STUDIES CONCERNING SELF COMPACTING CONCRETE
1. INTRODUCTION

• The concrete it is the man-made material which has the vastest utilization worldwide. This fact leads to important problems regarding its design and preparation to finally obtain an economic cost of the product on short and long time periods. The material has to be also “friendly with the environment” during its fabrication process and also its aesthetical appearance when it is used in the structures.

• Its success is due to the following:
• its raw materials have a large spreading into the world;
• the prices of raw materials are low;
• the properties and the performances of the concrete confers it a large scale of application (Concrete’s properties can vary and also can be exceptional: compression strength ranging between 0.1MPa to 800MPa, volumic masses between 100 kg/m3 up to 5000kg/m3).
• In Japan in the year 1988, self-compacting concrete (SCC) emerged on the scene and it has been the subject to numerous investigations in order to adapt it to modern concrete production. At the same time the producers of additives have developed more and more sophisticated plasticizers and stabilizers tailor-made for the precast and the ready-mix industry.

• Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.
ADVANTAGES OF SCC:

• - from the contractors point of view costly labour operations are avoided improving the efficiency of the building site;
• - the concrete workers avoid poker vibration which is a huge benefit for their working environment;
• - when vibration is omitted from casting operations the workers experience a less strenuous work with significantly less noise and vibration exposure;
• - SCC is believed to increase the durability relatively to vibrated concrete (this is due to the lack of damage to the internal structure, which is normally associated with vibration) [1].
1.1. Development of SCC

• For last 20 years, the problem of the durability of concrete structures was a major topic of interest. To make durable concrete structures, sufficient compaction by skilled workers is required. However, the gradual reduction in the number of skilled workers in construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures, independent of the quality of construction work, is the use of self-compacting concrete, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction (Fig. 1) [1].
Fig. 1 Necessity of Self-Compacting Concrete

Skill of workers

Self-Compacting Concrete

decreasing in the future

Durable concrete structures
Self compacting concrete (SCC) is a concrete which flows to a virtually uniform level under the influence of gravity without segregation, during which it de-aerates and completely fills the formwork and the spaces between the reinforcement [2]. It is a high-performance concrete with the special property of the fresh concrete of “self-compacting”. As with other high-performance concretes (e.g. high-strength concrete, acid-resistant concrete) the special properties of these concretes, which differ from normal concretes, are achieved only by systematic optimization both of the individual constituents and of the composition. The flowability and mix stability of the SCC are determined primarily by the interactions between the powder (cement and additions with a particle diameter < 0.125 mm), water and plasticizer. The gradation of the individual size groups in the overall grading curve also affects the property of the concrete of not being blocked by the reinforcement.
• It has been found that, in contrast to vibrated concrete, the workability properties required for self compaction cannot be maintained relatively easily over a fairly long period. Fluctuations in the workability of vibrated concrete can be largely offset by the intensity of vibration applied during placement, but this is not possible with SCC. The effects of production and transport on the workability properties of SCC must therefore be taken into account in the initial testing [2].
1.2. SCC Limitations

• One of the obvious limitations of producing SCC is the higher material costs - not only for the admixture itself, but for the increased quality-control testing needed for concrete and aggregates.
2. COMPOSITION AND PROPERTIES OF CONCRETE

• The basic components for the mix composition of SCC are the same as used in conventional concrete.

• In order to obtain the requested properties of fresh concrete for SCC a higher proportion of ultra fine materials and chemical admixtures (in particularly an effective superplasticizer and viscosity-modifying agent) are necessary to be introduced.

• Ordinary and approved filler materials are: limestone powder, quartzite powder and recycling industrial waste like fly ash, blast furnace slag and silica fume.
A typical mix design of SCC in comparison with conventional concrete is shown in figure 2 [3].
Self compacting concrete has the following three principal characteristics:

- the ability to flow into forms;
- the ability to freely pass through reinforcements;
- resistance to segregation.
Figure 3. The mix flow through spaces between reinforcement
Based on the original conception of Okamura and Ozawa, at this moment 3 types of SCC can be distinguished:

• - *Powder type*, increase of the flour grain content;

• - *Viscosity-Agent type*, use of viscosity-modifying admixture;

• - *Combination type*, a combination of both before designated types.
The requirements from “The European Guidelines for Self Compacting Concrete” for fresh self-compacting concrete shall be measured by means of the following tests (for characteristic):

- slump-flow and T500 test (for flowability);
- V-funnel test (for viscosity);
- L-box test for (passing ability);
- segregation resistance test.
Component materials:

- **Aggregates:**
  - Both natural and crushed aggregates can be used for self-compacting concrete. Crushed aggregate needs normally more paste. It has been shown that crushed sand can be used but the dosage of Superplasticizers is much larger. Less maximum aggregate size needs less paste content. Most frequently used maximum aggregate size taken in account both the consortium and other project is between 16-20mm [4]. As SCC is very sensitive to water content the humidity of the aggregates has to be measured carefully.
• **Filler:**

  - Natural filler together with a silica fume can be used to create necessarily paste content and together creating stable concrete. More superplasticizer must be used then for normal filler.

  - There are many types of filler that can be used for creating self-compacting concrete such as: limestone, dolomite, fly ash etc. Every filler has its on influence on the mix for self compacting concrete and must be investigated by different methods (mortar rheology tests) and mixing trials. The grading curve for the filler can be finer graded for house building concrete with fewer amounts of filler then for civil engineering. If possible avoid grading curve, which coincide with the cement’s grading curve. A relative flat grading curve, compared to the cement, has been shown to give good workability with a reasonable amount of admixture [4].
• **Viscosity agent:**

• The most critical influence from using a viscosity agent is the change in concrete strength development. When using a viscosity agent the early strength is considerably decreased. Investigation when using lime stone filler has shown that the earlier strength is increased. Lime stone filler can also replace cement. Other fine graded filler can also have the same effect e.g. possibility of replacing cement for a given concrete strength.

• Investigation on reducing filler by replacing with a viscosity agent has shown that up to about 10% of paste content can be replaced by using a viscosity agent.
• **Superplasticizers:**

• *Of the tested superplasticizers, Glenium 51 had the best tendency to give a stable mix with high slump flow values. Glenium 51 has the highest earlier compressive strength and final compressive strength.*
• Sika has developed a new range of ViscoCrete products:
  • Sika ViscoCrete-2 for self-compacting concrete with normal workability and cooler ambient temperatures.
  • Sika ViscoCrete-3 for self-compacting concrete with silica fume additions.
  • Sika ViscoCrete-5 for self-compacting concrete in precast concrete production.
Vinylcopolymers:
Modified polyacrilates:

These modified polyacrilates are used in ViscoCrete range.
The ViscoCrete admixtures are high performance 3rd generation high water reducers. Water reduction it is close to 40% of water reduction depending of the superplasticizer dosage. Due to that water reduction the strength development could be increased for the same cement content. Also the shrinkage behavior will be better with this mixes due to the lower water content.
Conformity criteria for the properties of SCC are presented in table 1 [3].

<table>
<thead>
<tr>
<th>Property</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump-flow class SF1</td>
<td>( \geq 520\text{mm}, \leq 700\text{mm} )</td>
</tr>
<tr>
<td>Slump-flow class SF2</td>
<td>( \geq 640\text{mm}, \leq 800\text{mm} )</td>
</tr>
<tr>
<td>Slump-flow class SF3</td>
<td>( \geq 740\text{mm}, \leq 900\text{mm} )</td>
</tr>
<tr>
<td>Slump-flow class specified as a target value</td>
<td>( \pm 80\text{mm} ) of target value</td>
</tr>
<tr>
<td>V-funnel class VF1</td>
<td>( \leq 10\text{s} )</td>
</tr>
<tr>
<td>V-funnel class VF2</td>
<td>( \geq 7\text{s}, \leq 27\text{s} )</td>
</tr>
<tr>
<td>V-funnel specified as a target value</td>
<td>( \pm 3\text{s} )</td>
</tr>
<tr>
<td>L-box class PA1</td>
<td>( \geq 0.75 )</td>
</tr>
<tr>
<td>L-box class PA2</td>
<td>( \geq 0.75 )</td>
</tr>
<tr>
<td>L-box specified as a target value</td>
<td>Not more than 0.05 below the target value</td>
</tr>
<tr>
<td>Sieve segregation resistance class SR1</td>
<td>( \leq 23 )</td>
</tr>
<tr>
<td>Sieve segregation resistance class SR2</td>
<td>( \leq 18 )</td>
</tr>
</tbody>
</table>
Following comments are made on test methods:

- **Slump-flow** – easy to carry out, can provide an indication of filling ability. Requirement on flow and T50 values should be different for different maximum sizes/shapes of aggregates and admixtures. It is difficult to assess the segregation/settlement tendency. The fresh concrete is poured into a mould in the shape of a frustum of a cone. When the cone is withdrawn upwards, the distance the concrete has spread provides a measure of the consistency of the concrete.
Figure 4. Slump test
• **L-box** – simulates better the real flow/passing ability condition. If bar spacing is selected appropriately it can provide information on self-leveling and on passing ability. Not easy to carry out, and the passing ability ratio depends largely on clear gap settings, on slump-flow and surface condition/wall effect as well as on the geometry of the L-box. It is difficult to identify segregation/settlement [5].
Gap + one smooth bar diameter
The fresh concrete is poured in the vertical part of the L-box. When the sliding gate is lifted the concrete spread provides a measure of the filling ability and the passing ability of the concrete. After the sliding gate is lifted the following parameters may be measured:

- The time for the concrete front to reach 200 mm;
- The time for the concrete front to reach 400 mm marking;
- When the concrete has stopped, the distances $H_1$ and $H_2$ are measured;
- Calculate $H_2/H_1$ (acceptable value of the passing ability ratio, $H_2/H_1$, is normally 0.80 - 0.85 but values as low as 0.60 has sometimes shown to give acceptable results in the actual structure) [7]
• V-funnel
The funnel time $t_V$ is often used to estimate the apparent viscosity of a mixture. However, many factors are playing a role and influencing the result of the V-funnel test: the amount, shape and size distribution of aggregates and also the viscosity and amount of paste etc. This means that the funnel time does not necessarily correspond with the viscosity of a mix measured e.g. by a rheometer.
3. APPLICATIONS OF SELF-COMPACTING CONCRETE

The main reasons for using the self-compacting concrete are:

- the construction period is shorter;
- the compaction in the structure it is assured: especially in confined zones where vibrating compaction is difficult;
- the noise due to vibration it is eliminated: effective especially at concrete products plants.
A typical application example of Self-compacting concrete is the two anchorages of Akashi-Kaikyo (Straits) Bridge opened in April 1998, a suspension bridge with the longest span in the world (1,991 meters). The volume of the cast concrete in the two anchorages amounted to 290,000 m³. A new construction system, which makes full use of the performance of self-compacting concrete, was introduced for this. The concrete was mixed at the batcher plant beside the site, and was pumped out of the plant. It was transported 200 meters through pipes to the casting site, where the pipes were arranged in rows 3 to 5 meters apart. The concrete was cast from gate valves located at 5 meter intervals along the pipes. These valves were automatically controlled so that a surface level of the cast concrete could be maintained. In the final analysis, the use of self-compacting concrete shortened the anchorage construction period by 20%, from 2.5 to 2 years [1].
Figure 8. *Akashi-Kaikyo (Straits) Bridge* using SCC
Self-compacting concrete was used for the wall of a large LNG tank belonging to the Osaka Gas Company, whose concrete casting was completed in June 1998. The volume of the self-compacting concrete used in the tank amounted to 12,000 m³. The adoption of self-compacting concrete means that:
• (1) the number of lots decreases from 14 to 10, as the height of one lot of concrete casting was increased.
• (2) the number of concrete workers was reduced from 150 to 50.
• (3) the construction period of the structure decreased from 22 months to 18 months.
Figure 9. Lattice wall using SCC
Figure 10. Surface detail on precast element with SCC filling under the formwork
Figure 11. Casting an SCC slab. Commercial centre, Ferrara, Italy
The uses of SCC can induce the next benefits for concrete producers:

- ergonomics - a reduction of noise during casting from vibrators;
- speed of placement, resulting in increased production efficiency;
- ease of placement, requiring fewer workers for a particular pour;
- better assurances of adequate consolidation;
- reduced wear and tear on forms from vibration;
- reduced wear on mixers due to reduced shearing action;
- homogeneity of the concrete production;
- improved surface quality (without blowholes or other surface defects);
- increased early strengths;
- consistent water-cement (w/c) ratios of less than 0.35;
The uses of SCC can induce the next benefits for concrete producers:

- reduced energy consumption from vibration equipment;
- reduced permeability;
- excellent pump ability;
- a shortening of the construction time (an improved productivity);
- waste recovery (friendly environment). Low noise-level in the plants and construction sites;
- eliminated problems associated with vibration;
- less labor involved;
- faster construction;
- improved quality and durability;
- higher strength.
## 4. PROPERTIES OF FRESH SELF COMPACTING CONCRETE

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling ability</td>
<td>Ability of to fill a formwork completely under its own weight.</td>
</tr>
<tr>
<td>Passing ability</td>
<td>Ability to overcome obstacles under its own weight without hindrance. Obstacles are e.g. reinforcement and small openings etc.</td>
</tr>
<tr>
<td>Segregation resistance</td>
<td>Homogeneous composition of concrete during and after the process of transport and placing.</td>
</tr>
</tbody>
</table>
• Because of its special fluidity, SCC requires modified fresh concrete testing methods compared with conventional concrete. The difficulty consists of the fact, that SCC responds very sensible to deviations of mixture proportions. Slightest deviations can lead to a concrete that does not has one ore more of these key characteristics. This is usually connected with substantial lack of the finished construction unit, which lower not least the durability drastically and make in the worst case a construction useless [8].
5. PROPERTIES OF HARDENED SELF-COMPACTING CONCRETE

• - the reached compressive strength of SCC and normal vibrated concrete of similar composition, after 28 days, does not differ significantly in the majority of the published test results; can be made just ultra high performance self-compacting concrete;

• - SCC has a tendency of a higher splitting tensile strength: the reason for this fact is given by the better microstructure, especially the smaller total porosity and the more even pore size distribution within the interfacial transition zone of SCC; further due to the higher content of ultra fines particles a dense cement matrix is present;
- the modulus of elasticity of SCC can be with 20% less compared with normal vibrated concrete having the same compressive strength and made of the same aggregates; as it is known, the modulus of elasticity of concrete depends on the proportion of the Young’s modulus of the individual components and their percentages by volume; on the other hand, the modulus of elasticity of concrete increases for high contents of aggregates of high rigidity, whereas it decreases with increasing hardened powders paste content and increasing porosity; a relative small modulus of elasticity can be explicated by the use of the high content of ultra fines powders and additives as dominating factors compared with minor occurrence of coarse and stiff aggregates at SCC;
- in the majority of the publications it is shown that the drying shrinkage of SCC is 10 to 50% higher than that of conventional concrete; a large influence on the shrinkage deformations seems to result from the aggregate combination, especially the relation of coarse to fine aggregates as well as fineness and content of ultra fines; furthermore, a denser microstructure of the cement paste can be achieved by addition of fillers with a fineness larger than that of cement, whereby the shrinkage dimension is positively affected; the shrinkage can be reduced by a higher content of coarse aggregates; however, a minimum paste volume must be present, in order to ensure an optimal self-compaction of SCC without segregation.
6. EXPERIMENTAL PROGRAMME

• 6.1. Experimental programme in the year 2005 made under direct observation of Civil Engineering Department of “Politehnica” University of Timisoara
The experimental programme has taken into account two prestressed beams which were prefabricated and tested on a special stands. The beams of Self-Compacting Concrete with the length of 24 m were prepared at “Beton-Star” KfT, Kecskenet, Hungary and used at the CASCO Satu-Mare.
• The pair of beams with the span of 24 m has been supported on two bearing and was loaded with 20 secondary beams in 4 steps:
• **Step 1** – with 8 secondary beams which represent a load of $8 \times \frac{P}{2} = 8 \times 35.5/2 = 142$ kN.

• **Step 2** – consist of 5 secondary beams which means $5 \times \frac{P}{2} = 88.75$ kN on each main beam. The sum of two steps is $13 \times \frac{P}{2} = 230.75$ kN.

• **Step 3** – was represented by other 3 secondary beams and the total load on each main girder is $16 \times \frac{P}{2} = 284$ kN.

• **Step 4** – was characterized by the last 4 secondary beam and the total load was $20 \times \frac{P}{2} = 355$ kN on each main beam. The total load is obtained by adding at 355 kN of self weight of each main beam, which is of 139.2 kN (5.8 kN/m), so the total load become 494.2 kN and it is 24.71 kN/m.
The load was applied in two cycles of charging-discharging during two days.

- The design loads used for a roof are:
  - weight of the component layers of the roof: 5.4 kN/m;
  - self weight of the beam: 5.8 kN/m;
  - variable weight (including snow): 5.4 kN/m.

Total load is: 16.6 kN/m
• The ratio between the design and experimental loads is:
  \[ \frac{P_{\text{exp.}}}{P_{\text{calc.}}} = \frac{24.71}{16.6} = 1.49 \]
• The theoretical deflection \( f_{ld} \) at final stage is:
  \[ f_{ld} = \frac{5}{384} \times \frac{ql^4}{E_b I} = 13.26\, \text{cm} \]
• were:

\[ E_{bd}^{ld} = \frac{0.8 E^b}{1 + 0.5 \nu \rho} = 14190 \, N/mm^2 \]

• The theoretical short term deflection is:

\[ f_{sd} = \frac{5}{384} \times \frac{q l^4}{E_{sd} I} = 2.38 \, cm \]

• were:

\[ E_{sd}^{sd} = 0.8 E_b = 27600 \, N/mm^2 \]
• The theoretical final deflection result:

\[ \Delta f = f_{ld} - f_{sd} = 13.96 - 2.38 = 10.88 \text{ cm} \]

\[ \Delta f_u = 10.88 - 3.5 = 7.38 \text{ cm} < f_a = \frac{l}{250} = 9.6 \text{ cm} \]

were: 3.5 cm is the negative deflection due to prestressing effect.
The experimental deflections measured during tests were:

\[ f_{\text{expl.}} = 8.2 \, \text{cm} < f_a = \frac{l}{250} = 9.6 \, \text{cm} \]
Figure 12. The pairs of beams charging
Figure 12. The pairs of beams charging
6.1.1. Conclusions of experimental tests

• The using of Self-Compacting Concrete in precast prestressed elements is a feasible solution.

• The tests on a pair of beams of 24 m span at static loads seem a well behavior at serviceability’s limit stages.
6.2. Experimental programme in year 2007

• This program it is a research contract, having time duration of 2 years. It is a CEEX – research-development project titled: “INNOVATIVE SOLUTION OF OPTIMIZATION OF SELF COMPACTING CONCRETE’S MICROSTRUCTURE FOR PERFORMAT REALISATION OF PRECAST CONCRETE ELEMENTS”
The partners in this contract are:

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<th>Organization’s name</th>
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<td>ICECON S.A BUCHAREST CO</td>
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<td>UNI</td>
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<td>TECHNICAL UNIVERSITY FROM CLUJ-NAPOCA</td>
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<td>ROR-IMM</td>
<td>SITCON PRIM S.R.L. P5</td>
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</tbody>
</table>
6.2.2. Experimental program started at “POLITEHNICA” University of Timisoara

- The main characteristics of Self Compacting Concrete which are of interest for us during this research are:
for fresh concrete:

- density
- slump flow
- tests in V-funnel
- tests in L-box
for hardened concrete

- density
- compression strength
- tension strength
- modulus of elasticity.
• Ten compositions will be taken into account as follows to obtain a minimum class of SCC of C35/45, with W/C=0.4 and S5 (180±30 mm):
Martor compositions consisting of:

- **A. First**
- cement type: CEM II/A-S 42.5 R;
- water
- crushed aggregates having calcarous-dolomitical nature and the following sorts:
  - 0-4 mm – in proportion of 46.4%
  - 4-8 mm – in proportion of 20.6%
  - 8-16 mm – in proportion of 25.2%
- calcareous filler – in proportion of 7.8%.
• **B. Second** – same as A adding steel fibers 40kg/m3.
• **3-5. Compositions of SCC** made with different percentages of GLENIUM ACE 30 additive produced by BASF Chemical Company.

• **6-8. Compositions of SCC** made with different percentages of ViscoCrete 20 H additive produced by Sika Company.

• **9 and 10 Compositions of SCC** using the optimum percentage for each additive and adding steel fibers.
6.2.2.1. A-Martor Concrete – TESTS

Figure 13. Slump test
Figure 14. V-funnel test
Figure 15. L-box test
Fresh concrete obtained properties were:

- $\rho_c = 2378 \text{ kg/m}^3$;
- slump class S4;
- V-funnel time = 23s;
- L-box: $T_{200} = 4\text{s}$; $H_1 = 450\text{mm}$; $H_2 = 100\text{mm}$. 
### 6.2.2.2 Characteristics of used additives

<table>
<thead>
<tr>
<th>Additive</th>
<th>GLENIUM ACE 30</th>
<th>Sika® ViscoCrete®-20H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produced by</td>
<td>BASF Chemical Company</td>
<td>Sika Company</td>
</tr>
<tr>
<td>Physical state</td>
<td>liquid</td>
<td>liquid</td>
</tr>
<tr>
<td>Colour</td>
<td>brown</td>
<td>light brown</td>
</tr>
<tr>
<td>Density at 20°C</td>
<td>Approx. 1.06 ± 0.02 g/cm³</td>
<td>Approx. 1.08 g/cm³</td>
</tr>
<tr>
<td>Solid substance contained</td>
<td>cca 30 M-% ± 1,5</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5 -7</td>
<td>4.3 +/- 0.5</td>
</tr>
<tr>
<td>Maximum chlorine content</td>
<td>0.10% related to mass</td>
<td>it doesn’t contain</td>
</tr>
<tr>
<td>Maximum alkali content</td>
<td>8.00% related to mass</td>
<td>-</td>
</tr>
<tr>
<td>Recommended optimum dosage</td>
<td>0.3 ÷ 1.0% related to cement mass</td>
<td>1.0 – 2.0% related to cement mass</td>
</tr>
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</table>
6.2.2.3. Self Compacting Concrete with GLENIUM ACE– TESTS

• The used additive percentage was 1.1% of Cement mass. Ratio W/C=0.40, expected concrete class C35/45.

• Slump test realized on fresh made concrete was not satisfactory, but the time obtained at V-funnel test was 1 min and 10 seconds (Figure 16). L-box test’s results were as following:
• $T_{200} = 3s$;
• $T_{400} = 6s$;
• $H_1 = 180 \text{ mm}$ and $H_2 = 120 \text{ mm}$
(see Figure 17)
Figure 16. V-funnel test on SCC with GLENIUM ACE 30
Figure 17. L-box test on SCC with GLENIUM ACE 30
• The test was made on fresh concrete in the middle of April, so the hardened concrete’s properties are not yet available.

• The next compositions will be carried out in the following days.
7. CONCLUSIONS

• The elimination of vibrating equipment improves the environment protection near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration.
• Self-Compacting Concrete is favorably suitable especially in highly reinforced concrete members like bridge decks or abutments, tunnel linings or tubing segments, where it is difficult to vibrate the concrete, or even for normal engineering structures.
• The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction. Based on these facts it can be concluded
Self-Compacting Concrete will have a bright future.
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• [2] Stefan Kordts, Hrost Grube: *Controlling the workability properties of Self-Compacting Concrete used as ready-mixed concrete*, Dusseldorf, Germany, 2006


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