Concrete constituents, concrete technology and concrete engineering

First concrete roundabout in Germany (Bad Sobernheim)
Cements with several main constituents

Historically, raw materials that were available in the various regions have been used to manufacture efficient cements that ensure safe and reliable concrete structures. Consequently, there has been a long tradition of using cements containing several main constituents. These days, because of increasing demands in terms of environmental protection, the manufacture and use of cements with several main constituents has taken on a new level of significance due to their ecological benefits.

With reference to conditions in Germany, the successful use in the building industry has proven the efficiency of CEM II and CEM III cements for challenging and durable concrete structures. The technical application properties of these cements, the ecological advantages of using them and examples of practical applications were described in a customer-oriented manner in the VDZ brochure “CEM II- und CEM III/A-Zemente im Betonbau – Nachhaltige Lösungen für das Bauen mit Beton” (CEM II- and CEM III/A cements in concrete constructions – sustainable solutions for building with concrete) from the German Cement Works Association (can be purchased from www.beton.org).

Ecological advantages

The positive ecological effect gained from the increasing use of cements with several main constituents can be seen in the changes in the building material profile for a metric ton of cement in Germany (Table V-1). In 2006, the contribution to the greenhouse effect and other environmental impacts was determined for an average German cement, consisting of the average proportions of cement clinker and other main constituents.

The environmental impacts of upstream supply chains, for example the electricity used to produce the material, were also considered. Compared to 1996, the contribution to the greenhouse effect had been reduced by 23% and consumption of non-renewable energies had fallen by 38%; contributions to other environmental impacts were also drastically reduced. These reductions reflect the fact that in Germany more cement is produced with several main constituents and that the increased use of secondary fuels has also had a positive effect on many key values.

Application regulations in Germany

The current concrete standards DIN EN 206-1 and the German DIN 1045-2 contain the application regulations for standard cements in relation to exposure classes. When these standards were introduced, application restrictions applied to some standard cements – based mainly on the lack of practical experience with these cements in Germany. In these cases, proof of suitability for use in specific exposure classes was provided by a general building authority approval (Technical Approval, TA) from the German Institute for Building Technology (DIBt).

Currently, in Germany the following cement types may be used in all exposure classes:

- Portland cement CEM I
- Portland-blast furnace cements CEM II/A-S and CEM II/B-S
- Portland-burnt shale cements CEM II/A-T and CEM II/B-T
- Portland-limestone cements CEM II/A-LL
- Portland-fly ash cements CEM II/A-V and CEM II/B-V
- Portland-composite cements CEM II/A-M with other main constituents S, LL, T, D and V
- Portland-composite cements CEM II/B-M with national technical approval for application
- Blast furnace cements CEM III/A *)

1) Exposure class XF4: CEM III/A in strength class ≥ 42.5 N or strength class 32.5 R with up to 50 mass % blast furnace slag

Since 2003, 18 general building authority approvals have been granted for CEM II/B-M (S-LL) and 4 approvals for CEM II/B-M (V-LL) in Germany. Apart from the approvals for CEM II/B-M (V-LL), 16 approvals are currently valid for CEM II/B-M (S-LL). In all the approvals, use is approved for concrete, reinforced concrete and pre-stressed concrete according to DIN EN 206-1 in conjunction with DIN 1045-2 for exposure classes XC3, XC4, XD1 to XD3, XS1 to XS3, XF1 to XF4, XA1 to XA3, XM1 to XM3 as a supplement to the exposure classes X0, XC1 and XC2 already permitted in DIN 1045-2.

In all approvals reference is made to use in mortar and concrete according to the former DIN 1045:1988 and the former pre-stressed concrete standard DIN 4227-1. Not permitted is use in grout for pre-stressing tendons according to DIN EN 447. In the meantime, uses for the manufacture of bore piles according to DIN EN 1536 in conjunction with DIN Technical Report 129 and for the manufacture of water-impermeable concrete according to the DAFStb Guideline on concrete structures with water-endangering materials have been included in four approvals. From a technical point of view, the extension applies to all these approvals. However, the owner of the approval must make a formal request to the DIBt. In addition to the above list of applications, CEM II-M cements with general building authority approval may be used in all areas where the corresponding regulations refer to cement according to DIN EN 197-1, DIN 1164 or include cement general building authority approval and with no specific usage restrictions. The following list contains several examples:

- DIN 1053-1 Masonry
- DIN 4158 Filler concrete joists for reinforced and pre-stressed concrete floors
- DIN EN 12843 Concrete masts and poles
- DIN 4261-1 Small sewage treatment plants
- DIN 18551 Sprayed concrete
- DIN 18148 (DIN 18162) Hollow lightweight concrete blocks for walls (not reinforced)
- DAFStb Guideline “Manufacture and use of dry concrete and dry mortar” (dry concrete guideline)
- DAFStb Guideline “Manufacture and use of cement-based flowable concrete and flowable mortar”

### Table V-1: Building material profile for cement: potential effects and consumption of primary energy (from non-renewable energies) for the manufacture of 1 t of cement in Germany (average)

<table>
<thead>
<tr>
<th>Effect category</th>
<th>Global greenhouse effect (GWP)</th>
<th>Ozone depletion (ODP)</th>
<th>Acidification (AP)</th>
<th>Overfertilisation (NP)</th>
<th>Summer smog (POCP)</th>
<th>Primary energy (not renewable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse effect (GWP)</td>
<td>872</td>
<td>670</td>
<td>0.16 x 10^9</td>
<td>0.92</td>
<td>0.20</td>
<td>0.12</td>
</tr>
<tr>
<td>Ozone depletion (ODP)</td>
<td>0</td>
<td>1.6 x 10^4</td>
<td>2.00</td>
<td>0.12</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Acidification (AP)</td>
<td>1.68</td>
<td>0.92</td>
<td>1.68</td>
<td>0.92</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Overfertilisation (NP)</td>
<td>0.20</td>
<td>0.12</td>
<td>0.20</td>
<td>0.12</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Summer smog (POCP)</td>
<td>0.07</td>
<td>0.10</td>
<td>0.07</td>
<td>0.10</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Primary energy (not renewable)</td>
<td>4355</td>
<td>2713</td>
<td>4355</td>
<td>2713</td>
<td>4355</td>
<td>2713</td>
</tr>
</tbody>
</table>

*1 Indicator was set to zero in 1996
*2 In 1996 the indicator was based on a different calculation method
More information on uses of cement according to EN 197-1 can be found in Building Rules List A, Part 1, Appendix 1.33 (2006/1). When engineering structures are built near highways in Germany (ZTV-ING) the customer must agree to the use of CEM II-M cements. Despite the restriction, numerous practical examples have also proven the suitability of CEM II/B-M cements with technical approval in this area of application. In the long term it should be possible to remove this addendum.

A working group of CEN/TC 104/SC1 “Concrete” has developed a synopsis of the national application documents (NAD) for the European concrete standard EN 206-1. It describes some considerable differences in the use of cement. Apart from the traditional differences in market conditions and construction practice, it also reflects the philosophies underlying the imposition of rules (see VDZ Activity Report 2005-2007). While the German application standard DIN 1045-2 lays down specifications for the application of all 27 basic cement types and for a number of CEM II-M cements, other NADs only regulate the application of a few cement types that have traditionally played a role in the respective national markets.

**Cement properties**

The properties of CEM II and CEM III/A cements have been continuously improved in the course of technical developments in the manufacturing process. They have also been adapted to suit current requirements, which has, in turn, considerably increased the bandwidth of potential applications. In particular, as regards early strength the manufacturers have adjusted the CEM II and CEM III/A cements so that they can be used in a similar way to the CEM I cements (Fig. V-1).

**Properties of concrete in construction practice**

In addition to the environmentally compatible manufacture of CEM II and CEM III/A cements, because of their composition and especially considering the many different technological guidelines for concrete, they also have several advantages when used in fresh concrete and hardened concrete. For specific applications – including bridge and tunnel construction and road and building construction – it is possible to produce optimally adjusted concretes. A number of important properties are described below:

**Strength development**

Under practical building conditions, the strength development of concrete with CEM II and CEM III/A cements is similar to that of CEM I concretes. To satisfy practical requirements for early strength CEM II/B and CEM III/A cements are also available in strength class 42.5 N. Fig. V-2 shows the relative compressive strength development of concretes based on conventional CEM I, CEM II and CEM III/A cements with similar concrete compositions and curing conditions. The relative values result from the relation of the compressive strength of concrete after 2, 7 and 28 days to the 28-day compressive strength of the concrete. The test values for a CEM III/A 32.5 N are shown as a comparison. These results allow the investigated concretes to be classified into medium and slow strength development classes. Accordingly, the concrete with the CEM III/A 32.5 N cement can be classified as a slow strength developer. This classification is important to define the time needed for after-treatment.

**Durability**

The durability of the concrete is one of the key requirements for every structure. The most important feature is that the concrete element used must be resistant to loads and environmental impacts for its intended period of use, assuming it is maintained and repaired adequately.

**Carbonation**

Investigations of reinforced concrete and pre-stressed concrete structures that were constructed with concretes of different strength classes and with different com-
positions have shown that with construction components that were weathered outdoors, the type of cements used in Germany generally have no effect on the carbonation behaviour. Although higher carbonation depths may be found on dry, interior elements, because of the lower moisture content of these elements there is no risk of the reinforcement corroding.

Chloride penetration resistance
Due to the finer pore system, in some cases the use of cements containing blastfurnace slag and fly ash can cause a marked increase in the concrete's resistance to the penetration of chlorides (Fig. V-3). With concretes intended for massive construction components according to the DAFStb Guideline and when a CEM III/A or CEM III/B cement of exposure class XD3 or XS3 is used, the highest permissible water-cement ratio of 0.45 may be increased to 0.50 with no change in the corrosion protection for the reinforcement.

Freeze-thaw resistance with or without de-icing salt
With the correct composition, processing and after-treatment according to DIN 1045, concretes with CEM II and CEM III/A cements have a high freeze-thaw resistance with or without de-icing salt. Consequently, they are very suitable for engineering structures and traffic areas. Only CEM III/A in strength class 32,5 N and CEM III/A 32,5 R with more than 50 mass % blastfurnace slag are excluded for exposure class XF4. Fig. V-4 shows some results from freeze-thaw-test with de-icing salt on concretes containing different cement types using the CDF method. If freeze-thaw resistance with de-icing salt has to be tested, as a general rule the following criterion is applied to evaluate the results: after 28 freeze-thaw cycles, scaling must not exceed 1 500 g/m² for a concrete that is meant to have adequate freeze-thaw resistance with de-icing salt. This corresponds to a scaling depth of around just 0.6 mm. This criterion may not be applied to samples taken from structures.

Application examples
In terms of the workability characteristics, strength development and durability of concrete, the CEM II and CEM III/A cements that have been produced in Germany to date have proven their reliability in practical applications over many decades. The current VDZ brochure “CEM II- und CEM III/A-Zemente im Betonbau – Nachhaltige Lösungen für das Bauen mit Beton” [CEM II- and CEM III/A cements in concrete constructions – sustainable solutions for building with concrete] contains many practical examples from different areas of concrete construction.

Outlook
As an industry that uses a high volume of energy and raw materials, the cement industry is very much affected by demands to conserve resources and reduce the use of energy and also by the global issue of climate control. Cement manufacturers are facing these challenges by continuously improving their production processes in terms of energy and raw materials consumption.

If the industry wishes to continue along this path consistently, this raises the issue of producing cement types that have, in the past, only been produced and used in small quantities or which are not even included in the European cement standard DIN EN 197-1, even if their compositions are not vastly different from the cements covered by DIN EN 197-1. A current research project entitled “Ecologically and technically optimised cements with several main constituents” is involved in investigating these similar cement compositions. This project is being carried out within the framework of the “klimazwei” research measure which is carrying out research work into climate control and controlling the effects of climate change (www.klimazwei.de) and is funded by the German Federal Ministry for Education and Research (BMBF).

The investigations are focussing on Portland-limestone cements with 30 and 35 mass % limestone and cements with 10 to 25 mass % limestone in combination with blastfurnace slag and siliceous fly ash. The
The development of compressive strength is shown in Fig. V-5. The results show that, in general, the strength of the cements produced in the laboratory for the durability investigations develops in the same way as in normal practice. To manufacture the concrete, aggregate (coarse Rhine sand from the research facility’s stocks) with a grain composition A16/B16 according to DIN 1045-2, Annex L was used. The composition of the coarse mixtures are based on the limit values for the composition and properties of concretes according to DIN Technical Report 100 “Concrete”.

Table V-2: Composition of the test cements with several main constituents

<table>
<thead>
<tr>
<th>Cement</th>
<th>Limestone fineness approx. 7000 cm²/g (Blaine)</th>
<th>Blastfurnace slag fineness approx. 4000 cm²/g (Blaine)</th>
<th>Fly ash fineness approx. 4000 cm²/g (Blaine)</th>
<th>Finesse of cement in cm²/g (Blaine)</th>
<th>Water demand in mass %</th>
<th>Origin of the constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 % LL</td>
<td>30 mass % limestone with 70 mass % CaCO₃</td>
<td>-</td>
<td>-</td>
<td>6265</td>
<td>31.5</td>
<td>Region 1</td>
</tr>
<tr>
<td>10 % S 25 % LL</td>
<td>25 mass % limestone with 70 mass % CaCO₃</td>
<td>10 mass % blastfurnace slag</td>
<td>-</td>
<td>6195</td>
<td>30.5</td>
<td>Region 1</td>
</tr>
<tr>
<td>20 % S 20 % LL</td>
<td>20 mass % limestone with 80 mass % CaCO₃</td>
<td>20 mass % blastfurnace slag</td>
<td>-</td>
<td>5150</td>
<td>30.5</td>
<td>Region 2</td>
</tr>
<tr>
<td>40 % S 10 % LL</td>
<td>10 mass % limestone with 80 mass % CaCO₃</td>
<td>40 mass % blastfurnace slag</td>
<td>-</td>
<td>4970</td>
<td>30.0</td>
<td>Region 2</td>
</tr>
<tr>
<td>10 % V 25 % LL</td>
<td>25 mass % limestone with 70 mass % CaCO₃</td>
<td>-</td>
<td>10 mass % siliceous fly ash</td>
<td>6325</td>
<td>30.0</td>
<td>Region 1</td>
</tr>
<tr>
<td>20 % V 20 % LL</td>
<td>20 mass % limestone with 70 mass % CaCO₃</td>
<td>-</td>
<td>20 mass % siliceous fly ash</td>
<td>5955</td>
<td>29.0</td>
<td>Region 1</td>
</tr>
</tbody>
</table>

Fig. V-5: Compressive strength of cements in relation to test age

Fig. V-6: Compressive strength of concrete in relation to test age

cements to be investigated were manufactured in the laboratory and also by large-scale cement works. During the manufacturing process granulometric optimisation of the main constituents of the cement and optimisation of the sulphur agents were carried out with consideration of the cements’ setting behaviour. Moreover, different types of main constituents were varied (for example, according to origin). The focus of the investigations was placed on the durability of concretes manufactured using these cement types. The results of several selected investigations that provide an overview of the cements and their compositions are presented below Table V-2. The following results cannot be generalised. They can, however, be used for further development work.

Compressive strength development

The development of compressive strength in several cements produced in the laboratory is shown in Fig. V-5. The results show that, in general, the strength of the cements produced in the laboratory for the durability investigations develops in the same way as in normal practice. To manufacture the concretes, aggregate (coarse Rhine sand from the research facility’s stocks) with a grain composition A16/B16 according to DIN 1045-2, Annex L was used. The compositions of the coarse mixtures are based on the limit values for the composition and properties of concretes according to DIN Technical Report 100 “Concrete”.

Fig. V-6 presents examples of the development of compressive strength in concrete with a water-cement ratio w/c = 0.50 and a cement content c = 320 kg/m³ using selected cements produced in the laboratory. As expected, the early strengths of the concretes with CEM II cements were higher than concretes manufactured with cements not included in DIN EN 197-1. Apart from two exceptions, the concretes at the age of 28 days had a similar strength level. Thus, it is generally possible to make a direct comparison of the properties that are relevant for durability even after this time.

Carbonation

Fig. V-7 shows examples of the development of carbonation depths over time in several concretes that were investigated. The concretes were manufactured with a cement content of c = 260 kg/m³ and a water-cement ratio of w/c = 0.65. The carbonation depths of the concretes containing the laboratory cements investigated here were almost all below the values of the CEM III/A concrete given as a reference. CEM III/A can be used for all applications (exposure classes).

Chloride penetration resistance

The concrete’s resistance to chloride penetration was determined with a rapid test
method (migration test). The test samples were cured in water for 35 and 98 days respectively. Concretes in exposure class XD2/XS2 were manufactured with a water-cement ratio of $w/c = 0.50$ and a cement content of $c = 320 \text{ kg/m}^3$. The chloride migration coefficients $D_{\text{Cl,M}}$ (Fig. V-8) that were determined when laboratory cements containing 30 mass % limestone was used were approximately $28 \cdot 10^{-12} \text{ m}^2/\text{s}$ after 35 days and approx. $18 \cdot 10^{-12} \text{ m}^2/\text{s}$ after 98 days, and are thus in the same range as concretes made with Portland cement. The concretes that were manufactured with cements containing fly ash or blastfurnace slag exhibited a lower chloride migration coefficient $D_{\text{Cl,M}}$, which was in the range of approx. 4 to $24 \cdot 10^{-12} \text{ m}^2/\text{s}$ after 35 days and approx. 3 to $10 \cdot 10^{-12} \text{ m}^2/\text{s}$ after 98 days.

**Freeze-thaw resistance with or without de-icing salt**

Results of the frost resistance tests according to the CF/CIF method and results of the tests into frost de-icing salt resistance according to the CDF method are presented and evaluated below. In Germany, assessment criteria for scaling (CF/CDF method) and assessment criteria for internal structural damage (CIF method) are defined by the German Federal Waterways Engineering and Research Institute (BAW) in the “Frost test of concrete” fact sheet.

In the investigations that were conducted with the CF method, the concretes (cement content $c = 320 \text{ kg/m}^3$, water-cement ratio $w/c = 0.50$) exhibited scaling well below the assessment criterion of $1.0 \text{ kg/m}^2$ after 28 frost-thawing sequences that is defined in the “Freeze-thaw test of concrete” fact sheet issued by the German Federal Waterways Engineering and Research Institute (BAW) (Fig. V-9). The BAW assessment criterion for the CIF method is a relative dynamic elastic modulus of 75% after 28 freeze-thaw cycles. As Fig. V-10 shows, the concretes containing cements with 30 mass % limestone and 10 mass % blastfurnace slag and 25 mass % limestone exhibited a relative dynamic elastic modulus of more than 80 % after 28 freeze-thaw cycles. When cements with a composition outside the standard were used, the criterion was not fulfilled within the scope of the investigations conducted by the Research Institute.

The CDF test is used to test resistance to freeze-thaw attack with simultaneous de-
Cement and admixtures

The use of concrete admixtures to control the properties of the fresh and hardened concrete is state of the art in concrete production today. Some 90% of the concrete produced in Germany contains concrete admixtures. In 2007, consumption of admixtures in Germany was about 12 kg per metric tonne of cement. Overall, more than 550 concrete admixtures which can be classified in 15 different functional groups are presently available in Germany. At approx. 75%, concrete plasticisers and super-plasticisers account for the lion’s share.

There is still a substantial lack of scientifically backed understanding of the precise working mechanisms of some concrete admixtures. The influence that concrete admixtures have on the hydration of cement and thus on the properties of fresh and/or hardened concrete is usually determined empirically and is the subject of some controversial discussion. This applies especially to super-plasticisers based on polymeric structures, such as polycarboxylate ethers, air-entraining concrete admixtures. These have been extensively investigated by the Research Institute.

Super-plasticisers

Synthetic organic polymers with carboxylic groups, such as polycarboxylate ethers (PCE), constitute an advance in the field of admixtures. These have been extensively investigated by the Research Institute.
the PCEs adsorb on the positively charged surfaces of the cement, its hydration products and other fine solids particles. The dispersing effect is largely attributable to the steric repulsion of the side chains. Variation of the charge and the length ratio of the main chain and the side chains allows adjustment of different properties, such as a strong initial plasticising effect and/or extended workability of fresh concrete.

In addition to parameters such as the exact point when the material is added, the mixing time and the temperature of the fresh concrete, the effects of the super-plasticisers are also affected by the cement that is used. Practical experience has shown that even if the same type and quantity of super-plasticiser and the same type of cement are used, in unfavourable cases effects such as rapid loss of consistency, segregation, intensive bleeding and delayed strength development may occur. While knowledge of the effects that traditional super-plasticisers have on Portland cement exists, there is still need for more research into the interactions between Portland-composite/blastfurnace cements and super-plasticisers based on polycarboxylate ether.

The Research Institute is investigating the effects of the main constituents of cement (clinker, blastfurnace slag and limestone) on super-plasticiser adsorption. In combination with rheological measurements it is being determined whether conclusions can be drawn as regards initial plasticising and the duration of plasticising of super-plasticisers on the basis of the zeta potential. The aim is to determine substance parameters that must be known to understand the methodical interaction between cement and super-plasticisers e.g. in order to prevent discolouration of fair-faced concrete surfaces as a result of sedimentation.

**Zeta potential investigations**

The zeta potential is an electro-kinetic potential in the interface between the mobile and the rigid part of the double layer formed at the transition zone between solids and aqueous solutions. The potential indicates the charge conditions on the particle surface. Changing this potential by adding super-plasticisers allows to investigate the adsorption of the super-plasticiser molecules on the surfaces of various main constituents of cement. In the Research Institute the zeta potential can be determined on suspensions rich in solids with normal w/c ratios using an electro-acoustic measuring method.

**Fig. V-14** shows the effect that various proportions of blastfurnace slag (S1, S2) and limestone (LL1, LL2) have on the zeta potential of laboratory cement pastes containing the same Portland cement clinker components. The zeta potential of the cement paste with no main constituents other than clinker was approx. -17 mV.

The zeta potential of the cement pastes containing blastfurnace slag shifted in the same manner from the negative range towards the isoelectric point (0 mV) as the content of S1 and S2 was increased. The reduction in zeta potential did not correlate with the increase in blastfurnace slag. In water the blastfurnace slags exhibited a zeta potential of approx. -15 mV. LL1 reduced the negative zeta potential of the pastes. This course is generally expected in limestone with a very high CaCO3 content, which usually exhibits a positive zeta potential in water. On the other hand, LL2 caused an increase in the negative zeta potential of the pastes. Based on initial findings, this can be attributed to the clay constituents in LL2.

The results show that blastfurnace slag and limestone can have a considerable influence on the zeta potential of cement pastes. Consequently, the sorption of super-plasticiser molecules can also be affected.

**Fig. V-15** presents the course of the zeta potential in pastes of selected laboratory cements containing blastfurnace slag and limestone respectively with increasing quantities of super-plasticiser (PCE). As the quantity of anionic PCE increased, the negative zeta potential of the cement paste with no other main constituents shifted towards the isoelectric point. This contradictory behaviour is attributed to a shift in the measuring level of the zeta potential caused by the adsorbed PCE molecules.
The zeta potential of the cement paste with 35 mass % S1 and 35 mass % LL1 was already reduced considerably in the same way as the cement with no other main constituents with small quantities of superplasticiser. The zeta potential of the cement paste with 65 mass % S1 was affected slightly by the addition of superplasticiser. It is likely that the molecules adsorb mainly on the clinker components and not on the blastfurnace slag S1 or limestone LL1.

The zeta potential of the paste with 35 mass % LL2 changed only slightly when about 0.3 mass % super-plasticiser was added. This is attributed to the large surface area of the clay constituents on to which a certain proportion of the super-plasticiser molecules adsorb non-specifically. When more super-plasticiser was added, this produced a marked shift of the zeta potential in the direction of the isoelectric point.

**Shrinkage reducing admixtures**

Shrinkage is caused by changes in the moisture content in concrete which result in changes in the inner forces in the structure of the hardened cement paste matrix due to environmental effects or drying in the concrete. This creates tensile stress that causes the hardened cement paste matrix to contract. Shrinkage of concrete leads to deformations that may cause stress in structural elements in case of constraint. As a consequence, cracks can occur that have a negative effect on the durability of the concrete. The Research Institute of the Cement Industry is currently investigating whether potentially negative effects can be significantly reduced through the use of shrinkage reducing admixtures.

To reduce shrinkage of concrete, shrinkage reducing admixtures (SRA) were developed in Japan at the start of the 1980s and have also been used in Europe since about 1997. In Germany, SRAs have been used only in the manufacture of screeds and cement-based mixtures. Since at present no general building inspectorate approvals have been issued for this type of admixture, SRAs may not be used in load-bearing structural elements made from concrete, reinforced concrete or pre-stressed concrete.

The Research Institute of the Cement Industry conducted investigations into the working mechanisms of shrinkage reducing admixtures as part of an AiF-sponsored research project. The results show that the shrinkage reducing effect does not correlate with the reduction in surface tension as assumed in a number of other investigations. Active substances in the SRAs may increase the so-called disjoining pressure effect of the pore solution, the reduction of which is essentially responsible for shrinkage of cement paste. Increased relative moisture in hardened cement paste may intensify the disjoining pressure effect of the pore solution. However, some active substances exhibit no shrinkage reducing effect. In fact, they increase shrinkage of hardened cement paste under sealed conditions and also when the paste is dried at 20 °C and 65 % relative humidity (dry curing). One of the reasons for this could be the considerable increase in the gel pore content compared to hardened cement pastes with no SRA. On the basis of these findings, the Research Institute is currently conducting a subsequent research project funded by AiF. In this project the effect of SRA on shrinkage, the mechanical properties and the durability of concrete are being investigated.

**Effect of SRA on concrete shrinkage**

The first results show that the properties of fresh concrete are not significantly affected by SRA, regardless of the water/cement ratio or the cement paste content.

Total shrinkage of concrete containing Portland cement can be reduced by up to about 40 % by SRA depending on the cement paste content and the form of cur-
ing. Fig. V-16 shows an example of total shrinkage (top) and shrinkage reduction (bottom) when the concrete was cured at 20 °C and 65 % relative humidity (20/65). The reduction in shrinkage is the shrinkage of concretes containing SRA in relation to the reference sample without SRA. During curing (L1), the test samples dry directly after demoulding within 24 hours. After one year, total shrinkage was reduced by shrinkage reducing admixture SRA1 and SRA2 respectively by about 20 % and 40 % respectively (see Fig. V-16, bottom). Fig. V-17 presents total shrinkage (top) and the corresponding shrinkage reduction (bottom) of concrete containing Portland cement after being cured for six days under water, followed by curing in a 20/65 climate (L2). In the top picture it can be seen that the subsequent curing of the concretes in water had only a minor effect on the extent of reduction after one year. When the sample was cured in water for seven days, the respective reduction in shrinkage (see Fig. V-17, bottom) was slightly less than with dry curing after one year and was approx. 10 % with SRA1 and approx. 30 % with SRA2. In the research project it is currently being investigated whether this behaviour also occurs in concretes containing different cements and different water/cement ratios. The results of investigations into the effect of SRA on the shrinkage of concrete with varying cement paste contents show that the increased extent of shrinkage associated with increasing cement paste content can be reduced with SRA. Hence, easily workable concretes rich in cement paste can be manufactured with low shrinkage.

Effect of SRA on the mechanical properties of concretes

Many publications state that the compressive strength of concretes can be reduced through SRA. The effect of SRA on the compressive strength of concrete was been investigated so far on Portland cement concretes with a water/cement ratio of w/c = 0.50. The concretes were cured in climates (L1), (L2) and sealed (L3). The concretes with SRA1 and SRA2 exhibited roughly 20 % (SRA2) less compressive strength than the respective reference concrete without SRA – largely regardless of age and curing method. The concrete with shrinkage reducing admixture SRA1 exhibited a higher compressive strength than the concrete with shrinkage reducing admixture SRA2 at all ages and with all three methods of curing.

The static modulus of elasticity of concrete with Portland cement and a water/cement ratio of w/c = 0.50 was reduced by up to 7 % with shrinkage reducing admixtures SRA1 and SRA2 with curing method L2 and after 91 days. With curing method L1 after 2 days the flexural tensile strength was about 12 % (SRA2) and approx. 20 % (SRA1) higher than in the concrete without SRA. In contrast, after 2 days curing in water the flexural tensile strength of the concretes with SRA was about 15 % lower than the reference sample with no SRA. After 91 days the effect of the SRA on flexural tensile strength was insignificant.

The results of the investigations into the effect of SRA on the mechanical properties of concrete largely confirm the results already determined for cement paste (see VDZ Activity Report 2005-2007).

Air-entraining admixtures

In unset concrete air-entraining admixtures are added to create a lot of small, evenly distributed air voids with a diameter ≤ 300 µm. In hardened concrete these voids serve as an expansion space to relieve the pressure created when the pore solution freezes. The air voids also interrupt the capillary pore system and reduce water absorption in the concrete. Both mechanisms of action contribute to the adequacy of the concrete’s resistance to freeze-thaw with de-icing salt. Road paving concrete which is covered with de-icing salt in winter must be manufactured as air-entrained concrete. Other areas of application are bridge caps, scraper tracks and concretes used in hydraulic engineering (exposure class XF3).

Manufacturing of proper air-entrained concrete requires a suitability test in which the main effects that the composition of the concrete, the temperature of the unset concrete and the mixing time have on the formation of air voids are determined. Suitable regulations for the composition and manufacture of air-entrained concrete are defined and have proven their worth in the past. Traditional super-plasticisers based on melamine, naphthalene and lignin sulfonate have long been used to regulate consistency for the manufacture of air-entrained concrete.

When super-plasticisers based on polycarboxylate ether (PCE) are used, it has been determined that the requirements for the formation of the air void system are not always fulfilled. Accordingly, in some cases the air void structure is not stable, which means that the total air content and the air void distribution can change. In a few cases, despite compliance with the total air content in the fresh concrete, the requirements for the air void parameters measured on hardened concrete (spacing factor and micro air void content) are not achieved. In cases such as this, the accurate adjustment of the micro air void content, which prevents frost and de-icing salt damage, is no longer guaranteed. To clarify the facts, in 2006 the German Committee for Structural Concrete (DAStb) formed a working group headed by the Research Institute. Extensive research work was also commenced.

Research at the Institute

Insufficient information is available about the precise interactions between air-entraining admixtures and super plasticisers, especially PCE. Because of this, during the period under review the Research Institute started work on an AiF-funded research project. The investigations will provide fundamental knowledge about the effects and interactions between the air-entraining admixtures and super plasticisers in combination with cement. The aim is to manufacture appropriate air-entrained concrete containing super plasticisers by identifying “robust” admixture combinations that enable the specific formation of air voids.

The formation of air voids is being investigated in cement pastes, mortar and concrete with different combinations of air-entraining admixtures, super plasticisers and cement. In cement paste and mortar, the formation of air voids and foam is being analysed in relation to the admixture-cement combination. Sorption of the super plasticiser on cement particles is determined with paste and flotation experiments. In addition, the formation of air voids on unset and hardened concrete will be determined using selected admixture-cement combinations. In the course of these experiments, the air entraining parameters will be determined for hardened concrete and the concretes’ de-icing resistance will be analysed using the CDF method. The research project is being carried out in close collaboration with the Institute of Building Materials Research (IBAC) at Aachen University in Germany. One of the focuses here is research into the interactions between air-entraining admixtures and super plasticisers when fly ash is used.

Formation of foam

Initial research has been carried out on the foam formation capacity of air-entraining admixture/super plasticiser combinations in cement suspensions. The maximum permissible amount of super plasticiser was added (3 mass % of cement). In a stand-
ardised experiment water, cement and admixture were mixed in a plain cylinder, fine air bubbles were introduced to the suspension and the height of the foam that formed was measured. **Fig. V-18** shows the formation of foam in relation to the amount of active agent in the air-entraining admixture and super plasticiser (PCE for ready-mixed concrete) that was added. The experiment was stopped when the foam overflowed from the cylinder (height of foam > 16 cm). This status is shown by the arrow in Figure V-18. First, in a “reference experiment” the formation of foam of a synthetic air-entraining admixture (syn. surfactant) and a natural air-entraining admixture (modified wood resin) with no added super plasticiser (only air-entraining admixture) were determined. Subsequently, the effect of the time when the super plasticiser was added was also investigated. In one case the super plasticiser was added before the air-entraining admixture (first SP) and in the second case the air-entraining admixture was added (height of foam approx. 8 cm) before the super plasticiser (first AEA). In the second option the aim was also to investigate whether the formation of foam was affected by the subsequent addition of super plasticiser.

With the same concentration of active agents, the synthetic air-entraining admixture exhibited a much stronger foam formation than the air-entraining admixture based on a natural active agent. Apart from this, the sequence in which the admixtures were added also had a major effect on the formation of foam. If about 8 cm of foam was produced by adding the air-entraining admixture first before the super plasticiser was added, there was less overall formation of foam. The formation of foam was hardly affected at all by the subsequent addition of the super plasticiser and the foam height of approximately 8 cm fell only slightly. If the super plasticiser was added before the air-entraining admixture, much more foam formed. A possible reason for this is the reduced sorption of the air-entraining admixture molecules on the cement particles when the sorption places are already filled by the super plasticiser molecules. The air-entraining admixture molecules can stabilise more air bubbles and more foam forms. It is possible that in practice the effects that occur during the formation of air voids in concrete can be attributed to these differences in the sequence in which the admixtures are added. Generally, when concrete is being manufactured the air-entraining admixture is added before the super plasticiser.

**Alkali-silica reaction**

In an alkali-silica reaction (ASR), all constituents in the aggregate containing silica that is sensitive to alkalis react with the alkalis of the pore solution in the cement paste. The reaction product is an alkali silica gel that endeavours to absorb water. The associated increase in volume is described as concrete expansion and can cause cracks in the concrete. In many concretes an ASR takes place with no damage. The triggers for and the course of a damaging ASR in concrete depend on the type, reactivity, quantity and particle size distribution of the alkali-reactive aggregate, the effective alkali content in the pore solution and on sufficient moisture being present. If one of the three requirements is missing, no damaging ASR occurs. If the conditions for a damaging ASR exist, visible cracks can appear in the concrete. However, it is not always possible to distinguish these cracks from other cracks that are the result of other damage, such as frost attack. If a damaging ASR is suspected, it is imperative that an expert carries out a thorough examination to clarify whether a damaging ASR has taken place.

**Regulations**

In Germany, the German Committee for Structural Concrete (DAfStb) issues guidelines – “Preventive measures against a damaging alkali reaction in concrete” – to prevent ASR damage, these guidelines are generally known simply as the Alkali Guidelines. The latest version of the Alkali Guidelines was published in February 2007. The guidelines are introduced by the building authorities with publication in Version 2008/1 of Construction Products List A, Part 1.

The Alkali Guidelines are split into three parts:
- Part 1: General
- Part 2: Aggregates containing opaline sandstone and flint
- Part 3: Crushed alkali-reactive aggregates

**Effects on building with concrete**

The guidelines offer practical solutions for building with concrete which, however, must be applied. In this connection, it must be mentioned that there is also the option of classifying an aggregate as non-reactive (E I) on the basis of a petrographic description with no other test being required. This applies to aggregates that are not listed in the guidelines or which are not excavated in regions listed in the guidelines. A requirement is that no damaging ASR has occurred with the aggregate when used under normal building conditions (**Fig. V-19**).

With the concrete formulations and cement contents generally used these days, there are also many uses in civil engineering and engineering structures (moisture classes WO, WF, and WA, **Table V-3**) for
aggregates that are classified as E II (medium reactive) or E III (reactive). Figures V-20 and V-21 illustrate the fact that in many cases even for aggregates classified as E II or E III according to Parts 2 and 3 of the Alkali Guidelines either no measures at all are required or that technically reliable and economically feasible solutions are available. Moisture class WA applies to concrete structural elements that are often moist or moist for long periods of time while they are in use and which are exposed to an external alkali supply often or for long periods. Examples of this are structural elements exposed to seawater and elements that are exposed to de-icing salt with additional high dynamic stress, such as paved and parking areas in multi-storey car parks or bridge caps (Table V-3).

Concrete road pavements and airfields require special treatment in the regulations because of the particular stress that they are subject to. Therefore, General Circulars on Road Constructions issued by the German Federal Ministry of Transport, Construction and Housing will continue to include requirements above and beyond the regulations contained in the Alkali Guidelines. These circulars allow flexible responses to new developments – such as the recent introduction of exposed aggregate concrete. In future, the Alkali Guidelines will thus include a description of moisture class WS. But the regulations for this moisture class will be included in TL Beton (German technical requirements of delivery for concrete) (see the section on road construction) and perhaps also in the General Circulars on Road Constructions. Preventive measures regarding concrete for airfields are not covered by the Alkali Guidelines, but have to be determined by experts because special de-icing agents are applied on airfields.

**Alkali reactivity of concrete compositions**

For aggregates that are classified as medium reactive (E II-O, E II-OF) or reactive (E III-O, E III-OF, E III-S), the Alkali Guidelines require that measures must be taken depending on the moisture class of the structural element and the cement content. In the past, these measures have included replacing the aggregate or using cements with a low effective alkali content (NA cement). So as to not unnecessarily exclude aggregates or cements from being used, the suitability of a concrete composition can be investigated in performance tests within the scope of expert opinions. The test allows a statement to be made as to whether for a specific concrete composition there is a risk of an ASR damaging the concrete in relation to its exposure (moisture class). To simulate impingement with de-icing agents or salts, concretes for moisture classes WA and WS and for airfields are tested with an external alkali supply.

In Germany, the accelerated concrete prism test at 60°C with and without external alkali supply and the alternating climate method are currently used as performance test procedures. The procedure may be included in a future Part 4 of the Alkali Guidelines.

Comparative investigations for the performance test were conducted at the Research Institute (accelerated concrete prism test at 60°C with and without external alkali supply) and at Bauhaus University Weimar (climate simulation chamber). As a basis for the performance tests a practice-oriented concrete formulation with w/c = 0.42, c = 370 kg/m³, air-

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### Figures V-19, V-20, V-21

**Fig. V-19:** Requirements for classifying an aggregate as non-reactive (E I) on the basis of a petrographic description with no other tests

**Fig. V-20:** ASR effects on concrete when using aggregates from a region according to Part 2 of the Alkali Guidelines (c = cement content, NA = NA cement according to DIN 1164-10)

**Fig. V-21:** ASR effects on building with concrete when using aggregates according to Part 3 of the Alkali Guidelines (c = cement content, NA = NA cement according to DIN 1164-10)
Examples for allocating exposure classes

Table V-3: Moisture classes according to the Alkali Guidelines or DIN 1045-2

<table>
<thead>
<tr>
<th>Name of class</th>
<th>Description of the environment</th>
<th>Examples for allocating exposure classes (informative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WO</td>
<td>Concrete, which after normal curing is not moist for long periods and which remains largely dry after it has dried out under normal use.</td>
<td>Interior elements in building construction; Building elements which are exposed to outdoor air but not, for example, atmospheric water, surface water or soil moisture and/or which are not constantly exposed to relative humidity of more than 80 %.</td>
</tr>
<tr>
<td>WF</td>
<td>Concrete that is moist often or for long periods during normal use.</td>
<td>Unprotected outdoor building elements that are subject, for example, to atmospheric water, surface water or soil moisture; Interior building elements in building construction for wet rooms, such as indoor swimming pools, laundries and commercial wet rooms in which relative humidity is generally higher than 80 %; Building elements that are regularly below the dew point, such as chimneys, heat transfer stations, filter chambers and cattle sheds; Bulky building elements according to the DAfStb Guideline “Bulky concrete building elements”, whose smallest dimension is larger than 0.80 m (regardless of the presence of moisture).</td>
</tr>
<tr>
<td>WA</td>
<td>Concrete which, in addition to stress according to Class WF is subjected to an external alkali supply frequently or for long periods.</td>
<td>Building elements exposed to seawater; Building elements exposed to de-icing salt with no additional high dynamic stress (e.g. spray water areas, driving and parking areas in multi-storey car parks); Building elements in industrial and agricultural buildings (e.g. manure tank) exposed to alkali salts. Concrete road surfaces in Class IV-VI</td>
</tr>
<tr>
<td>WS</td>
<td>Concrete that is subjected to high dynamic stress and an external alkali supply.</td>
<td>Building elements exposed to de-icing salt with additional high dynamic stress (concrete road pavements in Classes SV and I-III)</td>
</tr>
</tbody>
</table>

1) Building classes according to RStO; according to TL Beton-StB 07

### Figures

**Fig. V-22:** Expansion of concrete in accelerated concrete prism test with external alkali supply

**Fig. V-23:** Expansion of concrete in FIB alternating climate test with de-icing effect

entRAINING admixture (air content $4.5 \pm 0.5$ % by volume) was used.

As variables, five different alkali-reactive aggregates and four Portland cements CEM I (32.5 R and 42.5 N) with Na$_2$O equivalent values in the range between 0.56 and 0.89 mass % were included in the test programme. Figures **V-22** and **V-23** show the expansion of a concrete during the accelerated concrete prism test at 60 °C with a 10 % sodium chloride solution and in the climate simulation chamber with a 0.6 mole sodium chloride solution. To summarise, the investigations produced the following picture:

- A total of 12 concrete compositions for concrete road pavings were tested with FIB alternating climate test (ASR performance test) and the accelerated concrete prism test at 60 °C with and without external alkali supply (NaCl).
- In the examination of concrete compositions in moisture class WS in performance tests with external alkali supply, similar results were obtained for 11 concrete compositions with both methods; the results differed for only one concrete composition.
- The same results were obtained when 12 concretes were tested for moisture class WF (without alkali supply).

**Test cement**

A test cement with a high alkali content was used to test the alkali reactivity of aggregates according to Part 3 of the Alkali Guidelines. Cement that fulfils the re-
requirements of a test cement according to Part 3 of the Alkali Guidelines is no longer available in Germany. The Research Institute conducted experiments in order to make recommendations for future requirements for a test cement according to the Alkali Guidelines.

For this purpose three Portland cements with an Na₂O equivalent of (0.90 ± 0.15) mass % were chosen (Table V-4). The cements were boosted with potassium sulphate to obtain an Na₂O equivalent of 1.20 and 1.26 mass % (alkali content of earlier delivery batches of the test cement, described below as Test cement A and Test cement B).

Cement pastes were manufactured with the boosted cements. The chemical compositions of extruded pore solutions and supernatant solutions according to TGL 28104/17 were determined. The pH values of the boosted cements were similar to those of Test cement A. The addition of potassium sulphate is suitable to obtain a similar pH value in the pore solution to that of the unboosted cement.

Accelerated mortar bar tests (reference method according to Alkali Guidelines) were carried out using a crushed greywacke and the boosted cement. In all cases, the investigations were similar to those of Test cement A. The addition of potassium sulphate was found to be inert. According to our current knowledge, there are no adequate criteria that could prove the suitability of a test sand for aggregate tests. Consequently, assessments of coarse aggregates in which an unsuitable sand is used could have systematic errors.

To quantify the effects of a not completely inert test sand on the results of ASR concrete prism tests, a research project was initiated and funded by the German Federation of Industrial Research Associations (AiF).

Firstly, natural sands rich in quartz from various regions were selected, which differed in terms of their mineralogy and particle size distribution. In addition, crushed aggregates < 2 mm from pure limestone were used as an inert sand and crushed aggregates from alkali-reactive greywacke with a similar particle size were used as reactive sand. The characterisation of the
sands (petrography, alkali solubility, calcium-binding capacity) show differences in the detail, but it is not possible to clearly identify reactive sands. The test according to ASTM C289 (soluble silica) also showed no differences between the sands. In the accelerated mortar bar test the use of sands instead of crushed aggregate produced different expansion behaviour in some cases (Fig. V-26). All quartzitic sands caused increased expansion in the mortar; however, in some types a depressive tendency was exhibited. Other sands produced a constant increase in expansion, so that with an extended testing period even the expansion of the mortar with the reactive crushed greywacke sand was exceeded.

These sands were chosen for the accelerated concrete prism test and were combined with inert limestone or reactive coarse aggregate in a ratio of 30 % sand to 70 % coarse aggregate. The concretes were manufactured with a test cement according to the Alkali Guidelines. The concretes were tested according to the Alkali Guidelines with fog chamber storage at 40 °C, with storage in an outdoor exposure site and with the accelerated concrete prism test at 60 °C. Regardless of the test method used, the reactivity of the sands suggested in the accelerated mortar bar test had no effect on the assessment of the aggregate (Fig. V-27). Concrete expansion was achieved only with the reactive crushed greywacke sand in combination with inert limestone, which was in the range of the preliminary limit value. In some cases, the combination of quartzitic sands with the reactive aggregates led to less concrete expansion than when inert crushed limestone sand was used. However, in every case the expansion values were well above the limit value set for the test method. In other words, there is no need to fear incorrect classification of alkali-reactive aggregates as a non-reactive aggregate because of the reactivity of quartzitic test sand. To estimate whether the observed minor effects have any effect on the performance test of concrete compositions, more investigations are currently being carried out on concrete made with paving cement (CEM I with Na₂O equivalent ≤ 0.80 mass %) and CEM II/B-S.

**Field site tests**

As with all laboratory tests on concrete that are relevant to the durability of the concrete, it is important to ensure that the results from these tests can be transferred to how the concrete actually behaves in actual construction situations. The EU PART-NER project, partially funded by the European Union, had the overall objective of establishing a unified test procedure for evaluating the alkali reactivity of aggregates. In the project, the suitability of RILEM test methods and some regional test procedures have been investigated with different aggregates and types of aggregates that are excavated throughout Europe. The results of the accelerated laboratory tests were compared with the behaviour of these aggregates in real concrete structures and in concrete samples stored in field test sites. The Research Institute was in charge of the field tests.

To take account of different climatic conditions in Europe, the behaviour of concrete samples in various field sites was investigated. One of the issues pursued in the project was whether concrete that is partially submerged in water is damaged faster and more severely as a result of an ASR than concrete that is only exposed to ambient rainfall. Laboratory tests in the past have also shown that concrete samples containing reactive aggregates expand more when they are exposed to a de-icing salt solution rather than water. Therefore, it is generally assumed that de-icing salt could facilitate a damaging ASR in concretes containing reactive aggregate.

For the field site tests all the concrete cubes were manufactured for every aggregate combination and every aggregate. These were then transported to the laboratories and field sites of the participating partners. 13 aggregate combinations with which concrete was manufactured in 5 laboratories were monitored and investigated in 8 different field sites from Norway to Spain. (Fig. V-28). In Sweden, samples were stored in a forest in Borås and beside a motorway between Borås and Göteborg to examine the added effects of external alkali supply.

For each field site two 300 mm concrete cubes were made for each aggregate combination that was to be investigated. The concrete composition corresponded to that of the concrete prisms in the RILEM tests AAR-3 (concrete prism test at 38 °C) and AAR-4 (accelerated concrete prism test at 60 °C).
The samples were manufactured with a cement content of 440 kg/m³ and a Portland cement with a high alkali content (1.26 mass % Na₂O equivalent). To record any damage resulting from an ASR, the length changes on the top side and on two opposite sides as well as the width of any cracks were periodically recorded.

In 2008, the samples had been stored outdoors for about 4 years. For slowly reacting aggregates this period is too short to cause a damaging ASR. Because of this, it is only possible to draw preliminary conclusions. Table V-5 shows the current results of the field site tests and the laboratory experiments together so that a comparison can be made. The results of the accelerated laboratory tests were taken from other sub-projects of the PARTNER project.

The concrete cubes with aggregate composition B1(C+NRF) exhibit a lot of expansion > 0.04% (Fig. V-29) and cracks with a maximum width of ≥ 0.20 mm in all field sites from Norway to Spain, regardless of how they were stored.

Aggregate mixtures D2, G1, N1 and UK1 expanded more and had larger cracks in mild (Düsseldorf, Watford) and in warm climates (Milan, Valencia). Fig. V-30 illustrates this for aggregate mixture N1, which showed high expansion in Valencia, Düsseldorf and Watford, but which, to date, has not expanded in cold climates (Borås, Trondheim). The increase in expansion was higher in Southern Europe (Valencia) than in Central Europe (Düsseldorf, Watford). Fig. V-31 illustrates the expansion of aggregate composition G1, the crushed gravel from the Upper Rhine Valley.

The results suggest that a damaging ASR occurs in a similar manner in North and Southern Europe, the only difference being that with the same concrete composition the reaction can take place quicker in Southern Europe – which can probably be attributed to the higher average temperature.

It is also noteworthy and surprising that the samples which were exposed only to ambient rainfall expanded more and exhibited larger cracks than the samples that were stored partly immersed in water.

To date no differences have been detected in the behaviour of the concretes stored in a forest in Borås (without alkali supply) and alongside a motorway between Borås and Goteborg in Sweden (with external alkali supply).

After 4 years outdoor storage, the slowly reacting aggregates IT2, N2, N4, S1 and P1 and the non-reactive aggregates F1 and F2 are not exhibiting any noticeable expansion or cracks.

One of the conclusions of the PARTNER project was that in most cases the RILEM test procedures were suitable for identifying the alkali reactivity of the investigated aggregates (see Table V-5). The tests were especially suitable for identifying aggregate combinations that either react within a “normal” time scale (i.e. 5 to 20 years) or which are non-reactive. There was less certainty as regards identifying slowly reacting aggregates that react after more than 20 years. Further tests must be carried out to see whether these experiences can be generalised. Generally, in the cases where differences were observed between the results from the laboratory tests and practical experience, they can be attribut-
<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Fraction/Combination</th>
<th>Reactivity/Evaluation</th>
<th>Field site test after 4 years*</th>
<th>Reported reactivity in structures?</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 - Silicified limestone</td>
<td>F R R R/R</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C R C+R/R C+NRF R/R R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK1 - Greywacke</td>
<td>F R R R/R</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C R C+F R R/R R/R R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1 - Crushed Gravel with silicic limestone and chert</td>
<td>C R R R/-</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C+NRF R R/R R/- R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2 - Gravel with opaline sandstone and flint</td>
<td>C R R R/-</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N1 - Cataclasite</td>
<td>C R R R/R C+NRF R R/R R/R R</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2 - Sea Gravel with semi-dense flint</td>
<td>F R R R/R</td>
<td>Yes, 10 - 15 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C R R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F+NRC NR/MR R/MR R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IT2 - Gravel with quartzite</td>
<td>F R R NR/-</td>
<td>Yes, 50 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C R R</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>C+F NR R/R n.r.</td>
<td></td>
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</tr>
<tr>
<td>N2 - Sandstone</td>
<td>C R R NR/R C+NRF R -/R n.r.</td>
<td>Yes, 15 - 20 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N4 - Gravel with sandstone and cataclastic rocks</td>
<td>F R R R/R</td>
<td>Yes, 20 - 25 years</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>C R R</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>C+F MR R/- MR/MR n.r.</td>
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</tr>
<tr>
<td>F1 - Gravel with flint</td>
<td>C R NR NR/R C+NRF NR NR/NR NR/- n.r.</td>
<td>No, but known pessimum effect</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F NR NR</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>C NR</td>
<td></td>
<td></td>
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<tr>
<td>F2 - Non-reactive limestone</td>
<td>F NR NR</td>
<td>Yes</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>C+F NR NR/NR NR/NR n.r.</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1 - Gravel with metarhyolite and greywacke</td>
<td>F R R R/R</td>
<td>Yes, but source variable in composition</td>
<td></td>
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<tr>
<td></td>
<td>C R R</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>C+F NR MR/- NR/MR n.r.</td>
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</tr>
<tr>
<td>P1 - Silicified limestone</td>
<td>C R NR NR/- C+NRF NR MR/MR n.r.</td>
<td>Yes, but the information about the aggregate is uncertain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- **F** = fine aggregate
- **C** = coarse aggregate
- **NRF** = non-reactive fine aggregate (=N3F)
- **NRC** = non-reactive coarse aggregate (=F2C)
- **R** = reactive (according to the limit values for the different test methods)
- **NR** = non-reactive (according to the limit values for the different test methods)
- **MR** = marginally reactive (i.e. expansion was just above the limit value for the different test methods)
- **n.r.** = no rating yet possible
- * = The evaluation of preliminary results from the field site tests is based on measuring the maximum width of the crack after 4 years of storage outdoors and expansion during the last 3 years (measurement of expansion was re-started in 2005 as there were problems with zero measurement in some of the field sites.)

**Test Methods:**
- **AAR-1** = RILEM method AAR-1: petrographic method
- **AAR-2** = RILEM method AAR-2: accelerated mortar bar test at 80 °C in 1 mole sodium hydroxide
- **AAR-3** = RILEM method AAR-3: concrete prism test at 38 °C
- **AAR-4** = RILEM method AAR-4: accelerated concrete prism test at 60 °C
- **TI-B51** = Danish accelerated mortar bar test at 50 °C in a saturated sodium chloride solution
- **Chatterji** = Chemical test method according to Chatterji
- **Germany** = Concrete test on concrete bars and cubes with storage in the 40 °C fog chamber according to the Alkali Guidelines
- **Norway** = Norwegian concrete prism test at 38 °C
ed to variability in the aggregate source, pessimum behaviour or unreliable information about the behaviour of the aggregates under practical conditions. In many cases, the accelerated mortar bar test (RILEM AAR-2) and the accelerated concrete prism test at 60 °C (RILEM AAR-4) mirrored practical experience. One exception seems to be aggregates with pessimum behaviour. Thus, these procedures are suitable to assess aggregates with no pessimum behaviour against the background of local experience where these damage cases appear necessary in practice.

**Sulphate resistance**

In 2006, the German Committee for Structural Concrete (DAfStb) initiated a special research project entitled “An in-depth investigation into the sulphate resistance of concrete”. Funded by the German Concrete and Construction Engineering Association (DBV), the German Ready-Mixed Concrete Industry Association (BTB), VGB Power Tech and VDZ, experiments were started to underpin the existing sulphate resistance regulation when concretes containing fly ash are used. In particular, the aim was to check the results of laboratory-based experiments by means of field storage experiments under natural sulphate attack conditions. The series of experiments were started at the end of 2006. After a two-year exposure period, the findings obtained up until that point were aggregated in the form of a report at the beginning of 2009. Apart from the Research Institute of the Cement Industry (FIZ), the research programme also involved the Centre for Building Materials at the Technical University of Munich (cbm) and the F. A. Finger-Institute for Building Material Science at (FIB) Weimar University.

**Effects of aggregate containing carbonate/test in synthetic soils and waters**

In particular, investigations in the UK showed that in the event of a sulphate attack, carbonate from the binder or from the aggregate can act as a reaction partner, leading to damage as a result of thaumasite formation. Since these results were published, cements and aggregates containing limestone are suspected of having a negative effect on the sulphate resistance of standard concretes. Since in addition to that only quartzitic sands and gravels are used in the normal sulphate resistance tests, there is a lack of experience as regards the effect of aggregates containing carbonate. For this reason, in the Research Institute’s work package concrete test samples were manufactured with quartzitic and carbonate aggregates and subjected to a sulphate attack similar to the attacks that take place in practice. Table V-6 shows the formulations of the concretes used in the research programme.

The Research Institute carried out the field storage experiments in a gypsum/anhydrite opencast mine in the state of Lower Saxony, Germany. A total of 60 concrete test samples were stored in a calcium sulphate saturated lake near Stadtoldendorf. After one and two years’ exposure, test samples were removed from the lake and investigated. The remaining samples are to be stored as long as possible in the sulphurous lake water (10 years storage is planned). Only then will it be possible to make statements about the long-term behaviour of the concretes. In the second focus of the Research Institute’s investigation, concrete test samples were subjected to a defined practice-related sulphate attack in a synthetic soil. A 300-l plastic tank, called a lysimeter, was filled with alternate layers of limestone chippings, greywacke chippings and meal, quartz sand and potting soil. The concrete test samples were then stored in this “synthetic soil”. The sulphate attack was carried out using a sodium sulphate solution (1 500 mg sulphate per litre), with which the soil material was saturated. At regular intervals the sulphate solution was drained off so that the soil could be dried and then filled with a fresh solution. This simulated natural fluctuations in the groundwater. The soil was kept at 8 °C, which is the average soil temperature in Germany.
Table V-6: Names and formulations of the six concretes; Figures in kg/m³ or mass % of the cement

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement type</td>
<td>CEM I-SR</td>
<td>CEM I-SR</td>
<td>CEM III/B</td>
<td>CEM III/B</td>
<td>CEM I</td>
<td>CEM II/A-LL</td>
</tr>
<tr>
<td>Cement content</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>327</td>
<td>327</td>
</tr>
<tr>
<td>Fly ash</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Water</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Q 0/02</td>
<td>98</td>
<td>–</td>
<td>97</td>
<td>–</td>
<td>–</td>
<td>94</td>
</tr>
<tr>
<td>Q 0/2</td>
<td>409</td>
<td>–</td>
<td>407</td>
<td>–</td>
<td>–</td>
<td>393</td>
</tr>
<tr>
<td>Q 1/2</td>
<td>80</td>
<td>–</td>
<td>79</td>
<td>–</td>
<td>–</td>
<td>77</td>
</tr>
<tr>
<td>Q 2/8</td>
<td>569</td>
<td>–</td>
<td>566</td>
<td>–</td>
<td>–</td>
<td>547</td>
</tr>
<tr>
<td>Q 8/16</td>
<td>622</td>
<td>–</td>
<td>619</td>
<td>–</td>
<td>–</td>
<td>698</td>
</tr>
<tr>
<td>K 0/2</td>
<td>–</td>
<td>591</td>
<td>–</td>
<td>587.5</td>
<td>569</td>
<td>–</td>
</tr>
<tr>
<td>K 2/8</td>
<td>–</td>
<td>591</td>
<td>–</td>
<td>587.5</td>
<td>569</td>
<td>–</td>
</tr>
<tr>
<td>K 8/16</td>
<td>–</td>
<td>665</td>
<td>–</td>
<td>661</td>
<td>641</td>
<td>–</td>
</tr>
<tr>
<td>Q/K total</td>
<td>1 778</td>
<td>1 847</td>
<td>1 768</td>
<td>1 836</td>
<td>1 779</td>
<td>1 709</td>
</tr>
<tr>
<td>FM</td>
<td>–</td>
<td>1 %</td>
<td>–</td>
<td>0.75 %</td>
<td>2 %</td>
<td>–</td>
</tr>
</tbody>
</table>

Q: quartzitic aggregate  
K: carbonatic aggregate (limestone)

Results

Water samples were taken and analysed at the start of the investigation and every time the samples were assessed. In the lake water the sulphate concentration fluctuated between about 1,500 and 1,800 mg/l. Apart from about 600 mg/l calcium, roughly 500 mg/l of sodium and approximately 50 to 70 mg/l magnesium were discovered as cations (Table V-7). According to DIN 4030, concentrations above 300 mg/l magnesium are classified as slightly severe in terms of the level of attack.

At the end of the observation period no damage was identified on the samples in the lysimeter or on those stored in the lake (Fig. V-32). No flaking, cracks or partial surface softening was observed. Partial surface discolouration can be attributed to algae deposits and contact with various surrounding materials (e.g. the soil).

Fig. V-33 shows the compressive strengths of the samples. Even in the second year, an increase in strength was identified in all six concretes. Although no damage was identified, investigations were carried out on hardened concrete structures near the edge using scanning electron microscopy (SEM). In all of the concrete samples, undisturbed, dense structures were observed with no signs of expansion reactions or structural weakening.

In contrast to the results of the Research Institute, in the FIB field storage experiments damage was discovered on the concretes manufactured with Portland-lime stone cement and fly ash (M6). The concrete test samples stored in water in a gypsum cave containing sulphate exhibited signs of flaking and surface weakening after just one year. Ettringite and thaumasite had formed. The reasons for these different observations are to be clarified in supplementary investigations. These investigations are being funded by the
**Self-compacting concrete**

To assess the workability of self-compacting concretes, according to the DAfStb Guidelines for “Self-Compacting Concrete” the slump flow and the V-funnel flow time are to be tested during the initial test, the manufacturing works’ own production control and when the concrete is delivered to the building site. According to the DIN EN 12350 series of standards, two separate test procedures are necessary, namely the slump-flow test according to Part 8 and the V-funnel test according to Part 9. An alternative to these procedures is the flow-cone test, in which a cone slump flow and a cone flow time can be determined in one experiment on a concrete sample.

**Precise data for the flow cone**

The flow cone (Fig. V-34) was developed in the Research Institute of the Cement Industry between 2002 and 2006. In earlier experiments it was shown that there was no significant difference between cone slump flow and slump flow according to DIN EN 12350-8. Cone flow time is proportional to the flow time according to DIN EN 12350-9. Previously there has been a lack of precise data that would allow the process to be standardised throughout Europe. This was determined in a round robin test managed by the Research Institute. The round robin test was funded by the German Ready-Mixed Concrete Association, the German Society for Concrete and Construction Technology and the German Cement Works Association.

Concrete testers from four companies in the ready-mixed concrete industry were invited to the Research Institute. Together with a concrete tester from the Institute, over a period of two days they tested seven mixtures of a self-compacting concrete with the flow cone. In accordance with DIN EN 12350, the self-compacting concrete (powder type) used for the tests had an average slump flow of 770 mm and an average flow time of 5.0 seconds. To determine the precise data according to ISO 5725-2, a 5 % error probability was assumed. The reproducibility R (different testers) and the repeatability r (one tester) was then 2.78 times the standard deviation. Accordingly, with a 95 % probability the maximum difference between two individual results is r or R. Table V-8 shows the precise data that was determined for testing the cone slump flow and the cone flow time with the flow cone. The values in brackets show the results of a round robin test for corresponding...
tests according to DIN EN 12350 Parts 8 and 9 as a comparison.

**Ultra-high performance concrete**

Due to its very dense structure, ultra-high performance concrete (UHPC) is extremely durable when it is undamaged. However, it has not yet been clarified whether and under which conditions cracks that have a negative effect on the durability of the material can occur due to the high autogenous shrinkage of the concrete. Since the end of 2005, the Research Institute of the Cement Industry has been funded by the German Research Foundation (DFG) within the scope of the priority programme “Sustainable building with ultra-high performance concrete” to carry out research work into this aspect, which is very important for practical applications.

**Free autogenous shrinkage**

Autogenous shrinkage is the main shrinkage component in concretes that contain much less water than they require for the complete reaction of their hydraulically reactive constituents. This applies especially to UHPC. Here the equivalent water-cement ratio is usually between 0.15 and 0.25. Most autogenous shrinkage takes place in the first 24 to 48 hours. Since it is caused by inner drying and as UHPC has a very dense structure, it is difficult to affect autogenous shrinkage with external after-treatment. If deformation is prevented, which is often the case in practice, this can cause considerable restraint stress and result in a high cracking tendency.

**Start and measurement of autogenous shrinkage**

Autogenous shrinkage is part of the chemical shrinkage process. The latter starts when water and cement come into contact with each other; the reaction products occur in the initially water-saturated pores reducing the relative moisture and its good repeat and comparison accuracy at a constant temperature of 20 °C was proven. The experiments will soon be continued for other temperatures with various European partners.

**Restrained autogenous shrinkage**

The “ring test” was adapted in order to investigate restraint stress and cracking tendency as a result of restrained autogenous shrinkage. This procedure is especially popular in the USA to investigate plastic shrinkage. With a large number of experiments, the new shrinkage cone method for determining autogenous shrinkage was optimised and its good repeat and comparison accuracy at a constant temperature of 20 °C was proven. The experiments will soon be continued for other temperatures with various European partners.

| Tafel V-9: Investigated concrete compositions (data in kg/m³) |
|-------------|--------|--------|--------|
| Cement (c) 1) | 800    | 800    | 800    | 200    |
| Mixing water (w) | 168    | 168    | 168    | 176    |
| Silica fume (s) 2) | 130    | 130    | 130    | 130    |
| Super plasticiser 3) | 24    | 24    | 24    | 13    |
| Quartz sand 4) | 1019   | 1019   | 1000   | 1019   |
| Quartz meal 5) | 220    | 220    | 220    | 220    |
| SAP 6) | –    | 2.4    | –    | –    |
| SRA 7) | –    | –    | 7.56 | –    |
| GGBS 8) | –    | –    | –    | 600    |
1) CEM I 52.5 R-HS/NA  
2) 16.2 mass % of cement; proportion of amorphous SiO₂ approx. 98%  
3) Polycarboxylate ether basis (3.0 mass % of cement)  
4) Particle size 0.125–0.5 mm  
5) Particle size 0.0–0.125 mm  
6) Super-absorbent polymers (0.3 mass % of cement)  
7) Shrinkage-reducing admixture (4.5 mass % of cement)  
8) Ground granulated blastfurnace slag
In the investigations that were conducted 24 hours was in excess of 80%. Up to about 70% of the stress that cracking tendency occurred in the first 24 hours. With all behaviour of the concrete in this timeframe would be expected with purely elastic be. The cracking tendency as a ratio between restraint stress and tensile splitting strength, dotted area: extrapolated trend

**Modified slab test**

The regulations for concrete products, standard series EN 1338, 1339 and 1340, are currently being revised. The modified slab test, a method for determining the resistance to freeze-thaw with de-icing salt attack, is on the test rig. Essentially, the method differs from the slab test according to DIN CEN/TS 12390-9 in terms of the size and properties of the test areas, the preliminary storage of the specimens, the test age and the number of freeze-thaw cycles (Table V-10).

The evaluation of about 40 tests by VDZ member companies using the modified slab test showed scaling of roughly 20 g/m² to approx. 850 g/m² after 28 freeze-thaw cycles. In practise no damages have been recorded for concrete products with such scaling. This would confirm that the maximum scaling of 1000 g/m² according to the standard is an adequate criterion for durable concrete products. In addition to the statistical variation, the main reasons for the somewhat large range of individual scaling results would appear to be the sampling procedure itself, the condition of the samples and the number of samples. Because of this, it is recommended that the number of samples be increased from the present three to at least five and that representative sampling is ensured. Experience and recommendations are being discussed intensively in the BDB-VDZ Discussion Panel „Quality of concrete construction components“ and the results of these discussions should be considered in the regulations.

**Colour deviation in concrete products**

The above-mentioned discussion panel also examined the possible causes of occasional colour deviations in concrete products. At present there is very little known about the causes for colour deviations in concrete products.

Currently, the discussion panel is developing an investigation programme in which the effects of the concrete composition, the cement properties and the production technology will be examined systematically.
Table V-10: Comparison between slab test according to DIN CEN/TS 12390-9 and modified slab test according to EN 1338 to 1340, Annex D

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Slab Test (DIN CEN/TS 12390-9)</th>
<th>Modified Slab Test (EN 1338 to 1340, Annex D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimens</td>
<td>4 slabs 150 x 150 x 50 mm³ A = 90 000 mm²</td>
<td>7 500 &lt; A &lt; 25 000 mm², d &lt; 103 mm, acceptance test: 3 blocks</td>
</tr>
<tr>
<td>Test area</td>
<td>sawn (centre of cube)</td>
<td>Surface</td>
</tr>
<tr>
<td>Curing</td>
<td>1d mould; 6d water 20 °C 21 d 20/65</td>
<td>–</td>
</tr>
<tr>
<td>Preliminary storage</td>
<td>3 d with 3 % NaCl</td>
<td>7 d in 20/65, 3 d H₂O, 0.25 to 0.5 h with 3 % NaCl</td>
</tr>
<tr>
<td>Test age at preliminary storage</td>
<td>28 d</td>
<td>≥ 28 d, at acceptance test: 35 d</td>
</tr>
<tr>
<td>Testing direction</td>
<td>one side</td>
<td>one side</td>
</tr>
<tr>
<td>Tₘin/Tₘax; adm. ∆T at Tₘin</td>
<td>rate of cooling/thawing -18 °C/+20 °C; to ± 2 K 2.5 K/h / 6.5 K/h</td>
<td>-18 °C/+20 °C; to ± 2 K 2.5 K/h / 6.5 K/h</td>
</tr>
<tr>
<td>Duration /number freeze-thaw cycles</td>
<td>24 h / 56 freeze-thaw cycles</td>
<td>24 h / 28 freeze-thaw cycles</td>
</tr>
<tr>
<td>Testing criterion (scaling)</td>
<td>&lt; 1.0 kg/m² after 56 freeze-thaw cycles</td>
<td>&lt; 1.0 kg/m² after 28 freeze-thaw cycles, Indiv. value &lt; 1.5 kg/m³</td>
</tr>
</tbody>
</table>

Floor screeds

Cement-based floor screeds have been used in residential, commercial and industrial buildings for many years. Compared to other mineral bonded screeds they are superior in terms of resistance to moisture, which makes them ideal for indoor and outdoor use. The manufacture of cement screeds is a complicated process in which the choice of suitable constituents and the underlying conditions at the building site, such as transport, storage, mixing, pumping and laying at the location all play an important role.

Occasional problems in the manufacture of cement screeds in practice are still responsible for some reservations in the industry regarding the use of Portland-composite and blastfurnace cements in this area. The German Federal Association for Screeds and Coverings (BEB), based in Troisdorf, invited representatives from the cement and admixture industries to discuss their experiences as regards the use of CEM II cements in screeds. From the case studies it was not possible to show that the type of cement was the sole cause of any problems. Influences from the other constituents, the installation and the conditions at the building site must be included in the analysis. VDZ and its members examined the effects that the type of cement has on the properties of screeds.

The Research Institute assessed comparative studies of cement-based screeds with various cement compositions but otherwise with the same constituents and identical manufacturing and testing conditions. From a database of more than 700 individual results the following properties were analysed: workability and air content, strength development (Fig. V-37), final strength and surface strength, residual moisture (Fig. V-38), shrinkage and curling. No significant effect from the cement type could be identified and the structural engineering properties of cement screeds containing CEM I, CEM II and CEM III/ A cements were similar in the laboratory and under practical building conditions. In the evaluated investigations any effects on the test results resulting from temperature, the shape of the test piece or the testing method were independent of the cement type used.

At present, mainly the following CEM II cements are used to manufacture cement screeds:

- Portland-limestone cement CEM II/A-LL 32,5 R
- Portland-burnt shale cement CEM II/B-T 42,5 N
- Portland-slag cement CEM II/A-S 32,5 R
- Portland-slag cement CEM II/B-S 32,5 R
- Portland-composite cement CEM II/B-M (S- LL) 32,5 R

In practice, screed installers have reported occasional problems (such as low surface strength, formation of cavities, slow drying) when they changed from CEM I cement to CEM II cement. In some cases reported from the industry, it appears that cements were used that are not subject to...
third-party inspection by the VDZ quality surveillance organisation and which were manufactured by companies that do not belong to VDZ. In some cases it has been reported that also “CEM II-M cements” were delivered with no data about the main constituents and without a conformity certificate or the national compliance marks. These products should not be used.

The meetings between the German Cement Works Association (VDZ), the German Federal Association for Screeds and Coverings (BEB) and the Federal Specialist Group for Screeds and Coverings in the Central Association of the German Construction Industry (ZDB) in May 2008 resulted in a joint statement – “Information to manufacture cement-based screeds.” This statement paves the way for ensuring and disseminating high-quality methods for using cement screeds. In line with this, VDZ in collaboration with BEB and representatives of the cement and admixture industries examined the issues associated with the manufacture of cement screeds in relation to the different influences. The effects of the constituents and also of the manufacturing process, the installation and the conditions on the building site were all considered.

The basis for manufacturing screeds is the list of requirements in DIN EN 13813 as regards the construction method and the specific building project. Screed installers generally check the suitability of the screed composition with the planned constituents in the initial test at a working consistency normally found on building sites. If undesired screed properties (such as inadequate workability, inadequate strengths) are identified, suitable measures must be taken to improve the quality of the screed mortar. These measures include choosing a different aggregate (quality, supplier, grading curve), a different screed admixture (type of admixture, admixture manufacturer, amount of admixture) or a different cement (cement type, cement manufacturer, cement strength class) or changing the mixing ratio of the mortar and extending the after-treatment and the length of time that the screed must not be walked upon.

The results of the collaboration between VDZ and BEB are contained in instructions for the manufacture of cement screed mortars.

**Traffic route engineering**

It is expected that the amount of traffic on European roads will continue to increase in the long term; this is especially true for heavy transport. Despite the expansion of rail networks throughout Europe, a large proportion of the goods will still be moved by road. It is thus an advantage to have durable, low-maintenance construction methods that allow traffic to flow smoothly without any hindrances, for example due to road works. Within the scope of the infrastructure programme from 2009 funding will be provided to develop infrastructure facilities. Concrete construction methods are characterised by high load-bearing capacities and stability against deformation, low maintenance costs and a long service life and have, in the past, mainly been used to build major roads with a high proportion of heavy goods traffic. Concrete construction methods are also to be extended to cover the area of municipal road building. An important requirement for the planned expansion of the application areas is that the concrete structures are extremely durable. Because of this, durability has been one of the focuses of the Research Institute’s activities.

**Alkali-Silica Reaction**

During the period under review the new version of the Alkali Guidelines from the German Committee for Structural Concrete (DAfStb) “Preventive measures against damaging alkali reactions in concrete” was adopted. Road surfaces made from concrete in Classes SV and I to III are to be classified in moisture class “moist + external alkali supply + strong dynamic stress” (WS), road surfaces in Classes IV to VI are to be classified in the moisture class “moist + external alkali supply” (WA). In addition, TL Beton-StB 07 contains requirements for the cements and aggregates for concrete road surfaces (see article on Alkali-Silica Reaction).

The measures taken there should prevent the occurrence of a damaging alkali-silica reaction (ASR) in future.

Early measures to maintain road surfaces already damaged as a result of an ASR could possibly prolong their service life. A working group from the German Federal Ministry of Transport with the participation of the Research Institute compiled a list of technical options to maintain these concrete road surfaces. The targeted use of suitable measures should extend the life of the affected roads and avoid them having to be renewed prematurely. The measures were defined in relation to the degree of damage.

Three damage categories were formed: 1: start of crack formation, 2: serious cracking and 3: very serious cracking and concrete breaking off (loss of load-bearing capacity). Road surfaces in damage categories 2 and 3 have to be covered with asphalt in varying thicknesses to improve their load-bearing capacity. The effectiveness of other measures is to be investigated for road surfaces in Category 1, with only shallow cracks and where the load-bearing capacity is not reduced. For this purpose, a test section was set up on the A14 motorway in Germany (built in 2000). The road surface has two layers in which a reactive aggregate was used in the top course concrete. Various test sections were set up in summer 2008. Two different methods were investigated which are used in road maintenance to e.g. improve grip: a bitumen emulsion applied as DSK slurry surfacing and an epoxy resin coating. DSK slurry or coating was applied to the road surface and then a

![Fig. V.39: Impregnating the concrete road surface with linseed oil](image-url)
Polishing-resistant aggregate was spread over the surface. Two sections were also impregnated with linseed oil (Fig. V-39) and a hydrophobing agent respectively. With these four variants the moisture absorption of the concrete was reduced. If the effect is long term, this removes the conditions for a damaging ASR – swelling of the gel that occurs as a result of water absorption. In another variant the surface of the concrete road was treated with a lithium nitrate solution. Lithium bonds much better to the alkali-silicate gels than sodium or potassium. The gel that is formed does not swell as much when it comes into contact with water. A requirement is that the lithium can penetrate sufficiently deep into the roughly 7 cm thick damaged top course concrete. The fundamentals for lithium treatment were developed in a previous research project carried out by the Research Institute for the German Federal Ministry for Transport, Building and Urban Development (BMVBS). To assess the success of the measures, the test sections and additional reference sections are being monitored by the Federal Highway Research Institute (BASi). Crack development is determined at various points in time.

Concrete in municipal road construction

Areas of application for concrete road surfaces in the municipal area are, for example, roundabouts, bus stops and bus lanes, inner-city crossings, heavily used approach roads in major cities and also whitetopping, where a concrete overlay is applied to an existing asphalt surface. So far, there has been little use of concrete construction methods in these areas, which would suggest that there is a lot of potential. Consequently, pilot projects are to be carried out for the named areas to gather experience in all phases from planning through to implementation. The planned equipment engineering has to be adapted to suit the respective local conditions. If necessary, a partner-like cooperation should be established with the local concrete suppliers. The construction work can be carried out by regional construction companies. The only requirement is that these companies have sufficient experience in concrete construction. Upon completion of the pilot projects the knowledge gained from them should be documented and published.

One example of a successful pilot project is the first concrete roundabout in Germany, which was built in 2008 (Fig. V-40). Concrete roundabouts are now widespread in Austria, Belgium, the Netherlands and Switzerland.

Regulations

To achieve a standard design of the contractual fundamentals in terms of the special needs of municipal road construction, it would be advantageous to adapt the regulations (TL and ZTV Beton-StB 07). Suitable codes of practice should be drafted, for roundabouts for example. Experience has shown that this makes implementation much easier.

Modelling

On the basis of 50 normal cements manufactured in Germany with different compositions, investigations were carried out in the Research Institute within the scope of AiF research project no. 14767 N to identify the boundary conditions under which it is possible to calculate the standard compressive strength of 28-day old cement based on key cement data with the help of the Virtual Cement and Concrete Testing Laboratory (VCCTL) software product. The input data for the simulation calculation were chemical-mineralogical and physical parameters of cement and aggregate as well as key data that was determined by digital image analysis (e.g. clinker phase distribution). The simulation calculations were compared with the results from the experimental investigations (e.g. hydration heat, composition of the pore solution, porosity, compressive strength).

Simulation of cement hydration

Age-related simulation of cement hydration was carried out through iteration until a desired end point. The connection between the iteration steps and the actual progress of hydration was calculated in VCCTL for every cement via a time conversion factor, which determines the time comparison with the measured hydration heat. To simulate compressive strength after 28 days, as late a time as possible was chosen for the comparison, the hydration heat values after seven days.

Fig. V-41 shows the progress of hydration heat for two Portland cements CEM I 32,5 R from different origins. The 7-day comparison of the simulated hydration heat to the hydration heat determined by heat flow calorimetry (TAM) produced with some cements (Fig. V-41, left) a good correlation with the hydration heat trend while with others (Fig. V-41, right) the correlation was not so good.

The simulated hydration heat trend deviated from the measured hydration heat in many cements. In many cases the simulated development of hydration heat was well above the measured hydration heat. In these cases the simulated hydration proceeded faster than the actual hydration.

In the investigation as to whether groups of cements could be aggregated for the simulation calculations by choosing certain parameters, no direct connection between the strength class and the time conversion factor was identified.

While the simulation calculations for the effect of the tricalcium silicate content on compressive strength largely matched the experience values, the effect of sulphate agents on hydration heat development did not meet expectations.
With some cements, simulation of the composition of the pore solution produced sulphate and calcium ion concentrations in the pore solution that were clearly too high. Even when the sulphate agent was fully consumed with these cements, the simulated sulphate ion concentration in the pore solution remained at almost the same level. The programme code needs to be examined as regards consideration of the setting regulator types.

Porosity
The porosities for cement paste aged 7 and 28 days determined with mercury intrusion were up to 10 % by volume above the respective values of the simulation calculation. Among other things, this can be attributed to the fact that only “capillary porosity” is contained in the VCCTL programme. In many cases, the pore volume determined with mercury intrusion porosimetry was ≥ 0.01 µm of the simulated porosity. The measured porosities of standard mortar were, as expected, well below the measured porosity of the respective cement paste. In contrast, the mortar porosity simulated with VCCTL more or less matched the simulated porosity of the respective cement paste. This allows the conclusion to be drawn that the porosity of mortar has not been simulated correctly to date.

Compressive strength
Simulation of cement hydration provided the composition of the structure and, consequently, data about the space filling behaviour of the hydration products X(t) and about porosity P(t). With the help of Powers’ approach, which assumes a basic strength of the structure D₀ which is reduced by porosity, the course of the compressive strength was calculated using the following equations

\[ D(t) = D₀ \cdot X(t)ⁿ \]
\[ D(t) = D₀ \cdot (1 - P(t))ⁿ \]

The measured compressive strengths of cement paste and standard mortar were compared with the corresponding simulated development of compressive strength. To reflect the measured development of compressive strength by means of the simulated development of compressive strength, for each cement the variables D₀ and n had to be determined separately on the basis of the measured compressive strengths. Compared to the values D₀ = 203 MPa and n = 4.67 mentioned by Locher, the compressive strength of the pore-free cement paste D₀ and also the variable n were lower for most of the investigated cements. No general values for D₀ or n to approximate the development of compressive strength in different cement types and strength classes could be derived.

Alternatively, with the VCCTL software it is possible to calculate compressive strength on the basis of correlations with the modulus of elasticity independently from the simulated porosity. The values of the modulus of elasticity from the simulation calculations were, on average, about 2.6 GPa above the measured values. The compressive strengths measured on the basis of the simulated modulus of elasticity were below the measured compressive strengths and correlated with the simulated high porosities of standard mortar but not with the simulated high modulus of elasticity.

Consideration of the aggregate
To investigate the deviations between the simulated porosity and the calculated compressive strength and the corresponding measured value for standard mortar, the influence of various parameters were considered to take account of the aggregate in simulation calculations.

On the whole it became clear that especially the choice of the modulus of elasticity for the aggregate, the particle size distribution of the standard sand and the size and properties of the contact zone are important factors for the simulation calculation of compressive strength after 28 days.

Summary
To summarise, it can be said that the simulation of the development of compressive strength in standard mortar up to 28 days old could not be predicted reliably for the different cements without using information concerning the aggregate.

Apart from the parameters of the cements used, the parameters of the aggregate and the transition zone from stone to unaffected cement matrix are also important for the result of the simulation. Simply varying these parameters within the normal fluctuation range can have a serious effect on the result of the simulation.

Basically, the VCCTL model seems suitable for mapping hydration of cement. However, the software requires further development especially in terms of simulating porosity of mortar and the composition of the pore solution and also as regards the influence of sulphate on the hydration process.
Table V-11: Exposure class-related requirements for a planned life of at least 50 years in terms of the minimum and maximum values and the most frequently used value for minimum concrete cover, the minimum compressive strength class, the maximum permissible water-cement value and the minimum cement content

<table>
<thead>
<tr>
<th>Exposure class</th>
<th>Minimum concrete cover, mm</th>
<th>Minimum compressive strength class</th>
<th>Maximum permissible water-cement value</th>
<th>Minimum cement content in kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>max</td>
<td>m.f.u.v.</td>
<td>min</td>
</tr>
<tr>
<td>XC1</td>
<td>10</td>
<td>20</td>
<td>NS</td>
<td>C25/50</td>
</tr>
<tr>
<td>XC2</td>
<td>15</td>
<td>35</td>
<td>NS</td>
<td>C28/55</td>
</tr>
<tr>
<td>XC3</td>
<td>10</td>
<td>35</td>
<td>NS</td>
<td>C32/40</td>
</tr>
<tr>
<td>XC4</td>
<td>15</td>
<td>40</td>
<td>NS</td>
<td>C32/40</td>
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<tr>
<td>XD1</td>
<td>25</td>
<td>40</td>
<td>NS</td>
<td>C40/50</td>
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<td>NS</td>
<td>C50/60</td>
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<td>40</td>
<td>NS</td>
<td>C40/50</td>
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<td>45</td>
<td>NS</td>
<td>C40/50</td>
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<tr>
<td>XS3</td>
<td>30</td>
<td>50</td>
<td>NS</td>
<td>C50/60</td>
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<tr>
<td>XF1</td>
<td>–</td>
<td>–</td>
<td>NS</td>
<td>C32/40</td>
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<td>NS</td>
<td>C35/45</td>
</tr>
<tr>
<td>XF3</td>
<td>–</td>
<td>–</td>
<td>NS</td>
<td>C40/50</td>
</tr>
<tr>
<td>XF4</td>
<td>–</td>
<td>–</td>
<td>NS</td>
<td>C40/50</td>
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<tr>
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<td>–</td>
<td>–</td>
<td>NS</td>
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<td>–</td>
<td>NS</td>
<td>C40/50</td>
</tr>
<tr>
<td>XA3</td>
<td>–</td>
<td>–</td>
<td>NS</td>
<td>C40/50</td>
</tr>
</tbody>
</table>

m.f.u.v.: most frequently used value
NS: No specification

Standardisation

The European concrete standard EN 206-1

According to the CEN regulations, CEN standards have to be routinely reviewed every five years. For European concrete standard EN 206-1 this review would have been due in 2005. However, since at that time the standard had not yet been applied in some EU countries and in others had only recently been adopted, the responsible bodies had little experience with the standard. Consequently, it was decided that there would be little point in CEN/TC 104, “Concrete and related products” reviewing EN 206-1 before 2010. This decision was confirmed at the CEN meetings in Larnaca in November 2005 in the corresponding resolutions.

A working group of CEN/TC 104/SC1 “Concrete” has developed a synopsis of the national application documents (NAD) for the European concrete standard EN 206-1. This synopsis has made it clear that it will be almost impossible to further standardise definitions that are relevant to durability. Table V-11 provides an overview of the requirements in terms of minimum and maximum values and the most frequently used values as regards minimum concrete cover, the minimum compressive strength class, the maximum permissible water-cement value and the minimum cement content. The most frequently used value is the value that has been chosen by more CEN member states than any other; but this should not immediately be interpreted as meaning that this value is actually used by most CEN member states. The following conclusions were drawn:

- In the majority of cases the values used most frequently for the maximum permissible water-cement value and the minimum cement content correspond to the values recommended in EN 206-1, Table F.1.
- In Denmark, where the lowest minimum cement contents are prescribed, compliance with a minimum powder content is also required. In Denmark, the minimum cement content cannot be reduced if Type II additions are used.
- In five cases (XC1, XC2, XC4, XD1 and XD3) the most frequently used values for the minimum compressive strength class, the maximum permissible water-cement value and the minimum cement content in all three categories match the values recommended in EN 206-1, Table F.1.

At its meeting in Stockholm in June 2007, CEN/TC 104/SC1 defined a road map for further revision of the European concrete standard EN 206-1. In June 2008, CEN/TC 104/SC1 put the road map into more specific terms. For the revision date in 2010 status papers have been compiled for issues such as the equivalent durability concept, the use of concrete additions, conformity assessment of concrete and alkali-silica reactions (ASR). These papers are the cornerstones for the subsequent new version of the standard.
Principles for revision of European concrete standard EN 206-1

- **Equivalent durability procedure (EDP)**
  - Regulation for durability-relevant aspects
  - Application possible only if put into force nationally (definition of a “reference concrete”)

- **Type II additions**
  - The currently standardised additions, fly ash, silica fume and ground-granulated blastfurnace slag are handled
  - The k-value concept can be used for all Type II additions
  - Cements with several main constituents should be considered

- In principle, the regulations for conformity assessment and production control for concrete should remain unchanged

- **Alkali-Silica Reaction**
  - No general classification of aggregates at an European level
  - Preventative measures regulated nationally

**Equivalent durability procedure (EDP)**

The concept described in Annex E of EN 206-1 has hardly been applied anywhere in Europe to date. The Dutch system of so-called “Attestbeton” or certified concrete could be described as an exception. The concept according to Annex E can be used to prove that the performance (essentially the durability) of concrete with additions is at least equivalent to a reference composed according to the descriptive rules (min c, max w/c, etc.) of the corresponding national annex. In Germany, this principle can only be applied within the scope of national technical approvals from the German Institute for Building Technology (DIBt). In the course of the revision it is now to be examined to what extent the procedure described in Annex E, which has so far been limited to proof for concrete additions, could be used in case of deviations from the descriptive approach and, at the same time, how this procedure can be put into more specific terms. This includes defining the reference situation (“reference concrete”) and the issue of which test methods are suitable and generally acceptable. The aim is to discover both opportunities (proof of equivalent durability of new concrete constituents) and challenges (softening well-tried and proven descriptive rules or negative assessments of solutions that have been proven in practice). The principle of equivalent durability should not be confused with the concept described in the UK concrete standard: the combinations principle. In the combinations principle, defined combinations of certain cements and concrete additions are to be inspected; largely corresponding to the inspection prescribed in EN 197-2. The “equivalence” of combinations of Portland cement together with GGBS, fly ash or limestone meal with cements of a suitable composition is implied on the basis of the results of a strength test pursuant to EN 196-1. Even if it is accepted that this procedure can be used only for known combinations of Portland cement and additions, in Germany it is inconceivable at the present time that it could be applied without an initial test and the corresponding durability tests. Apart from that, further national technical approvals would be required. The following principles were defined for the revision:

- A principle of equivalent durability should be included for all exposure classes.
- A detailed description will be possible for exposure classes XC, XD and XS.
- The option of specifying performance (= durability) directly on the basis of limit values should still be available. EN 206-1 may possibly recommend the test methods but will not specify any values.
- The concept can be used only when a CEN member state has defined its “reference concretes”.

**Concrete additions**

The general suitability of concrete additions for manufacturing concrete according to EN 206-1 is proven for stone dusts according to EN 12620, pigments according to EN 12878 (almost inactive additions Type I), the pozzolanic concrete additions fly ash according to EN 450-1 and silica fume according to EN 13263-1 (Type II). Type II additions may be counted together with the cement content and the water-cement value if they have been proven to be suitable in the concrete composition (k-value approach). The suitability of this approach is deemed to have been proven for fly ash and silica fume. However, the k-value approach in the form described in EN 206-1 is not used in many countries – and also not in Germany. Thus, the aim should be to get a general description and extend this to cements with several main constituents. The future EN 206-1 should also contain a reference to the European product standard for granulated blastfurnace slag, EN 15167-1. Apart from the k-value approach, which most countries with a national application rule have chosen for GGBS as a concrete addition, the principle of the equivalent durability concept and the UK combinations concept should also be examined. The following principles have been defined for the revision:

- The k-value concept and the equivalent durability concept will remain unchanged.
- General aspects of the combinations concept used in the UK should be added.
- A reference to GGBS should be made in combination with the above-mentioned concepts.
- The concepts for using additions should be described together with CEM II cements and in a general form. Detailed rules for their use will continue to be regulated nationally.

**Alkali-Silica Reaction (ASR)**

To coordinate further activities in regard to ASR (see section on Alkali-Silica Reaction), a joint working group of the CEN standardisation committees for cement and building lime (TC 51), aggregates (TC 154) and concrete (TC 104) has been set up under the leadership of the Research Institute of the Cement Industry. The working group makes the following recommendations:

- A (complete) specification to prevent damaging ASR is not possible within the scope of European concrete standard EN 206-1. Only principles can be described.
- Alkali reactivity of aggregates can be classified only on a national level.
- EN 206-1 cannot contain any limit values for effective alkali contents in concrete, as this requires a classification of aggregate combinations with consideration of national experience.
A2 and A3 changes to DIN 1045-2

The European concrete standard EN 206-1 “Concrete – Part 1: Specification, performance, production and conformity; German version of EN 206-1:2000” allows as a non-mandated and, thus, non-harmonised standard National Application Documents (NAD) with various sections in order to take account of different climatic and geographical conditions, different protection levels and long-established regional customs and experience. In Germany, these National Application rules are defined in DIN 1045-2. The national standards committee on concrete technology has voted on a list of changes to be made to DIN 1045-2. This was necessary due to application experience and the updating of other product standards for concrete constituents and their national application regulations. The A2 changes were published in June 2007.

Within the scope of the A2 changes the standard was revised with regard to the following points:

- **Adaptation to the new and revised European standards for concrete constituents**
  In the meantime, European standards for silica fume (EN 13263) and an amended version of the standard for fly ash (EN 450) have been published. Reference is made to these standards. The application regulations from the drafts of the E DIN V 20000-106/107 series of standards envisaged for Germany in terms of the environmental compatibility of fly ash and the application regulations for silica fume and silica suspensions have been adopted.

- **K-value concept for fly ash also in exposure classes XF2 and XF4 for frost attack with de-icing agents and the corresponding change to the application regulations for cements containing fly ash**
  It is now also possible to use the k-value concept for fly ash for exposure classes XF2 and XF4 (frost with de-icing agent) with the known regulations. In this connection the use of cements containing fly ash is no longer excluded in these and other exposure classes. For example, in the past if Portland-fly ash cement CEM II/A-V or Portland-composite cement CEMII/A-M (P-V) were used in concrete for exposure class XF3, it was not permissible to use the k-value concept with fly ash used as a concrete addition for the water-cement value or for the minimum cement content. This restriction no longer exists, nor do the usage restrictions for CEM II/A-V in exposure classes XF2 and XF4 or CEM II/B-V in exposure classes XF2, XF3 and XF4. In addition, CEM II/A-M (S-V) and CEM II/A-M (V-T) can now be used in concretes according to DIN EN 206-1 and DIN 1045-2 with no restrictions. For cements CEM II/B-M (D-V) and CEM II/B-M (P-V) there is no longer any restriction on use for exposure class XF3. The application regulation for fly ash as a concrete addition goes further than the ZTV-ING regulations. In these regulations fly ash can be counted only for exposure class XF2 and only for tunnel construction. In the ZTV-ING area, the “saturation value” of the concrete must also be determined within in the scope of an extended initial test (see ZTV-ING, Part 3 “Massive Construction”, Section 1 “Concrete”, Paragraph 3.2 (7) “Use of additions”).

- **Consideration of the definitions of the Alkali Guidelines from the German Committee for Structural Concrete (DAfStb)**
  Integration of the moisture classes on the basis of the exposure classes The German Committee for Structural Concrete (DAfStb) has revised and issued a new version of the “Alkali Guidelines”. The regulations were integrated into the respective points of DIN 1045-2/A2. The so-called moisture class must now be stated in the definition of a concrete. The “Exposure Class” table of DIN 1045-2 has been supplemented by a corresponding section for the moisture classes of the “Alkali Guidelines” (see section on “Alkali-Silica Reaction”). Since the customer must state the moisture class for every definition of a concrete, consequently, the ready-mixed concrete delivery specification must also contain the moisture class. In future, every ready-mixed concrete delivery ticket must include the moisture classes that are possible for the respective concrete (WO, WF, WA or WS). In the past, this was necessary only in the “core application area” of the Alkali Guidelines (e.g. North Germany).

- **Consideration of fibres according to European standard EN 14889-1/2**
  Fibres for concrete (steel fibres and polymer fibres) have now been standardised throughout Europe. Use in concrete according to EN 206-1/DIN 1045-2 will be allowed with the A2 change. Fibres according to this standard may be added to the concrete; however, their load-bearing effect may not be considered. Further national technical approvals are required here; for instance, in the same way as steel fibres are to be considered in a DAfStb guideline. With the A2 change general information is provided for handling and adding fibres based on the regulations for additions. Polymer fibres and steel fibres were used in concrete for exposure classes XF2 and XF4 for frost attack with de-icing agents (e.g. North Germany). In these regulations fly ash can be counted only for exposure class XF2 and only for tunnel construction. In the ZTV-ING area, the “saturation value” of the concrete must also be determined within in the scope of an extended initial test (see ZTV-ING, Part 3 “Massive Construction”, Section 1 “Concrete”, Paragraph 3.2 (7) “Use of additions”).

- **Stating the sulphate content of the groundwater in exposure class QA when the concrete is specified and ordered**
  Another footnote has been included in Table 2 of DIN 1045-2. Accordingly, in exposure class QA and with sulphate concentrations above 600 mg/l in the groundwater, the customer must state the sulphate content when specifying the concrete. The ready-mixed concrete manufacturer can then choose a suitable cement with a high sulphate resistance (HS-cement), take account of the regulations for the use of fly ash and identify the concretes in the delivery documents accordingly.

- **Adapting the procedure to determine strength development in a concrete in case of a proof age for compressive strength other than 28 days.**
  The regulations from the DAfStb guideline for “Massive concrete construction components” have been adopted. In special applications the compressive strength of a concrete is determined more after 28 days, for these concretes the calculation of strength development (see DIN 1045-2, Tab. 12, r-value) must be adapted. Strength development should then be determined from the ratio of average compressive strength after two days and the average compressive strength at the time the compressive strength is determined. That means that it is not the strength after 28 days that is used for the calculation, but rather the value after 56 or 91 days. This procedure corresponds with the regulation that was already introduced in the DAfStb guideline for “Massive concrete construction components”.

- **Integration of the A1 changes to DIN 1045-2 from 2005.**
  The A1 changes already published in 2005 have been adopted and integrated into the A2 changes.

The following points were implemented in another change (A3 change):
The previous standards DIN V 20000-100 (application regulations for concrete admixtures), DIN V 20000-103 (application regulations for aggregates) and DIN V 20000-104 (application regulations for lightweight aggregates) have been adopted;

Supplementary definitions from the Technical Construction Regulations (e.g. for pigments) and the list of construction rules were integrated into the A3 change;

Application regulations for cements according to DIN EN 197-1, German version of EN 197-1:2001+A1:2004+A2 (SR cements) +A3 (fly ash) have been adopted.

As an application regulation for the SR cements the following comment has been added at the appropriate places: “Until DIN EN 197-1/A2 is available, the definitions in DIN 1164-10 must be complied with for HS cements. As soon as E DIN EN 197-1/A2 can be used, the requirements for HS cements are deemed to be fulfilled if a cement with high sulphate resistance according to E DIN EN 197-1/A2 (CEM I-3 SR 3 or lower, CEM III/B-SR, CEM III/C-SR) is used.”

Cements containing fly ash used to manufacture concrete according to DIN 1045-2 may contain only fly ash with up to 5% loss on ignition.

A consolidated version of DIN 1045-2 was published in August 2008. This now contains the A2 and A3 changes to DIN 1045-2:2001-07 and the requirements from DIN V 20000-100, DIN V 20000-103, DIN V 20000-104, DIN V 20000-106 and DIN V 20000-107. The changes to DIN 1045-2:2001-07, resulting from DIN 1045-2/A2:2007-06, E DIN 1045-2/A3:2008-01 and the results of the consultations regarding objections to E DIN 1045-2/A3 are marked with vertical lines beside the text. In addition, changes were made to the standard references to take account of the current status of the reference documents; however, these are not marked. An updated version of DAFStb booklet 526 will be published some time in 2009.

DAFStb Guideline “Massive concrete construction components”

The reason for the revision of the guideline was the new issue of DIN 1045, Parts 1 to 3, in August 2008. Use of the k-value concept for fly ash also in exposure classes XF2 and XF4 for frost attack with de-icing agents (see above) as described in DIN 1045-2:2008-08 was transferred to concrete compositions for massive construction components.

Fire protection

In terms of fire protection, a distinction is generally made between preventive and defensive fire protection. Defensive fire protection applies only when a fire has already started and essentially covers the fire brigade’s work in extinguishing the fire. In contrast, preventive fire protection is used to prevent or limit the start or spread of fires. In addition to technical fire protection, which in particular includes fire alarm systems and automatic extinguishing systems, structural fire protection is one of the crucial pillars for the necessary level of safety in the area of preventive fire protection. Structural fire measures are permanent and offer the required level of protection without having to be triggered by operational or mechanical processes, which always harbour a risk of failure. Defensive fire protection depends on the deployment of the fire brigade, where there is also a risk of failure.

Concrete structural elements are a relatively simple way of fulfilling fire protection requirements and usually involve no major additional expenditure. The non-flammable construction material, concrete, can be used to build structural elements with a high resistance to fire and with a correspondingly stable shielding effect. This means that in the event of a fire, concrete structures retain their stability for a long time and that fires can be restricted to confined areas. These fire protection properties of concrete and concrete building members contribute to safety for human life, which has top priority in statutory fire protection requirements. However, saving the building itself or the contents of the building are also important in terms of protecting assets. Even if legislation has made protection of property the personal responsibility of the building owner and users, saving assets is in the interest of both private individuals and the general public. Furthermore, structural fire protection measures also protect the environment if effective fire limitation reduces smoke and gas emissions as well as the amount of extinguishing water that is needed and when the extinguishing water, which is generally contaminated, can be retained.

National regulations (Germany)

DIN 4102 “Fire behaviour of building materials and building components”

VDZ participated in the development of the A2 change to DIN 4102-4 “Synop-
Other important changes in the new standard are the consideration of facility protection systems (e.g. self-activating fire extinguishing systems) for the reduction of fire loads and new definitions for the consideration of openings in the calculation of heat dissipation.

**European cooperation**
The European associations for precast concrete (BIBM, Bureau International du Béton Manufacture), ready-mixed concrete (ER-MCO, European Ready Mixed Concrete Organisasion) and the cement industry with the participation of representatives from 14 nations are working together in the European Concrete Platform working group “Fire Safety with Concrete” to promote concrete construction under fire protection aspects. Within the scope of this cooperation, developments in the field of international standardisation regarding fire safety are also being monitored.

A brochure developed by the working group at the start of 2007 entitled “Comprehensive fire protection and safety with concrete” was also published in 2008 in German as “Umfassender Brandschutz mit Beton” (Fig. 42). This brochure is aimed at architects, building owners, authorities, insurance companies and the general public. The idea behind it is to show how concrete can be used to implement comprehensive fire protection; in other words, protection of human life, property and the environment.

**International developments in the field of fire protection**
The traditional load-bearing design for fire cases is carried out using standard tables in which the minimum dimensions or protective cladding for individual building members are defined so that they achieve the required fire resistance class. These tables are based on standard fires that map a standardised temperature rise over a certain period, such as the temperature-time curve in accordance with DIN 4102 Part 2. For concrete construction components, high fire resistance times of more than 120 minutes without cladding or intumescent coatings must be achieved if the building members and their concrete cover are properly dimensioned.

Fire Safety Engineering (FSE) methods have been developed over the last ten to fifteen years. Their goal is to enable a realistic, holistic estimate of the effects of a fire on a building or part of a building. In other words, the aim is no longer to base assessments simply on individual building members or standard fires. In a typical design using fire safety engineering methods, the first thing to do is define protection goals. The top priority is to protect human life and health; but property protection targets can also be defined. Fires are modelled with consideration of the actual existing fire loads and the geometry of the fire compartments under consideration, while the thermal and mechanical effects on the surrounding construction components are also determined. For example, the assessments take account of automatic fire detection and active fire fighting via automatic fire extinguishing systems or by the fire brigade. Computer programmes are used to simulate the effects of a fire or the behaviour of groups of people trying to escape from a burning building. In many cases the requirements for fire protection in the individual construction components are reduced when applying FSE.

The Eurocodes, the harmonised European standards for the design of building structures, also include Fire Safety Engineering methods. The ten Eurocodes consist of 58 parts, all of which were published by the end of 2007. Eurocode 2, consisting of four parts, regulates the design and construction of reinforced and prestressed concrete structures. At present, the participating member states are compiling the National Annexes, in which national choices for specific parameters or processes are specified. Guidance Paper L from the European Commission envisages complete implementation of the Eurocodes by 2010.

Fig. V-43 shows the various different possibilities of fire design according to the Eurocodes. Fire Safety Engineering methods are included here under the heading “Ad-
nty and expert advisory services rendered by the Research Institute of the Cement Industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. This principally applies to the industry has increased considerably over the past years. 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strength of the sealed LC was approx. 4 N/mm² after six months. The flowability of the LC was assessed on the basis of rheological investigations. The laboratory results showed that the LC flowed sufficiently well and was easily pumped up to temperatures of 30 °C and for about six hours. Under practical conditions with temperatures of approximately 20 °C, the LC flowed and could be pumped for roughly 11 hours. The LC exhibited no corrosion-promoting effects on steel.

**Filling the reactor chamber**

To ensure the quality of the LC, the Research Institute drafted a monitoring concept defining measures for third-party inspection of the constituents, of the properties of the fresh concrete while the reactor chamber was being filled and of the hardened concrete properties after the chamber had been filled. Within the scope of this third-party inspection concept, the Research Institute inspected the quality and uniformity of the constituents before the filling process commenced. The suitability of the constituents for manufacturing LC for the filling was investigated on the basis of chemical-mineralogical analyses and performance tests. The portioning of the constituents before the filling was also monitored. During the filling the following fresh concrete properties were monitored:

- Bulk density of the fresh concrete,
- Temperature of the fresh concrete,
- pH-value,
- Shearing resistance,
- Sedimentation stability.

A total of 20 batches of LC each approx. 25 m³ were mixed (Fig. V-45). All batches fulfilled the requirements defined in the third-party inspection concept and the client’s requirements. The filling of about 500 m³ LC into the reactor chamber was completed in roughly 10 hours.

Besides providing concrete technology consultancy and expert advisory services, the Research Institute can also carry out virtually all concrete technology investigations and tests under the terms of contract investigations. Customary standardised testing is accredited according to EN ISO 17025. In order to be braced for any future questions arising, the pool of testing equipment is continually extended.