The European Guidelines for Self-Compacting Concrete

Specification, Production and Use



May 2005

FOREWORD

These Guidelines and specifications were prepared by a project group comprising five European Federations dedicated to the promotion of advanced materials, and systems for the supply and use of concrete. The Self-Compacting Concrete European Project Group was founded in January 2004 with representatives from:

BIBM The European Precast Concrete Organisation.
CEMBUREAU The European Cement Association.
ERMCO The European Ready-mix Concrete Organisation.
EFCA The European Federation of Concrete Admixture Associations.
EFNARC The European Federation of Specialist Construction Chemicals and Concrete Systems.

All comments on "The European Guidelines for Self Compacting Concrete" should be submitted to the EPG Secretary at:
www.efca.info or **www.efnarc.org**

ACKNOWLEDGEMENT

The European Project Group acknowledges the contribution made in drafting this document by a wide range of expertise from within the concrete and construction industry. The five EPG working groups drew on the SCC experience of more than 50 people from 12 European countries and on collaboration with the The UK Concrete Society and the EC "TESTING-SCC" project 2001-2004.

Diagrams and photographs provided by:
Betonson BV, NL
Degussa
Doka Schalungstechnik GmbH
Hanson
Holcim
Price and Myers Consulting Engineers
Lafarge
Sika
The "TESTING-SCC" project
W. Bennenk

Although care has been taken to ensure, to the best of our knowledge that all data and information contained herein is accurate to the extent that it relates to either matters of fact or accepted practice or matters of opinion at the time of publication, the SCC joint project group assumes no responsibility for any errors in or misrepresentation of such data and/or information or any loss or damage arising from or related to its use.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, recording or otherwise, without prior permission of the SCC European Project Group.

CONTENTS

1	Introduction	1
2	Scope	1
3	Referenced standards	3
4	Terms and definitions	3
5	Engineering properties	5
	5.1 General	
	5.2 Compressive strength	
	5.3 Tensile strength	
	5.4 Static modulus of elasticity	
	5.5 Creep	
	5.6 Shrinkage	
	5.7 Coefficient of thermal expansion	
	5.8 Bond to reinforcement, prestressing and wires	
	5.9 Shear force capacity across pour planes	
	5.10 Fire resistance	
	5.11 Durability	
	5.12 References	
6	Specifying SCC for ready-mixed & site mixed concrete	10
	6.1 General	
	6.2 Specification	
	6.3 Requirements in the fresh state	
	6.4 Consistence classification	
	6.5 Specification examples	
7	Constituent materials	15
	7.1 General	
	7.2 Cement	
	7.3 Additions	
	7.4 Aggregates	
	7.5 Admixtures	
	7.6 Pigments	
	7.7 Fibres	
	7.8 Mixing water	
8	Mix composition	19
	8.1 General	
	8.2 Mix design principles	
	8.3 Test methods	
	8.4 Basic mix design	
	8.5 Mix design approach	
	8.6 Robustness in the fresh state	

9 Production for ready-mixed and site mixed SCC 24
- 9.1 General
- 9.2 Storage of constituent materials
- 9.3 Mixing equipment and trial mixes
- 9.4 Plant mixing procedures
- 9.5 Production control
- 9.6 Transportation and delivery
- 9.7 Site acceptance

10 Site requirements and preparation 28
- 10.1 General
- 10.2 Site control
- 10.3 Mix adjustment
- 10.4 Supervision and skills
- 10.5 Formwork pressure
- 10.6 Formwork design
- 10.7 Formwork preparation
- 10.8 Formwork for pumping bottom up

11 Placing and finishing on site 32
- 11.1 General
- 11.2 Discharging
- 11.3 Placing procedure and rate
- 11.4 Placing by pump
- 11.5 Placing by concrete chute or skip
- 11.6 Vibration
- 11.7 Finishing slabs
- 11.8 Curing

12 Precast concrete products 37
- 12.1 General
- 12.2 Specifying SCC for use in precast concrete products
- 12.3 Mix design of SCC for precast concrete products
- 12.4 Moulds
- 12.5 Factory production
- 12.6 Placing
- 12.7 Finishing, curing and de-moulding

13 Appearance and surface finish 40
- 13.1 General
- 13.2 Blowholes
- 13.3 Honeycombing
- 13.4 Colour consistency and surface aberrations
- 13.5 Minimising surface cracking

ANNEX

A Specification of SCC 43
- A.1 Scope
- A.2 Normative references
- A.3 Definitions, symbols and abbreviations
- A.4 Classification
- A.5 Requirements for concrete and methods of verification
- A.6 Delivery of fresh concrete
- A.7 Conformity control and conformity criteria
- A.8 Production control

B Test methods for SCC 47
- B1: Slump-flow and T_{500} time
- B2: V-funnel test
- B3: L-box test
- B4: Sieve segregation resistance test

C Improving the finish of SCC 60

1 Introduction

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.

Concrete that requires little vibration or compaction has been used in Europe since the early 1970s but self-compacting concrete was not developed until the late 1980's in Japan. In Europe it was probably first used in civil works for transportation networks in Sweden in the mid1990's. The EC funded a multi-national, industry lead project "SCC" 1997-2000 and since then SCC has found increasing use in all European countries.

Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demoulding and faster use of elements and structures.

The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration.

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.

In 2002 EFNARC published their "Specification & Guidelines for Self-Compacting concrete" which, at that time, provided state of the art information for producers and users. Since then, much additional technical information on SCC has been published but European design, product and construction standards do not yet specifically refer to SCC and for site applications this has limited its wider acceptance, especially by specifiers and purchasers.

In 2004 five European organisations BIBM, CEMBUREAU, ERMCO, EFCA and EFNARC, all dedicated to the promotion of advanced materials and systems for the supply and use of concrete, created a "European Project Group" to review current best practice and produce a new document covering all aspects of SCC. This document **"** serves to particularly address those issues related to the absence of European specifications, standards and agreed test methods.

2 Scope

" **"** represent a state of the art document addressed to those specifiers, designers, purchasers, producers and users who wish to enhance their expertise and use of SCC. The Guidelines have been prepared using the wide range of the experience and knowledge available to the European Project Group. The proposed specifications and related test methods for ready-mixed and site mixed concrete, are presented in a pre-normative format, intend to facilitate standardisation at European level. This approach should encourage increased acceptance and utilisation of SCC.

define SCC and many of the technical terms used to describe its properties and use. They also provide information on standards related to testing and to associated constituent materials used in the production of SCC.

Durability and other engineering properties of hardened concrete are covered to provide reassurance to designers on compliance of SCC with EN 1992-1-1 Design of concrete structures (Eurocode 2)

The Guidelines cover information that is common to SCC for the ready-mixed, site mixed and the precast concrete industry. Chapter 12 is devoted to the specific requirements of precast concrete products.

The Guidelines are drafted with an emphasis on ready-mixed and site mixed concrete where there are requirements between the purchaser and supplier in relation to the specification of the concrete in both the fresh and hardened state. In addition, the Guidelines cover specific and important requirements for the purchaser of SCC regarding the site preparation and methods of placing where these are different to traditional vibrated concrete.

The specification of precast concrete is usually based on the quality of the final concrete product in its hardened state according to the requirements of the relevant product standards and on EN 13369: Common rules for precast concrete products. EN 13369 refers only to the parts of EN 206-1 that concern the requirements for the concrete in the hardened state. The requirements for the concrete in the fresh state will be defined by the manufacturers own internal specification.

The document describes the properties of SCC in its fresh and hardened state, and gives advice to the purchaser of ready-mixed and site mixed concrete on how SCC should be specified in relation to the current European standard for structural concrete, EN 206-1. It also describes the test methods used to support this specification. The appended specification and test methods are presented in a pre-normative format that mirrors current EN concrete standards.

Advice is given to the producer on constituent materials, their control and interaction. Because there are a number of different approaches to the design of SCC mixes, no specific method is recommended, but a comprehensive list of papers describing different methods of mix design is provided.

Advice is given to the contractor/user of ready-mixed and site mixed concrete on delivery and placing. Whilst accepting that SCC is a product used by both the precast and in-situ industries, the Guidelines attempt to give specific advice related to the differing requirements of the two sectors. For example, early setting and early strength are important to precasters, whereas workability retention may be more important in in-situ applications.



3 Referenced standards

EN 197-1	Cement – Part 1: Composition, specifications and conformity criteria for common cements
EN 206-1	Concrete – Part 1: Specification, performance, production, and conformity
EN 450-1	Fly ash for concrete – Part 1: Definitions, specifications and quality control
EN 450-2	Fly ash for concrete – Part 2: Conformity control
EN 934-2	Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures - Definitions and requirements
EN 1008	Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete
EN1992-1	Eurocode 2: Design of concrete structures Part 1-1 – General rules and rules for buildings Part 1-2 – General rules – Structural file design
EN 12350-1	Testing fresh concrete: Part 1: Sampling
EN 12350-2	Testing fresh concrete: Part 2: Slump test
EN 12620	Aggregates for concrete
EN 12878	Pigments for colouring of building materials based on cement and/or lime – Specification and methods of test
EN 13055-1	Lightweight aggregates – Part 1: Lightweight aggregates for concrete, mortar and grout
EN 13263-1	Silica fume for concrete – Part 1: Definitions, requirements and conformity control
EN 13263-2	Silica fume for concrete – Part 2: Conformity evaluation
EN 13369	Common rules for precast concrete products
EN 13670	Execution of concrete structures
EN 14889	Fibres for concrete
EN 15167-1	Ground granulated blastfurnace slag for use in concrete, mortar and grout – Part 1: Definitions, specifications and conformity criterion
EN 15167 -2	Ground granulated blastfurnace slag for use in concrete, mortar and grout – Part 2: Conformity evaluation
EN ISO 5725	Accuracy (trueness and precision) of Measurement Methods and Results
EN ISO 9001	Quality management systems – Requirements

Note: Some of these EN standards are still in preparation; the latest version of undated standards should be referred to.

4 Terms and definitions

For the purposes of this publication, the following definitions apply:

Addition
Finely-divided inorganic material used in concrete in order to improve certain properties or to achieve special properties. This publication refers to two types of inorganic additions defined in EN 206-1 as:
nearly inert additions (Type I); pozzolanic or latent hydraulic additions (Type II)

Admixture
Material added during the mixing process of concrete in small quantities related to the mass of cementitous binder to modify the properties of fresh or hardened concrete

Binder
The combined cement and Type II addition

Filling ability
The ability of fresh concrete to flow into and fill all spaces within the formwork, under its own weight

Fines
See Powder

Flowability
The ease of flow of fresh concrete when unconfined by formwork and/or reinforcement

Fluidity
The ease of flow of fresh concrete

Mortar
The fraction of the concrete comprising paste plus those aggregates less than 4 mm

Paste
The fraction of the concrete comprising powder, water and air, plus admixture, if applicable

Passing ability
The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking

Powder (Fines)
Material of particle size smaller than 0.125 mm
NOTE: It includes this size fraction in the cement, additions and aggregate

Proprietary concrete
Concrete for which the producer assures the performance subject to good practice in placing, compacting and curing, and for which the producer is not required to declare the composition

Robustness
The capacity of concrete to retain its fresh properties when small variations in the properties or quantities of the constituent materials occur

Self-compacting concrete (SCC)
Concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction

Segregation resistance
The ability of concrete to remain homogeneous in composition while in its fresh state

Slump-flow
The mean diameter of the spread of fresh concrete using a conventional slump cone

Thixotropy
The tendency of a material (e.g. SCC) to progressive loss of fluidity when allowed to rest undisturbed but to regain its fluidity when energy is applied

Viscosity
The resistance to flow of a material (e.g. SCC) once flow has started.
NOTE: In SCC it can be related to the speed of flow T_{500} in the Slump-flow test or the efflux time in the V-funnel test

Viscosity Modifying Admixture (VMA)
Admixture added to fresh concrete to increase cohesion and segregation resistance.

5 Engineering properties

5.1 General

Self-compacting concrete and traditional vibrated concrete of similar compressive strength have comparable properties and if there are differences, these are usually covered by the safe assumptions on which the design codes are based. However, SCC composition does differ from that of traditional concrete so information on any small differences that may be observed is presented in the following sections. Whenever possible, reference is made to EN1992-1 and EN206-1:2000 [1] [2].

Durability, the capability of a concrete structure to withstand environmental aggressive situations during its design working life without impairing the required performance, is usually taken into account by specifying environmental classes. This leads to limiting values of concrete composition and minimum concrete covers to reinforcement.

In the design of concrete structures, engineers may refer to a number of concrete properties, which are not always part of the concrete specification. The most relevant are:

Compressive strength
Tensile strength
Modulus of elasticity
Creep
Shrinkage
Coefficient of thermal expansion
Bond to reinforcement
Shear force capacity in cold joints
Fire resistance

Where the value and/or the development of a specific concrete property with time is critical, tests should be carried out taking into account the exposure conditions and the dimensions of the structural member.

5.2 Compressive strength

Self-compacting concrete with a similar water cement or cement binder ratio will usually have a slightly higher strength compared with traditional vibrated concrete, due to the lack of vibration giving an improved interface between the aggregate and hardened paste. The strength development will be similar so maturity testing will be an effective way to control the strength development whether accelerated heating is used or not.

A number of concrete properties may be related to the concrete compressive strength, the only concrete engineering property that is routinely specified and tested.

5.3 Tensile strength

Self-compacting concrete may be supplied with any specified compressive strength class. For a given concrete strength class and maturity, the tensile strength may be safely assumed to be the same as the one for a normal concrete as the volume of paste (cement + fines + water) has no significant effect on tensile strength.

In the design of reinforced concrete sections, the bending tensile strength of the concrete is used for the evaluation of the cracking moment in prestressed elements, for the design of reinforcement to control crack width and spacing resulting from restrained early-age thermal contraction, for drawing moment-curvature diagrams, for the design of unreinforced concrete pavements and for fibre reinforced concrete.

In prestressed units the splitting tensile stresses around the strands as well as their rate of drawn-in (slippage) in the end section when releasing the prestressing forces are related to $f`_{ct}$, the compressive strength at release. Cracks due to splitting tensile stresses should generally be avoided.

5.4 Static modulus of elasticity

The modulus of elasticity (E-value, the ratio between stress and strain), is used in the elastic calculation of deflection, often the controlling parameter in slab design, and of pre or post tensioned elements.

As the bulk of the volume of concrete is aggregate, the type and amount of aggregate as well as its E-value have the most influence. Selecting an aggregate with a high E-value will increase the modulus of elasticity of concrete. However, increasing the paste volume could decrease the E-value. Because SCC often has a higher paste content than traditional vibrated concrete, some differences can be expected and the E-value may be somewhat lower but this should be adequately covered by the safe assumptions on which the formulae provided in EN1992-1-1 are based.

If SCC does have a slightly lower E modulus than traditional vibrated concrete, this will affect the relationship between the compressive strength and the camber due to prestressing or post-tensioning. For this reason, careful control should be exercised over the strength at the time when the prestressing and post-tensioning strands or wires are released.

5.5 Creep

Creep is defined as the gradual increase in deformation (strain) with time for a constant applied stress, also taking into account other time dependent deformations not associated with the applied stress, i.e. shrinkage, swelling and thermal deformation.

Creep in compression reduces the prestressing forces in prestressed concrete elements and causes a slow transfer of load from the concrete onto the reinforcement. Creep in tension can be beneficial in that it in part relieves the stresses induced by other restrained movements, e.g. drying shrinkage and thermal effects.

Creep takes place in the cement paste and it is influenced by its porosity which is directly related to its water/cement ratio. During hydration, the porosity of the cement paste reduces and so for a given concrete, creep reduces as the strength increases. The type of cement is important if the age of loading is fixed. Cements that hydrate more rapidly will have higher strength at the age of loading, a lower stress/strength ratio and a lower creep. As the aggregates restrain the creep of the cement paste, the higher the volume of the aggregate and the higher the E-value of the aggregate, the lower the creep will be.

Due to the higher volume of cement paste, the creep coefficient for SCC may be expected to be higher than for normal concrete of equal strength, but such differences are small and covered by the safe assumptions in the tables and the formulae provided in the Eurocode.

5.6 Shrinkage

Shrinkage is the sum of the autogenous and the drying shrinkage. Autogenous shrinkage occurs during setting and is caused by the internal consumption of water during hydration. The volume of the hydration products is less than the original volume of unhydrated cement and water and this reduction in volume causes tensile stresses and results in autogenous shrinkage.

Drying shrinkage is caused by the loss of water from the concrete to the atmosphere. Generally this loss of water is from the cement paste, but with a few types of aggregate the main loss of water is from the aggregate. Drying shrinkage is relatively slow and the stresses it induces are partially balanced by tension creep relief.

The aggregate restrains the shrinkage of the cement paste and so the higher the volume of the aggregate and the higher the E-value of the aggregate, the lower the drying shrinkage. A decrease in the maximum aggregate size which results in a higher paste volume increases the drying shrinkage.

The values and formulae given in the Eurocode for normal concrete are still valid in the case of SCC.
As concrete compressive strength is related to the water cement ratio, in SCC with a low water/cement ratio drying shrinkage reduces and the autogenous shrinkage can exceed it.

Tests performed on creep and shrinkage of different types of SCC and a reference concrete [7] show that

- the deformation caused by shrinkage may be higher
- the deformation caused by creep may be lower
- the value for the sum of the deformations due to shrinkage and creep are almost similar

Due to the restrain of the presence of reinforcement in a cross section the shrinkage strain will cause tension in concrete and compression in the reinforcement.

5.7 Coefficient of thermal expansion

The coefficient of thermal expansion of concrete is the strain produced in concrete after a unit change in temperature where the concrete is not restrained either internally (by reinforcing bars) or externally.

The coefficient of thermal expansion of concrete varies with its composition, age and moisture content. As the bulk of concrete comprises aggregate, using an aggregate with a lower coefficient of thermal expansion will reduce the coefficient of thermal expansion of the resulting concrete. Reducing the coefficient of thermal expansion leads to a proportional reduction in the crack control reinforcement.

While the range of the coefficient of thermal expansion is from 8 to13 microstrains/K, EN 1992-1-1 states that unless more accurate information is available, it may be taken as 10 to 13 microstrains/K. The same may be assumed in the case of SCC.

5.8 Bond to reinforcement, prestressing and wires

Reinforced concrete is based on an effective bond between concrete and the reinforcing bars. The concrete bond strength should be sufficient to prevent bond failure. The effectiveness of bond is affected by the position of the embedded bars and the quality of concrete as cast. An adequate concrete cover is necessary in order to properly transfer bond stresses between steel and concrete.

Poor bond often results from a failure of the concrete to fully encapsulate the bar during placing or bleed and segregation of the concrete before hardening which reduce the quality of contact on the bottom surface. SCC fluidity and cohesion minimise these negative effects, especially for top bars in deep sections [5].

In the case of strands the transfer and anchorage length in different types of SCC have been compared with the performance in vibrated concrete of the same compressive stress. The transfer length for strands embedded in SCC was shown to be on the safe side when compared with the calculated values according the EN1992-1 and EN206-1 see also [7] [8].

Even if bond properties are generally enhanced when SCC is used, for a given compressive strength the formulae used in the Code should be used.

5.9 Shear force capacity across pour planes

The surface of hardened SCC after casting and hardening may be rather smooth and impermeable. Without any treatment of the surface after placing the first layer, the shear force capacity between the first and second layer may be lower than for vibrated concrete and may therefore be insufficient to carry any

shear force. A surface treatment such as surface retarders, brushing or surface roughening should to be sufficient, [7] [9].

5.10 Fire resistance

Concrete is non-combustible and does not support the spread of flames. It produces no smoke, toxic gases or emissions when exposed to fire and does not contribute to the fire load. Concrete has a slow rate of heat transfer which makes it an effective fire shield for adjacent compartments and under typical fire conditions, concrete retains most of its strength. The European Commission has given concrete the highest possible fire designation, A1.

The fire resistance of SCC is similar to normal concrete [7] In general a low permeability concrete may be more prone to spalling but the severity depends upon the aggregate type, concrete quality and moisture content [6]. SCC can easily achieve the requirements for high strength, low permeability concrete and will perform in a similar way to any normal high strength concrete under fire conditions [7].
The use of polypropylene fibres in concrete has been shown to be effective in improving its resistance to spalling. The mechanism is believed to be due to the fibres melting and being absorbed in the cement matrix. The fibre voids then provide expansion chambers for steam, thus reducing the risk of spalling. Polypropylene fibres have been successfully used with SCC.

5.11 Durability

The durability of a concrete structure is closely associated to the permeability of the surface layer, the one that should limit the ingress of substances that can initiate or propagate possible deleterious actions (CO_2, chloride, sulphate, water, oxygen, alkalis, acids, etc.). In practice, durability depends on the material selection, concrete composition, as well as on the degree of supervision during placing, compaction, finishing and curing.

Lack of compaction of the surface layer, due to vibration difficulties in narrow spaces between the formwork and the re-bars or other inserts (e.g. post-tensioning ducts) has been recognised as a key factor of poor durability performance of reinforced concrete structures exposed to aggressive environments. Overcoming this was one of the main reasons for the original development of SCC in Japan.

Traditional vibrated concrete is subjected to compaction via vibration (or tamping), which is a discontinuous process. In the case of internal vibration, even when correctly executed, the volume of concrete within the area of influence of the vibrator does not receive the same compaction energy.
Similarly, in the case of external vibration, the resulting compaction is essentially heterogeneous, depending on the distance to the vibration sources.

The result of the vibration is, therefore, a concrete in the structure with uneven compaction and, therefore, with different permeabilities, which enhances the selective ingress of aggressive substances. Naturally, the consequences of incorrect vibration (honeycombing, segregation, bleeding, etc.) have a much stronger negative effect on permeability and, hence, on durability.

Self-compacting concrete with the right properties will be free from those shortcomings and result in a material of consistently low and uniform permeability, offering less weak points for deleterious actions of the environment and, hence, better durability. The comparison of permeability between SCC and normal vibrated concrete will depend on the selection of materials and the effective water cement or water binder ratio.

There are test methods, either standardised nationally or recommended by RILEM to measure the permeability of concrete, in the laboratory and in-situ, as durability indicators. EN1992-1 and EN206 -1 both take into account durability by specifying environmental classes leading to limiting values of concrete composition and to minimum concrete cover to reinforcement [1] [2].

5.12 References

[1] EN1992-1 – Eurocode 2:Design of concrete structures Part 1 –1 – General rules and rules for buildings -Part 1-2 – General rules – Structural file design

[2] EN206-1: 2000 - Concrete Part 1 – Specification, performance, production and conformity

[3] BROOKS, J Elasticity, shrinkage, creep and thermal movement. Advanced Concrete Technology – Concrete properties, Edited by John Newman and Ban Seng Choo, ISBN 0 7506 5104 0, 2003.

[4] HARRISON, T A Early-age thermal crack control in concrete. CIRIA Report 91, Revised edition 1992 ISBN 0 86017 329 1

[5] SONEBI, M, WENZHONG,Z and GIBBS, J Bond of reinforcement in self-compacting concrete – CONCRETE July-August 2001

[6] CATHER, R Concrete and fire exposure. Advanced Concrete Technology – Concrete properties, Edited by John Newman and Ban Seng Choo, ISBN 0 7506 5104 0, 2003.

[7] DEN UIJL, J.A., Zelfverdichtend Beton, CUR Rapport 2002-4 -Onderzoek in opdracht van CUR Commissie B79 Zelfverdichtend Beton, Stichting CUR, ISBN 90 3760 242 8.

[8] VAN KEULEN, D, C, Onderzoek naar eigenschappen van Zelfverdichtend Beton, Rapport TUE/BCO/00.07, April 2000.

[9] JANMAAT, D, WELZEN.M.J.P, Schuifkrachtoverdracht in schuifvlakken van zelfverdichtend beton bij prefab elementen, Master Thesis, Rapport TUE/CCO/A-2004-6.



Figure 5.1: Surface detail on precast element with SCC filling under the formwork.

6 Specifying SCC for ready-mixed and site mixed concrete

6.1 General

The specification, performance and conformity requirements for structural concrete are given in EN 206-1. However, in the case of SCC some properties in the fresh state exceed the limits and classes provided in this standard. None of the test methods in the current EN 12350 series 'Testing fresh concrete' are suitable for assessment of the key properties of fresh SCC. Appropriate test methods for SCC are given in Annex B of these Guidelines and it is envisaged that the EN 12350 series will be extended to cover these test methods.

The filling ability and stability of self-compacting concrete in the fresh state can be defined by four key characteristics. Each characteristic can be addressed by one or more test methods:

Characteristic	**Preferred test method(s)**
Flowability	Slump-flow test
Viscosity (assessed by rate of flow)	T_{500} Slump-flow test or V-funnel test
Passing ability	L-box test
Segregation	Segregation resistance (sieve) test

These test methods for SCC are described in Annex B.

Full details for the specification, performance, production and conformity of SCC, where these complement EN 206-1, are described in Annex A.

Further advice on specification of SCC in the fresh state is given in Clauses 6.3 and 6.4.

6.2 Specification

SCC will normally be specified as a prescribed or proprietary concrete.

The prescribed concrete method is most suitable where the specifier and producer/user are the same party, e.g. in site mixed.

For commercial reasons the ready-mixed concrete producer will probably prefer the proprietary method of specification (see annex A), following consultation between the purchaser and the producer. The proprietary method focuses on the performance of the concrete and places responsibility on the producer to achieve this performance. It is not usually practical for the specifier to develop their own SCC and then specify the mix proportions to the producer and if they do follow this route, they cannot also specify a strength class.

The specification for self-compacting concrete using the proprietary concrete method shall contain:

a) basic requirements given in Sub-clause 6.2.1 of these Guidelines

b) additional requirements given in Sub-clause 6.2.2 where required

6.2.1 Basic requirements

The specification for self-compacting concrete shall contain:

a) requirement to conform to 'The European Guidelines for SCC, May 2005, Annex A' ;

b) compressive strength class (see Note 1 and EN 206-1: 2000, **4.3.1**);

c) exposure class(s) and/or limiting values of composition, e.g. maximum w/c ratio, minimum cement content (see provision valid in the place of use);

d) maximum nominal upper aggregate size;

e) chloride class (see EN 206-1: 2000, **5.2.7**);

f) slump-flow class or, in special cases, a target value (see Annex A, Table A.6).

NOTE 1: In some EU Member States only specific strength classes are applied according to National Application Documents (NAD)

NOTE 2: Consideration should be given to specifying a requirement for the producer to operate an accredited quality system meeting the requirements of EN ISO 9001.

6.2.2 Additional requirements

In addition to the basic requirements (Sub-clause 6.2.1), the specification for self-compacting concrete shall contain any of the following additional requirements and provisions that are deemed to be necessary, specifying performance requirements and test methods as appropriate:

a) T_{500} value for the slump-flow test (see Annex A, Table A.2) or a V-funnel class (see Annex A, Table A.3);

b) L-box class or, in special cases, a target value (see Annex A, Table A.4);

c) Segregation resistance class or, in special cases, a target value (see Annex A, Table A.5);

d) Requirements for the temperature of the fresh concrete, where different from those in EN 206-1: 2000, **5.2.8**;

e) Other technical requirements.

NOTE 1. Where these tests are required routinely, the rate of testing shall be specified.

6.3 Requirements in the fresh state

Specific requirements for SCC in the fresh state depend on the type of application, and especially on:

- confinement conditions related to the concrete element geometry, and the quantity, type and location of reinforcement, inserts, cover and recesses etc.
- placing equipment (e.g. pump, direct from truck-mixer, skip, tremie)
- placing methods (e.g. number and position of delivery points)
- finishing method

The classifying system detailed in Annex A allows for an appropriate specification of SCC to cover these requirements, which are characterised as:

• Flowability	Slump-flow SF	3 classes
• Viscosity, (measure of the speed of flow)	Viscosity VS or VF	2 classes
• Passing ability, (flow without blocking)	Passing ability PA	2 classes
• Segregation resistance	Segregation resistance SR	2 classes

Details of the test methods for these characteristics can be found in Annex B.
Information on selection of parameters and classes is given in Clause 6.4.

Self-compacting concrete requirements in the fresh state that are appropriate for a given application should be selected from one or more of these four key characteristics and then specified by class or target value according to Annex A.

For ready-mixed or site mixed concrete, characteristics and classes should be carefully selected, controlled and justified on the basis of contractor and concrete producer experience or by specific trials. It is therefore important that the concrete purchaser and concrete producer discuss and define clearly those characteristics before starting the project.

The concrete purchaser should only select those fresh concrete characteristics necessary for the particular SCC application and over specification of both the concrete characteristic and class should be avoided. Slump-flow will normally be specified for all SCC.

Passing ability, viscosity and segregation resistance will affect the in-situ properties of the hardened concrete but should only be specified if specifically needed.

- If there is little or no reinforcement, there may be no need to specify passing ability as a requirement.
- Viscosity may be important where good surface finish is required or reinforcement is very congested but should not be specified in most other cases.
- Segregation resistance becomes increasingly important with higher fluidity and lower viscosity SCC but if it needs to be specified, class 1 has been shown to be adequate for most applications.

See Clause 6.4 for additional advice on specifying.

The required consistence retention time will depend on the transportation and placing time. This should be determined and specified and it is the responsibility of the producer to ensure that the SCC maintains its specified fresh properties during this period.

Self-compacting concrete should, if possible be placed in one continuous pour so delivery rates should be matched to placing rate and also be agreed with the producer in order to avoid placing stoppages due to lack of concrete or long delays in placing after the concrete reaches site.

6.4 Consistence classification

6.4.1 Slump-flow

Slump-flow value describes the flowability of a fresh mix in unconfined conditions. It is a sensitive test that will normally be specified for all SCC, as the primary check that the fresh concrete consistence meets the specification. Visual observations during the test and/or measurement of the T_{500} time can give additional information on the segregation resistance and uniformity of each delivery.

The following are typical slump-flow classes for a range of applications:

SF1 (550 - 650 mm) is appropriate for:

- unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (e.g. housing slabs)
- casting by a pump injection system (e.g. tunnel linings)
- sections that are small enough to prevent long horizontal flow (e.g. piles and some deep foundations).

SF2 (660 - 750 mm) is suitable for many normal applications (e.g. walls, columns)

SF3 (760 – 850 mm) is typically produced with a small maximum size of aggregates (less than 16 mm) and is used for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. SF3 will often give better surface finish than SF 2 for normal vertical applications but segregation resistance is more difficult to control.

Target values higher than 850 mm may be specified in some special cases but great care should be taken regarding segregation and the maximum size of aggregate should normally be lower than 12 mm.

6.4.2 Viscosity

Viscosity can be assessed by the T_{500} time during the slump-flow test or assessed by the V-funnel flow time. The time value obtained does not measure the viscosity of SCC but is related to it by describing the rate of flow. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time.

Viscosity (low or high) should be specified only in special cases such as those given below. It can be useful during mix development and it may be helpful to measure and record the T_{500} time while doing the slump-flow test as a way of confirming uniformity of the SCC from batch to batch.

> VS1/VF1 has good filling ability even with congested reinforcement. It is capable of self-levelling and generally has the best surface finish. However, it is more likely to suffer from bleeding and segregation.
>
> VS2/VF2 has no upper class limit but with increasing flow time it is more likely to exhibit thixotropic effects, which may be helpful in limiting the formwork pressure (see Clause 10.5) or improving segregation resistance. Negative effects may be experienced regarding surface finish (blow holes) and sensitivity to stoppages or delays between successive lifts.

6.4.3 Passing ability

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. In defining the passing ability, it is necessary to consider the geometry and density of the reinforcement, the flowability/filling ability and the maximum aggregate size.

The defining dimension is the smallest gap (confinement gap) through which SCC has to continuously flow to fill the formwork. This gap is usually but not always related to the reinforcement spacing. Unless the reinforcement is very congested, the space between reinforcement and formwork cover is not normally taken into account as SCC can surround the bars and does not need to continuously flow through these spaces.

Examples of passing ability specifications are given below:

> PA 1 structures with a gap of 80 mm to 100 mm, (e.g. housing, vertical structures)
> PA 2 structures with a gap of 60 mm to 80 mm, (e.g. civil engineering structures)

For thin slabs where the gap is greater than 80 mm and other structures where the gap is greater than 100 mm no specified passing ability is required.

For complex structures with a gap less than 60 mm, specific mock-up trials may be necessary.

6.4.4 Segregation resistance

Segregation resistance is fundamental for SCC in-situ homogeneity and quality. SCC can suffer from segregation during placing and also after placing but before stiffening. Segregation which occurs after placing will be most detrimental in tall elements but even in thin slabs, it can lead to surface defects such as cracking or a weak surface.

In the absence of relevant experience, the following general guidance on segregation resistance classes is given:

> Segregation resistance becomes an important parameter with higher slump-flow classes and/or the lower viscosity class, or if placing conditions promote segregation. If none of these apply, it is usually not necessary to specify a segregation resistance class.

SR1 is generally applicable for thin slabs and for vertical applications with a flow distance of less than 5 metres and a confinement gap greater than 80 mm.

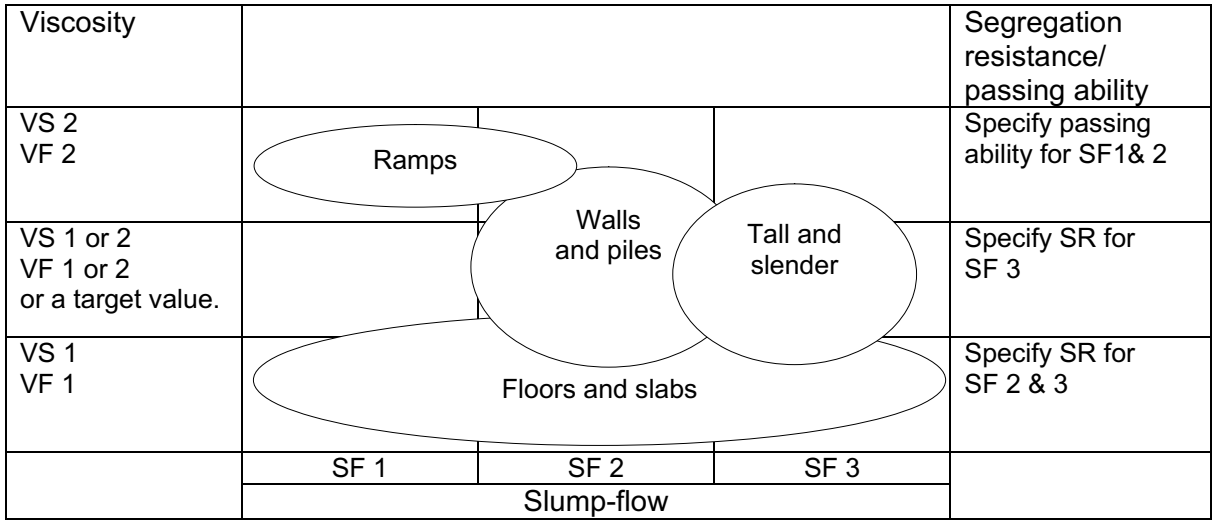
SR2 is preferred in vertical applications if the flow distance is more than 5 metres with a confinement gap greater than 80 mm in order to take care of segregation during flow.

SR2 may also be used for tall vertical applications with a confinement gap of less than 80 mm if the flow distance is less than 5 metres but if the flow is more than 5 metres a target SR value of less than 10% is recommended.

SR2 or a target value may be specified if the strength and quality of the top surface is particularly critical.

6.5 Specification examples

The following table highlights the initial parameters and classes to be considered for specifying SCC in different applications. It does not take account of specific confinement conditions, element geometry, placing method or characteristics of the materials to be used in the concrete mix. Discussions should normally be held with the concrete producer before a final specification decision is made.



Properties of SCC for various types of application based on Walraven, 2003

Walraven J (2003) Structural applications of self compacting concrete *Proceedings of 3rd RILEM International Symposium on Self Compacting Concrete*, Reykjavik, Iceland, ed. Wallevik O and Nielsson I, RILEM Publications PRO 33, Bagneux, France, August 2003 pp 15-22

7 Constituent materials

7.1 General

The constituent materials for SCC are the same as those used in traditional vibrated concrete conforming to EN 206-1. In most cases the requirements for constituents are individually covered by specific European standards. However, in order to be sure of uniform and consistent performance for SCC, additional care is needed in initial selection and also in the continual monitoring for uniformity of incoming batches.

To achieve these requirements the control of the constituent materials needs to be increased and the tolerable variations restricted, so that daily production of SCC is within the conformity criteria without the need to test and/or adjust every batch.

7.2 Cement

All cements which conform to EN 197-1 can be used for the production of SCC. The correct choice of cement type is normally dictated by the specific requirements of each application or what is currently being used by the producer rather than the specific requirements of SCC.

7.3 Additions

Due to the fresh property requirements of SCC, inert and pozzolanic/hydraulic additions are commonly used to improve and maintain the cohesion and segregation resistance. The addition will also regulate the cement content in order to reduce the heat of hydration and thermal shrinkage.

The additions are classified according to their reactive capacity with water:

TYPE I	Inert or semi-inert	• Mineral filler (limestone, dolomite etc) • Pigments
TYPE II	Pozzolanic	• Fly ash conforming to EN 450 • Silica fume conforming to EN 13263
	Hydraulic	• Ground granulated blast furnace slag (If not combined in an EN 197-1 cement, national standards may apply until the new EN 15167 standard is published)

Additions, other than those combined in an EN 197-1 cement, may not be as well controlled in terms of particle size distribution and composition as some other concrete constituents so increased monitoring of deliveries may be necessary.

Self-compacting concrete is often selected for its high quality finish and good appearance but this may be compromised if the source of the addition does not have good colour consistency.

7.3.1 Mineral fillers

The particle size distribution, shape and water absorption of mineral fillers may affect the water demand /sensitivity and therefore suitability for use in the manufacture of SCC. Calcium carbonate based mineral fillers are widely used and can give excellent rheological properties and a good finish. The most advantageous fraction is that smaller than 0.125 mm and in general it is desirable for >70% to pass a 0.063mm sieve. Fillers specifically ground for this application offer the advantage of improved batch to batch consistency of particle size distribution, giving improved control over water demand and making them particularly suitable for SCC compared with other available materials.

7.3.2 Fly ash

Fly ash has been shown to be an effective addition for SCC providing increased cohesion and reduced sensitivity to changes in water content. However, high levels of fly ash may produce a paste fraction which is so cohesive that it can be resistant to flow.

7.3.3 Silica fume

The high level of fineness and practically spherical shape of silica fume results in good cohesion and improved resistance to segregation. However, silica fume is also very effective in reducing or eliminating bleed and this can give rise to problems of rapid surface crusting. This can result in cold joints or surface defects if there are any breaks in concrete delivery and also to difficulty in finishing the top surface.

7.3.4 Ground blastfurnace slag

Ground granulated blast furnace slag (ggbs) provides reactive fines with a low heat of hydration. GGBS is already present in some CEM II or CEM III cements but is also available as an addition in some countries and may be added at the mixer. A high proportion of ggbs may affect stability of SCC resulting in reduced robustness with problems of consistence control while slower setting can also increase the risk of segregation. Ground blast furnace slag is also available in some countries as a type I addition.

7.3.5 Other additions

Metakaolin, natural pozzolana, ground glass, air cooled slag and other fine fillers have also been used or considered as additions for SCC but their effects need to be carefully and individually evaluated for both short and long term effects on the concrete.

7.4 Aggregates

Normal-weight aggregates should conform to EN 12620 and meet the durability requirements of EN 206-1. Lightweight aggregates should conform to EN 13055-1.
NOTE: Aggregate particles smaller than 0,125 mm are deemed to contribute to the powder content of the SCC.

The moisture content, water absorption, grading and variations in fines content of all aggregates should be closely and continuously monitored and must be taken into account in order to produce SCC of constant quality. Using washed aggregates will normally give a more consistent product. Changing the source of supply is likely to make a significant change to the concrete properties and should be carefully and fully evaluated.

The shape and particle size distribution of the aggregate is very important and affects the packing and voids content. Some mix design methods use the voids content of the aggregate in predicting the volumes of paste and of mortar required. Single size aggregates and/or a gap in the grading between coarse and fine aggregates are used in some mix designs.

7.4.1 Coarse aggregate

Coarse aggregates conforming to EN 12620 are appropriate for the production of SCC. Lightweight aggregate has been successfully used for SCC but note that the aggregate may migrate to the surface if the paste viscosity is low and this may not be detected by the sieve segregation resistance test.

The reinforcement spacing is the main factor in determining the maximum aggregate size. Aggregate blocking must be avoided as SCC flows through the reinforcement and the L-box test is indicative of the

passing ability of an SCC mix. The maximum aggregate size should generally be limited to 12 – 20 mm, although larger sizes are being used.

The particle size distribution and the shape of coarse aggregate directly influence the flow and passing ability of SCC and its paste demand. The more spherical the aggregate particles the less they are likely to cause blocking and the greater the flow because of reduced internal friction.

7.4.2 Fine Aggregate / Sands

The influence of fine aggregates on the fresh properties of the SCC is significantly greater than that of coarse aggregate. Particles size fractions of less than 0.125 mm should be include the fines content of the paste and should also be taken into account in calculating the water powder ratio.

The high volume of paste in SCC mixes helps to reduce the internal friction between the sand particles but a good grain size distribution is still very important. Many SCC mix design methods use blended sands to match an optimised aggregate grading curve and this can also help to reduce the paste content. Some producers prefer gap-graded sand.

7.5 Admixtures

Superplasticisers or high range water reducing admixtures conforming to EN 934-2 Tables 3.1 and 3.2 are an essential component of SCC. Viscosity modifying admixtures (VMA) may also be used to help reduce segregation and the sensitivity of the mix due to variations in other constituents, especially to moisture content. Other admixtures including air entraining, accelerating and retarding may be used in the same way as in traditional vibrated concrete but advice should be sought from the admixture manufacturer on use and the optimum time for addition and they should conform to EN 934-2.

Choice of admixture for optimum performance may be influenced by the physical and chemical properties of the binder/addition. Factors such as fineness, carbon content, alkalis and C_3A may have an effect. It is therefore recommended that compatibility is carefully checked if a change in supply of any of these constituents is to be made.

Admixtures will normally be very consistent from batch to batch but moving to another source or to another type from the same manufacturer is likely to have a significant effect on SCC performance and should be fully checked before any change is made.

7.5.1. Superplasticiser / High range water reducing admixtures

Most admixture manufacturers will have a range of superplasticising admixtures tailored to specific user requirements and the effects of other mix constituents.

The admixture should bring about the required water reduction and fluidity but should also maintain its dispersing effect during the time required for transport and application. The required consistence retention will depend on the application. Precast concrete is likely to require a shorter retention time than for concrete that has to be transported to and placed on site.

7.5.2 Viscosity modifying admixtures

Admixtures that modify the cohesion of the SCC without significantly altering its fluidity are called viscosity modifying (VMA). These admixtures are used in SCC to minimise the effect of variations in moisture content, fines in the sands or its grain size distribution, making the SCC more robust and less sensitive to small variations in the proportions and condition of other constituents. However, they should not be regarded as a way of avoiding the need for a good mix design and careful selection of other SCC constituents.

At present EN 934-2 does not cover VMAs but they should conform to the general requirements in Table 1 of EN 934-2. In addition, evidence of performance should be provided by the supplier. A draft method for establishing suitability of VMAs (based on EN 934-2) is given on the EFCA web site www.efca.info.

7.5.3 Air entraining admixtures

Air entraining admixtures may be used in the production of SCC to improve freeze-thaw durability. They are also used to improve the finishing of flat slabs and air entrainment is particularly useful in stabilising low powder content, lower strength SCC.

7.6 Pigments

Pigments conforming to EN12878 can be used successfully with SCC, applying the same attention and limitations as in traditional vibrated concrete. However, they can affect fresh properties so they should not be added to an existing SCC without first doing a trial.

In general, due to the high fluidity of SCC, the dispersion of the pigment is more efficient and more uniform colours are usually achieved, both within and between batches. However, the higher paste content of SCC may result in a higher dosage of pigment to achieve the required colour density.

7.7 Fibres

Both metallic and polymer fibres have been used in the production of SCC, but they may reduce flowability and passing ability. Trials are therefore needed to establish the optimum type, length and quantity to give all the required properties to both the fresh and hardened concrete.

Polymer fibres can be used to improve the stability of SCC, as they help prevent settlement and cracking due to plastic shrinkage of the concrete.

Steel or long polymer structural fibres are used to modify the ductility/toughness of the hardened concrete. Their length and quantity is selected depending on the maximum size of aggregate and on structural requirements. If they are used as a substitute for normal reinforcement, the risk of blockage is no longer applicable but it should be emphasised that using SCC with fibres in structures with normal reinforcement significantly increases the risk of blockage.

7.8 Mixing water

Water conforming to EN 1008 should be used in SCC mixes. Where recycled water, recovered from processes in the concrete industry, is used the type/content and in particular any variation in content of suspended particles should be taken into account as this may affect batch to batch uniformity of the mix.

8 Mix composition

8.1 General

The mix composition is chosen to satisfy all performance criteria for the concrete in both the fresh and hardened states. In the case of ready-mixed concrete, these criteria will be supplied as a specification by the purchaser and should meet the requirements set out in Chapter 6 of this document.

8.2 Mix design principles

To achieve the required combination of properties in fresh SCC mixes:

- The fluidity and viscosity of the paste is adjusted and balanced by careful selection and proportioning of the cement and additions, by limiting the water/powder ratio and then by adding a superplasticiser and (optionally) a viscosity modifying admixture. Correctly controlling these components of SCC, their compatibility and interaction is the key to achieving good filling ability, passing ability and resistance to segregation.

- In order to control temperature rise and thermal shrinkage cracking as well as strength, the fine powder content may contain a significant proportion of type I or II additions to keep the cement content at an acceptable level.

- The paste is the vehicle for the transport of the aggregate; therefore the volume of the paste must be greater than the void volume in the aggregate so that all individual aggregate particles are fully coated and lubricated by a layer of paste. This increases fluidity and reduces aggregate friction.

- The coarse to fine aggregate ratio in the mix is reduced so that individual coarse aggregate particles are fully surrounded by a layer of mortar. This reduces aggregate interlock and bridging when the concrete passes through narrow openings or gaps between reinforcement and increases the passing ability of the SCC.

These mix design principles result in concrete that, compared to traditional vibrated concrete, normally contains:

- lower coarse aggregate content
- increased paste content
- low water/powder ratio
- increased superplasticiser
- sometimes a viscosity modifying admixture.

8.3 Test methods

A wide range of test methods have been developed to measure and assess the fresh properties of SCC. Figure 8.1 lists the most common tests grouped according to the property assessed. Full details on five of these methods can be found in Annex B. These are the methods which find the most widespread use across Europe and to which specification classes could be assigned with some confidence as detailed in Annex A. Details on most of the other methods in Table 8.1 are given in the EFNARC SCC Guidelines available from their web site www.efnarc.org or in the report of the EU funded "Testing-SCC project", managed by Paisley University. Project web site
http://www.civeng.ucl.ac.uk/research/concrete/Testing-SCC/.

No single test is capable of assessing all of the key parameters, and a combination of tests is required to fully characterise an SCC mix. The European Project Group which drafted these Guidelines concluded that there should only be a small number of test methods used for specification purposes and has proposed the five test methods detailed in Annex B because they can be related to specification classes, as detailed in Annex A.

Other test methods may be appropriate for development of SCC mixes, for performance evaluation in relation to specific uses and for site identity testing by agreement between the producer and the purchaser.

The J-ring is a strong contender for evaluation of passing ability on site but at the time of drafting these Guidelines, it was considered that further development work was needed before specification classes could be assigned to its use.

Characteristic	Test method	Measured value
Flowability/filling ability	Slump-flow	total spread
	Kajima box	visual filling
Viscosity/ flowability	T_{500}	flow time
	V-funnel	flow time
	O-funnel	flow time
	Orimet	flow time
Passing ability	L-box	passing ratio
	U-box	height difference
	J-ring	step height, total flow
	Kajima box	visual passing ability
Segregation resistance	penetration	depth
	sieve segregation	percent laitance
	settlement column	segregation ratio

Table 8.1: Test properties and methods for evaluating SCC

In addition to the test methods detailed in Table 8.1, smaller cone and funnel tests have been used for laboratory based mix development to assess the flow of the paste and the mortar components of SCC. The small truncated cone is usually 60 mm high with diameters of 100 mm at the base and 70 mm at the top. The small V-funnel typically has a height of 240 mm, a width of 270 mm and a depth of 30 mm tapering to a 30 x 30x 60 mm high nozzle section. The Marsh cone is also being used to assess the flowability of the paste and the mortar components.

8.4 Basic mix design

There is no standard method for SCC mix design and many academic institutions, admixture, ready-mixed, precast and contracting companies have developed their own mix proportioning methods.

Mix designs often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles. Some methods try to fit available constituents to an optimised grading envelope. Another method is to evaluate and optimise the flow and stability of first the paste and then the mortar fractions before the coarse aggregate is added and the whole SCC mix tested.

Further information on mix design and on methods of evaluating the properties of SCC can be found in the EFNARC Guidelines for SCC (available as a free download from www.efnarc.org).

Some mix design methods developed at academic and other institutions have been published:

- Okamura H and Ozawa K. Self-compactable high performance concrete. International Workshop on High Performance Concrete. American Concrete Institute; Detroit. 1994, pp31-44.
- Ouchi M, Hibino M, Ozawa K, and Okamura H. A rational mix-design method for mortar in self-compacting concrete. Proceedings of Sixth South-East Asia Pacific Conference of Structural Engineering and Construction. Taipei, Taiwan, 1998, pp1307-1312.

- Nawa T, Izumi T, and Edamatsu Y. State-of-the-art report on materials and design of self-compacting concrete. Proceedings of International Workshop on Self-compacting Concrete. August 1998; Kochi University of Technology, Japan. pp160-190.
- Domone P, Chai H and Jin J. Optimum mix proportioning of self-compacting concrete. Proceedings of International Conference on Innovation in Concrete Structures: Design and Construction, Dundee, September 1999. Thomas Telford; London. pp277-285.
- Billberg, P. Self-compacting concrete for civil engineering structures – the Swedish Experience. Report no 2:99. Swedish Cement and Concrete Research Institute. Stockholm, 1999
- Su N, Hsu K-C and Chai H-W A simple mix design method for self-compacting concrete Cement and Concrete Research, 31, (2001) pp 1799-1807
- Gomes P.C.C, Gettu R, Agullo L, Bernard C, Mixture proportioning of high strength, Self-Compacting Concrete: Performance and Quality of concrete structures. Third CANMET/ACI Intnl Conf. (Recefi, Brazil) Supplementary CD, 2002, 12p.
- Bennenk, H. W. & J.Van Schiindel: The mix design of SCC, suitable for the precast concrete industry. Proceedings of the BIBM Congress, 2002 Istanbul, Turkey.
- Billberg, P. Mix design model for SCC (the blocking criteria). Proceedings of the first North American conference on the design and use of SCC, Chicago 2002.

These Guidelines are not intended to provide specific advice on mix design but Table 8.2 gives an indication of the typical range of constituents in SCC by weight and by volume. These proportions are in no way restrictive and many SCC mixes will fall outside this range for one or more constituents.

Constituent	Typical range by mass (kg/m^3)	Typical range by volume ($litres/m^3$)
Powder	380 - 600	
Paste		300 - 380
Water	150 - 210	150 - 210
Coarse aggregate	750 - 1000	270 - 360
Fine aggregate (sand)	Content balances the volume of the other constituents, typically 48 – 55% of total aggregate weight.	
Water/Powder ratio by Vol		0.85 – 1.10

Table 8.2 Typical range of SCC mix composition

8.5 Mix design approach

Laboratory trials should be used to verify properties of the initial mix composition with respect to the specified characteristics and classes. If necessary, adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale in the concrete plant and if necessary at site to verify both the fresh and hardened properties.

The mix design is generally based on the approach outlined below:

- evaluate the water demand and optimise the flow and stability of the paste
- determine the proportion of sand and the dose of admixture to give the required robustness
- test the sensitivity for small variations in quantities (the robustness)
- add an appropriate amount of coarse aggregate
- produce the fresh SCC in the laboratory mixer, perform the required tests
- test the properties of the SCC in the hardened state
- produce trial mixes in the plant mixer.

The design process is graphically presented in Figure 8.3

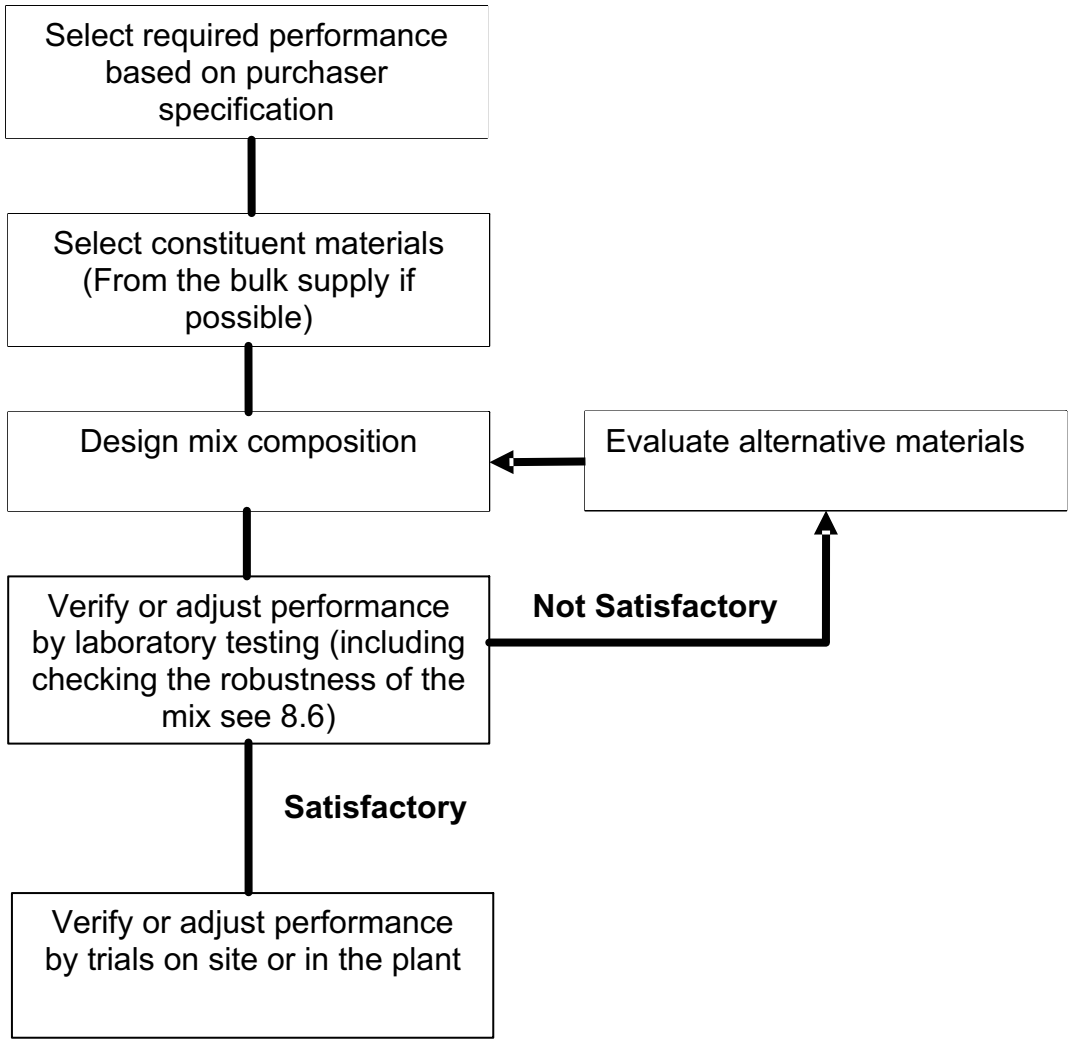


Figure 8.3 Mix design procedure

In the event that satisfactory performance is not obtained, consideration should be given to a fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate:

- adjust the cement/powder ratio and the water/powder ratio and test the flow and other properties of the paste
- try different types of addition (if available)
- adjust the proportions of the fine aggregate and the dosage of superplasticiser
- consider using a viscosity modifying agent to reduce sensitivity of the mix
- adjust the proportion or grading of the coarse aggregate.

Further guidance in the event of unsatisfactory performance may be found in Annex C Improving the finish of SCC.

8.6 Robustness in the fresh state

Self-compacting concrete mix design aims to achieve an acceptable balance between the fresh state characteristics. Any variation in the uniformity of the constituents can upset this balance, resulting in a lack of filling/passing ability or to segregation. Most constituent variability can be equated to a change in water requirement, either due to changes in moisture content of the materials or changes in grading/specific surface both of which change the water demand of the mix.

Well designed SCC can give acceptable tolerance to daily fluctuations in these parameters, easing the pressure on testing/production control and reducing the possibility of problems on the job site. This tolerance is usually termed 'robustness' and is controlled by good practice in sourcing, storage and handling of basic constituents and by appropriate content of the fine powders and/or by use of a VMA.

A well designed and robust SCC can typically accept a 5 to 10 litre/m^3 change in water content without falling outside the specified classes of performance when fresh. When designing an SCC mix, it can be helpful to test at plus and minus 5 and 10 litres of the target water content and measure the change in fresh state properties. This confirms the robustness of the mix or indicates that further adjustments to the design are needed.



Figure 8.4 Sieve segregation resistance test

9 Production for ready-mixed and site mixed SCC

9.1 General

Self-compacting concrete is less tolerant to changes in constituent characteristics and batching variances than lower workability concrete. Accordingly, it is important that all aspects of the production and placing processes are carefully supervised.

The production of self-compacting concrete should be carried out in plants where the equipment, operation and materials are suitably controlled under a Quality Assurance scheme. It is recommended (and is a requirement in some EU member countries) that the producer will be accredited to ISO 9001 or equivalent.

It is important that that all personnel who will be involved in the production and delivery of SCC receive adequate training prior to production from a person with previous experience of self-compacting concrete. This training may include observing trial batches being produced and tested.

9.2 Storage of constituent materials

Storage of constituent materials for SCC is the same as that which should be followed for normal concrete but because the mix is more sensitive to variations, additional importance and attention should be paid to the following points:

Aggregates: should be properly stored to avoid cross-contamination between different types and sizes and protected from weather to minimise the fluctuation of surface moisture content and movement of fines. Ground stock should be stored in purpose built partitioned bays, which will allow free drainage of excess moisture in the aggregates and rainwater.

There must be adequate storage capacity for aggregates as any significant disruption in the supply that causes a break in placing could cause serious complications. It is recommended that all material stores are filled in advance of a self-compacting pour.

Cements, additions and admixtures: There are no special requirements for the storage over that of normal concrete. Manufacturer's recommendations for storage should always be followed. It is recommended that all material stores are filled in advance of a self-compacting pour to avoid the potential variations in performance following a fresh delivery.

9.3 Mixing equipment and trial mixes

Self-compacting concrete can be produced with any efficient concrete mixer including paddle mixers, free fall mixers and truck mixers but force action mixers are generally preferred. However, with SCC it is particularly important that the mixer is in a good mechanical condition and that it can ensure full and uniform mixing of the solid materials with sufficient shear action to disperse and activate the superplasticiser.

Experience has shown that the time necessary to achieve complete mixing of SCC may be longer than for normal concrete due to reduced frictional forces and to fully activate the superplasticiser. It is important that preliminary trials are carried out to ascertain the efficiency of individual mixers and the optimum sequence for addition of constituents. The volume of concrete for preliminary full-scale trials should not be less than half the capacity of the mixer.

Prior to commencing supply it is recommended that plant trials be conducted to ensure that in full scale production, the mix still conforms to the specification requirements for both fresh and hardened properties.

9.4 Plant mixing procedures

The high paste content and fluidity of SCC can make it more difficult to achieve a uniform mix than concrete of lower consistence. The main difficulty is the formation of unmixed "balls" of constituents and once these have formed they are not easily broken down. "Balling" is more likely to occur in free-fall mixers (particularly truck mixers) than forced action mixers. This problem can be avoided by first batching the concrete to a lower consistence than a self-compacting level until it is uniformly mixed. Addition of further water and superplasticiser will increase the consistence to the required level while avoiding "balling".

Time of addition of admixture during the batching is important as it can alter the effectiveness. When using VMA a late addition to the mix is preferred. A standard procedure should be adopted following plant trials and this procedure then strictly followed in order to reduce the potential for between-batch variances.

Admixtures should not be added directly to dry constituent materials but dispensed together with or in the mixing water. Different admixtures should not be blended together prior to dispensing unless specifically approved by the admixture manufacturer. This also applies to the potential for mixing of different admixtures in the dispenser or dosage lines. If air entraining admixtures are being used, they are best added before the superplasticiser and while the concrete is at a low consistency.

Due to the powerful effect of modern superplasticisers, it is important that dispensers are calibrated regularly and where manual addition of admixtures takes place, measurement of the dosage is by a calibrated container or accurate dispensing equipment. Where more than one dosage addition is required to complete a batch there should be a means of counting the individual amounts added.

During production, there may be a number of factors that individually or collectively contribute to variations in the uniformity. The main factors are changes in the free moisture of the aggregate, aggregate particle size distribution and variations in batching sequence. Changes in properties may also be observed when new batches of other constituents are introduced. Because it is normally not possible to immediately identify the specific cause, it is recommended that adjustments to the consistence should be achieved by adjusting the level of superplasticiser.

There are a number of ways to load the mixer and the following examples have been shown to give good results:

9.4.1 Free-fall plant and truck mounted mixers

Approximately two thirds of the mixing water is added to the mixer. This is followed by the aggregates and cement. When a uniform mix is obtained, the remaining mixing water and the superplasticiser are added. Where VMA is used, this should be added after the superplasticiser and just prior to final consistence adjustment with water.

Truck mixers are likely to require additional mixing time for SCC as they are less efficient than plant mixers. Splitting the load into two or more batches can improve mixing efficiency. The condition of the truck mixer drum and mixing blades are particularly important for SCC and should be regularly inspected. The rotational speed of the drum during the mixing cycle should comply with the manufacturer's recommendations but the mixing speed for SCC will normally be in the range 10 – 15 rpm.

9.4.2 Forced action mixers

Aggregate is generally added to the mixer first, together with the cement. This is immediately followed by the main mixing water and superplasticiser. Where used, the VMA is added with the final water. The high shear produced by a forced action mixer improves the fluidity and it may be possible to reduce the addition rate of the superplasticiser compared to a free-fall mixer.

Due to the wide variation in mixers available, the exact methodology for loading the mixer should be determined by trials before commencing production.

9.5 Production Control

9.5.1 Constituents

Self-compacting concrete is more sensitive than normal concrete to variation in the physical properties of its constituents and especially to changes in aggregate moisture content, grading and shape, so more frequent production checks are necessary.

It is recommended that the aggregates are evaluated each production day prior to commencing batching. Thereafter, visual checks should be carried out on each delivery of aggregate; any noticeable change should be evaluated prior to accepting or rejecting the delivery. The moisture content of aggregates should be continuously monitored and the mix adjusted to account for any variation.

When new batches of cement, addition or admixture are delivered, additional performance tests may be necessary to monitor any significant changes or interactions between constituents.

9.5.2 Production

The production and supply of SCC shall be subject to normal production control under the responsibility of the producer, and in the case of ready-mixed concrete, this shall be in accordance with contractual arrangements between purchaser and producer and the requirements of EN 206-1: 2000, Clause 9.

The type of application will determine the specified characteristics and classes that the purchaser has given the producer. The production control must ensure that these are carefully complied with during production and any drift outside of the specified parameters should be immediately communicated to the batching plant operator and technical manager.

In the absence of previous experience with a particular mix design, additional resources may be needed for supervision of all aspects of initial production and testing of SCC.

In order to ensure consistent self-compacting properties, it is recommended that the producer tests every load for slump-flow until consistent results are obtained. Other key tests may also be needed to confirm compliance with the contract specification. Subsequently, every delivered batch should be visually checked before transportation to site or point of placing, and routine testing carried out to the frequency specified in Annex A. Particular care is needed following each delivery of constituent materials, especially aggregates. For example, adjustment to the water content may be needed to compensate for variation in moisture of the aggregates.

9.6 Transportation and delivery

One of the main advantages of SCC is the increase in speed of placing. However, it is essential that the production capacity of the plant, journey time and placing capability at site are all balanced to ensure that site personnel can place the concrete without a break in supply and within the consistence retention time. Production stops can result in thixotropic gelling of concrete that has already been placed and this may affect the filling ability on restarting and or result in lift lines on the vertical surface.

9.7 Site acceptance

In the case of ready-mixed concrete, it is important that there is an agreed and documented standardised procedure for receiving and accepting the SCC at site. The producer and specifier should agree the procedure at the start of a contract. This should include visual inspection of every batch of the concrete and any specific tests and compliance parameters.

The producer is required by EN 206-1 to test concrete at least to the minimum rate given in EN 206-1 for consistence, strength and other properties. This is called "conformity testing".

For testing purposes, the producer can group concretes into families, but until more experience of SCC is gained it is recommended that SCC is not combined into families with normal concretes.

Annex A sets minimum rates of testing for the fresh properties of SCC and uses the normal rates of testing given in EN 206-1 for hardened concrete properties. If additional testing is required such as testing every load for consistence (see 9.5.2) until the required uniformity of supply is achieved, this can be made part of the contract of supply.

Alternatively, the specifier can organise additional testing that in this is case it is called "identity testing". The criteria for accepting/rejecting SCC are given in Annex A.

The documented procedure should include details of responsibility for testing as well as a procedure for action to be taken in the event of non-compliance:

- The specifier shall ensure that all site identity testing is carried out by competent, trained personnel in an environment that is vibration-free and protected against the weather. Equipment shall be with well maintained and calibrated and the test area should have a solid, level area for performing the tests.

- Concrete shall be remixed in the truck mixer for a least one minute (high speed) before a representative sample is taken.

- Sampling shall be carried out in accordance with EN 12350-1. The first SCC from a truck mixer may not be representative. (NOTE: Where a representative sample cannot be obtained, the tolerances given in Annex A may need to be increased.)

- When making SCC samples for compressive strength and other testing, the mould shall be filled in a single layer without compaction.

The recommended test for characterising SCC on site is slump-flow. This gives a good indication of the uniformity of concrete supply. Slump-flow is a measure of the total fluidity and therefore filling ability of the concrete. A visual assessment for any indication of mortar/paste separation at the circumference of the flow and any aggregate separation in the central area also gives some indication of segregation resistance.

There should be continuous observation of the placed concrete to monitor effective filling and any indications of blocking, segregation or settlement.



Figure 9.1. Slump-flow test

10 Site requirements and preparation

10.1 General

Prior to delivery of the concrete, the contractor/user must ensure that appropriate site preparations have been made. These should include:

- confirming that the specified SCC mix is appropriate for the job (see Chapter 6)
- that the site can place the concrete at the agreed delivery rate
- that acceptance procedures for the SCC are agreed and documented
- that site personnel are trained in the specific requirements for placing SCC
- that formwork is properly prepared.

10.2 Site control

A quality control procedure shall be documented and followed on the job site for acceptance of self-compacting concrete. (see Clause 9.7).

It is recommended that every batch of SCC delivered should be tested for slump-flow until uniformity of supply is confirmed. Visual assessment by a competent person is then normally sufficient unless a batch is considered to be marginal. As the producer is required to undertake conformity testing, additional identity testing on site is generally unnecessary and should be restricted to critical applications.

10.3 Mix adjustment

In general, modification of SCC on site is undesirable as the producer should be capable of supplying the specified mix with the required properties for the job. However if special circumstances exist or if some experimentation is expected/planned in order to optimise the mix for specific formwork configurations and surface finish, it may be prudent to establish a further documented procedure for minor adjustment of the concrete, under supervision at site.

The adjustment should be controlled and evaluated by the concrete technologist of the producer and under his responsibility. All modifications shall be recorded.

- Additions of admixtures such as for set control can be made on site before placing, provided the effect has been fully evaluated.
- Concretes that are found to have a slump-flow outside the conformity criteria (see Annex A, table A.6) should only be adjusted provided the procedure is agreed and documented. Any addition of constituents into the truck mixer shall require an agreed minimum mixing time for the concrete (e.g. 1 minutes for every cubic metre with a minimum of 4 minutes)

10.4 Supervision and skills

It is essential that the site personnel used to place self-compacting concrete have been trained/instructed in the specific requirements for placing this type of concrete.

Site personnel should be made aware of the advice given in Chapter 10 and 11 of these Guidelines and particular emphasis should be placed on the following:

- effect of vibration on mix stability
- rate of placing
- the effect of a break/stoppage during placing
- actions to be taken if a break/stoppage occurs
- observation for blockages, segregation or air release
- requirements for placing by pump, skip or chute, including positioning to induce flow
- finishing top surfaces and curing.

10.5 Formwork pressure

Formwork pressure depends on the flowability and cohesion of the SCC, rate of vertical rise and the method of placing (from the top/from the bottom). Formwork design, including support and fixing systems, should normally assume that the full hydrostatic concrete pressure is applied to the formwork. If the SCC is being pumped from the bottom then locally, pressure can be above hydrostatic close to the pump entry point, especially on restart if there is an interruption in pumping.

Trials have shown that, with an appropriate level of thixotropy, formwork pressure below hydrostatic can be achieved when casting from the top but should only be used on the basis of verification trials and agreement between the contractor, producer and formwork supplier.

References:

- Andreas Leeman, Cathleen Hoffman. *Pressure of self-compacting concrete on the formwork*. EMPA, Swiss Federal Laboratories of Materials Testing and Research, Switzerland.
- Peter Billberg. *Formwork pressure generated by self-compacting concrete*. Swedish Cement Research Institute, CBI.
- Wolfgang Brameshuber, Stephan Uebachs. *Investigations on the formwork pressure using self-compacting concrete*. Institute of Building Materials Research (ibac) Aachen University.

10.6 Formwork design

The absence of vibration can allow some novel formwork detailing such as that achieved by magnetically attached shape formers to metal formwork. This can be particularly useful in precast applications of SCC where detailed design can produce an enhanced product with intricate surface detailing. Unusual or complex shapes can be produced that would not be possible with vibrated concrete.

The high flowability of SCC can result in flotation of any buoyant formwork units, stop ends or detailing that is not securely fixed. Particular attention should be given to fixing and sealing the formwork to the base where uplift could be a problem. Leakage at joints can occur and reduce an otherwise high quality of finish, however SCC generally leaks less than concrete that has to be vibrated.

Because full hydrostatic concrete pressure should be assumed when using SCC, particular attention should be paid to both the outer supports and the tie rod system and spacing to ensure that the formwork cannot deform during placing.

10.7 Formwork preparation

SCC normally produces a very high quality finish giving a mirror copy of the formwork. This gives opportunity for enhanced design but if care is not taken, SCC shows up any deficiencies in the formwork material, finish or the release agent and this will detract from the final appearance. Movement at joints or bending of the formwork under pressure from the concrete may also be more noticeable with SCC.

Good formwork preparation as detailed below applies to all types of concrete but is essential if the surface finish of SCC is to be optimised.

10.7.1 Formwork release agents

Self-compacting concrete places explicit demands on type and application rate of mould release agents because of its ability to achieve a very high quality of surface finish. Much formwork used for SCC will be steel or resin surfaced plywood. These are either non-absorbent or have very low absorbency. Excess release agent at the form face and concrete interface can result in staining, retention of air bubbles and other imperfections.

Vegetable, mineral or water based mould release agents need to be applied extremely thinly, almost to the point that they are just wiped on with a cloth. It is also imperative that the mould release agents have not been diluted or adulterated in any way.

Self-compacting concrete will normally allow entrapped air to escape between the concrete and the formwork. Consequently, the release agent must also be of a type which will allow air to migrate in a controlled manner and escape from the concrete.

Certain release agents, when used in combination with impermeable formwork, are too viscous to allow air to escape effectively and this can result in air voids adhering to the surface of the formwork, resulting in blowholes in the concrete. Without pre-evaluation, release agents should only be used with permeable or semi-permeable formwork in order to ensure a reliable surface finish.

The type of formwork can dictate the pre-treatment, the type of release agent and the way it is used.

10.7.2 Uncoated wood formwork

If a good finish is required, avoid dry or completely new wood that is strongly absorbing and that may cause a chemical reaction and lead to staining or retardation of the concrete surface. Surface defects and grain effects will stand out on the concrete surface and any wood grain that is raised may become trapped in the concrete surface.

New timber formwork should be well finished, sealed and a high active release agent applied. Untreated wood should be moist and preferably pre treated with dilute cement slurry that will seal it and reduce the risk of staining or retardation due to sugars in the wood.

With timber formwork that has had several previous uses, the amount of release agent should be reduced to avoid surface staining.

10.7.3 Synthetic coated or resin surfaced wood and steel sheeting formwork

Such materials are non-absorbent or have very low absorbency. An economical, thin but thorough application of a good quality release agent is important. Extremely smooth formwork used for high walls calls for an increased bonding ability of the release agent. For the optimum finish, advice should be sought from the supplier.

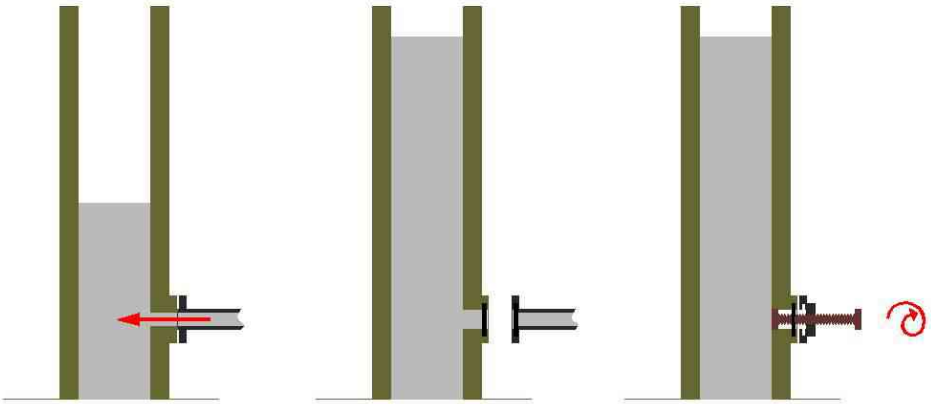
10.8 Formwork for pumping bottom up

SCC allows novel methods of placing concrete including pumping bottom up. In this case the pump is connected via a special connector piece with slide valves into the formwork. The formwork design must be calculated to resist at least the full hydrostatic concrete pressure.

If possible, the pumping point should be in the middle of the wall, thus minimizing the horizontal length of flow. The horizontal spacing of the pumping points will depend on the reinforcement and the flow capacity of the SCC and has to be agreed with the concrete supplier.

The vertical spacing of the pumping points depends on the maximum pressure that the formwork can take and has to be clarified with the formwork supplier.

After pumping from the bottom, the valve is closed and locked. At this time, protruding concrete can be pushed flush with the inner surface of the formwork via a special spindle. See figure 10.1. Alternatively, protruding concrete must be removed and the surface made good after removing the formwork.



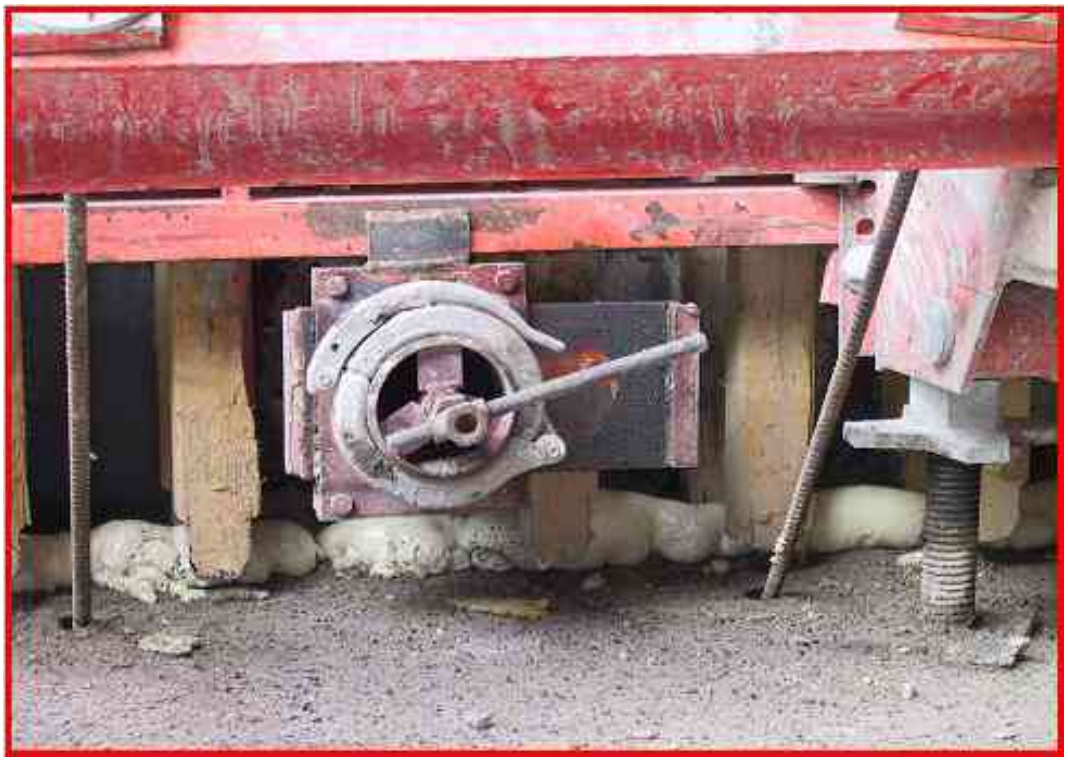


Figure 10.1: After pumping from the bottom, protruding concrete can be pushed flush with the inner surface of the formwork via a special spindle or the surface made good after removal of the formwork.

11 Placing and finishing on site

11.1 General

Self-compacting concrete is designed to have a very high flow combined with cohesion characteristics that ensure that the aggregate is uniformly suspended and does not segregate. The use of vibrators will affect this balance and will usually lead to significant segregation. For this reason, vibrating equipment should not be used with self-compacting concrete except in the special circumstances described in Clause 11.6. Particular attention should be given to possible external sources of vibration from, for instance, nearby equipment.

During placing, the concrete should be regularly checked to ensure that coarse aggregate is remaining at or very near the surface and that there is no indication of segregation. The concrete should form a regular advancing front at a shallow angle and be observed to flow round and fully enclose reinforcing bars without forming void pockets. There should not be excessive release of large air bubbles that would suggest air is being entrapped by the placing process. Check formwork for signs of leakage.

After completion of the first section of a job the quality of the hardened concrete should be checked and evaluated by both the producer and the specifier. Look for top surface laitance, a non-uniform surface colour, specific areas where air is being trapped and any other unwanted effects that are visible.

High quality surface finishes are a feature of SCC but to obtain a surface without blowhole, blemishes or discolouring, requires more than just concrete of good mix design and quality. No guidance currently exists on how to reliably and consistently obtain excellent surface finishes using SCC. However, the formwork face must be faultless and the execution of the casting work and finishing treatment must be of the highest quality. Concrete placers as well as site managers/foremen must understand and take into account the importance of each separate element of the execution, and must carry it out effectively.

It is essential that the personnel used to place self-compacting concrete have been trained/instructed in the specific requirements for placing this type of concrete.

11.2 Discharging

Discharge should not take place before control checks have taken place (see clauses 9.7).

Self-compacting concrete can be placed by direct discharge from truck mixers via a chute. Alternatively it can be first discharged into a skip (with tremie pipe) or to a pump. A receiving hopper/holding vessel with agitator may be used if necessary if the SCC is to be held on site for any length of time before placing.

11.3 Placing procedure and rate

Prior to placing SCC, it should be confirmed that reinforcement and formwork are arranged as planned and the formwork is free of water or debris.

The release of the concrete into the formwork must be in relation to the density of reinforcement, the concrete's flow characteristics and to the potential for entrapment of air.

A reasonable length of flow helps any excess air to escape. However a flow length of more than about 10 metres may create a greater risk of dynamic segregation or void formation.

A fast vertical casting rate may not allow air the time to rise to the surface and escape, causing an increased number of air voids to be trapped in the concrete and blowholes on the surface.

The casting process should be continuous and without interruption as this helps to maintain flow and reduces surface marks and colour variation.

Some SCC, especially those with a slow rate of flow (high T_{500} or V-funnel time), can show a tendency to thixotropic gelling, causing stiffening when at rest, but regaining flowability if sufficient further shearing/stirring energy is applied. Thixotropic gelling can be avoided by keeping the concrete agitated on route to the site and prior to placing. Placing should be without interruptions and the filling locations of the form should be located to keep the casting front moving at all times. Once placing is finished, thixotropic gelling can be an advantage as leakage at joints and formwork pressure are both reduced soon after movement stops.

Self-compacting concrete is more cohesive and usually less prone to segregation than normal concrete but free fall of concrete during placing may still cause some segregation and increase the content of entrapped air so it should be avoided if possible. If unavoidable, free fall height should be limited and tests should be carried out to determine the effect.

When casting extensive horizontal areas where part of the total area must be completed before casting successive areas, permanent stop ends are required and metal lathing has been successfully used with SCC for this application.





Figure 11.1: Casting an SCC slab. Commercial centre, Ferrara, Italy.

11.4 Placing by pump

Pumping is the most common method of placing SCC and consequently the method from which most experience has been gathered.

If the pump has not been primed with a cement mortar the first part of the load (100 – 150 litres) should be run through the pump and recycled back into the truck. This lubricates the pump lines, while the residual coarse aggregate is remixed into the bulk of the SCC.

Self-compacting concrete is well suited to pumping through a valve from the bottom of the formwork provided it has good segregation resistance. This method gives a smooth and clean concrete surface and has proved to be very successful when casting walls in buildings, with system formwork and also in tunnel linings and columns. It has also been used for strengthening existing concrete or for placing new concrete within existing structures.

Pumping from the bottom of the formwork through a valve normally gives the best surface finish for any vertical element. It takes less air into concrete and allows faster casting rates than pumping from the top. The hopper and pump line must be kept completely full of concrete to ensure that air is not introduced at the bottom. It must also be remembered that restarting after a stop can lead to an increase in pressure on formwork.

After pumping from the bottom, the valve is closed and locked. Protruding concrete can be removed after removing of the formwork but special equipment is also available to get a smooth concrete surface without further actions after formwork removal (see clause 10.8).

When pumping from the top, and when surface finish needs to be optimised, SCC should be placed with a submerged hose in order to minimise the possibility of entrapped air. Casting should start at the lowest part of the form, and at a place where the pumping hose can be located as close as possible to the bottom of the form. As soon as sufficient depth has built up, the hose should then be submerged into the concrete. The end of the pump hose should, if possible, be maintained below the concrete surface at all times, including when changing its location so that air is never allowed into the hose.

The pumping should be controlled to produce a continuous and even rate of rise of the concrete in the formwork, with as few breaks in delivery as possible.

11.5 Placing by concrete chute or skip

Although casting of SCC by a pump is recommended both concrete chute and skip have been successfully used. When discharging with a chute, the outlet from the chute should be directed towards the farthest end of the casting and withdrawn as casting proceeds.

When casting SCC from a crane and skip the following points should be considered:

- The skip method is normally only useful for relatively small units or short walls due to the casting capacity (typically 12–20 m^3/hour), but depends on the size of the concrete skip and the manoeuvrability of the crane.
- The skip has to be 'tight' to prevent loss of mortar or paste during transport
- The skip should not be subject to vibration or excessive shaking to avoid segregation of the concrete
- A prolonged stagnation of the mix in the skip can cause thixotropic stiffening so that it will not run from the skip spontaneously and smoothly when opened for discharge.
- Slow delivery rate can cause a prolonged period of stagnation in the form resulting in surface crusting or thixotropic stiffening and this can lead to visible horizontal mark between lifts.

- When casting high or thin walls the casting should take place through a tremie pipe or stocking (collapsing hose) from the skip. The use of a stocking rather than a rigid hose helps to keep the stocking full and prevents air being drawn into the concrete, this is especially important if the surface finish needs to be optimised. If a rigid tremie pipe is used, the end should be kept below the concrete surface at all times and extra care is needed to ensure that air is not drawn into the concrete.

11.6 Vibration

Vibration of SCC should generally be avoided as it is likely to result in significant settlement of the coarse aggregate. If the desired compaction is not being achieved, the concrete should first be checked for conformity to the specification. If it is in conformity but full compaction is not being achieved, consider changing the specification.

There are some occasions when carefully controlled and light vibration may be needed:

- In some structures the formwork shape may cause air to be trapped at certain locations. This can normally be removed by localised tapping or simple rodding in the affected area.

- Slabs, especially those cast from SCC in the lower slump-flow class may require light tamping or a very gently vibrating screed bar to give a level finish, free of protruding coarse aggregate.

- Following a break in placing if the live surface has crusted or stiffened to the extent that a cold joint or surface blemish could form.

11.7 Finishing slabs

Slabs will generally require a lower slump-flow class than SCC for walls and columns. This consistence, combined with the lack of bleed and tendency to thixotropic stiffening can make the concrete feel sticky and difficult to finish. Initial finishing needs to be carried out as soon as possible after the correct level has been reached, before thixotropic stiffening starts and before any surface drying (crusting) has occurred.

Vibrating floats and light vibrating screeds have proved to be effective in the screeding of SCC provided the slab is not inclined but manual equipment should be used if there is any risk of aggregate segregation. Steel floats function better than those of wood or polyurethane cell foam.

If the surface of the slab slopes more than 2-3 % care is required in the use of even light vibrating equipment as this can cause a sideways slipping or other unwanted movement of the fresh SCC.

Levelling of slabs is best carried out with the aid of light shimmying with a skip float (see Figure 11.1). This 'wakens' the surface concrete and gives sufficient compacting work, without causing unwanted aggregate segregation. Correct consistence and execution of the concrete work will give a level and smooth surface without unduly enriching the matrix in the surface. Use of air entraining admixture has been shown to give good finishing properties in some cases.



Figure 11.1 Levelling SCC with a skip float

After-treatment such as the use of steel trowel finishing or float-finishing may be carried out as vibrated concrete. However, if the SCC shows thixotropic stiffening, judging the correct time to start this part of the finishing can be difficult.

11.8 Curing

Curing is important for all concrete but especially so for the top-surface of elements made with SCC. These can dry quickly because of the increased quantity of paste, the low water/fines ratio and the lack of bleed water at the surface. Initial curing should therefore commence as soon as practicable after placing and finishing in order to minimise the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation.

12 Precast concrete products

12.1 General

The precast industry supplies its customers with hardened concrete products that are installed at the site and which may, depending on the structural design, be combined with in-situ concrete. The process starts when the customer specifies the required performances of the precast concrete structure or the precast concrete product.

12.2 Specification of precast concrete products with SCC

For structural products, the specification requirements should either be according to the relevant harmonised product standard (based on EN 13369: Common Rules for precast concrete products) or when relevant, directly to EN 13369 which refers to the relevant parts of EN 1992-1 (Eurocode 2) and to EN 206-1.

The properties of the fresh concrete are defined by the manufacturer, depending on the requirements of the product and on the characteristics of the production process.

When the fresh properties of SCC for precast need to be specified for a particular application, SCC should be characterised according to Chapter 6 of this document and the classification system detailed in Annex A.

Requirements for durability and for concrete cover are the same as those for traditional vibrated concrete and are defined in the relevant product standards and/or EN 13369.

12.3 Mix design of SCC for precast concrete products

The primary concrete specification for precast applications is usually to meet the exposure class and the characteristic compressive strength at 28 days. However for the producer, the strength requirements at early age may become the dominant requirement, in order to enable the workers to demould, to prestress or to move the element within the production cycle.

The constituent materials are selected in accordance with Chapter 7 and in addition, with any requirements in the relevant products standard and/or EN 13369.

The mix design must meet the previously defined requirements for the hardened SCC, combined with the necessary properties for SCC in the fresh state such as fluidity, viscosity and stability, depending on the confinement, placing and finishing conditions.

The reduced time required for transportation and placing, typically no more than 30 minutes, means that long consistence retention is not necessary, allowing the use of a SCC having a short consistence retention, fast set and early strength development. This faster start of the hardening process is beneficial for the early strength, typically at 14 ± 2 hours, required to maintain the production cycle.

High early strength SCC can be achieved through the mix design and/or be stimulated by heat curing, often steered and controlled by maturity testing equipment.

Precast concrete plants will normally develop a set of standard mix designs to meet the general requirements for each type of product. These standard mixes can then be modified for specific requirements. The SCC mix design for the precast products is generally based on the approach outlined in Chapter 8.

12.4 Moulds

The mould type, whether it is steel moulds for repetitive use or coated plywood moulds for limited use, will not change substantially from traditional vibrated concrete for most precast products.

The lack of vibration can allow some other novel formwork detailing such as that achieved by magnetically attached shape formers to metal formwork. This can be particularly useful in precast applications of SCC where detailed design can produce an enhanced product with intricate surface detailing. Unusual or complex shapes can be produced that would not be possible with traditional vibrated concrete.

Using SCC can allow some products to be cast in one operation where for traditional vibrated concrete a one day interruption of casting is required.

Although the wear due to the lack of vibration equipment or poker contact on the mould surface will be less, the stiffness and strength of the mould are dependent on the concrete pressure during casting and full hydrostatic pressure should be assumed (see Clause 10.5).

Further information on mould design, surface preparation and mould release agents is given in Clauses 10.6 and 10.7.

12.5 Factory production

Precast concrete has the same general principals for production as outlined in Chapter 9. The precast manufacturer should also note the following requirements.

All concrete delivered to the mould shall be checked visually for homogeneity and consistence before acceptance and placing. A proportion of all the deliveries should also be checked for slump-flow. In case of doubt other relevant tests may provide additional information about the properties of the fresh SCC

It is recommended (and is a requirement in some EU member countries) that the producer implement factory production control following the requirements of the relevant product standards and/or EN 13369, Annex D. The production control includes:

- equipment inspection
- materials inspection
- process inspection
- finished product inspection
- switching rules.

If temporarily storage of fresh concrete is required because of the mixer output and/or production demand, an agitated holding tank can be used to allow uninterrupted placing of SCC for each individual product.



Figure 12.1 Use of an auger holding tank/hopper to activate the SCC just prior to placing.

12.6 Placing

For precast concrete it is very important that, as with site placed concrete all personnel who will be involved in the casting of SCC receive adequate training prior to placing operations due to the different techniques required.

The placing guidance in Chapter 11 and especially Clauses 11.1 to 11.3 and 11.6 apply. It is essential to fill the mould at a pace that will let air escape and in a way that ensures that no air is entrapped. The casting operation should be carried out continuously as temporary breaks may cause internal joints between layers that can affect strength, durability and appearance. If a break in vertical casting occurs, the contact energy of fresh concrete being placed should be increased when casting the next layer, e.g. by increasing casting height, so that the surface of the first layer is livened up, avoiding the formation of a joint.

Some casting units have outlets of a reduced size to increase the energy of the SCC flowing out during placing operations.

Anchors to connect precast elements for example with masonry walls can be pre-bent and then positioned in the concrete surface after casting.

12.7 Finishing, curing and de-moulding

If the self-compacting concrete is not completely self levelling, the surface can be lightly raked or floated to produce a level surface. Mechanical vibration should only be used following careful trials to check for in-situ segregation (see Clause 11.6).

The final finishing technique is similar to that for normal vibrated concrete but generally starts later, depending on composition, properties and on the ambient and concrete temperature.

Exposed fresh concrete surfaces of precast products made from SCC should be cured in the same way as for normal vibrated concrete (see Clause 11.8).

The use of heat to stimulate and accelerate the strength development of the cast element is as effective for SCC as when applied for normal concrete. Maturity testing is used to steer and control the strength development.

When heat treatment is applied to SCC in order to accelerate its hardening, the characteristics of the thermal treatment should meet the requirements of EN 13369, Clause 4.2.1.4.

13 Appearance and surface finish

13.1 General

High quality surface finishes are a feature of SCC but careful attention to mix design and job site workmanship is required if this is to be achieved.



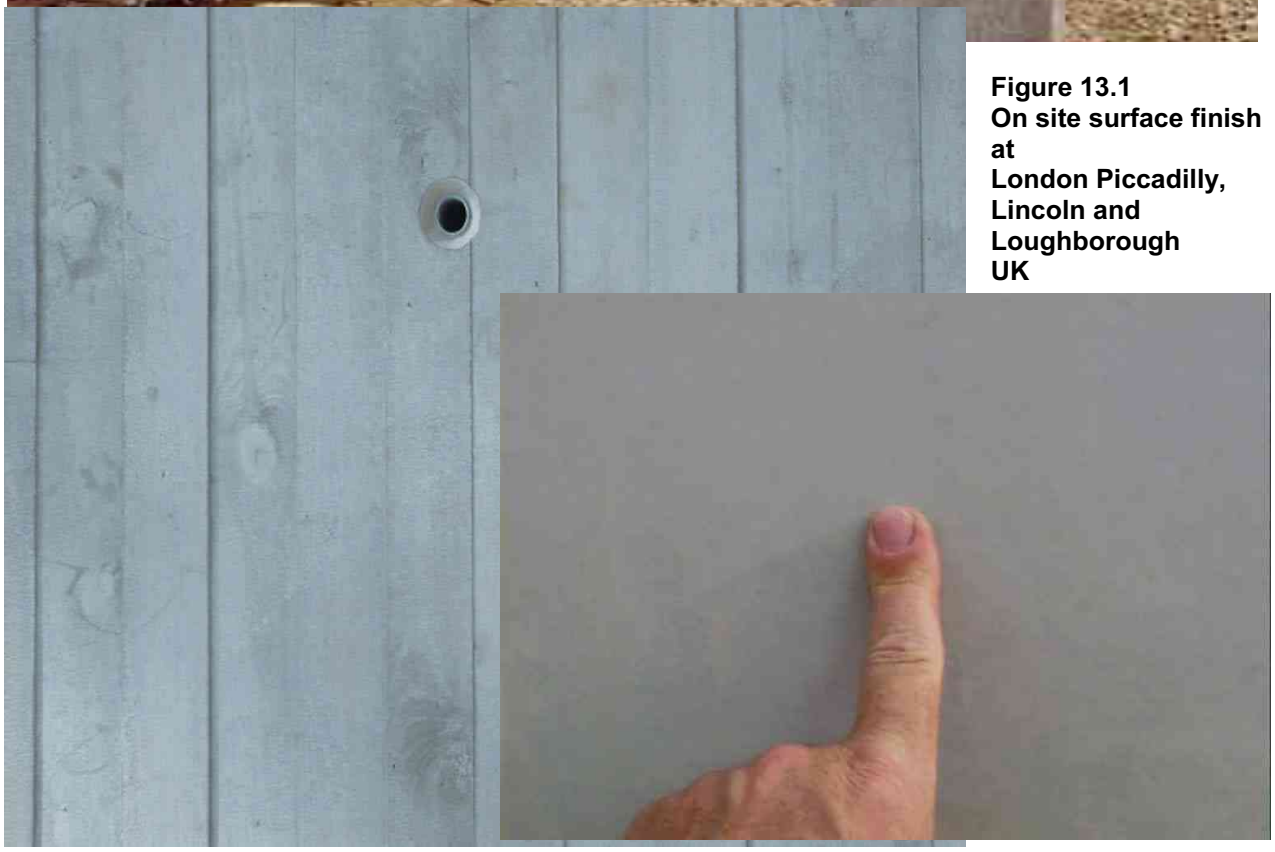


Figure 13.1
On site surface finish at
London Piccadilly, Lincoln and Loughborough
UK

The appearance of an element cast with SCC mainly depends on:

- the type of cement and addition used
- the mix composition of the SCC
- the quality of the mould and release agent
- the placing procedure.

The appearance is usually better than for normal concrete:

- the colour is generally more uniform
- it is easier to avoid defects due to leakage spots at the location of mould joints and around strand or wires exit points
- the edges may be sharp if the mould is well designed and maintained
- blowholes are always present, but may be limited in number and size
- air voids under horizontal parts of the mould can be limited in size and number, when the mould is filled properly.

The following list of defects can be found in all types of concrete but with care, SCC can give an improved finish compared to traditional concrete:

- blowholes
- honeycombing
- vertical stripes and other colour variations
- plastic or drying shrinkage cracking.

A checklist of probable causes of defect causes and prevention is given in Annex C.

Additional information on some defects is given in the following clauses.

13.2 Blowholes

Air is introduced into concrete during the mixing process but also during the transportation and casting. The extent to which air is either stabilised within SCC or is lost during placing depends on the cohesion of the mix. A high slump-flow SF3 and low plastic viscosity VS/VF1 are beneficial in helping to achieve perfect surfaces as they make it easier for the air to leave the concrete. A mix that is close to segregation will usually give the best surface.

Blowholes are formed when small air bubbles become trapped or adhere on the formwork surface. In addition to the factors detailed above, blowholes can also be due to the surface quality of the formwork and the type and/or quantity of release agent used. Advice should be sought from both the release agent supplier and the concrete producer.

Air will be released more easily if the rate of rise of the concrete in the formwork is limited and also if it has to move sideways in the mould for several metres.

Pumping from the bottom of the formwork generally produces better surface finish. If this is not possible the casting hose should be kept below the concrete surface at all times. If the concrete is allowed to free fall, this may increase the number of larger entrapped air voids both on the surface and within the body of the concrete.

13.3 Honeycombing

Honeycombing may be due to leakage in the formwork but is more usually caused by poor passing ability resulting in aggregate bridging and voids behind reinforcement.

SCC with poor passing ability is usually due to:

- slump-flow class too low
- viscosity too high
- maximum aggregate size too large
- Insufficient paste or too much coarse aggregate.

If honeycombing occurs and is not due to formwork leakage, the concrete should be checked against the specification. If conformity to the specification is confirmed, consideration should be given to revising the specification.

13.4 Colour consistency and surface aberrations

Vertical stripes at the SCC surface are rare and usually caused by bleed water. Any bleed water tends to accumulate at the vertical mould surface and flow upwards leaving visible stripes on the hardened concrete surface due to washout and or floatation of the mould oil.

There are several reasons why bleeding may occur:

- high water to powder ratio
- viscosity too low
- low temperature
- retarded set.

Other reasons for colour variations are:

- Uneven drying of surface (for example caused by new or dry timber moulds or plastic sheet that touch part of the concrete during the curing period)
- Over application or poor choice of release agent
- Differences in material source between batches of concrete.

13.5 Minimising surface cracking

SCC is designed to be stable and resistant to segregation but, like traditional vibrated concrete, it may suffer from plastic settlement cracking above reinforcing bars if aggregate settlement does occur. Some SCC mix designs, especially those where a very high quality finish is required, can be very close to the aggregate segregation point so extra control may be required. The use of a VMA, together with appropriate powder content may help to make the concrete more robust and decrease the risk of plastic settlement and cracking.

Plastic settlement cracks may be wide but normally they are not very deep so the surface can often be repaired by trowelling before the concrete sets.

Because SCC has little or no bleed it can loose surface water, resulting in drying shrinkage cracks if curing is not started at an early age.

The European Guidelines for Self-Compacting Concrete

Annex A: Requirements of self-compacting concrete

Introduction
Self-compacting concrete should be regarded as an extension of normal high consistence concrete.

A performance-based specification is provided using the proprietary concrete method of specification. For properties and requirements, other than those related to self-compaction, EN 206-1 is cited or, in the case of precast concrete products and/or EN 13369.

A.1 Scope
This Annex gives requirements and conformity criteria for self-compacting concrete.

A.2 Normative references
This Annex incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this Annex only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 206-1 Concrete – Part 1: Specification, performance, production, and conformity
EN 13369 Common rules for precast concrete products

Annex B, Testing fresh concrete – Part 1: Slump-flow test
Annex B, Testing fresh concrete – Part 2: V-funnel test
Annex B, Testing fresh concrete – Part 3: L-box test
Annex B, Testing fresh concrete – Part 4: Segregation resistance test

NOTE. These test methods are being recommended for standardisation at the European level.

A.3 Definitions, symbols and abbreviations
For the purpose of this Annex, the terms and definitions given in EN 206-1 and the following apply.

A.3.1.1
proprietary concrete
concrete for which the producer assures the performance subject to good practice in placing, compacting and curing, and for which the producer is not required to declare the composition

A.3.1.2
self-compacting concrete (SCC)
concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction

A.3.1.3
filling ability
ability of fresh concrete to flow into and fill all spaces within the formwork, under its own weight

A.3.1.4
viscosity
The resistance to flow of fresh concrete once flow has started

NOTE. This property of SCC is assessed indirectly by measuring the flow time from the V-funnel or by the T_{500} value.

A.3.1.5
passing ability
ability of fresh concrete to flow through tight openings, such as spaces between steel reinforcing bars, without segregation or blocking

A.3.1.6
segregation resistance
ability of fresh concrete to remain homogeneous in composition while in its fresh state

A.3.2 Symbols and abbreviations

For the purpose of this Annex, the symbols and abbreviations given in EN 206-1 and the following apply.

SCC	Self-compacting concrete
SF1 to SF3	Consistence classes expressed by slump-flow
VS1 to VS2	Viscosity classes expressed by T_{500}
VF1 to VF2	Viscosity classes expressed by V-Funnel time
PA1 to PA2	Passing ability classes expressed by passing ability (L-Box test)
SR1 to SR2	Segregation classes expressed by a sieve segregation test.

A.4 Classification

A.4.1 General

The classifications given in EN 206-1: 2000, Clause **4** apply.

A.4.2 Classification used in the specification of SCC

Where the properties of SCC are classified, Tables A.1 to A.5 apply.

NOTE. It is normal to specify only a slump-flow class. In some situations it is also necessary to specify, as initial tests, an L-box class and/or a segregation resistance class and/or either the T_{500} value or a V-funnel class.

Table A.1 – Slump-Flow classes

Class	Slump-flow in mm
SF1	550 to 650
SF2	660 to 750
SF3	760 to 850

Table A.2 –Viscosity classes

Class	T_{500}, s	V-funnel time in s
VS1/ VF1	≤ 2	≤ 8
VS2/ VF2	> 2	9 to 25

Table A.3 – Passing ability classes (L-box)

Class	Passing ability
PA1	≥ 0,80 with 2 rebars
PA2	≥ 0,80 with 3 rebars

Table A.4 – -Segregation resistance classes (sieve segregation)

Class	Segregation resistance in %
SR1	≤ 20
SR2	≤ 15

NOTE. The preferred method of specifying is to use the classification given above, but in special cases target values may be specified.

A.5 Requirements for concrete and methods of verification

A.5.1 Basic requirements for constituent materials

EN 206-1: 2000, Clause **5.1** applies or, in the case of precast concrete products, the relevant product standard and/or EN 13369: 2004, Clause 4.1.

A.5.2 Basic requirements for composition of concrete

EN 206-1: 2000, clause **5.2** applies or, in the case of precast concrete products, the relevant product standard and/or EN 13369: 2004, Clause 4.2.1.

A.5.3 Requirements related to exposure class

The concrete shall satisfy the requirements given in the provisions valid in the place of use related to the specified exposure class(es) and/or the specified limiting values or the specific precast product standard.

A.5.4 Requirements for fresh concrete

Where the properties of self-compacting concrete are to be determined, they shall be measured by means of the following tests:

- Slump-flow and T_{500} test conforming to Annex B Part 1
- V-funnel test conforming to Annex B Part 2
- L-box test conforming to Annex B Part 3
- Segregation resistance test conforming to Annex B Part 4

Where specified directly or indirectly via exposure class, the concrete shall conform to the relevant requirements given in EN 206-1: 2000, **5.4.2** to **5.4.4**. or the relevant product standard and/or EN 13369: 2004, Clause 4.2.2.

A.5.5 Requirements for hardened concrete

EN 206-1: 2000, Clause **5.5** applies or, in the case where the tests are on precast products, EN 13369 and/or other relevant product standards.

A.6 Delivery of fresh concrete

A.6.1 Information from the user of the concrete to the producer

EN 206-1: 2000, **7.1** applies.

A.6.2 Information from the producer of the concrete to the user

On request, the producer shall supply the following information:

a) results of relevant previous tests for the concrete;
b) strength development.

A.6.3 Delivery ticket for ready-mixed concrete

The general information given in EN 206-1: 2000, **7.3** shall be included on the delivery ticket plus the following:

- strength class;
- exposure classes;
- chloride content class;
- classes or target values specified for the property of self-compaction;
- limiting values of concrete composition, if specified;
- maximum nominal upper aggregate size;
- any other specified property.

A.7 Conformity control and conformity criteria

NOTE: In the case of ready-mixed concrete, conformity is undertaken to verify that the claims made on the delivery ticket are valid.

In the case of precast and site made concrete where the user and producer are the same party, testing and verification is undertaken as part of the production control at the same rate of testing and using the same criteria as for conformity. In this case, failure to satisfy the criteria does not lead to a declaration of non-conformity but to an internal investigation to assess whether this indicates a non-conformity with the requirements of the hardened concrete.

The rate of testing the slump-flow shall be that given in EN 206-1 for consistence or, in the case of precast products, EN 13369 and/or other relevant product standards. The T_{500} value, V-funnel time, L-box testing and sieve segregation resistance testing shall only be undertaken if specified.

Conformity to the properties of SCC is confirmed if the specified criteria satisfy the limits given in Table A.6.

Table A.6 – Conformity criteria for the properties of SCC

Property	Criteria
Slump-flow class SF1	≥ 520mm, ≤ 700mm
Slump-flow class SF2	≥ 640mm, ≤ 800mm
Slump-flow class SF3	≥ 740mm, ≤ 900mm
Slump-flow class specified as a target value	± 80mm of target value
V-funnel class VF1	≤ 10s
V-funnel class VF2	≥ 7s, ≤ 27s
V-funnel specified as a target value	± 3s
L-box class PA1	≥ 0,75
L-box class PA2	≥ 0,75
L-box specified as a target value	Not more than 0,05 below the target value
Sieve segregation resistance class SR1	≤ 23
Sieve segregation resistance class SR2	≤ 18

For the other properties and requirements specified, the rate of testing and conformity criteria given in EN 206-1 apply or, in the case of precast products, the relevant product standards and/or EN 13369.

A.8 Production control

The principles of production control of fresh concrete given in EN 206-1: 2000, Clause 9 apply to the specified properties of SCC. In the case of precast products, for other aspects of production EN 13369: 2004, Clause 6.3 and/or other relevant product standards apply.

Annex B: Test Methods
Annex B.1

Testing fresh concrete — Part B1: Slump-flow and T_{500} time for self-compacting concrete

Introduction

The slump-flow and T_{500} time is a test to assess the flowability and the flow rate of self-compacting concrete in the absence of obstructions. It is based on the slump test described in EN 12350-2. The result is an indication of the filling ability of self-compacting concrete. The T_{500} time is also a measure of the speed of flow and hence the viscosity of the self-compacting concrete.

1 Scope

This document specifies the procedure for determining the slump-flow and T_{500} time for self-compacting concrete. The test is not suitable when the maximum size of the aggregate exceeds 40 mm.

2 Normative references

This document incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this document only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to (including any amendments) applies.

EN 12350-1, Testing fresh concrete — Part 1: Sampling

EN 12350-2, Testing fresh concrete — Part 2: Slump test

ISO 5725:1994, Precision of test methods — Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.

3 Principle

The fresh concrete is poured into a cone as used for the EN 12350-2 slump test. When the cone is withdrawn upwards the time from commencing upward movement of the cone to when the concrete has flowed to a diameter of 500 mm is measured; this is the T_{500} time. The largest diameter of the flow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump-flow.
Note: Measurement of the T_{500} time may be omitted if not requested.

4 Apparatus

The apparatus shall be in accordance with EN 12350-2 except as detailed below:

4.1 Baseplate, made from a flat plate with a plane area of at least 900 mm x 900 mm on which concrete can be placed. The plate shall have a flat, smooth and non-absorbent surface with a minimum thickness of 2 mm. The surface shall not be readily attacked by cement paste or be liable to rusting. The construction of the plate shall be such as to prevent distortion. The deviation from flatness shall not exceed 3 mm at any point when a straight edge is placed between the centres of opposing sides.

The centre of the plate shall be scribed with a cross, the lines of which run parallel to the edges of the plate and with circles of 200 mm diameter and 500 mm diameter having their centres coincident with the centre point of the plate. See figure 1.

4.2 Rule, graduated from 0 mm to 1000 mm at intervals of 1 mm.
A stop watch measuring to 0,1 s.

4.3 Stop watch, measuring to 0,1 s.

4.4 Weighted collar (optional), having a mass of at least 9 kg.
NOTE: the weighted collar allows the test to be carried out by one person.

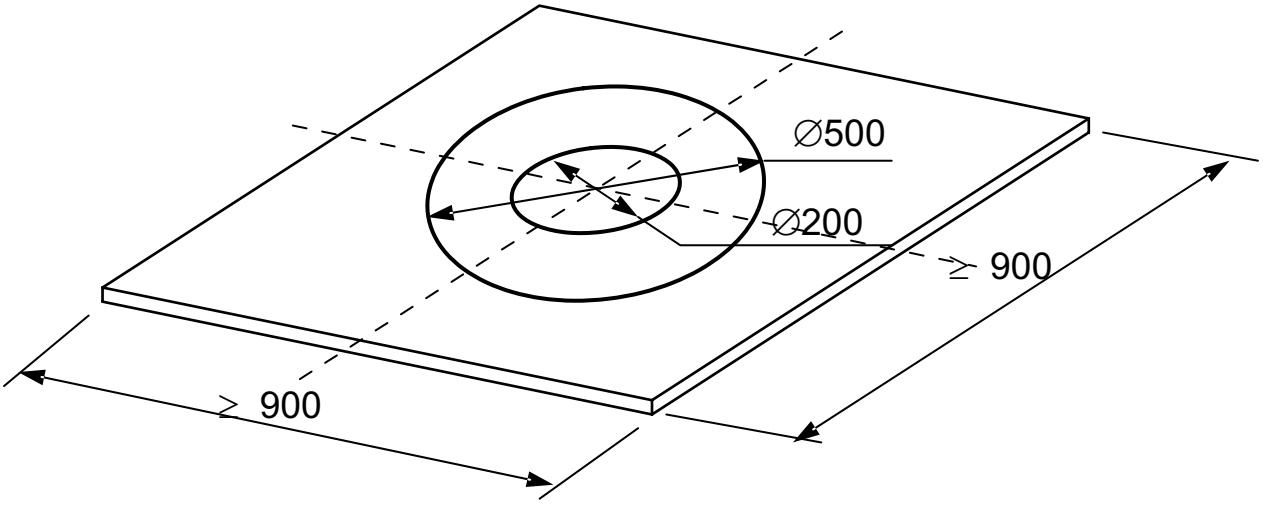


Figure 1, Baseplate reference Clause 4.1

5 Test sample

The sample shall be obtained in accordance with EN 12350-1.

6 Procedure

Prepare the cone and baseplate as described in EN 12350-2.
Fit the collar to the cone if being used.
Place the cone coincident with the 200 mm circle on the baseplate and hold in position by standing on the foot pieces (or use the weighted collar), ensuring that no concrete can leak from under the cone.

Fill the cone without any agitation or rodding, and strike off surplus from the top of the cone. Allow the filled cone to stand for not more than 30s; during this time remove any spilled concrete from the baseplate and ensure the baseplate is damp all over but without any surplus water.

Lift the cone vertically in one movement without interfering with the flow of concrete. If the T_{500} time has been requested, start the stop watch immediately the cone ceases to be in contact with the baseplate and record the time taken to the nearest 0,1 s for the concrete to reach the 500 mm circle at any point. Without disturbing the baseplate or concrete, measure the largest diameter of the flow spread and record

as d_m to the nearest 10 mm. Then measure the diameter of the flow spread at right angles to d_m to the nearest 10 mm and record as d_r to the nearest 10 mm.
Check the concrete spread for segregation. The cement paste/mortar may segregate from the coarse aggregate to give a ring of paste/mortar extending several millimetres beyond the coarse aggregate. Segregated coarse aggregate may also be observed in the central area. Report that segregation has occurred and that the test was therefore unsatisfactory.

7 Test result

The slump-flow is the mean of d_m and d_r expressed to the nearest 10 mm.

The T_{500} time is reported to the nearest 0,1 s.

8 Test report

The test report shall include:

a) identification of the test sample;
b) location where the test was performed;
c) date when test performed;
d) slump-flow to the nearest 10 mm;
e) any indication of segregation of the concrete;
f) time between completion of mixing and performance of the tests;
g) any deviation from the procedure in this document.

The report may also include:

h) T_{500} time to the nearest 0,1 s;
i) the temperature of the concrete at the time of test;
j) time of test.

B.1 Annex (informative)

Precision

The repeatability $r$and reproducibility R have been determined by a programme including 8 laboratories, 16 operators and 2 replicates, and interpreted in accordance with ISO 5725:1994.

The resulting values for $r$and R are given in table 1.

Table A.1 — Precision results

Slump-flow mm	**< 600**	**600 750**	**> 750**
Repeatability $r$mm	n/a	42	22
Reproducibility R mm	n/a	43	28
T_{500} time s	**< 3,5**	**3,5 – 6,0**	**> 6,0**
Repeatability rs	0,66	1,18	n/a
Reproducibility R s	0,88	1,18	n/a

Annex B: Test Methods
Annex B.2

Testing fresh concrete — Part B2: V-funnel test

Introduction

The V-funnel test is used to assess the viscosity and filling ability of self-compacting concrete.

1 Scope

This document specifies the procedure for determining the V-funnel flow time for self-compacting concrete. The test is not suitable when the maximum size of the aggregate exceeds 20 mm.

2 Normative references

This document incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this document only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to (including any amendments) applies.

EN 12350-1, *Testing fresh concrete — Part 1: Sampling*

ISO 5725:1994, *Precision of test methods — Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.*

3 Principle

A V shaped funnel is filled with fresh concrete and the time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time.

4 Apparatus

4.1 *V-funnel*, made to the dimensions (tolerance ± 1 mm) in figure 1, fitted with a quick release, watertight gate at its base and supported so that the top of the funnel is horizontal. The V-funnel shall be made from metal; the surfaces shall be smooth, and not be readily attacked by cement paste or be liable to rusting.

4.2 *Container*, to hold the test sample and having a volume larger than the volume of the funnel and not less than 12 l.

4.3 *Stop watch*, measuring to 0,1 s.

4.4 *Straightedge*, for striking off concrete level with the top of the funnel.

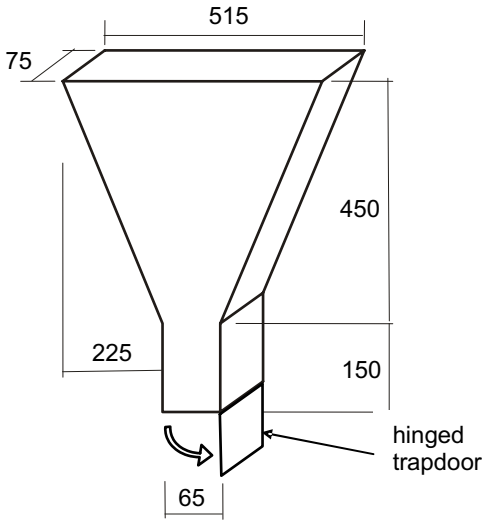


Figure 1 — V funnel

5 Test sample

A sample of at least 12 l shall be obtained in accordance with EN 12350-1.

6 Procedure

Clean the funnel and bottom gate, the dampen all the inside surface including the gate. Close the gate and pour the sample of concrete into the funnel, without any agitation or rodding, then strike off the top with the straight edge so that the concrete is flush with the top of the funnel. Place the container under the funnel in order to retain the concrete to be passed. After a delay of (10 ± 2) s from filling the funnel, open the gate and measure the time t_v, to 0,1 s, from opening the gate to when it is possible to see vertically through the funnel into the container below for the first time. t_v is the V-funnel flow time.

7 Test report

The test report shall include:

a) identification of the test sample;
b) location where the test was performed;
c) date when test performed;
d) V-funnel flow time (t_v) to the nearest 0,1 s;
e) time between completion of mixing and performance of the tests;
f) any deviation from the procedure in this document.

The report may also include:

h) the temperature of the concrete at the time of test;
i) time of test.

B.2 Annex (informative)

Precision

The repeatability r and reproducibility R have been determined by a programme including 10 laboratories, 20 operators and 2 replicates, and interpreted in accordance with ISO 5725:1994.

The values of r and R are given by the following equations where C is the correlation coefficient.

$r = 0{,}335\ t_V - 0{,}62$, with $C^2 = 0{,}823$, when $3 \leq t_V \leq 15$; and $r = 4{,}4$ when $t_V > 15$

and

$R = 0{,}502\ t_V - 0{,}943$, with $C^2 = 0{,}984$, when $3 \leq t_V \leq 15$; and $R = 6{,}6$ when $t_V > 15$

Values of r and R, for typical values of t_V, calculated from these equations, are given in table A.1.

Table A.1 — Repeatability and reproducibility for typical values V-funnel flow time

V-funnel flow time s	**3,0**	**5,0**	**8,0**	**12,0**	**> 15,0**
Repeatability r s	0,4	1,1	2,1	3,4	4,4
Reproducibility R s	0,6	1,6	3,1	5,1	6,6

Annex B: Test Methods
Annex B.3

Testing fresh concrete — Part B3: L-box test

Introduction

The L-box test is used to assess the passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking. There are two variations; the two bar test and the three bar test. The three bar test simulates more congested reinforcement.

1 Scope

This document specifies the procedure for determining the passing ratio, using the L-box test, for self-compacting concrete.

2 Normative references

This document incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this document only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to (including any amendments) applies.

EN 12350-1, *Testing fresh concrete — Part 1: Sampling*

ISO 5725:1994, *Precision of test methods — Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.*

3 Principle

A measured volume of fresh concrete is allowed to flow horizontally through the gaps between vertical, smooth reinforcing bars and the height of the concrete beyond the reinforcement is measured.

4 Apparatus

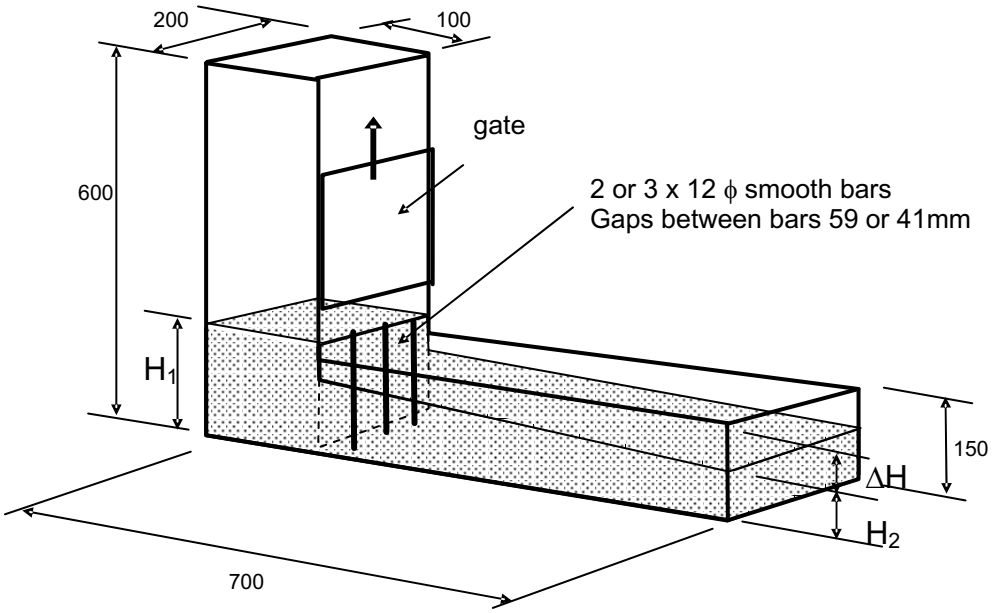
4.1 *L-box*, having the general arrangement as shown in figure 1 and the dimensions (tolerance ± 1 mm) shown in figure 2. The L-box shall be of rigid construction with surfaces that are smooth, flat and not readily attacked by cement paste or be liable to rusting. The vertical hopper may be removable for ease of cleaning. With the gate closed, the volume of the vertical hopper shall be (12,6 – 12,8) l when filled level with the top.

The assemblies holding the reinforcement bars shall have 2 smooth bars of 12 mm diameter with a gap of 59 mm for the two bar test and 3 smooth bars of 12 mm diameter with a gap of 41 mm for the three bar test. These assemblies shall be interchangeable and locate the bars in the L -box so that they are vertical and equidistant across the width of the box.

NOTE: A steel mould is preferred but12 mm coated formwork plywood with the end grain sealed has been found to suitable.

4.2 *Rule*, graduated from (0 – 300) mm in intervals of 1,0 mm.

4.3 *Container*, to hold the sample and having a volume not less than 14 l.



All dimensions mm

Figure 1 — General assembly of L-box

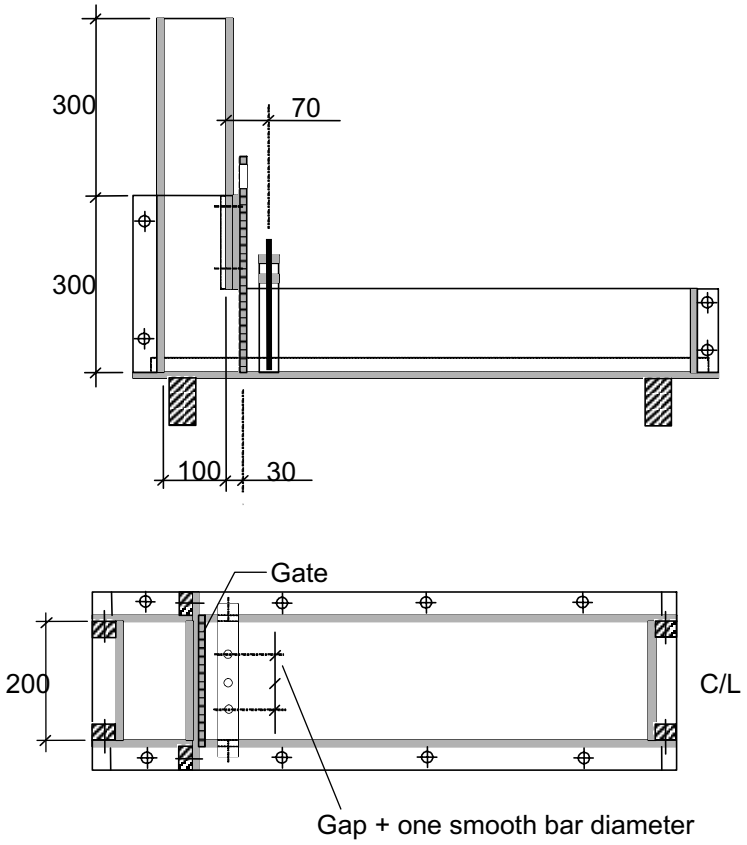


Figure 2 — Dimensions and typical design of L-box

5 Test sample

A sample of approximately 17 l shall be obtained in accordance with EN 12350-1.

6 Test procedure

Support the L-box on a level horizontal base and close the gate between the vertical and horizontal sections. Pour the concrete from the container into the filling hopper of the L-box and allow to stand for (60 ± 10) s. Record any segregation and then raise the gate so that the concrete flows into the horizontal section of the box.

When movement has ceased, measure the vertical distance, at the end of the horizontal section of the L-box, between the top of the concrete and the top of the horizontal section of the box at three positions equally spaced across the width of the box. By difference with the height of the horizontal section of the box, these three measurements are used to calculate the mean depth of concrete as H2 mm. The same procedure is used to calculate the depth of concrete immediately behind the gate as H1 mm.

7 Test result

The passing ability PA is calculated from the following equation.

$$PA = H2/H1$$

8 Test report

The test report shall include:

a) identification of the test sample;
b) location where the test was performed;
c) date when test performed;
d) any segregation observed while filling the L-box;
e) whether two bar or three bar test:
f) passing ratio to the nearest 0,01;
g) time between completion of mixing and performance of the tests;
h) any deviation from the procedure in this document.

The report may also include:

i) the temperature of the concrete at the time of test;
j) time of test.

Addendum

There is a proposal to express the L-box test result as PA = H2/Hmax

Where Hmax is 91 mm and is the theoretical H2 height if the vertical hopper contains exactly 12,7 litres of SCC and completely self levels in the test.
Using this calculation makes measurement easier and improves the test precision.
However, the volume of SCC in the hopper and all the mould dimensions must be correct if this constant is to be used.

Warning:
The value of PA using H2/Hmax will be different to that obtained using H2/H1 and should not be used for showing compliance with the requirements of Annex A of these Guidelines.

B.3 Annex (informative)

Precision

The repeatability r and reproducibility R have been determined by a programme including 11 laboratories, 22 operators and 2 replicates, and interpreted in accordance with ISO 5725:1994.

For the three bar test the values for r and R are given by the following equations where C is the correlation coefficient.

$r = 0{,}074 - 0{,}463\ P_L$, with $C^2 = 0{,}996$, when $P_L \geq 0{,}65$; and $r = 0{,}18$ when $P_L < 0{,}65$

and

$R = 0{,}454 - 0{,}425\ P_L$, with $C^2 = 0{,}989$, when $P_L \geq 0{,}65$; and $R = 0{,}18$ when $P_L < 0{,}65$

Values of r and R, for typical values of P_L, calculated from these equations, are given in table A.1.

Table A.1 — Repeatability and reproducibility for typical values of the passing ratio

H2/H1	**≥0,8**	**<0,8**
Repeatability r	0,11	0,13
Reproducibility R	0,12	0,16

Annex B: Test Methods
Annex B.4

Testing fresh concrete — Part B4: Sieve segregation resistance test

Introduction

The sieve segregation resistance test is used to assess the resistance of self-compacting concrete to segregation.

1 Scope

This document specifies the procedure for determining the sieve segregation resistance of self-compacting concrete.

2 Normative references

This document incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this document only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to (including any amendments) applies.

EN 12350-1, Testing fresh concrete — Part 1: Sampling

ISO 3310-2, Test sieves — Technical requirements and testing — Part 2: Test sieves of perforated metal

ISO 5725:1994, Precision of test methods — Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.

3 Principle

After sampling, the fresh concrete is allowed to stand for 15 min and any separation of bleed water is noted. The top part of the sample is then poured into a sieve with 5 mm square apertures. After 2 min the weight of material which has passed through the sieve is recorded. The segregation ratio is then calculated as the proportion of the sample passing through the sieve.

4 Apparatus

4.1 Perforated plate sieve, having 5 mm square apertures, frame diameter 300 mm and height 40 mm, conforming to ISO 3310-2, complete with a receiver from which the sieve can easily removed by lifting vertically.

4.2 Weighing machine, having a flat platform which can accommodate the sieve receiver and having a capacity of at least 10 kg, calibrated in increments of ≤ 20 g.

4.3 Sample container, made from plastics or metal construction having an internal diameter (300 ± 10) mm, a capacity of (11 – 12) l, and a lid.

5 Test sample

A sample which fills the sample container shall be obtained in accordance with EN 12350-1.

6 Procedure

Place(10 ± 0,5) l of concrete in the sample container and fit the lid. Allow to stand in a level position, without disturbance, for (15 ± 0,5) min.

Ensure the weighing machine is level and free from vibration. Place the sieve receiver on the weighing machine and record its mass (Wp g). Then place the sieve on the receiver and again record the mass.

At the end of the standing period remove the lid from the sample container and record whether any bleed water has appeared on the surface of the concrete. With the sieve and receiver still on the weighing machine, and with the top of the sample container (500 ± 50) mm above the sieve, immediately pour (4,8 ± 0,2) kg concrete (including any bleed water) onto the centre of the sieve. Record the actual mass of concrete (W_C g) on the sieve. Allow the concrete to stand in the sieve for (120 ± 5) s and then remove the sieve vertically without agitation. Record the mass of the receiver and concrete that has passed into it from the receiver (W_{PS} g).

7 Test result

The segregated portion SR is calculated from the following equation and reported to the nearest 1 %.

$$SR = (Wps – Wp)\ 100 / Wc\ \%$$

8 Test report

The test report shall include:

a) identification of the test sample;
b) location where the test was performed;
c) date when test performed;
d) presence of bleed water, if any, after standing for 15 min;
e) segregated portion to the nearest 1%;
f) time between completion of mixing and performance of the tests;
g) any deviation from the procedure in this document.

The report may also include:

h) the temperature of the concrete at the time of test;
i) time of test.

B.4 Annex (informative)

Precision

The repeatability r and reproducibility R have been determined by a programme including 11 laboratories, 22 operators and 2 replicates, and interpreted in accordance with ISO 5725:1994.

The resulting values for r and R are given in table 1.

Table A.1 — Precision results

Segregated portion %	**≤ 20**	**> 20**
Repeatability r%	3,7	10,9
Reproducibility R %	3,7	10,9

Annex C: Improving the finish of SCC

The table below outlines the main defects that may appear during or after the placement of self-compacting concrete. Some of the defects described are also applicable to traditionally vibrated concrete. However, some defects are easier to avoid using SCC due to the nature of the product. It should be noted that surface defects such as blowholes and other surface aberrations affect the appearance of the concrete face, other problems such as honeycombing, joints/layers between batches, scaling, and cracking may impact on concrete integrity.

Type of defect	Primary causes	Practical reasons	How to prevent or correct
Blow holes	entrapped air entrapped water entrapped form oil	• excessive fines/ high specific surface area	• reduce fines
		• heavy or uneven application of mould oil	• minimal application rate applied evenly
		• rough mould surface	• ensure mould surfaces is clean • use of geo-textile form liner will absorb air
		• pouring rate too fast	• ensure steady discharge into forms
		• too long flowing length	• limit flow distance to 5 m
		• too short flowing length	• extend flow distance to 1 m
		• Large free falling distance	• lower free fall to < 1 m • use of soft-wall tremi in deep lifts • pump from bottom up will help to expel air
		• concrete temperature too high	• reduce concrete temperature to below 25°C
		• placing rate too slow	• plan concrete delivery rate and site resources to ensure continuity of pouring
		• settlement of constituents in superplasticiser, particularly defoamer	• concrete producer: improve storage, use by date and stock rotation
		• too high viscosity	• reduce dosage of VMA • review mix proportioning
		• unsuitable aggregate grading	• use of VMA or entrained air
		• too long mixing time induces air	• review mixing time
		• admixture/cement interaction	• assess admixtures/cements compatibility prior to production
Physical reasons:	poor filling ability, poor passing ability high viscosity or high yield stress low slump-flow and / or long T_{500} time rapid slump-flow reduction		

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Vertical stripes or water scouring visible on concrete surface	bleeding of water and fines	• too high water to powder ratio • too low viscosity	• use of VMA may assist • increase viscosity through additional fines • use air entrainer to overcome poor particle size distribution
Physical reason: low stability			

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Colour variations	along the surface differences between batches	• too low temperature	• maintain concrete and in-form temperature during winter conditions
		• too high slump-flow, too low viscosity	• increase viscosity by increasing fines or consider using VMA
		• retarding effect of admixture or release agent	• careful selection of admixtures to open-life requirement • reduce water content or reduce plasticiser addition rate • consider using a mild accelerator • use geo-textile form liner
		• changes in rate of pour	• continuous casting
		• plastic curing membrane irregularly in contact with concrete surface	• ensure consistent contact
		• surface-dry timber moulds	• wet mould before casting • preferably use coated form-face
Physical reasons: retarding or staining effect caused by oil, admixture etc. too high plastic viscosity or yield stress			

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Poor uneven, cast surface	deformation of mould "finger-prints" from mould to concrete surface	• fast pouring rate or weak form design	• reduce casting speed to reduce hydrostatic head • use VMA to increase viscosity • redesign formwork
		• form face worn-out • adhering residual concrete	• renew formwork • clean face prior to casting
		• unsuitable release agent or method of application	• experiment to establish best release agent • apply at correct rate with proper equipment using right pressure and spray nozzle
		• too high water/powder ratio	• increase superplasticiser addition rate or use VMA
Physical reasons: high formwork pressure too low plastic viscosity			

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Honeycombing	insufficient paste or fines concrete segregated due to too low plastic viscosity concrete not able to fill the part of the mould	• low paste/fines content	• increase fines, use at least 450 kg powder/m^3 • add air entrainer
		• unsuitable grading	• continuous grading
		• aggregate size too large compared to free space	• smaller max aggregate size
		• leakage of mould	• check integrity of mould, particularly at joints
Physical reasons: incomplete filling ability incomplete passing ability incomplete stability too low slump-flow and / or T_{500} time segregation of coarse aggregate/paste			

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Scaling	surface layer contains only fine material and has set too fast	• no curing or limited curing	• ensure proper curing according the ambient conditions
		• segregation and/or bleeding caused by the too low amount of fines	• increase powder content • use of VMA • add air entrainer
Physical reasons: incomplete stability segregation and or bleeding too fast drying			

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Visible joint planes between different batches (commonly referred to as "cold joints")	Formation of surface-crust prevents monolithic jointing of subsequent concrete	• intermittent deliveries of concrete	• continuous casting: no breaks
		• concrete stiffening quickly	• pretesting: not too fast stiffening aloud
		• high concrete or air temperature	• lower temperature of concrete than 25°C
		• segregation of coarse aggregates	• review mix proportioning • reduce flowing distance
		• too high specific surface of fines	• reduce fine/powder content
Physical reasons: incomplete filling ability thixotropic setting too fast slump-flow loss too high viscosity admixture - cement interaction			

Type of defect	Primary reasons	Practical reasons	How to prevent or correct
Plastic cracking (early shrinkage and plastic settlement)	too fast drying sedimentation rebar positioning	• poor early age curing regime	• start curing immediately after placing/finishing • proper curing according the ambient conditions
		• segregation and bleeding	• close the plastic cracks prior to concrete setting • increase powder content • use VMA • use air entraining agent
		• extreme ambient conditions (temp, RH, wind etc)	• apply finishing according to prevailing conditions
		• deep lift with rebar close to surface	• rebar cage redesign
Physical reasons: increased plastic drying shrinkage poor stability			