view, highly stable SCC can develop better microstructure and homogeneity of in-situ properties, including bond and greater stability of the air-void system.

PERFORMANCE REQUIREMENTS OF SCC

In general, the performance requirements of SCC are complex and depend on several parameters, including service loading and environmental conditions, intended placement method, labor skill, quality assurance and quality control measures. The most important performance criteria that differentiate it from a conventional concrete lie in the properties of the fresh concrete. Such requirements are as follows:

- Self-placing and self-consolidation – the SCC must have high deformability and ability to flow into place without the need for vibration consolidation.
- Retention of deformability – such retention must be compatible with duration of concrete transport and any constraints regarding possibilities of field adjustments. The retention of deformability is more important in the case of restrained flow than free unrestrained flow.
- High stability during transport and placement – this is referred to as dynamic stability and includes the resistance to material separation during the pumping and flow through restricted spacing where there is higher risk of turbulent flow.
- High stability following casting – this involves the resistance to segregation, bleeding, and surface settlement during the dormant period of cement hydration.
- Limited bleeding and settlement to reduce cracking and microstructural defects.
- Uniform surface quality, and homogeneous distribution of in-situ properties.

Achieving the above performance requirements is not easy and often involves a compromise between the various requirements that affect the mixture proportioning of SCC, as shown in Fig. 1 (2). In addition, the level of the above performance requirements is not the same for every project. Therefore the proportioning techniques used should be adjusted to meet these, as well as the hardened properties requirements.

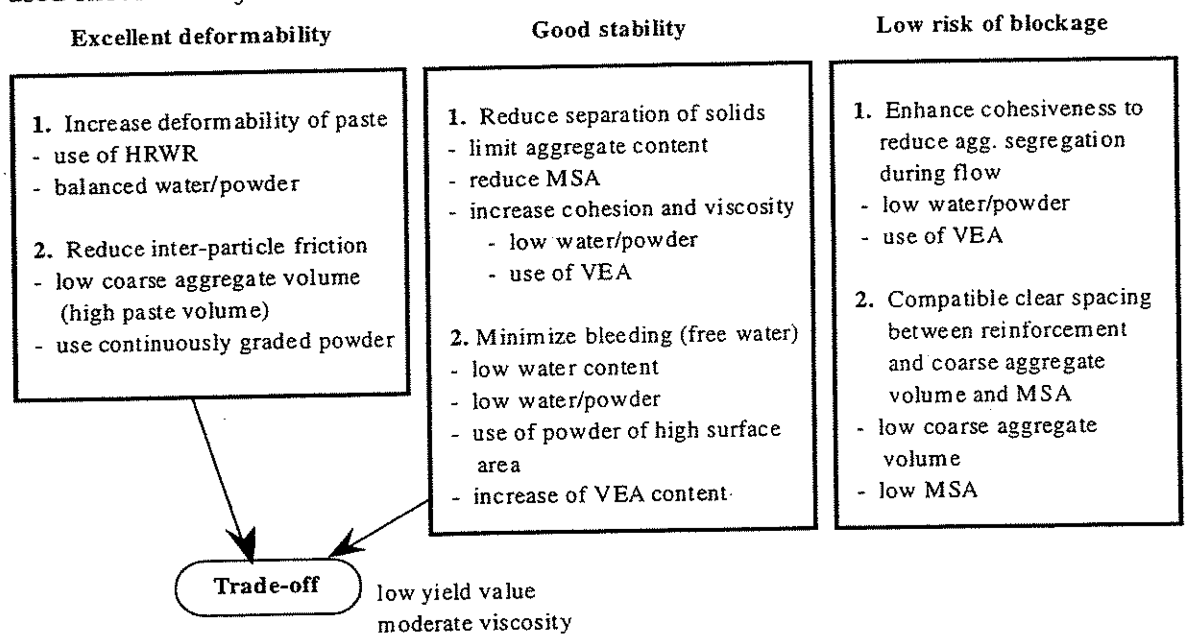

Fig. 1 Principles of SCC formulation

The fresh properties of SCC, particularly its ability to spread into place and among obstacles without vibration, are what make this technology so attractive to producers and contractors. However, for the successful application of SCC, both the fluidity and mixture stability must be managed. To enhance the economical viability of SCC it is important to tailor the specific fresh properties to the application. In the overall optimization process this is considered the performance optimization stage. Essentially, four main sets of variables can influence the workability requirements necessary to achieve high-performance SCC. The following sections briefly explain the influence of each of these requirements on the characteristics of SCC.

Hardened Properties

The required hardened properties of the structure being built will have an influence on the fresh properties of SCC. For example, the casting of SCC in cold climate necessitates that the concrete exhibits high resistance to freezing and thawing, and in some cases to de-icing salt scaling. The concrete must then be proportioned to secure an adequate air-void system that can remain stable during the mixing, transport, placement, and hardening of the concrete. The entrainment of air reduces viscosity and can lead to segregation in some cases. Therefore, the fresh concrete properties and mixture proportioning should take into account these factors. Special care to reduce bleeding and settlement is required when casting of deep structural elements to ensure homogeneous bond to embedded reinforcement. The top-bar effect is closely related to the level of stability, especially when highly flowable SCC is used. In addition, some proportioning techniques suggest the use of higher sand volumes and cementitious contents in the concrete mixture. These techniques will increase the overall paste and mortar fraction of the concrete mixture. In general these will tend to affect other hardened properties such as compressive creep, shrinkage and modulus of elasticity. Therefore a balance between the fresh properties desired and the hardened properties needed must be established.

Element Characteristics

The characteristics of a given element dramatically influence the fresh performance properties required of the SCC mixture (3). These characteristics include, reinforcement level, element shape intricacy, element depth, importance of surface finish, element length, coarse aggregate content and wall thickness. These characteristics dictate both the level of fluidity and stability required for a particular application. For example, the intricacy of the element's shape has a direct effect on the required level of slump flow. If a double-tee girder is compared to an ornate architectural piece, one should intuitively realize that the ornate piece will require a higher level of fluidity to ensure that the form detail is realized in the final piece. Closely spaced reinforcing steel or prestressing strand can inhibit the flow of the SCC. This can then require the modification of the fluidity characteristics of the mixture or the changing of the mixture proportioning to minimize blocking and maximize the passing ability of the concrete. The ability to flow through tight reinforcement or to produce a blemish-free surface is significantly affected by the fluidity and stability properties of the concrete mixture as well as the mixture characteristics, including paste volume, and aggregate nominal size and volume.

The casting of concrete in high lifts requires special attention to formwork pressure. The fresh concrete is then required to exhibit a high level of thixotropy so that the cohesiveness of the plastic concrete can rapidly increase after placement, thus reducing the lateral pressure exerted by the concrete.

Placement Techniques and Conditions

Given the high fluidity nature of SCC, some of the transport and placement techniques may be modified for a given project or production facility to ensure the required performance criteria of the concrete. Historically, the energy delivered into the concrete during the casting process has been largely ignored because there was usually significant labor on hand to move the material into its final position. However, with SCC, the goal is to cast and consolidate concrete with minimal effort, thereby effectively minimizing the labor on hand. This makes the technique used in casting that much more important.

The issues to consider when evaluating the casting process are: the distance of free-fall of the concrete in the formwork, the rate at which it is discharged from the transport vessel, whether or not the casting process (of the individual element) will be continuous or discontinuous, and the single discharge volume. At the discharge point, the distance of the free-fall of the concrete into the formwork can affect segregation and must be kept to a minimum. If the placement technique delivers a volume insufficient to fill the form in a single pour and if there is a delay between successive deliveries of the concrete to the bed, this technique would be considered discontinuous. A discontinuous pour will require that the producer develop a mixture that will not create lift lines. Therefore, delays must be avoided, especially in mixtures exhibiting some degree of thixotropy.

Material Considerations

As in any concrete mixture the raw materials being used to produce SCC mixtures are of great importance. Each producer, on a case-by-case basis, must consider the limitations of available materials. The overall particle size distribution of the aggregate skeleton significantly affects both the mobility of the concrete and its stability. Large spikes in individual sieve sizes can lead to mobility problems while large gaps between successive sieve sizes can result in a tendency to bleed and segregate. In addition, the composition of the powder fraction of the mixture can affect performance. Often, one or two types of supplementary cementitious materials, and in some cases fillers, are employed in proportioning SCC to reduce HRWR dosage and overall cost while enhancing the performance of the fresh and hardened concrete. Mixtures with low contents of silica fume and considerable replacements of the cement with either fly ash or granulated blast-furnace slag have been successfully used.

The majority of SCC mixtures are proportioned with a chemical admixture other than the HRWR, including VMA, water-reducing or set-retarding admixture, and air-entraining admixture. The selected admixtures must be compatible with each another and with the cement and supplementary cementitious materials.

THE OPTIMIZATION PROCESS

The initial step is to optimize the fresh performance properties required for a given project. This step of "determining what is needed" should not be based solely on achieving the highest slump flow possible with the given set of materials. A higher level of fluidity than needed for a particular application may not be cost effective and may provide little or no additional benefit. The SCC performance versus benefits relationship reaches a point of diminishing returns for each type of project. This thought process is analogous to complying with compressive strength requirements. Certainly an over design is useful in ensuring a minimum level of performance, however, the over design should be within reason. Therefore, consideration of the engineering requirements, basic element characteristics, placement techniques and raw material characteristics should be part of the process in establishing the correct performance targets. Once the performance targets are established, then the mixtures can be proportioned to meet those parameters.

The second step is to optimize the actual mixture proportions. In this step, the raw materials, admixtures and quantities are optimized to achieve the required levels of performance at the most reasonable cost. The mixture optimization process must consider both the hardened and the fresh properties and, if necessary, strike a balance between the two. It may be that a particular application requires a certain maximum allowable shrinkage. This in turn would result in a desire to keep coarse aggregate contents as high as possible. However, it has been shown that lower volumes of coarse aggregate help to promote stability at higher fluidity levels. This being the case, the hardened and fresh requirements are now at odds and a balance must be achieved. For this example it has been shown that by lowering the level of fluidity to promote stability and keeping the aggregate content high, both the hardened and fresh requirements for some applications can be satisfied. Going through the optimization process requires one to look at the overall picture of the technology to ensure that all parties involved are realizing benefits.

CONCLUSIONS

The value of SCC has been described to identify all aspects of performance that must be quantified by matching performance levels to specific job requirements. The holistic approach points out the influence of many variables, such as element characteristics, the hardened concrete requirements, placement techniques, and material. These variables should be examined and used to establish the optimized performance characteristics and mixture proportions. SCC has the potential of revolutionizing the concrete construction industry. If the industry can look beyond initial perceptions to truly quantify the value based on the optimized performance criteria, then in time SCC will be a mainstream and well-accepted material that can further promote the use of concrete as the construction material of choice.

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