Self compacting concrete

١. Introduction

For several years beginning in ١٩٨٣, the problem of the durability of concrete structures was a major topic of interest in Japan. The creation of durable concrete structures requires adequate compaction by skilled workers. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One solution for achievement of durable concrete structures independent of the quality construction work is the employment of self-compacting concrete, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. The necessity of this type of concrete was proposed by Okamura ١٩٨٦. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, have been carried out by Ozawa and Maekawa at the University of Tokyo (Ozawa ١٩٨٩, Okamura ١٩٩٣ & Maekawa ١٩٩٩).

Several European countries recognized the significance and potentials of SCC developed in Japan. During ١٩٨٩, they founded European federation of natural trade associations representing producers and applicators of specialist building products (EFNARC) ١٢.١٨.

Self –compacting concrete (SCC), which flows under its own weight and does not require any external vibration for compaction is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding. Such concrete should have a relatively low yield value to ensure high flow ability, a moderate viscosity to resist segregation and bleeding, and must maintain its homogeneity during transportation, placing and curing to ensure adequate structural performance and long term durability. The successful development of SCC must ensure a good balance between deformability and stability.

Researchers have set some guidelines for mixture proportioning of SCC, which include (i) reducing the volume ratio of aggregate to cementitious material [١-٢]; (ii) increasing the paste volume and water-cement ratio (w/c); (iii) carefully controlling the maximum coarse aggregate particle size and total volume; and (iv) using various viscosity enhancing admixtures (VEA) [١].

For SCC, it is generally necessary to use super plasticizers in order to obtain high mobility. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The powdered materials that can be added are fly ash, silica fume, lime stone powder, glass filler and quartzite filler.

Self–compacting concrete has been described as "the most revolutionary development in concrete construction for several decades". Originally developed in Japan to offset a growing shortage of skilled labor, it has proved to be beneficial from the following points.

- Faster construction
- Reduction in site manpower
- Better surface finishes
- Easier placing
- Improved durability
- Great freedom in design
- Thinner concrete sections
- Reduced noise level, absence of vibration
- Safer working environment

٢. Material for SCC

a) Cement

Ordinary Portland cement, ٤٣ or ٥٣ grade can be used.

b) Aggregates

The maximum size of aggregate is generally limited to ٢٠ mm. Aggregate of size ١٠ to ١٢ mm is desirable for structures having congested reinforcement. It is also possible size of aggregate higher than ٢٠mm could also be used. Well graded cubical or rounded aggregates are desirable. Aggregates should be of uniform quality with respect to shape and grading.

Fine aggregates can be natural or manufactured. The grading must be uniform throughout the work. The moisture content or absorption characteristics must be closely monitored as quality of SCC will be sensitive to such changes.

Particles smaller than ٠.١٢٥mm i.e. ١٢٥ micron size are considered as FINES which contribute to the powder content.

c) Mixing Water

Water quality must be established on the same line as that for using reinforced concrete or prestressed concrete.

d) Chemical admixtures

Superplasticizers are an essential component of SCC to provide necessary workability. The new generation superplasticizer termed poly-carboxylated ethers(PCE) is particularly useful for SCC.

Other types may be incorporated as necessary, such as viscosity modifying agents (VMA) for stability, air entraining agents (AEA) to improve freeze-thaw resistance, and retarders for control of setting.

٣. Mineral Admixtures

١. Fly ash

Fly ash in appropriate quantity may be added to improve the quality and durability of SCC.

٢. Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS which is both cementitious and pozzolanic material may be added to improve rheological properties.

٣. Silica Fume

Silica fume may be added to improve the mechanical properties of SCC.

٤. Stone Powder

Finely crushed lime stone, dolomite or granite may be added to increase the powder content. The fraction should be less than ١٢٥ micron.

٥. Fibers

Fibers may be used to enhance the properties of SCC in the same way as for normal concrete.

The SCC mixes are designed and tested to meet the demands of the projects. It is reported that SCC for mass concrete was designed for pumping and depositing at a fairly high rate in the construction of the anchorages of the Akashi-Kaikyo batching plant and pumped through a pipe line to the location of anchorages ٢٠٠ m away. The SCC was dropped from a height of ٥ m without segregation. For mass concrete, the maximum size of coarse aggregate was as large as ٥٠ mm. The SCC construction reduced the construction time for the anchorages from ٢.٥ years to ٢ years. The coarse aggregate size for reinforced concrete generally varies from ١٠ mm to ٢٠ mm.

٤. Types of SCC

There are three ways in which SCC can be made

- Powder type
- Viscosity modifying agents (VMA)
- Combined type

In powder type SCC is made by increasing the powder content. In VMA type it is made by using viscosity modifying admixture. In combined type it is made by increasing powder content and using VMA. The above three methods are made depending upon the structural conditions, constructional conditions, available material and restrictions in concrete production plant etc.

٥. Requirements for self-compacting concrete

The main characteristics of SCC are the properties in the fresh state. The mix design is focused on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own weight, and the ability to retain homogeneity without segregation. The workability of SCC is higher than "very high" degree of workability mentioned in IS ٤٥٦ : ٢٠٠٠.

A concrete mix can only be classified as self-compacting if it has the following characteristics

- Filling ability
- Passing ability

- Segregation resistance

For the initial mix design of SCC all three workability parameters need to be assessed to ensure that all aspects are fulfilled. A full-scale test should be used to verify the self-compacting characteristics of the chosen design for a particular application.

For site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are Slump-flow and V-funnel or Slump-flow and J-ring. With consistent raw material quality, a single test method operated by a trained and experienced technician may be sufficient.

٦. Production, Placing and Curing of SCC

Aggregates

Aggregate should come from same source. There should not be many variations in size, shape and moisture content.

Mixing

Any suitable mixer could be used. Generally, mixing time need to be longer than for conventional concrete. Time of addition of admixture is important. A system should be established for optimum benefit during the trial itself.

In the beginning there may be fluctuations in the quality of freshly mixed concrete. It is recommended that every batch must be tested until consistent and compliant results are obtained. Subsequently, checking could be done "by the eye" and routine testing is sufficient.

٦.١ Placing

Formwork must be in good conditions to prevent leakage. Though it is easier to place SCC than ordinary concrete, the following rules are to be followed to minimize the risk of segregation

- Limit of vertical free fall distance to ٥ meter
- Limit the height of pour lifts (layers) to ٥٠٠ mm

- Limit of permissible distance of horizontal flow from point of discharge to ١٠ meters.

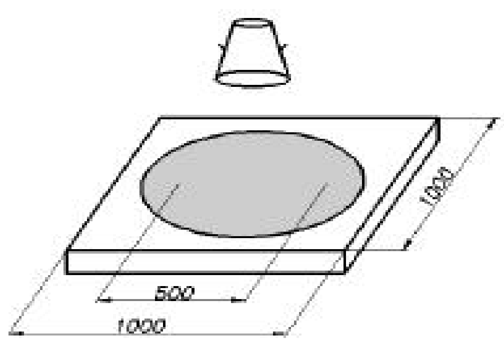
٦.٢ Curing

On account of no bleeding or very little bleeding, SCC tends to dry faster and may cause more plastic shrinkage cracking. Therefore, initial curing should be commenced as soon as practicable. Alternatively the SCC must be effectively covered by polyethylene sheet. Due to the high content of powder, SCC can show more plastic shrinkage or creep than ordinary concrete mixes. There are disagreements on the above statement. These aspects should be considered during designing and specifying SCC. It should also be noted that early curing is necessary for SCC.

٧. Test methods

Slump flow test and T٥٠cm test

The slump flow test is done to assess the horizontal flow of concrete in the absence of obstruction. It is most commonly used test and gives good assessment of filling ability. It can be used at site. The test also indicates the resistance to segregation.



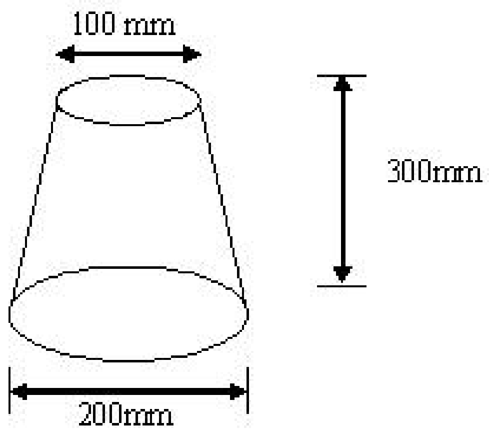


Fig. ١ Slump flow test

Equipment

The apparatus is shown in figure ١.

- mould in the shape of a truncated cone with the internal dimensions ٢٠٠ mm diameter at the base, ١٠٠ mm diameter at the top and a height of ٣٠٠ mm.
- base plate of a stiff non absorbing material, at least ٧٠٠mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of ٥٠٠mm diameter
- trowel
- scoop
- ruler
- stopwatch (optional)

Procedure

About ٦ liter of concrete is needed to perform the test, sampled normally.

Moisten the base plate and inside of slump cone,

Place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly.

Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.
Remove any surplus concrete from around the base of the cone.
Raise the cone vertically and allow the concrete to flow out freely.
Simultaneously, start the stopwatch and record the time taken for the concrete to reach the ٥٠٠mm spread circle. (This is the T٥٠ time).
Measure the final diameter of the concrete in two perpendicular directions.

Calculate the average of the two measured diameters. (This is the slump flow in mm).
Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Interpretation of result

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of *at least* ٦٥٠mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± ٥٠mm, as with the related flowtable test, might be appropriate.

The T٥٠ time is a secondary indication of flow. A lower time indicates greater flowability. It is suggested that a time of ٣-٧ seconds is acceptable for civil engineering applications, and ٢-٥ seconds for housing applications.

Slump Flow/J-Ring combination test

Introduction

The principle of the J-Ring test may be Japanese, but no references are known. The JRing test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (٣٠mm x ٢٥mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, ٣x the maximum aggregate size might be appropriate. The diameter of the ring of vertical bars is ٣٠٠mm, and the height ١٠٠ mm.

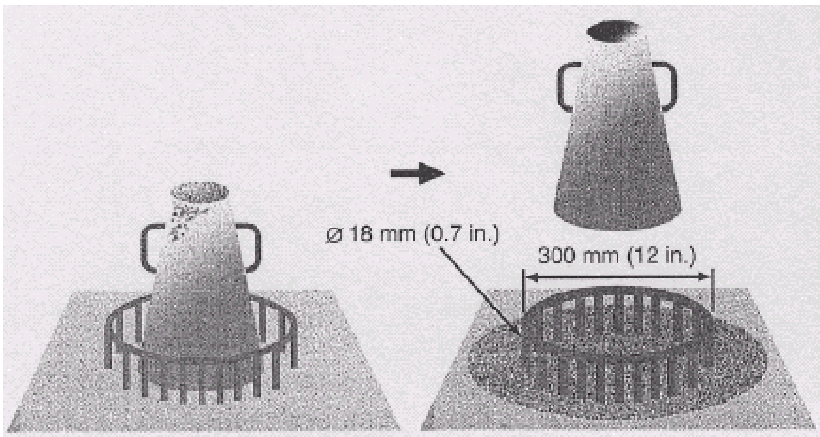


Fig. ٢ Slump Flow/J-Ring combination test (Kosmatka et al., ٢٠٠٢).

Equipment

- mould, without foot pieces, in the shape of a truncated cone with the internal dimensions ٢٠٠ mm diameter at the base, ١٠٠ mm diameter at the top and a height of ٣٠٠ mm.
- base plate of a stiff non absorbing material, at least ٧٠٠mm square, marked with a circle showing the central location for the slump cone, and a further concentric circle of ٥٠٠mm diameter
- trowel
- scoop
- ruler
- JRing a rectangular section (٣٠mm x ٢٥mm) open steel ring, drilled vertically with holes.

In the holes can be screwed threaded sections of reinforcement bar (length ١٠٠mm, diameter ١٠mm, Spacing ٤٨ +/- ٢mm)

Procedure

About ٦ liter of concrete is needed to perform the test, sampled normally.

Moisten the base plate and inside of slump cone,

Place base-plate on level stable ground.

Place the J-Ring centrally on the base-plate and the and the slump-cone centrally inside it and hold down firmly.

Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.

Remove any surplus concrete from around the base of the cone.

Raise the cone vertically and allow the concrete to flow out freely.

Measure the final diameter of the concrete in two perpendicular directions.

Calculate the average of the two measured diameters. (in mm).

Measure the difference in height between the concrete just inside the bars and that just outside the bars.

Calculate the average of the difference in height at four locations (in mm).

Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

V-funnel test and V-funnel test at T٥ min.

Viscosity of the self-compacting concrete is obtained by using a V-funnel apparatus, which has certain dimensions (Figure ٣), in order for a given amount of concrete to pass through an orifice (Dietz and Ma, ٢٠٠٠). The amount of concrete needed is ١٢ liters and the maximum aggregate diameter is ٢٠ mm. The time for the amount of concrete to flow through the orifice is being measured. If the concrete starts moving through the orifice, it means that the stress is higher than the yield stress; therefore, this test measures a value that is related to the viscosity. If the concrete does not move, it shows that the yield stress is greater than the weight of the volume used. An equivalent test using smaller funnels (side of only ٥ mm) is used for cement paste as an empirical test to determine the effect of chemical admixtures on the flow of cement pastes.

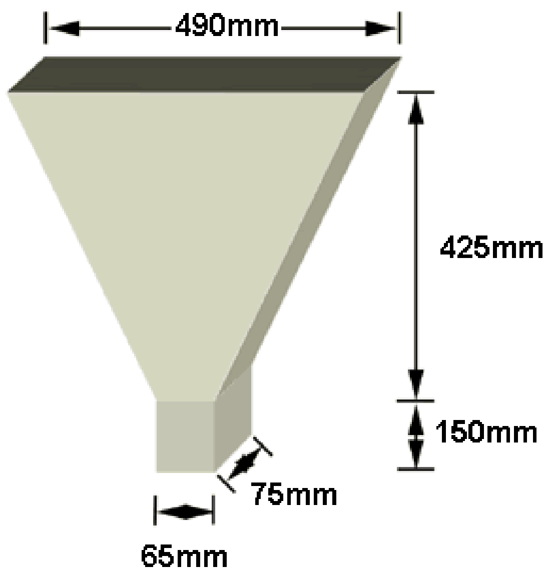


Fig. ٣ V-funnel (Dietz and Ma, ٢٠٠٠)

Procedure flow time at T ٥ minutes

Do not clean or moisten the inside surfaces of the funnel again. Close the trap door and refill the V-funnel immediately after measuring the flow time. Place a bucket underneath. Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete level with the top with the trowel. Open the trap door ٥ minutes after the second fill of the funnel and allow the concrete to flow out under gravity. Simultaneously start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time at T ٥ minutes). This is taken to be when light is seen from above through the funnel.

L-Box test

This method uses a test apparatus comprising of a vertical section and a horizontal trough into which the concrete is allowed to flow on the release of a trap door from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus (Dietz and Ma, ٢٠٠٠). The time that it takes the concrete to flow a distance of ٢٠٠mm (T-٢٠) and ٤٠٠mm (T-٤٠) into the horizontal section is measured, as is the height of the concrete at both ends of the apparatus (H١ & H٢). The L-Box test can give an indication as to the filling ability and passing ability.

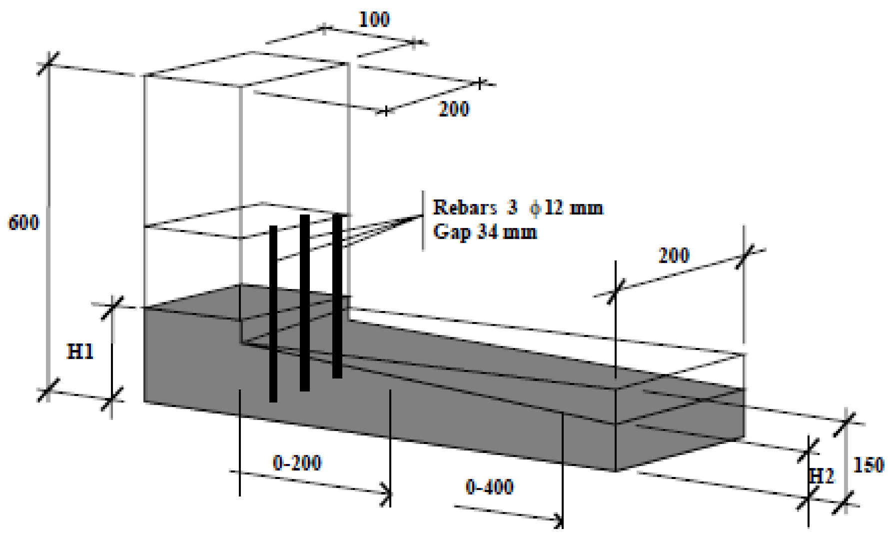


Fig. ٤ L box

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U-box test

Of the many testing methods used for evaluating self-compactability, the U-type test (Figure ٥) proposed by the Taisei group is the most appropriate, due to the small amount of concrete used, compared to others (Ferraris, ١٩٩٩). In this test, the degree of compactability can be indicated by the height that the concrete reaches after flowing through obstacles. Concrete with the filling height of over ٣٠٠ mm can be judged as self-compacting. Some companies consider the concrete self-compacting if the filling height is more than ٨٥% of the maximum height possible.

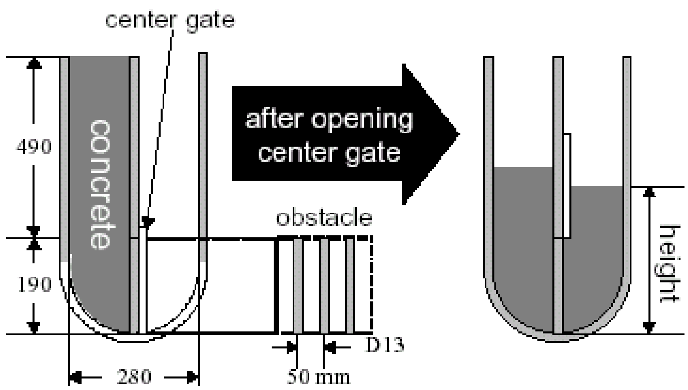
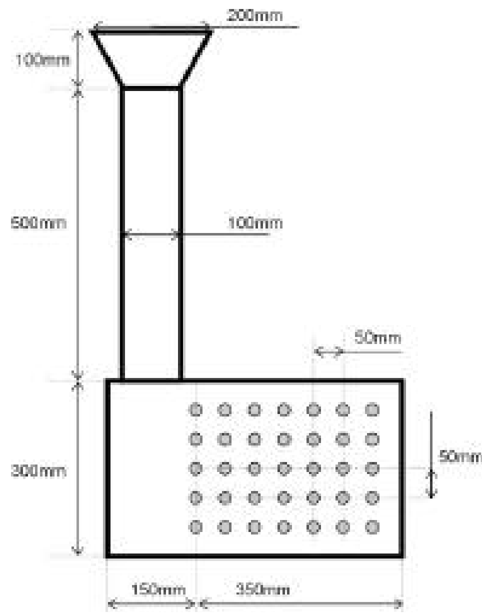


Fig. ٥ U-type test (Ouchi and Hibino, ٢٠٠٠).

Fill box test

This test is also known as the 'Kajima test '.The test is used to measure the filling ability of self-compacting concrete with a maximum aggregate size of ٢٠mm. The apparatus consists of a container (transparent) with a flat and smooth surface. In the container are ٣٥ obstacles made of PVC with a diameter of ٢٠mm and a distance centre to centre of ٥٠mm: see Figure ٦. At the top side is put a filling pipe (diameter ١٠٠mm height ٥٠٠mm) with a funnel (height ١٠٠mm). The container is filled with concrete through this filling pipe and the difference in height between two sides of the container is a measure for the filling ability.

This is a test that is difficult to perform on site due to the complex structure of the apparatus and large weight of the concrete. It gives a good impression of the self-compacting characteristics of the concrete. Even a concrete mix with a high filling ability will perform poorly if the passing ability and segregation resistance are poor.



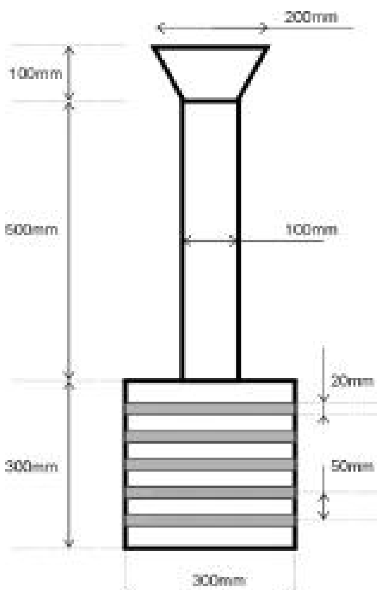


Fig.٦ Fill box test

Orimet test

The test is based on the principle of an orifice rheometer applied to fresh concrete (Bartos, ٢٠٠٠). The test involves recording of time that it takes for a concrete sample to flow out from a vertical casting pipe through an interchangeable orifice attached at its lower end. The shorter the Flow-Time, the higher is the filling ability of the fresh mix. The Orimet test also shows potential as a means of assessment of resistance to segregation on a site.

Orimet / J-Ring combination test

This recently developed test involves the J-Ring being placed centrally below the orifice of the Orimet apparatus, allowing the discharged mix to fall into it and flow outwards (Bartos, ٢٠٠٠). The Orimet time is recorded as in the conventional Orimet test, along with the diameter of the concrete spread and the height of the concrete within the JRing. The more dynamic flow of concrete in this test simulates better the behaviour of a SCC mix when placed in practice compared with the Slump-Flow variation. The Orimet/J-Ring combination test will be used in the future as a method of assessing filling ability, passing ability and resistance to segregation (Bartos, ٢٠٠٠).

GTM Screen stability test

This test was developed by French contractor GTM, to assess segregation resistance (stability). It consists of taking a sample of ١٠ liter of concrete allowing it to stand for a period to allow any internal segregation to occur, then pouring half of it on to a ٥mm sieve of ٣٥٠ mm diameter, which stands, on a sieve pan on weigh scale. After two minutes, the mortar which passed through ٥ mm sieve is weighted, and expressed as a percentage of the weight of the original sample on the ٥mm sieve.

References

١ EFNACR, Association House, " Specification and Guidelines for Self-Compacting Concrete", Association House, ٩٩ West Street, Farnham, Surrey GU٩ ٧EN, UK, February ٢٠٠٢ , www.efnarc.org.

٢ M.S. Shetty "Concrete Technology", Multicolour Illustrative Edition, S. CHAND & COMPANY LTD., (An ISO ٩٠٠١ : ٢٠٠٠ Company), Ram Nagar, New Delhi – ١١٠٠٥٥, pp. ٥٧٣-٥٨٧.

٣ Paratibha AGGARWAL, Rafat SIDDIQUE, Yogesh AGGARWAL, Surinder M GUPTA "Self-Compacting Concrete-Procedure for Mix Design", Leonardo Electronic Journal of Practices and Technologies ISSN ١٥٨٣-١٠٧٨, Issue ١٢, January-June ٢٠٠٨, pp.١٥-٢٤.

٤ P. Rathish Kumar and K. Srikanth "Mechanical Characteristics of Fiber Reinforced Self Compacting Mortars", Asian Journal OF Civil Engineering (Building and Housing) Vol. ٩, NO. ٦ (٢٠٠٨), pp. ٦٤٧-٦٥٧.

٥ H.J.H. Brouwers and H.J. Radix "Self-Compacting Concrete : The Role of The Particles Size Distribution", First International Symposium on Design, Performance and Use of Self-Consolidating Concrete, SCC'٢٠٠٥ - China, ٢٦ - ٢٨ May ٢٠٠٥, Changsha, Hunan, China, pp. ١٠٩-١١٨.