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Polymer-Modified Self-Filling Concrete Compounds – A Concept for Dry-Mix Concrete

ABSTRACT

Self-filling concrete compounds - SFCCs - are a kind of 2-component systems, consisting of coarse aggregates and special drymix mortar compositions. Those customized drymix mortars are formulated with additives and specific, flowable dispersible polymer powders to obtain the required performance - mainly compressive strength, setting time, flow behavior and abrasion resistance.

In the application of SFCC the desired particulate material: Aggregates, such as gravel or grit (component 1) and the drymix mortar (component 2) – are present separately. On the construction site, the grit is first spread on or into the prepared casting mold, the drymix mortar is mixed with water and then pumped over the grit layer. The highly flowable mass quickly fills the air voids between the grit particles, which constitute about 50% of the volume, and binds them to form a solid concrete structure. Instead of fully filling, it's also possible to generate a porous agglomeration while spraying the SFCC onto the aggregate and generate single particle bonding, to get a pervious structure. Depending on the formulation, the system sets very quickly, in even less than an hour, if so desired. The flow characteristics, or the rheology, of the SFCC are particularly important. The SFCC has to contain a flowable dispersible polymer powder that promotes flow and stabilizes the very liquid mixture in order to prevent segregation or separation during the mold filling process.

In contrast to conventional concrete, SFCC is almost free of shrinkage, as particles are already fully in direct contact with each other. The shrinkage in regular concrete is usually up to two percent. The filled voids in the SFCC application experiment are at most one centimeter long and shrinkage is correspondingly small - tension or cracks therefore cannot occur in the casted element easily.

1 INTRODUCTION AND STANDARDS ON CONCRETE

Concrete, its requirements, properties and tests are described in detail in EN 206, which also defines exposure categories. Basically, concrete consists of cement, aggregate and water, with its properties being controlled or modified with further additives to meet specific requirements. During the production of ready-mix concrete, the addition of water irreversibly initiates hydration. As a result, the cement forms all kinds of reaction products, known as hydrate phases, which cause the mixture to solidify. When the transport route from the concrete plant to the processing site is being planned, retarder is added to the concrete in an amount that takes account of the distance, travel time and, e.g., elevated ambient temperatures, to ensure that there is enough time to process it on site. Under ideal conditions, a nationwide network of ready-mix concrete plants is available and supply routes are short. However, lengthy hold-ups en route to or on the construction site itself require either countermeasures to be taken quickly at the transport vehicle or the concrete to be processed elsewhere and, in the worst case, even disposed of. Where supply routes are not ideal and if demand is high enough, an alternative is to erect a temporary, mobile concrete mixer on site. Should both of these options prove to be impractical, yet a further possibility is to mix raw materials that are present on site or to revert to drymix mortars as second component. As may be seen from the foregoing, there is a gap in the concrete supply chain that the technology described below can fill. Just-in-time production eliminates dependence on the weather and other adverse conditions.

2 PRINCIPLE BEHIND SFCC

The technology behind self-filling concrete compounds (SFCC) was inspired by a traffic jam in a large city and musings on how high-quality building materials might be provided without any of the associated adverse factors. The obvious answer is dry-mix mortars, as they are well proven solutions. However, the availability of suitable particle sizes acts as a constraint here. Aggregates with particle sizes larger than 4 mm are rarely encountered in mixing plants because they can be bulky and abrasive to both mixers and bagging equipment. Thus was born the idea of separating the coarse aggregates from the binder compound, as the production of SFCC drymix mortar does not require any coarse particles larger than 1 mm. Actual application on the construction site requires just two components to be processed: one is the coarse aggregates, i.e. gravel or grit, which can be supplied regionally and therefore without time constraints, and the other is the drymix mortar compound. As this compound is subject to quality controls during manufacture, it is possible to produce a compound whose composition is tailored to the properties needed at the construction site. What is more, the fact that the compound is mixed with water just before use creates two important degrees of freedom, namely the setting time and the compressive strength or the development thereof. These could be exploited where there is a need for a fast-drying repair technology for reinstating roads at night time when traffic volumes are low, or where complex elements need to be produced: almost anything is possible. At the construction site, the coarse aggregate is first spread out over the prepared section of roadway, after which the drymix mortar is then combined with water and pumped over the layer of grit. The compound fills all the voids between the grit particles, binding them into a solid layer of concrete. Depending on the formulation, the system can set very quickly – in even less than an hour, if the customer so desires. This capability is delivered by customized drymix mortars which have been modified with dispersible polymer powders. As the bed already has a particle-on-particle structure, a strong bond is quickly achieved: essentially, the layer of stone can be walked on straight away. The SFCC needs to have the right flow characteristics – the right rheology. This need is met by adding a specialty dispersible powder which yields a unique rheology that cannot be achieved with conventional superplasticizers. On one hand, the liquid mixture must not flow too slowly or too quickly through the stony structure and, on the other, the formulation must be stable enough not to separate. If the mixture stops flowing too soon or if air bubbles become trapped, the actual functionality is endangered and the stability of the entire concrete component is at risk.

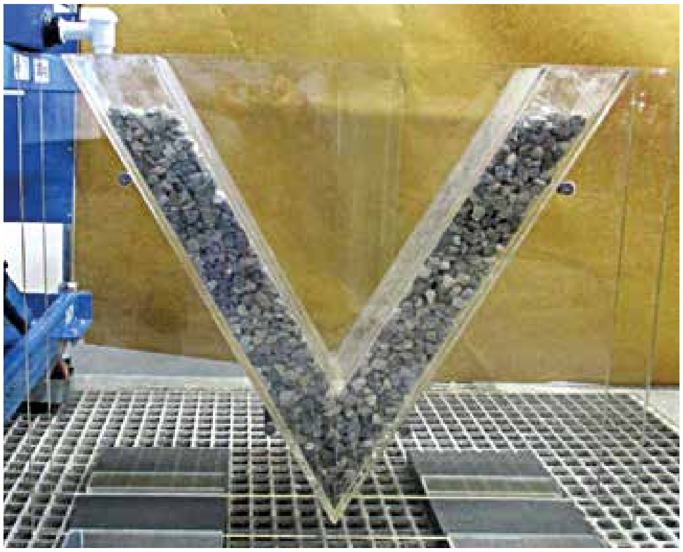



Fig. 1 (left) grit visible in the transparent V shaped mold and Fig 2 (right) illustrates the almost fully filled grit with SFCC, flow direction from the top left wing down and up in the right wing. Inner cross section = 70 mm x 70 mm

The performance capability has been simply illustrated in a laboratory trial on a V-shaped acrylic glass tube [Fig. 1 and Fig. 2]. SFCC is poured into one end of the tube which is filled with the component (1) aggregate, crushed mono-grain of a size between 10mm and 20mm. For better flow performance the grit should be dust free and non-water absorbing, as both factors will have an impact in the water cement ratio and finally in the flow behavior. The fine concrete slowly flows down one side to the bend and then rises up the other, filling up the entire V-shaped element. As the voids between the aggregate are just 10 mm to 15 mm in size, the SFCC must flow through the component as if through a tube and fill it up.

3 MIX DESIGN AND SHRINKAGE OF SFCC

SFCC also offers another major advantage over traditional concrete in that it is virtually shrinkage-free: volume changes and contraction are only minor. Shrinkage in concrete is determined by many factors, such as particle structure and water-cement ratio, and is in the order of one to two percent over the long term. The longer the element is, the greater is the absolute shrinkage. In this new concept, the particles are already lying against each other and so the volume, in the concrete form, cannot be compressed so much any further. The voids to be filled with SFCC are at most 10-15 mm wide and the absolute shrinkage is correspondingly low. Thus, stresses or cracks cannot occur in the element, as it remains at rest in situ from the beginning.

Table 1: Mix Design for SFCC

Formulation No. (in g)	KBO 1-17
Portland cement CEM I 42.5R	517.00
Microsilica Elkem 940GU	33.00
Silica sand HR 81 T 0.1-0.4 mm	93.91
Silica sand BSC 413	288.50
Polymer powder	56.43
Agitan P 801	0.48
Calcium formate	10.00
Li carbonate	0.52
Retardan P	0.16
Total	1000.00
Water demand ml/kg	225
w/c ratio	0.435

Table 2: Strength values for the mixture KBO 1-17 (prisms 40 mm x 40 mm x 160 mm)

Flexural strength 24 h	N/mm²	2.84
Standard deviation	N/mm²	0.24
Compressive strength 24 h	N/mm²	13.32
Standard deviation	N/mm²	0.72
Flexural strength 28 d	N/mm²	7.78
Standard deviation	N/mm²	1.00
Compressive strength 28 d	N/mm²	44.30
Standard deviation	N/mm²	4.08

4 RESTRAINED SHRINKAGE, ASTM C 1581

We used ASTM C 1581 in order to determine the stress built up in the system during shrinkage and also to find out if our SFCC design concept developed any cracks. ASTM C 1581 describes a "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage".

The ring mold consist of two rings, see figure 2.:

a) The inner ring, made from 13mm steel, with an outer dimeter of 330mm

b) The outer molding ring, which has an inner dimeter of 406mm,

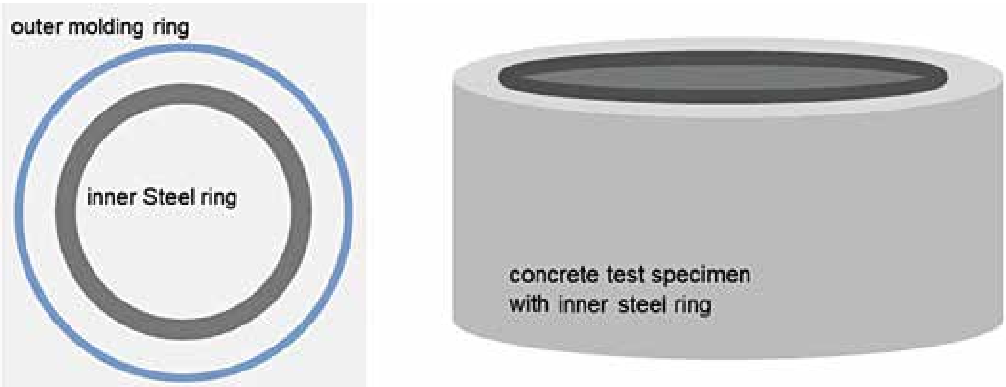
c) Having a height of 150mm.

d) Resulting in a final concrete thickness of 38mm.

As the shrinkage is restrained by the inner steal ring, the stress will result in strain or having a crack in the concrete if the shrinkage is too high. The strain in µm was measured inside the inner steal ring.

During the preparation acc. to C1581 the ring molds were filled with slightly more than 25 kg of grit. During the filling process, the circumference of the rings was tapped 30 times with a rubber mallet to try to settle the grit in the mold. 30 kg of SFCC mortar was mixed with 6.75 kg of water (22.5%) to fill the voids of the grit in the mold.

Fig. 2 Illustration of the ring system acc.to ASTM C1581. Inner ring made out of steel, outer ring has basically a molding function.



Tests conducted in accordance with ASTM C 1581 show that stress did build up due to shrinkage, but that no stress-induced crack failure occurred during them. When the tests were over, the concrete ring was detached from the steel body. Unlike the polymer modified reference concrete formulation which, when a slight incision was made in it, cracked as a result of tensile stress relaxation and emitted a loud cracking noise, all of the SFCC had to be removed mechanically.

Table 2 and Figure 3 shows the shrinkage undergone by standard concrete without polymer, polymer-modified concrete, and polymer modified SFFC concrete.

Unlike the standard concrete, which exhibited extensive shrinkage after just 14 days and for which one crack sufficed to terminate the measurement, the polymer-modified formulations were crack-free until we stopped the measurement at 60 days. The polymer-modified concrete experienced a continuous rise in stress, whereas the SFCC, as expected, relieved all stresses that occurred, it reached a maximum strain at 22 days.

Table 2: Restrained shrinkage test results acc. to ASTM 1581C

In µm	5d	10d	15d	20d	25d	30d	35d	40d	45d	50d	55d	60d
SFCC	-15	-31,8	-32	-41,4	-38,90	-20,60	-8,65	5,33	13,2	16,92	- a)	-
2% Polymer	-5,89	-14,7	-21,6	-27	-31,25	-34,97	-38,8	-42,3	-45,5	-47,70	-49,6	49,8
reference	-41,3	-50,4	- b)	-	-	-	-	-	-	-	-	-

a) Stopped the measurement without substantial crack
b) Broken test specimen, test stopped

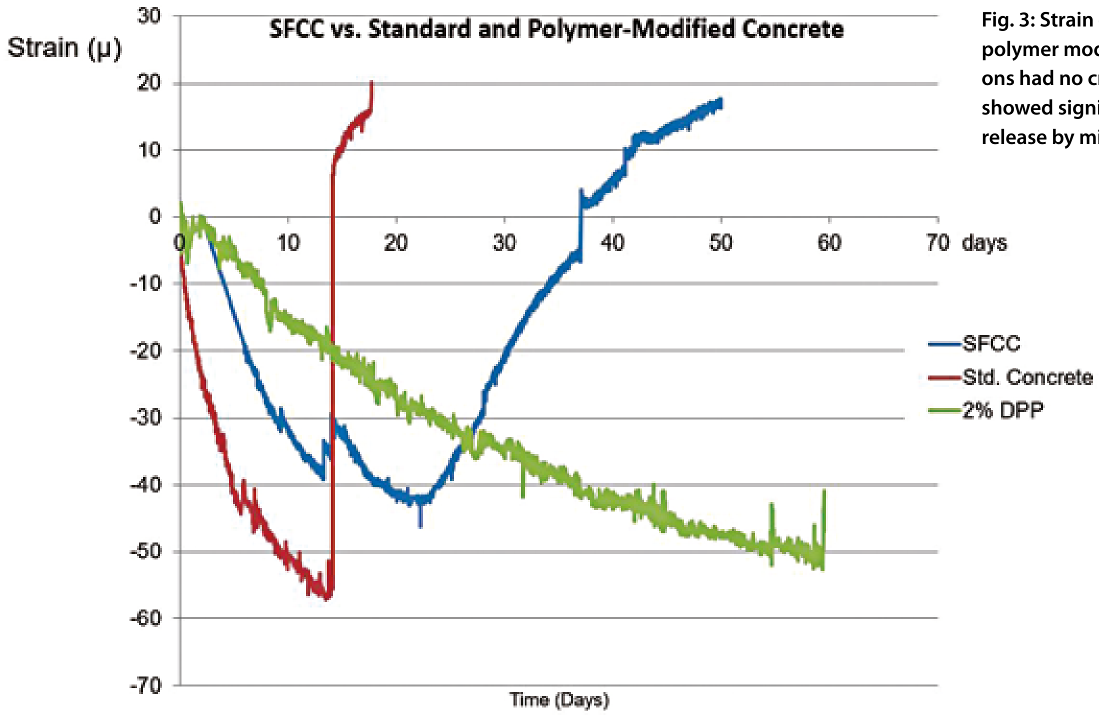


Fig. 3: Strain over time, polymer modified formulations had no cracking and SFCC showed significant strain release by micro cracking.

After the ASTM C 1581 test was finished and the concrete ring must be removed, we could see, or better hear a difference. While the standard mortar needed only a small initial cut to break with a strain release crack noise and the steal ring got released. It was not the same for the SFCC sample, it needed to be cut fully, it didn't break on its own, as the strain was not there anymore (see Fig.4).

Figure 4: Cut into the concrete ring, without stress release cracking. SFCC during demolding from the ASTM C 1581 ring after 96 d of testing. No substantial crack appeared.

5 SUMMARY AND OUTLOOK

The described method is suitable for producing components ranging from common surfaces, such as roads, to complex elements, which have low shrinkage thanks to the particle-on-particle structure. The use of drymix mortars allows formulations to be developed specifically for a wide range of needs. Aside from compressive strength, setting time and strength development are of particular interest, especially for fast-setting binder components, as these create numerous degrees of freedom for development. Just-in-time production of the SFCC enables the user to use the right amounts to suit his needs.

6 NEW APPLICATIONS UNDER EVALUATION

One advantage of the new WACKER development is, that stones which have come loose, or other solid recyclable materials can be crushed and then mixed with the SFCC (in-place recycling). This allows old construction materials to be immediately on site reincorporated. Since our modified drymix mortar can be mixed with water on site, the use of SFCC allows materials to be recycled right on the construction site. Consequently, much less filler material has to be transported.

The technology behind the SFCC makes many application ideas possible. One example is a gabion. This stone-filled cage is used for reinforcement, visual screens and noise abatement in landscape architecture and in the construction of roads, paths and waterways. With the use of the SFCC, the wire cage can be dispensed with and the desired stone structure retained. All that is needed is a mold that can be removed again afterwards.

7 LITERATURE

[1] Concrete – Specification, performance, production and conformity;German version EN 206:2013+A1:2016

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