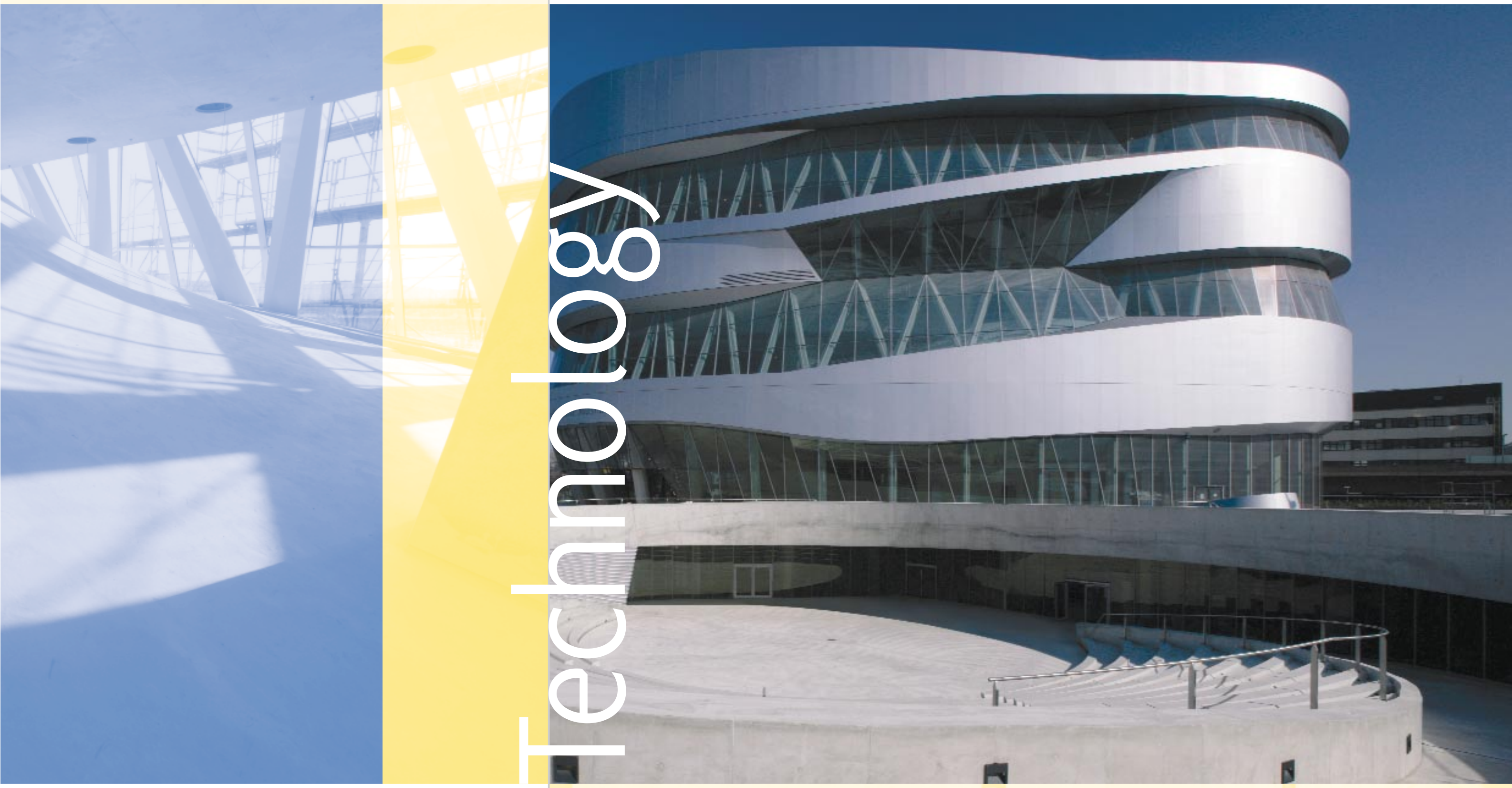
Information Pamphlet

Modern Superplasticisers in Concrete Technology – The Production and Use of Concrete with PCE

Concrete Technology



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DEUTSCHE BAUCHEMIE e.V.

Solid solutions
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Preliminary Remarks

This information pamphlet "Modern Superplasticisers in Concrete Technology – The Production and Use of Concrete with PCE" was prepared by a project group in DEUTSCHE BAUCHEMIE e.V.'s Special Committee 2, "Concrete Technology".

We would be pleased if you would share your thoughts and ideas on this information pamphlet with DEUTSCHE BAUCHEMIE e.V., 60329 Frankfurt am Main, Karlstraße 21.

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Table of Contents

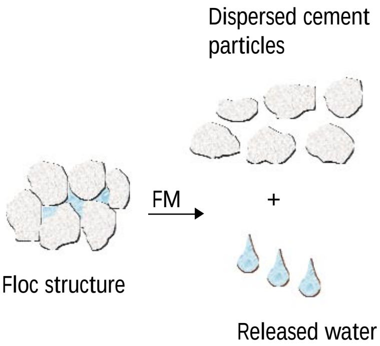
1 Introduction

Up until the 1990's, superplasticisers were generally composed of three main groups of raw materials and a number of mixtures of these raw materials. Naphthalene sulphonate, melamine sulphonate and lignosulphonate dominated this field for many years and significant developments in concrete technology were only possible through their use. Flowing concrete, water impermeable concrete and also high strength concrete could only be accurately and economically produced with the aid of these superplasticisers. However, these superplasticisers leave little room for further development because of their molecular structure.

The door to fundamental innovation was again opened when polycarboxylate ethers (abbreviated PCE), a new class of active ingredients, were introduced. The molecular structure of PCE offers producers of concrete admixtures a number of possibilities. Through variation of the chemical structure of the polymers, it is possible to optimise certain properties of the superplasticisers. Just a little more than 10 years ago, these superplasticisers which were first put on the market in Japan played a decisive role in the development of self-compacting concrete (SCC).

Because of their technological diversity, products that contain PCE have meanwhile gained a large segment of the market for superplasticisers in Europe. In view of the increased significance of this group of superplasticisers, the producers of concrete admixtures organised in Deutsche Bauchemie e.V. would like to make the most important information concerning this class of active ingredients, their mechanism of action and their applications available to concrete technologists, concrete producers, users and all other interested parties by publishing this information pamphlet. This pamphlet will show what is now possible in concrete construction but also present the conditions that must be taken into account if these products are to perform as intended.

2 Structure and Mechanism of Action



During initial hydration, positive and negative charges form on the cement particles. As a result, the particles are attracted to each other; they flocculate and a floc structure forms in the cement suspension.

On the one hand, this leads to the formation of larger, less mobile agglomerates; on the other, water is fixed in the floc structure which can no longer contribute to the flowability of the concrete. By attaching to the surface of the cement, superplasticisers cause the agglomerate to disperse and at the same time the dispersed particles are stabilised.

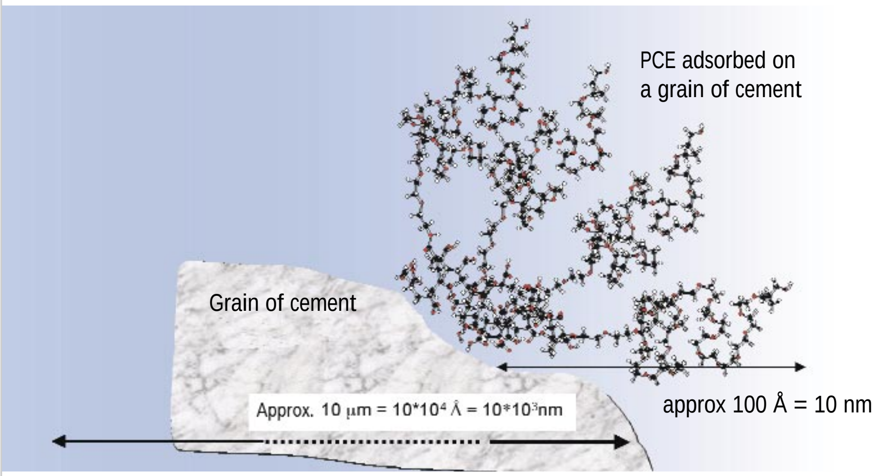
The molecules of naphthalene, melamine and lignin sulphonates have many negative charges. A part of the molecule attaches to the surface of the cement particle, imparting a negative charge which causes the cement particle to disperse mainly due to the electrostatic repulsion force.

Polycarboxylate ethers are also anionic (negatively charged) polymers. They consist of a principal chain or backbone and many side chains that hang from the principal chain. The structure of the polymers looks like a comb which is why this type of polymer is also called a comb polymer.

The negative charges of PCE are attached to the principal chain which attaches to the surface of the cement particle. The long side chains project from the surface of the cement particle into the solution and, in addition to electrostatic repulsion, ensure a steric (spatial) stabilisation of the particles.

Adsorption on the surface of the cement and the steric effect of the side chains are both decisive for the action of PCE. Adsorption can be controlled by the quantity of negative charges. This allows the development of quickly adsorbing superplasticisers with a high initial plasticizing effect or slowly adsorbing superplasticisers that maintain workability for a long time. The viscosity of the cement paste and the development of the strength of the cement can be influenced by the structure of the side chains.

The essential difference between PCE and naphthalene, melamine and lignin sulphonates lies in the diverse possibilities to vary its chemical structure, allowing superplasticisers to be selectively produced for different applications.



3 Range of Use

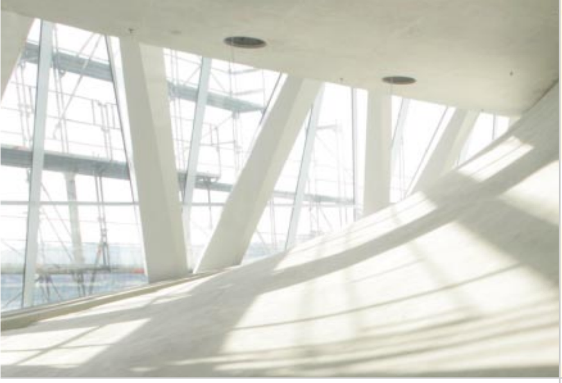
The quantity of concrete produced in consistence class F4 to F6 has continuously risen over the past years. The essential reason for this is clearly to facilitate handling and placing.

With the development of self-compacting concrete (SCC) which no longer needs to be compacted when placed, the most sophisticated concrete concept to date regarding workable consistence has been achieved from a concrete technology standpoint. The use of this concrete in practice was only made possible by the use of polycarboxylate ether raw materials. With self-compacting concrete, architectural building elements made of concrete can be now produced that were not possible with this building material before.

Self-compacting concrete is a high performance concrete that is not covered by the set of rules in the concrete standard. The higher requirements concerning supervision have been stipulated in the [German] DAfStb Guideline, "Selbstverdichtender Beton" [Self-Compacting Concrete] issued in 2003. The use of SCC in the Federal Republic of Germany is at present limited to special structures and construction measures, mainly because of the strict supervision by concrete technologists that is required for this type of concrete.

To reduce this expense, highly flowable concrete (HFC) was developed. This concrete fulfils the requirements of the concrete standard and as it is in consistence class F6 it needs very little compaction when worked.

High strength concrete is a further application area in which superplasticisers based on polycarboxylate ether are especially suitable. These concretes are produced with very low w/c ratios to achieve the required strengths. High water savings can be achieved with moderate doses of PCE. High strength concretes are still being produced with conventional superplasticisers but these have only mediocre consistence retention and very high dosages are needed which, as a rule, reduce early strength.



Further requirements on concretes beyond consistence and strength class result from the respective application in which they are used.

In the ready-mixed concrete industry, concretes are required that retain their consistence over the period of an hour or more. Less loss of consistence during this time means that it is not necessary to add superplasticisers at the construction site to achieve the desired consistence for placing. Such concretes can be produced at the ready-mixed concrete plant when PCE is used. They can also ensure a possibly even longer transit time without an essential loss of consistence so that the consistence of the concrete will at least not fall below the consistence class originally formulated at the plant.

Another requirement for ready-mixed concrete is shorter stripping times. With a suitable concrete composition, low to moderate retardation times can be achieved so that stripping is possible the next day.

In the precast concrete industry, concretes with very good early strength development are normally required to achieve the required strengths for lifting and pre-stressing as quickly as possible with only a minimal expenditure of heating energy. With the superplasticisers developed for this purpose, a very good plasticizing effect can be combined with very good early strength development of the concretes when suitable mix compositions are used.

Since the concrete used in precast plants is usually placed within 30 to 60 minutes, the superplasticisers for precast applications are designed so that the concretes will retain good consistence and can be easily cast during this period.

After the concrete has been cast, it should initially set quickly so that if any finishing is necessary it can be carried out as soon as possible after the concrete has been placed. These properties are easily achieved with modern superplasticisers for precast applications.

In the precast concrete product industry, PCE is used to improve the workability and willingness to compact of earth-moist concretes.

The good early strength development that can be achieved with polycarboxylate ethers even with high consistencies is of special importance when placing industrial floors.

4 Production of Concretes

Mix design

A trend now observed in the concrete industry is the increasing replacement of cement by admixtures so that cement content is often one of the lesser ingredients. This makes sense for economic as well as for ecological reasons. However, a reduction of the finest constituents reduces the robustness of the concretes produced. Since PCE is mainly used for flowable concretes, it makes sense to adjust the concrete composition to increase robustness. Attention should be paid to ensure that there is sufficient powder content, particularly in the case of highly flowable concretes and SCC. A further variable for increasing the robustness of concretes is the sand content. By increasing the amount of sand or through selective use of fine sand, the robustness of concretes can also be increased. In general it can be stated that the higher the consistence class, the higher the powder content the concrete should have.

PCEs are highly effective superplasticisers; the dependence of their effectiveness on the cement used is therefore somewhat greater than with conventional superplasticisers.

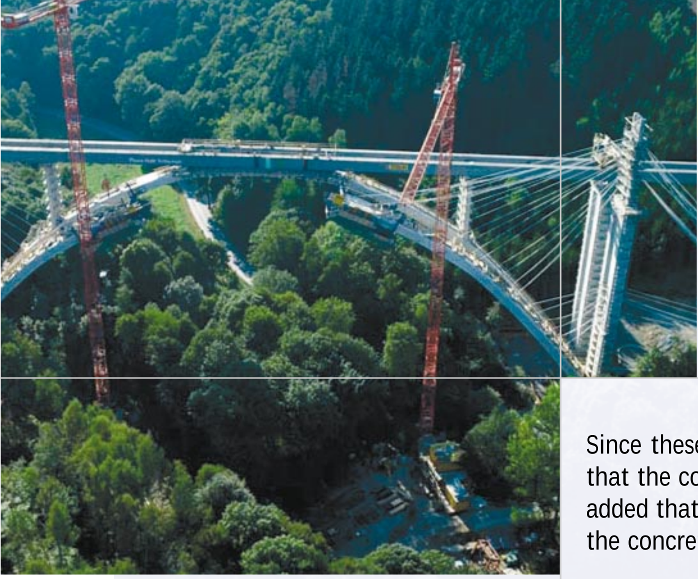
The source of cement should not be changed unless agreed with the superplasticiser supplier to ensure that the desired cement/admixture combination is able to fulfil all desired requirements.

When selecting a superplasticiser and designing formulas for concrete mixes, other factors that influence dosage, consistence retention and strength development of a concrete such as the temperature of the concrete, water content and the type of cement used must be determined by initial testing and taken into account.

As with conventional superplasticisers, the plasticizing effect in particular must be examined at different temperatures. At high concrete temperatures in summer, PCE shows its enhanced capabilities in regard to consistence retention. As mentioned above, the effect of this superplasticiser is determined by its adsorption behaviour on the surface of the cement. Since this depends on temperature, the plasticizing effect is reduced at low concrete temperatures and the concrete may re-plasticize during transit. In such cases and in coordination with the manufacturer, superplasticisers should be used that are especially suitable for use at low temperatures.

Production

To achieve an optimal effect, the wet mixing time in a positive mixer must be sufficiently long. As a rule, mixing time should not be less than 45 seconds. The optimal mixing time will depend on the type of mixer used, the composition of the concrete mix and the fresh concrete temperature. This should be optimised in trials at the plant. If the required minimum mixing times are not observed, superplasticiser that has not completely dissolved can lead to re-plasticization during subsequent transport and in extreme cases the concrete may even segregate. When producing concrete, the admixture can be added as a concrete plasticiser (BV) and as a superplasticiser (FM) at the plant as well as subsequently using a superplasticiser (FM) at the job site. To achieve optimal effectiveness, the concrete admixture should be added at the same time the mixing water is added or dosed into the wet concrete mix after the water has been added; the products should never be added to the dry concrete mix. If re-dosing at the job site is necessary, the same admixture should be used.



Since these superplasticisers are highly effective products, it is essential to ensure that the correct total water content is batched. Deviations in the quantity of water added that are too great can lead to considerable fluctuations in the consistence of the concrete.

In the beginning when they were first introduced on the market, the correct dosage of PCE products in ready-mixed concrete was often difficult to determine because they had been designed for use in high strength and self-compacting concretes and already reacted very sensitively to very slight deviations in the dosed quantity or, e.g. the w/c ratio. Currently, many products are available that are distinguished by being less sensitive to dosage. In spite of this, attention should be paid to sufficient dosing accuracy when dispensing equipment is selected so that the consistence can be reliably adjusted.

To ensure the quality of the delivered concrete it may be necessary, even when PCE is used, to adjust the consistence of the concrete to a certain slump flow at the time of delivery since initial hydration of the cement can lead to a certain drop in consistence during the first 30 minutes.

Mixing these superplasticisers together with other admixtures in dispensing equipment and in storage containers should generally be avoided since the concrete admixtures might not always be compatible with each other. Corresponding recommendations given by the manufacturer should also be taken into account. When using different concrete admixtures in the concrete, their suitability must be proved by initial testing.

When producing air-entrained concrete with superplasticisers based on PCE, it should be remembered that because of their chemical structure these superplasticisers contain de-foaming agents for use in concrete. To successfully produce air-entrained concrete, the air-entraining agent selected must be coordinated to the superplasticiser. Combinations recommended by the manufacturer should be used, the suitability of which was proved within the scope of tests for effectiveness.

Along with these measures, the usual procedures for producing air-entrained concrete as described, for example, in Deutsche Bauchemie e.V.'s information pamphlet "Herstellen von Luftporenbeton" [The Production of Air-Entrained Concrete] should be observed.

Transport

With a suitable PCE and a concrete mix designed for the requirements, workability times of 90 minutes can be realised as a rule. If good early strength development is desired, it is especially interesting that this property can be achieved with just little retardation, as opposed to conventional superplasticisers.

The usual custom of adjusting placement consistence by having the driver of the concrete mixing vehicle re-dose a superplasticiser at the job site is no longer necessary.

Placement

When the fresh concrete is placed, the stabilising effect of PCE positively influences the cohesion of the concrete particularly with very fluid consistencies. This stabilising effect can lead to increased stickiness of the fresh concrete when the surface is directly worked (screeding, finishing). This can be controlled to a certain degree by the selection of suitable formula parameters.

The use of spherical grains and natural sand as well as sufficient water content can have a favourable effect. However, if the effect is too pronounced, a more suitable superplasticiser in this regard should be used.

Because they are highly effective and have a positive influence on cohesion, superplasticisers on a PCE base are often used to produce flowing capable concrete in consistence classes F4 to F6. As a rule, these flow easily and are easy to compact. The type of compacting is selected according to the concrete consistence. In the case of F6 concretes, very gentle vibration, rodding or screeding is sufficient.

Along with consistence, these superplasticisers can also influence the rheology of concretes.

Because of its thixotropic properties such concrete may appear to have a rather stiff consistence in the quiescent state but become much more fluid again when it is placed through the compaction energy that is applied, e.g. through internal vibrators or when screeding. In this case, the compaction energy should be adjusted to this more fluid consistence since there is a risk of segregation otherwise.

If the construction method makes finishing the surface necessary, e.g. when producing precast concrete elements or industrial floors, attention must be paid to this particular characteristic. Even experienced workers may start finishing too early. In these cases, the time at which finishing should commence must be carefully coordinated to the actual consistence when energy is applied. To avoid unnecessary waiting times or failed attempts, it is recommended to determine the correct time through suitable preliminary trials, taking the most important influencing variables such as temperature into consideration.

Curing

Concretes that have been produced with modern superplasticisers must also be cured. Curing the fresh concrete protects the surface of the concrete from drying out too quickly and thus safeguards the desired quality of the concrete. If the concrete is left unprotected too long and water is allowed to evaporate from the surface, particularly in higher outdoor temperatures or in windy environments, the surface will dry out too quickly. When this happens, elephant skin or a layer of sinter may form which makes the surface much more difficult to finish.

All measures that prevent water from evaporating too quickly and strongly can be used. A suitable curing agent can be applied to the fresh concrete, for example, or concrete surfaces can be protected from drafts by covering with plastic sheets.

5 Summary

Superplasticisers based on polycarboxylate ethers offer today's concrete technologists new, sophisticated and economical solutions. Highly flowable concrete (HFC) for use in precast and ready-mixed plants can also be produced and worked as a high strength concrete with a minimum of personnel and equipment. Concretes with high early strengths for use in precast concrete can reduce energy requirements for heating and increase productivity. With ready-mixed concretes that reliably remain workable for more than 90 minutes, re-dosing superplasticisers at the job site is no longer necessary. These are examples of the further developments in concrete technology that have only become possible through the use of superplasticisers.

To be able to utilise the full potential of these products, it is necessary to understand their mechanism of action and their dependencies and to take this into consideration, starting with the mix design all the way to placing and curing the concrete.

Modern superplasticisers on a PCE base can then make a considerable contribution to the economical production of concretes that have reliable properties when placed.

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