High Performance Concrete Using Viscosity-Modifying Admixture

By

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Dissertation submitted in partial fulfillment
of the requirements for the
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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

YONG KONG CHIN

ACKNOWLEGDEMENT

I would like to take this opportunity to thank all parties involved in making this Final Year Project (FYP) a great education and experimental session as well as a great success.

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All the challenges and difficulties were taken as a yardstick of how much was learned. Through the FYP, immense knowledge was acquired and the objectives of FYP were achieved.

ABSTRACT

The use of viscosity modifying admixture (VMA) has proved to be very effective in stabilizing the rheological properties and consistency of self-compacting concrete (SCC). SCC was developed in Japan in the late 1980s, and recently, this concrete has gained wide use with a steadily increasing number of applications in many developed countries such as Europe country and United States but not yet being utilized in Malaysia. SCC is known for its excellent deformability, high resistance to segregation and use, without applying vibration, in congested reinforced concrete structures characterized by difficult casting condition. Identification or production of new low-cost VMA is then essential. This paper presents the performance of local VMA supplied by one manufacturer in enhancing the rheological and consistency properties of cement paste.

The study of the rheological properties and consistency of concrete to screen the dosage of VMA to be used in SCC is a promising approach. Investigation was carried out on concrete with VMA and HRWR to verify both admixtures' performance on workability, segregation, filing ability with obstacles, compressive strength and porosity. Besides, fresh and hardened concrete properties will be studied and mixes with various dosage of VMA to investigate the relationship between all properties.

The combined use of proper dosages of VMA and high-range water reducer (HRWR) is shown clearly contribute to higher workability and lesser segregation. The type of VMA and SP used in this study is Vismocrete and Adva that are provided by same manufacturer. Different mix proportion of concrete under same condition must be tested in order to obtain the optimum dosage for best result. Besides, the relationship between fresh and hardened concrete properties were determined in this report.

TABLE OF CONTENT

LIST OF ILLUSTRATION

List of Figures

List of Tables

CHAPTER 1
INTRODUCTION

1.1 Background of study

The application of concrete without vibration in highway bridge construction is not new. For example, placement of seal concrete underwater is done by the use of a tremie without vibration, mass concrete has been placed without vibration, and shaft concrete can be successfully placed without vibration. These seal, mass and shaft concretes are generally of lower strength and difficult to attain consistent quality. Modern application of self-compacting concrete (SCC) is focused on high performance, better and more reliable quality, dense and uniform surface texture, improved durability, high strength, and faster construction (4).

SCC is commonly used for casting congested structural members that are often encountered in heavily reinforced mat foundations and in reinforced concrete structures in seismic regions. It is also used in restricted areas where the access for placement and consolidation is limited, as in the case of tunnel lining. The use of SCC to facilitate the casting of congested or restricted areas can result in an unstable dispersion of cement paste and aggregate particles since the tendency of the heterogeneous materials to separate increases with the reduction in viscosity. This can be obtained when the consistency of the SCC increases or when the concrete is subjected to high shear rate, such as that encountered in pumping and consolidation.

The incorporation of viscosity modifying admixture (VMA) in SCC can enable the production of a stable and yet highly flowable concrete to facilitate filling congested reinforced members with minimal vibration and segregation. The improved homogeneity of the concrete can enhance bond strength to reinforcement and aggregate, thereby decreasing permeability. VMA are also used in shotcrete for the repair of deteriorated structures, since it can enhance the sagging resistance of the concrete and enable the application of thicker lifts. The rheological behaviour of specialty cement grouts intended for the underwater sealing of cracks in dams, offshore structures, massive foundations, or fissures in rock can be enhanced by incorporating VMA. Viscosity is the measure of the resistance and internal friction of a liquid whereas rheology refers to study of deformation and flow characteristics of matter in terms of viscosity and friction. Grouts made with VMA are also used for filling post-tensioning ducts, where it is important to ensure high resistance to sedimentation and bleeding, hence ensuring corrosion protection of stressed tendons.

Recognizing the lack of uniformity and complete compaction of concrete by vibration, researchers at the University of Tokyo, Japan, started out in late 1980's to develop SCC. By the early 1990's, Japan has developed and has used SCC that does not require vibration to achieve full compaction by adding VMA [(4)]. Japan has used SCC in bridge, building and tunnel construction since the early 1990's. In the last five years, a number of SCC bridges have been constructed in Europe. In the United States, the application of SCC in highway bridge construction is very limited at this time. However, the US precast concrete industry is beginning to apply the technology to architectural concrete. SCC has high potential for wider structural applications in highway bridge construction.

SCC offers many advantages for the precast, prestressed concrete industry and for cast-in-place construction. Several European countries were interested in exploring the significance and potentials of SCC developed in Japan. In the United States, SCC is beginning to gain interest, especially by the precast concrete industry and admixture manufacturers. However, SCC with combination of VMA has not been widely used in Malaysia. There is lack of evidence or studies regarding VMA in Malaysian Construction society. Anyhow, it is a very powerful technology as the precast concrete industry is beginning to apply the technology to commercial projects when specifications permit.

1.2 Problem Statement

The use of viscosity modifying admixtures (VMA) has proved very effective in stabilizing the rheology of SCC. VMA tends to modify the viscosity of the cement paste to delay the time for aggregate to settle before setting. Commercial VMAs currently available on the market are costly, which increases the cost of such a concrete. There are several differences in the practical application and structural configuration of admixtures in the production of SCC between different countries. The local VMA is still under development in Malaysia and the performance is yet to be explored.

1.3 Objective

The main objective of this project is to investigate the performance of VMA with HRWR based on various tests of rheology properties, fluidity, segregation and washout resistance of the cement pastes. Fresh and hardened concrete properties will be studied and mixes with various dosage of VMA to investigate the relationship between all properties. Investigation is necessary to explore the potential use of local VMA, which is desired to produce a competitive SCC to help reducing the cost and evolving admixtures technology in Malaysia.

1.4 Scope of Study

The scope of study of this project is more towards concrete technology and admixtures. Knowledge governing the practical application of admixtures in the production of concrete concerning composition, mixing, placing and curing are required to develop high performance concrete. Other than these two important scopes, other scopes such as material science and selection, engineering documentation and presentation as well as engineering ethics are essential to accomplish the project.

CHAPTER 2
LITERATURE REVIEW/THEORY

2.1 Self-compacting Concrete (SCC)

SCC represents one of the most outstanding advances in concrete technology during the last decade. Due to its specific properties, SCC may contribute to a significant improvement of the quality of concrete structures and open up new fields for the application of concrete. SCC describes a concrete with the ability to compact itself only by means of its own weight without the requirement of vibration. It fills all recesses, reinforcement spaces and voids, even in highly reinforced concrete members and flows free of segregation nearly to level balance. It is not a traditional high-slump concrete and it flows like a viscous liquid rather than exhibiting the traditional slump of a high slump concrete (1). While flowing in the formwork, SCC is able to deaerate almost completely.

With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated normal concrete, which are cement, aggregates, water, additives and admixtures. However, the high amount of high-range water reducer (HRWR) for reduction of the liquid limit and for better workability, the high powder content as "lubricant" for the coarse aggregates, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. In principle, the properties of the fresh and hardened SCC, which depend on the mix design, should not be different from normal concrete. One exception is only the consistency. SCC should have a slump flow of approximately 50 to 70 cm after pulling the flow cone. Figure 1 shows the basic principles for the production of SCC (2). A comparison of a typical mix design of SCC and conventional concrete is shown in Figure 2 (1). On the basis of the stated differences between SCC and conventional concrete it is necessary to prove the existing design rules based on years of experience on normal concrete.

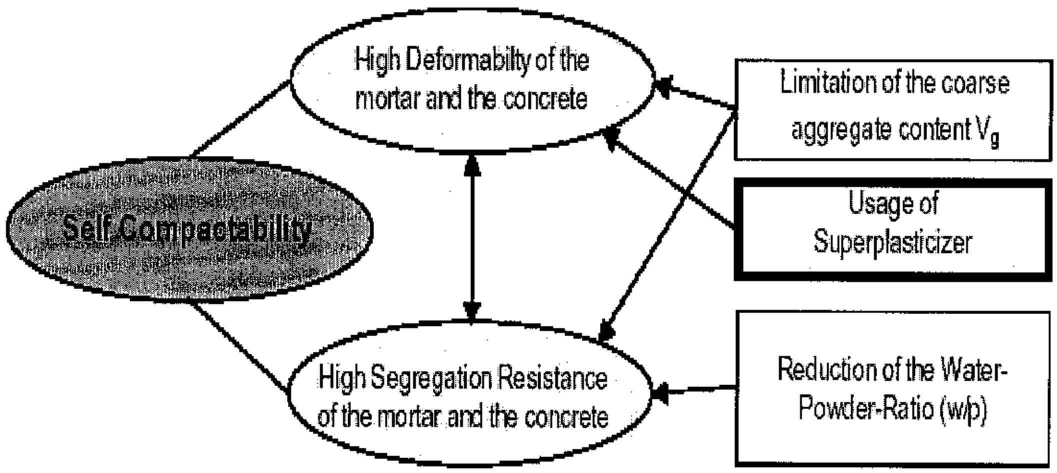

Figure 1: Basic Principles for the production of Self-Compacting Concrete [2]

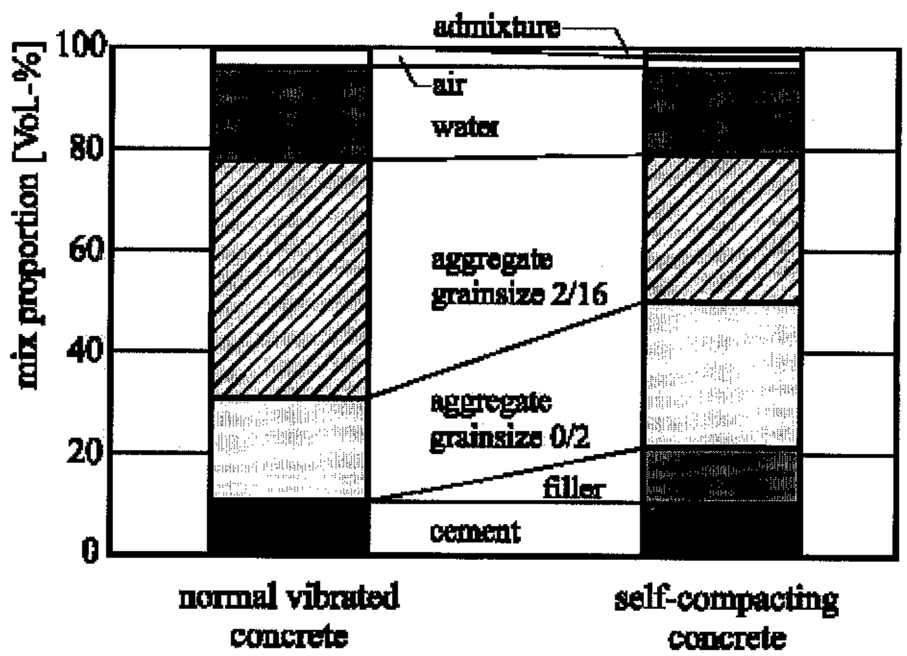

Figure 2: Mix composition of SCC in comparison with normal vibrated concrete [1]

Traditionally, high-slump concretes have been plagued with the tendency to bleed and segregate. The development of SCC makes it possible to produce a concrete that would fall under the category of high-slump concrete; however, its behaviour far exceeds that of a high-slump mix. An SCC mix has the following characteristics [5]:

- Non-Segregating: The aggregate will stay in suspension in the mix as it flows into the form,
- Non-Bleeding: Water will not rise to the top of the mix or be observed on the outer edges of a flow test,
- Vibration: No vibration is required during placement. SCC will flow around rebar and other inclusions in the form under its own weight,
- Flow spreads: Flow spreads of 500 or greater are obtainable,
- Set time: The initial set time in many SCC mixes will increase upwards of 90 minutes, depending on the admixtures used and water content of the mix. This may be a desirable trait for many concreting operations in the drilled shaft industry.

The use of SCC offers many benefits to the construction practice: the elimination of the compaction work results in reduced costs of placement, a shortening of the construction time and therefore in an improved productivity. The application of SCC also leads to a reduction of noise during casting, better working conditions and the possibility of expanding the placing times in inner city areas. Other advantages of SCC are an improved homogeneity of the concrete production and the excellent surface quality without blowholes or other surface defects [3]. Often the material costs of SCC will be higher than the equivalent material costs of a normal vibrated concrete. However, when SCC is sensibly utilized, the reduction of costs caused by better productivity, shorter construction time and improved working conditions will compensate the higher material costs and, in many cases, may result in more favourable prices of the final product.

2.2 High-Range Water Reducer (HRWR)

High-range water reducers (HRWR) are water-soluble organic polymers which have to be synthesized, using a complex polymerization process, to produce long molecules of high molecular mass [7]. The main action of the long molecules of HRWR is to wrap themselves around the cement particles and give them a highly negative charge so that they repel each other. These results in deflocculation and dispersion of cement particles. The resulting improvement in workability can be exploited in two ways: by producing concrete with a very high workability or concrete with a very high strength. At a given water/cement (W/C) ratio and water content in the mix, the dispersing action of HRWR increases the workability of concrete, typically by raising the slump from 75mm to 200mm, the mix remaining cohesive [6]. The resulting concrete can be placed with little or no compaction and is not subject to excessive bleeding or segregation.

The second use of HRWR is in the production of concrete of normal workability but with an extremely high strength owing to a very substantial reduction in the W/C ratio. W/C ratios down to 0.2 have been used with 28-day cylinder strengths of about 150 MPa [7]. HRWR do not alter fundamentally the structure of hydrated cement paste, the main effect being a better distribution of cement particles and, consequently, their better hydration. This would explain why, in some cases, the use of HRWR was found to increase the strength of concrete at a constant W/C ratio [8].

For increasing the workability of the mix, the normal dosage of HRWR is between 1 and 3 litres per cubic metre of concrete, the liquid HRWR containing about 40 per cent of active material. When HRWR are used to reduce the water content of the mix, their dosage is much higher: 5 to 20 litres per cubic metre of concrete [7]. The effectiveness of a given dosage of HRWR depends on the W/C ratio of the mix. Specifically, at a given dosage of the HRWR, the percentage water reduction which maintains a constant workability is much higher at low W/C ratio than at high W/C ratio; for example, at W/C ratio of 0.40, the reduction was observed to be 23 per cent, and only 11 per cent at W/C ratio of 0.55 [9].

It is logical to assume that the first dosage of the HRWR must be applied soon after the cement and water have come into contact with one another. Otherwise, the initial reactions of hydration would make it impossible for the HRWR to effect adequate deflocculation of the cement particles [10]. The theoretical optimum time for adding a HRWR is what would be approximately the beginning of the dormant period without the HRWR. N fact, addition at that time was found to result in the highest initial workability and in the lowest rate of loss of workability [11]. This particular time depends on the properties of cement and would have to be established by experiment. In actual construction, it is the practicality of adding the HRWR that governs.

The effectiveness of HRWR in preventing re-agglomeration of cement particles lasts only as long as sufficient HRWR molecules are available to cover the exposed surface of cement particles. As some of the HRWR molecules become entrapped in the products of hydration of cement, the supply of HRWR becomes inadequate and the workability of the mix is rapidly lost. It is likely that, with prolonged mixing or agitation, some of the products of initial hydration of the cement shear off the surface of the cement particles. This enables the hydration of the hitherto unexposed cement to take place. Both the presence of the detached products of hydration and the additional hydration have the effect of reducing the workability of the mix [7].

2.3 Viscosity-modifying Admixture (VMA)

Viscosity-modifying admixtures (VMA), also known as anti-washout admixtures, are relatively new admixtures used to enhance the cohesion and stability of cement-based systems. Such VMA are water-soluble polysaccharides that enhance the water retention capacity of the paste. They are used in concrete intended for underwater repair of marine and hydraulic structures, and tremie concrete for the construction of curtain walls and deep foundation walls. Such admixtures can also reduce the risk of separation of the heterogeneous constituents of concrete during transport, placement, and consolidation and provide added stability to the cast concrete while in a plastic state (12).

2.3.1 Mode of Action

The mode of action of a VMA depends on the type and concentration of the polymer in use. In the case of welan gum and cellulose derivatives, the mode of action can be classified in three categories, as follows (13):

Adsorption

The long-chain polymer molecules adhere to the periphery of water molecules, thus adsorbing and fixing part of the mix water and thereby expanding. This increases the viscosity of the mix water and that of the cement-based product

Association

Molecules in adjacent polymer chains can develop attractive forces, thus further blocking the motion of water, causing a gel formation and an increase in viscosity.

Intertwining

At low rates of shear, and especially at high concentrations, the polymer chains can intertwine and entangle, resulting in an increase in the apparent viscosity. Such entanglement can disaggregate, and the polymer chains can align in the direction of the flow at high shear rates, hence resulting in shear thinning.

2.3.2 Rheological Properties and HRWR Effect

The various water-soluble VMA forms viscous solutions that bind some of the mixing water in the fresh cement paste, thus increasing viscosity and yield value of the cement-based system. The yield value refers to the minimum shear stress needed to overcome the internal resistance of a fluid to initiate plastic flow. The extent of the increase in water viscosity depends on the type and concentration of the VMA, as well as on the applied shear rate. Figure 3 compares the increased viscosity of aqueous solutions of 0.01 M NaCl containing welan gum and HPMC at a low shear rate of $0.1s^{-1}$ (13). The increase in VMA dosage results in a sharp increase in viscosity, especially in the case of welan gum addition. Systems modified with a VMA exhibit a shear thinning (or pseudoplastic) behaviour where the apparent viscosity decreases rapidly with the increase in shear rate. As shown in Figure 4, aqueous solutions containing VMA exhibit a shear thinning behaviour where relatively high viscosity at low shear rate drops significantly with the increase in shear rate (12).

A cement-based system incorporating a VMA can be sticky and viscous, especially when there is a high concentration of VMA. The incorporation of a VMA increases the yield value, plastic viscosity, and apparent viscosities, both at low and high shear rates, for cement-based materials regardless of the W/C and dosage of HRWR (14, 15). Cement grouts containing a VMA also exhibit high reduction in fluidity over time because of their thixotropic nature.

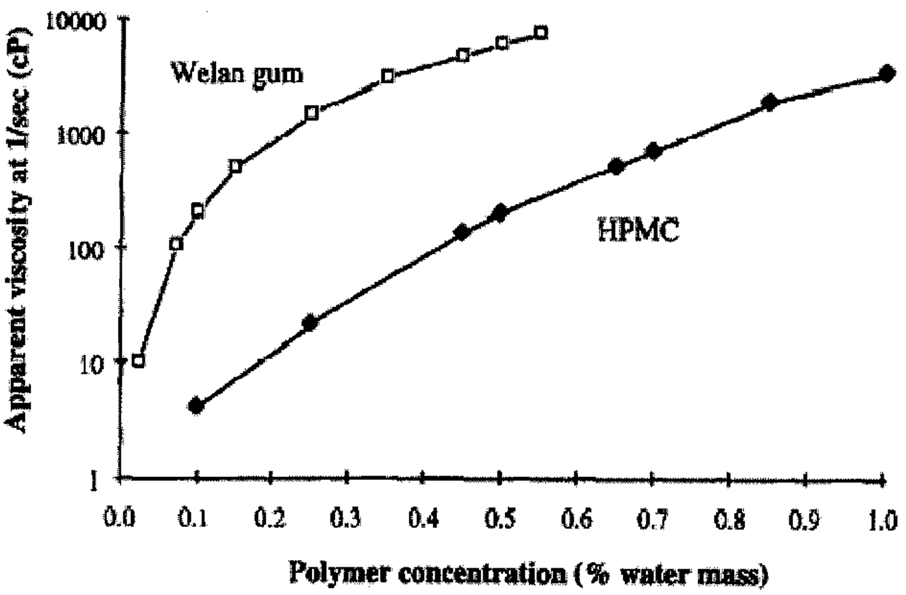

Figure 3: Variations of apparent viscosity at $0.1s^{-1}$ of aqueous solution containing various VMA contents (13)

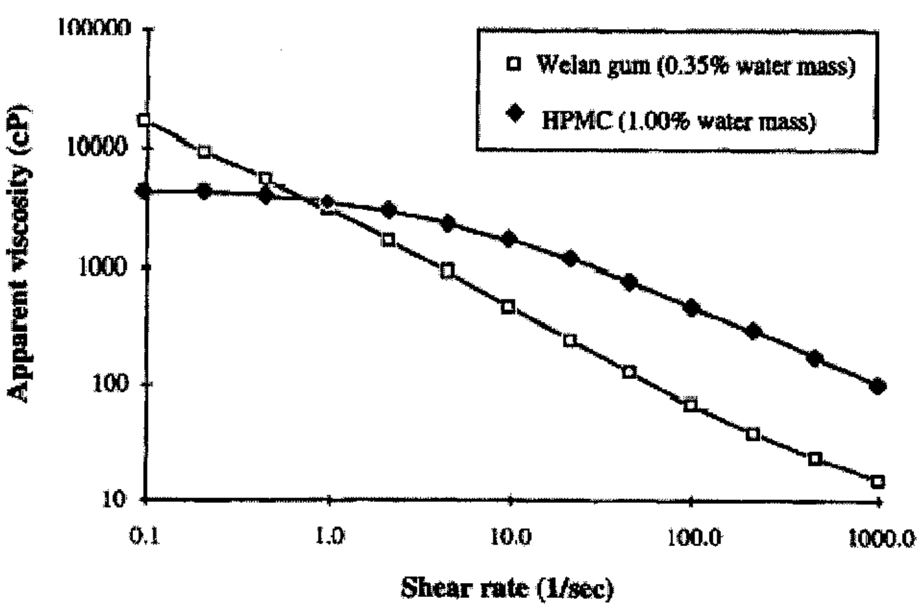

Figure 4: Variations of apparent viscosity of aqueous solutions with shear rate (12)

The increase in VMA dosage increases the yield value and apparent viscosity, both at high and low shear rates, in an almost linear fashion regardless of the HRWR content. The demand of the HRWR required to obtain a given fluidity increases with the increase in the VMA dosage and the reduction in yield value, plastic and apparent viscosities, especially in grouts containing low dosages of VMA (16). In Figure 5, the viscosity at low shear rate of a cement grout incorporating various concentrations of welan gum VMA is shown to decrease with the increase in HRWR content. The grouts evaluated incorporated various concentrations of a naphthalene-based HRWR and a fixed W/C of 0.40. For a given decrease in apparent viscosity, the required dosage of additional HRWR is shown to increase with in creased VMA content (16).

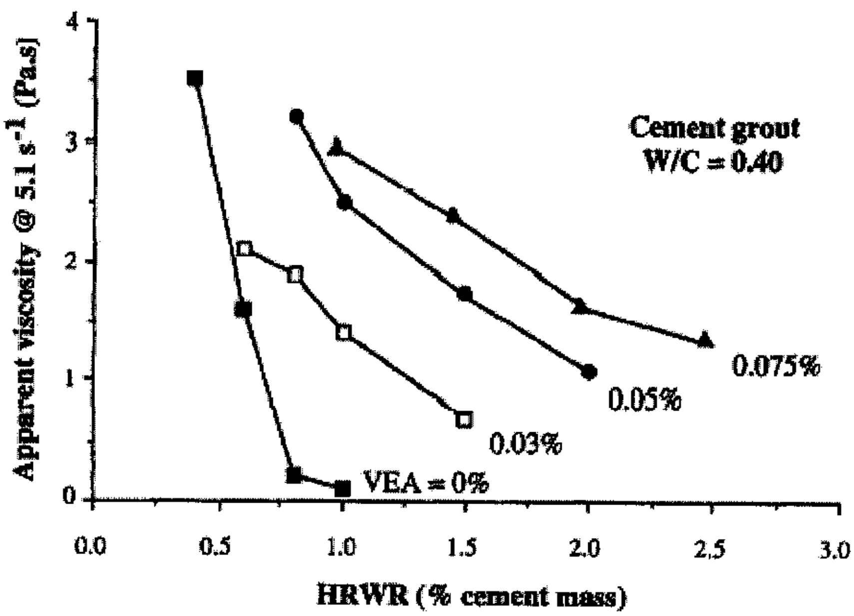

Figure 5: Variations in apparent viscosity at low shear rate with welan gum-HRWR concentrations (16)

The increase in the dosage of HRWR disperses cement grains; this can liberate some of the water entrapped between cement grains, hence increasing the amount of free water in the system. The combined use of proper VMA and HRWR contents help secure a highly fluid yet cohesive grout, reduce water dilution, and enhance the degree of suspension of various solids.

2.4 Concrete Properties

Concrete is basically a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (sand and gravel or crushed stone) into a rocklike mass as the paste hardens because of the chemical reaction of the cement and water. Aggregates are generally divided into two groups: fine and coarse. Fine aggregates consists of natural or manufactured sand with particle sizes ranging up to 3/8 inch; coarse aggregates are those with particles retained on the No. 16 sieve and ranging up to 6 inch. The most commonly used maximum aggregate size is ¾ inch or 1 inch.

The paste is composed of Portland cement, water, and entrapped air or purposely entrained air. Cement paste ordinarily constitutes about 25 % to 40 % of the total volume of concrete. Air content ranges up to about 8 % of concrete volume, depending on the maximum size of coarse aggregate, whereas aggregates make up about 60 % to 75 % of concrete volume.

High performance concrete requires concrete possessing specific properties. To assure that these properties are obtained, quality control and acceptance testing are indispensable parts of the study. Past experience and sound judgments or comparison between reference concrete and test concrete must be relied on in evaluating tests and assessing their significance in the ultimate performance of the concrete. The importance of obtaining truly representative samples of freshly mixed concrete and hardened concrete for control tests must be emphasized. Unless the sample is representative, test results will be misleading. Samples should be obtained and handled in accordance with ASTM C172.

2.3.1 Fresh Concrete Properties

Fresh concrete is a transient material with continuously changing properties. It is, however, essential that the concrete can be handled, transported, placed, compacted and finished to form a homogenous, usually void-free, solid mass that realizes the full potential hardened properties.

Workability

The ease of placing, consolidating, and finishing freshly mixed concrete is called workability. It refers to the relative mobility of a freshly mixed cement paste or mortar or to its ability to flow. Concrete with HRWR most often exhibit high slump value. High slump value indicates high workability of concrete. The separation of the particles made possible by HRWR in effect strongly reduces the shear threshold of the fresh cement paste, giving a concrete that flows under its own weight alone, with, however, a velocity that depends on the viscosity of the mixture. One of the important properties regarding SCC is the ability to flow through obstacles. This property is applied when SCC is poured into congested area whereby vibration is not applicable. However, the filing ability is very much dependent on the aggregate grading and water/cement ratio. Factors affecting workability are [17]:

- *Water content*

  Within limits, it contributes to workability because the water added increases inter-particle lubrication.

- *Aggregate type and grading*

  Along with water content, the effect of aggregate type and grading should be considered to achieve maximum density without segregation. For example, finer particles require more water to wet their larger specific surface. And angular aggregate, due to its irregular shape and rougher texture, require more water than rounded aggregate.

- *Aggregate/cement ratio*

At constant water/cement ratio, when the aggregate/cement ratio is reduced, workability increases because the surface area of the particles to be wetted is now lower.

- *Coarse aggregate/fine aggregate ratio*

A higher coarse aggregate/fine aggregate ratio by volume can lower the workability, resulting in segregation. Although a lower value will increase the workability, the durability of the resulting concrete will be adversely affected.

- *Presence of admixtures*

For a given workability, air-entrainment reduces the water requirement.

- *Time*

With time, fresh concrete stiffens, causing a loss of workability.

- *Temperature*

A higher temperature of concrete reduces its workability.

Segregation and Bleeding

Fresh concrete is a mixture of solid particles with specific gravities ranging from about 2.6 (most aggregates) to 3.15 (Portland cement). After the concrete has been placed, the particles tend to settle and the water to rise. This can lead to segregation, in which the larger aggregate particles fall to the lower parts of the pour, and bleeding, in which water or water-rich grout rises to the surface of the concrete to produce laitance, a weak surface layer, or becomes trapped under the aggregate particles thus enhancing interface transition zone effects. These processes are hindered by the interlocking of the particles and for the smaller particles, the surface forces of attraction. It follows that the major causes of segregation and bleed are poorly graded aggregates and excessive water contents. Factors contributing to segregation are [17]:

- Large maximum particle size (>25 mm),
- Large proportion of large aggregate,
- High specific gravity of coarse aggregate,
- Decreased amount of fines (sand or cement),
- Increased irregular shape or rough texture, and
- Mixes those are too wet or too dry.

Some bleed is unavoidable, and may not be harmful. For example, if the concrete is placed in hot or windy conditions, the loss of bleed water from the surface may not cause any distress, and the water/cement ratio of the remaining concrete may be reduced. However, if the rate of evaporation of the water is greater than the rate of bleeding, plastic shrinkage, which can lead to surface cracking, will occur. The combined effects of bleed and particles settlement are that, after hardening, the concrete in the lower part of a pour of any significant depth can be stronger than that in the upper part.

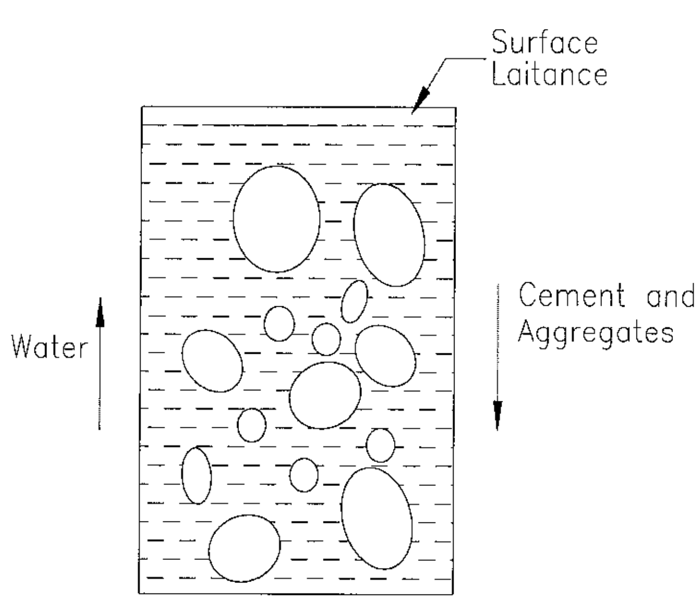

Figure 6: Bleeding of concrete

2.3.2 Hardened Concrete

Compressive Strength

Compressive strength may be defined as the measured maximum resistance of a concrete or mortar specimen to axial loading. It is generally expressed in Mega Pascal (MPa) at an age of 3 days, 7 days and 28 days or more for high performance concrete. The principal factors affecting strength are water-cement ratio, age, curing condition, humidity, air content, aggregate characteristic, roughness, grading or the extent to which hydration has progressed. Compressive strength increases with age and increases as the water-cement ratio decreases.

Porosity

Porosity and pore structure, in turn, are influenced by the original packing of cement, mineral admixtures, and the aggregate particles; the water-to-solid ratio; the rheology; and the conditions of curing. There is no doubt that porosity defined as the total volume of the overall volume of pores larger than gel pores, expressed as a percentage of the overall volume of the hydrated cement paste, is a primary factor influencing the strength of the cement paste. A linear relation between strength and porosity, within the range of the latter between 5 and 28 per cent, was established by Rossler and Odler (24). The effect of pores smaller than 20 nm in diameter was found to be negligible. Consequently, in addition to total porosity, the effect of pore size distribution on strength must be considered. Generally, at a given porosity, smaller pores lead to a higher strength of the cement paste. The total porosity of concrete were calculated using the following equations (Cabrera and Hassan, 1997).

$$P = (W_{SA}-W_d)/(W_{SA}-W_{SW}) \times 100 \text{ where:}$$

P = Total porosity (%)

WSA = Weight of saturated surface dry samples in air (g)

WSA = Weight of saturated surface dry samples in water (g)

Wd = Weight of oven dry samples (g)

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project Work

The general sequence of my research is as follows:

3.1.1 Literature Review

Literature review is the basic yet most important aspect of the project. In order to successfully complete this project, a strong knowledge on product design must be accomplished. This is done through a thorough literature review on journals, publications and books from the field of engineering design. Comparison between information from different types of books or journals must be done to verify the truthfulness of the information obtained from literature review

3.1.2 Discussion and Collaboration

Weekly discussion session with supervisor will be done to discuss on activities done and knowledge gained. This is to avoid misleading data that may deviate the student from the actual objective. The exchange of view is critical to ensure that the student is on the right track.

3.1.3 Materials and Equipments Preparation

Proper planning must be done in order to prepare the materials and equipments needed. If the required equipments are not available in the laboratory, the student needs to find ways to either buy it or construct it on their own. Same goes to the materials.

3.1.4 Experiment and Test

Experiment must be conducted to analyze and test the proposed material used at a certain dosage. Segregation and compressive strength are important properties to be tested. Experiment will be repeated at different conditions or with different dosage until the best result is obtained and thus, finalizing the product design. The Experiments include:

- Slump flow test
- V-Funnel test
- Kajima box test
- Segregation test
- Compressive strength test
- Porosity test

3.1.5 Data Analysis

All the results data from the laboratory tests will be used to analyze the sample. The appropriate tables or graphs will be constructed to get the clearer view of the results in this project.

3.1.6 Documentation

All engineering design should be accompanied with proper documentation. The documentation for VMA includes researches and findings, proposed material used, recommended range of dosage, limit of segregation for homogeneity, setting time at compliance dosage and others.

3.2 Materials Preparation

As indicated above, it is necessary to get the maximum performance out of all of the materials involved in producing high strength concrete. For convenience, the various materials are discussed separately below. However, it must be remembered that prediction with any certainty as to how they will behave when combined in a concrete is not feasible. Particularly when attempting to make high strength concrete, any material incompatibilities will be highly detrimental to the finished product. Thus, the culmination of any mix design process must be the extensive testing of trial mixes. High strength concrete will normally contain not only Portland cement, aggregate and water, but also superplasticizer (SP) and viscosity-modifying admixture (VMA).

3.2.1 Portland Cement

There are two different requirements that any cement must meet: it must develop the appropriate strength; and it must exhibit the appropriate rheological behaviour. High strength concretes have been produced successfully using cements meeting the ASTM Standard Specification C150. Portland cement is not a simple chemical compound; it is a mixture of many compounds. Four of these make up 90 % or more of the weight of Portland cement: tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite. In addition to these major compounds, several others play important roles in the hydration process. Different types of Portland cement contain the same four major compounds but in different proportions. The Portland cement is shown in Appendix 1.

3.2.2 Coarse Aggregate

It is commonly assumed that a smaller maximum size of coarse aggregate will lead to higher strengths, largely because smaller sizes will improve the workability of the concrete. However, this is not necessarily the case. Aggregates of 20 mm maximum size will be used in this study since some of the concrete technologists reported that 20 – 25 mm maximum size might be used for high strength concrete. Sieve analysis was used to get the desired size aggregates. Besides, the aggregate must be saturated surface dry to avoid the absorption of water that might affect the water/cement ratio, for it is crucial to the performance of concrete. Since the available aggregate was exposed under the hot sun, saturated surface dry aggregate was prepared by soaking it into the water for one day and leaving it at room temperature one day for the surface water to evaporate.

3.2.3 Fine Aggregate

The fine aggregate should consist of smooth rounded particles to reduce the water demand. The fineness of sand is the main factor to determine the workability of concrete. Of course, the sand must be free of silt and clay particles. Same as coarse aggregates, the sand must be of saturated surface dry. However, the sand would not be soaked into the water. Instead, by scrapping off the surface layer of sand that was exposed to the hot sun, inner part of the sand with certain amount of moisture content was taken. The sand would then be exposed at room temperature for one day for the surface water to evaporate. Unlike coarse aggregate, this method is not likely to obtain best result since the sand is good water absorber. If the result obtained from freshly mixed concrete test contains significant error, moisture content of the sand will be recorded in order to justify the water/cement ratio of the concrete.

3.2.4 High-Range Water Reducer (HRWR)

In modern concrete practice, it is essentially impossible to make high strength concrete at adequate workability in the field without the use of HRWR. Unfortunately, different HRWR will behave quite differently with different cements. This is due to in part to the variability in the minor components of the cement, and in part to the fact that the acceptance standards for HRWR themselves are not very tightly written. Adva, which is HRWR that supplied by one manufacturer, will be used in this study. It is brownish and visually observed as a viscous liquid. Since the behaviour of Adva is unknown, the proportioning of first trial mix will be based fully on the proposed dosage.

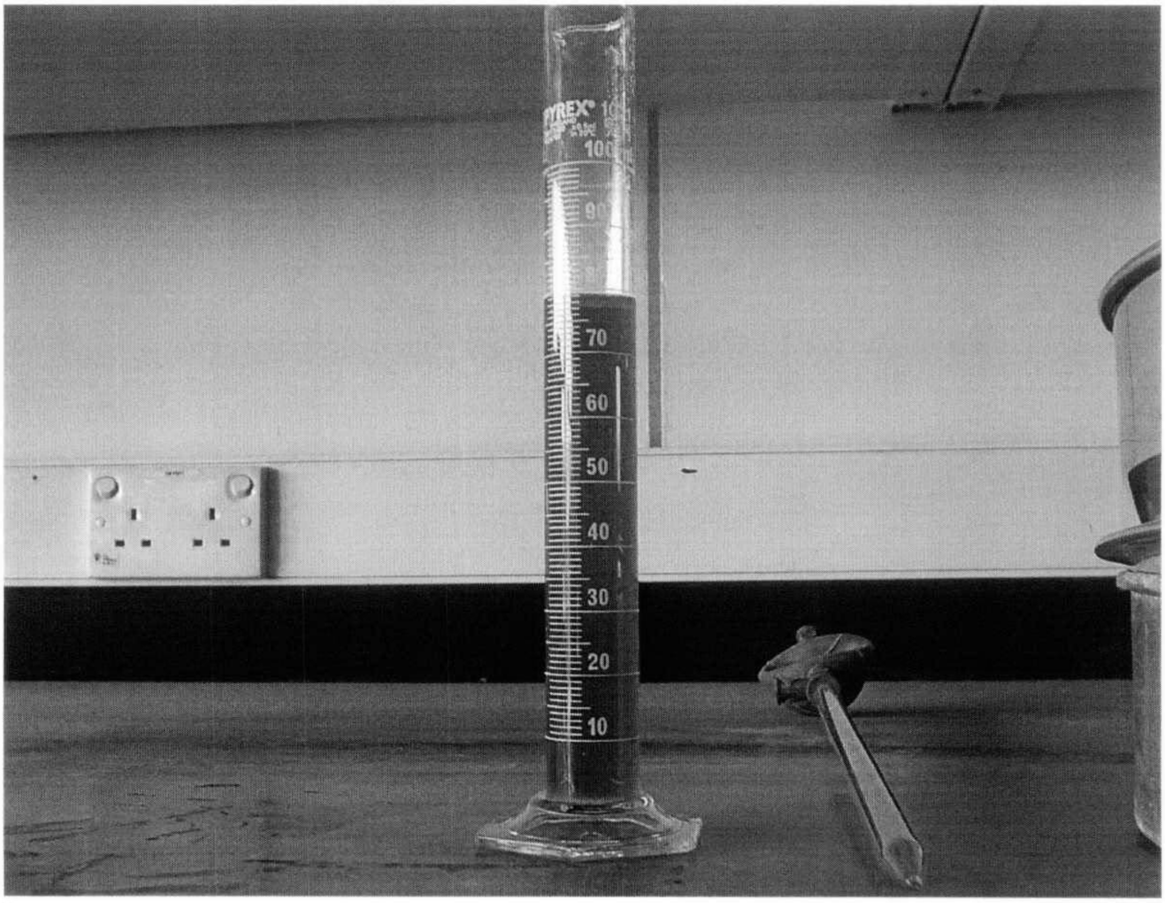

Figure 7: HRWR (Adva)

3.2.5 Viscosity-modifying Admixture (VMA)

VMA is admixture that tends to increase the friction or viscosity between the particles and thus, reducing segregation. It is a form of gel-like material that behaves like normal gum. As mentioned in segregation, water tends to rise up while aggregate tends to go down in normal concrete. The addition of VMA may delay the 'rising up' and 'going down' time so that the concrete sets before water rise up and aggregates go down as to maintain the uniform distribution of particles. However, the behaviour of VMA being used in this study is unknown since the same manufacturer supplies it. Thus, the proportioning will also be based on the proposed dosage.

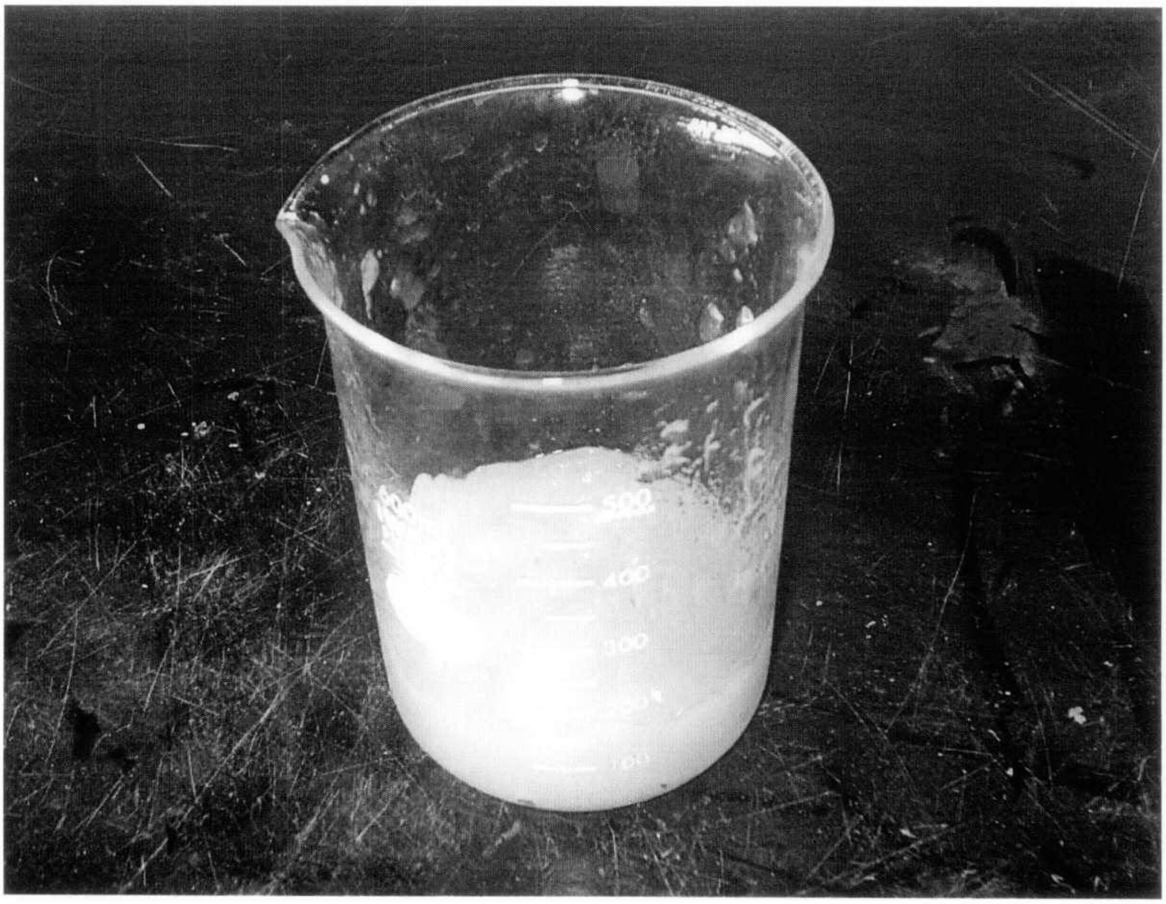

Figure 8: VMA (Vismocrete)

3.3 Concrete Mixing

All concrete should be mixed thoroughly until it is uniform in appearance, with all ingredients evenly distributed. Mixers should not be loaded above their rated capacities and should not be operated at approximately the speeds for which they were designed. To ensure that they are combined into a homogeneous mix requires effort and care. The sequence of charging ingredients into the mixer plays an important part in the uniformity of the finished product. The sequence, however, can be varied and still produce a quality concrete. The procedure of mixing the concrete incorporating HRWR and VMA is shown as follows:

1. Pour all coarse and fine aggregates into the mixer and mix for 25 seconds to ensure the uniform distribution of both materials.
2. Pour half of the water and mix for 1 minute.
3. Leave the mixes for 8 minutes to let both sand and coarse aggregate to absorb water.
4. Pour all Portland cement into the mixer and mix for 1 minute.
5. Pour another half of the water and add in HRWR to mix for 3 minutes.
6. Add in VMA and mix for another 2 minutes.
7. Finally perform hand mixing until the mix is in uniform stage.

3.4 Curing Condition

In general, the highest concrete strengths will be obtained with specimens continuously moist cured (at 100% relative humidity) until the time of testing. After the removal of mould on the second day, the cylinder will be placed and cured in a water tank at room temperature for strength development.

3.5 Test Method

The test methods were carried out on concrete mix incorporating lcoal VMA to determine the workability, stability, bleeding, segregation, setting time and compressive strength.

3.5.1 Slump Flow Test

The slump flow test [(18)] was used to assess the horizontal free flow of SCC in the absence of obstructions. It gave no indication of the ability of the SCC to pass between reinforcement without blocking, but some indication of resistance to segregation. The equipments included a truncated cone with the internal dimension of 200 mm diameter at the base, 100mm diameter at the top, and a height of 300mm with a base plate of a stiff non-absorbing material. The truncated cone was filled with SCC without tamping, followed by raising the cone vertically to allow the SCC flowing out freely. The final diameters of the SCC in two perpendicular directions were measured as workability of the SCC and an average slump flow value was calculated.

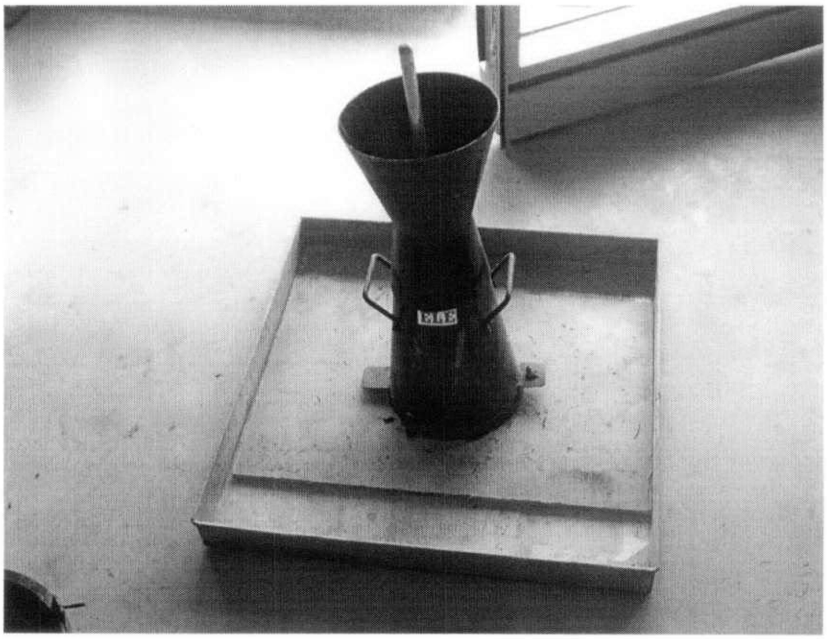

Figure 9: Slump flow test equipment

3.5.2 V-funnel Test

The deformability through restricted areas can be evaluated using V-funnel test [19]. In this test, the funnel was filled completely with concrete and the bottom outlet would then be opened, allowing the concrete to flow out. The time of flow from the opening of outlet to the seizure of flow was recorded. Flow time can be associated with a low deformability due to high paste viscosity, high interparticle friction or blockage of flow. Flow time should be below 6s for the concrete to be considered as SCC. All well-performed mixes must not have significant segregation and jamming of aggregate at the contraction. High flow time can also be associated with low deformability due to a high paste viscosity, and with high interparticle friction. While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of SCC are not clear. Since V-funnel was not available in concrete laboratory, the equipment was manufactured by using 12-in fiber glass of size 6 ft (1828.8 mm) x 4 ft (1219.2 mm) (kindly refer to Appendix 1).

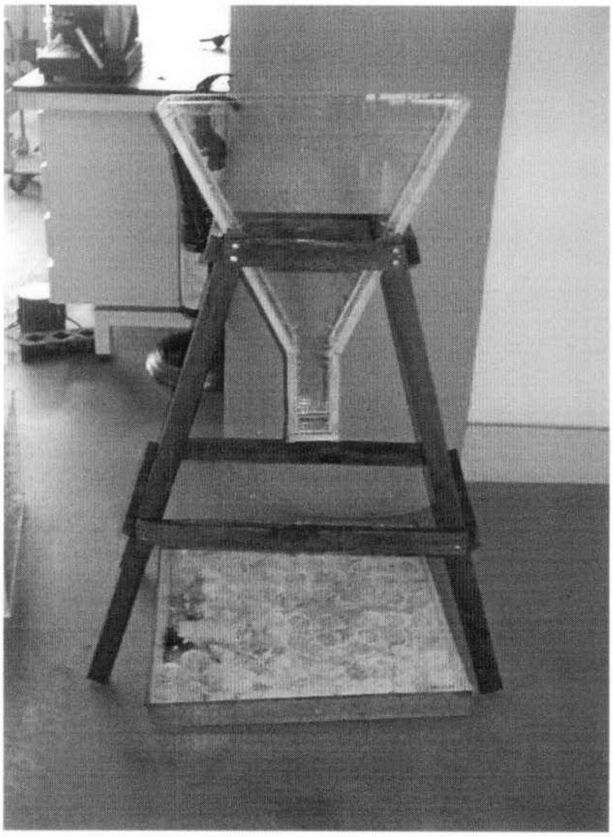

Figure 10: V-funnel

3.5.3 Segregation Test

The segregation test method, which is developed by Fujiwara [20] was used. The method included pouring fresh concrete over a 5 mm mesh and measuring the mass of the mortar passing through the screen after 5 minutes. The segregation index (SI) was taken as the ratio of the mortar passing to that contained in the original concrete sample.

3.5.4 Filling Vessel Test Method (Also known as Kajima Box Method)

The Kajima Box test method [21] was used to measure the filling ability of SCC with a maximum aggregate size of 20 mm. The apparatus consisted of a container with a flat and smooth surface. In the container were 35 obstacles made of wood bar with a diameter of 16 mm and a distance center to center of 50 mm. Since it was not available in the laboratory, like V-funnel apparatus, it was constructed manually (kindly refer to Appendix 2). The container was filled with SCC through the hole and the difference in height between two sides of the container was a measure of the filling ability.

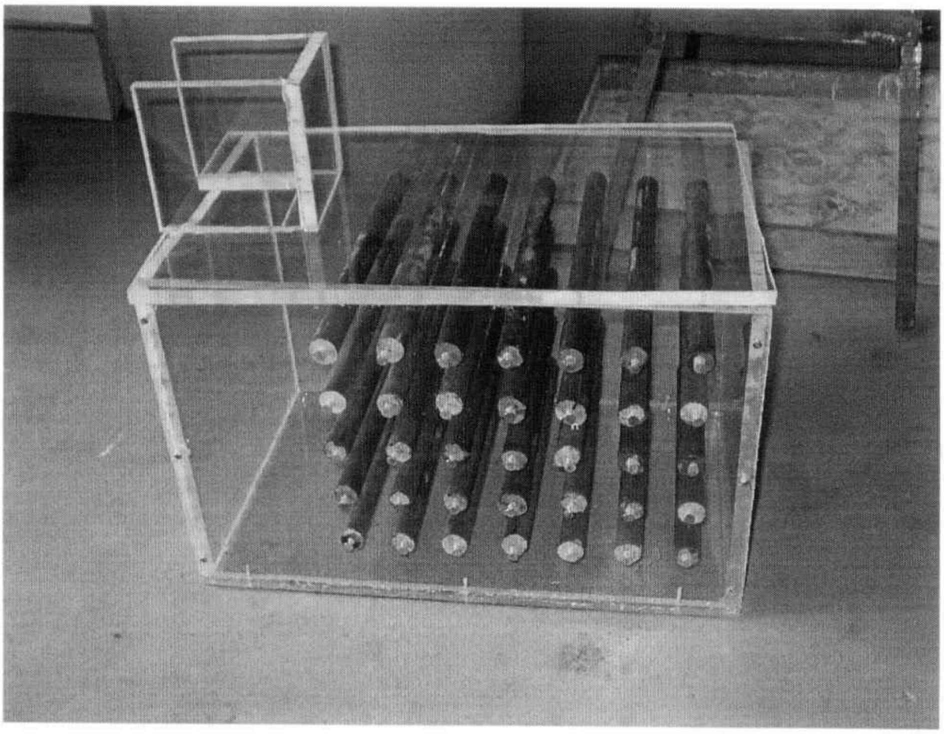

Figure 11: Kajima box

3.5.5 Compressive Strength Test

Comparative performance of hardened concrete is investigated by measuring the development of compressive strength with curing age from 3, 7, 28 to 60 days. Three 100 x 200-mm cylinders were cast in order to get the average value. Reference concretes were cast with vibration but test concretes were cast without consolidation efforts and both samples were stored in a water container for proper curing. The compressive strength was taken as the maximum compressive load it could carry per unit area.

Figure 12: Compressive strength test equipment

3.5.6 Porosity Test

The total porosity of a porous material, such as concrete, is defined as the fraction of the bulk volume occupied by the voids. The voids may be filled with air and/or water depending upon the degree of pore saturation. For a partially saturated condition, the total porosity is the combination of the part of water filled and air filled voids usually termed as open porosity, which corresponds to the term of empty porosity as used by Ujike and Nagataki (1988). There are number of methods used to determine the total porosity of concrete and mortar, however, the technique of vacuum saturation is perhaps the most simple, cheap and direct method of measurement. The procedures are shown as below:

1. The slab was first cored into 5-cm diameter and 5-cm height cylinder.
2. The samples were vacuumed in the vacuum saturation apparatus for 30 minutes.
3. The samples were then submerged into the water and vacuumed for another 6 hours.
4. The samples were left for one day in the water for saturation and weighted in air and /or water.
5. The oven-dried weight was taken after drying the samples in oven for one day.

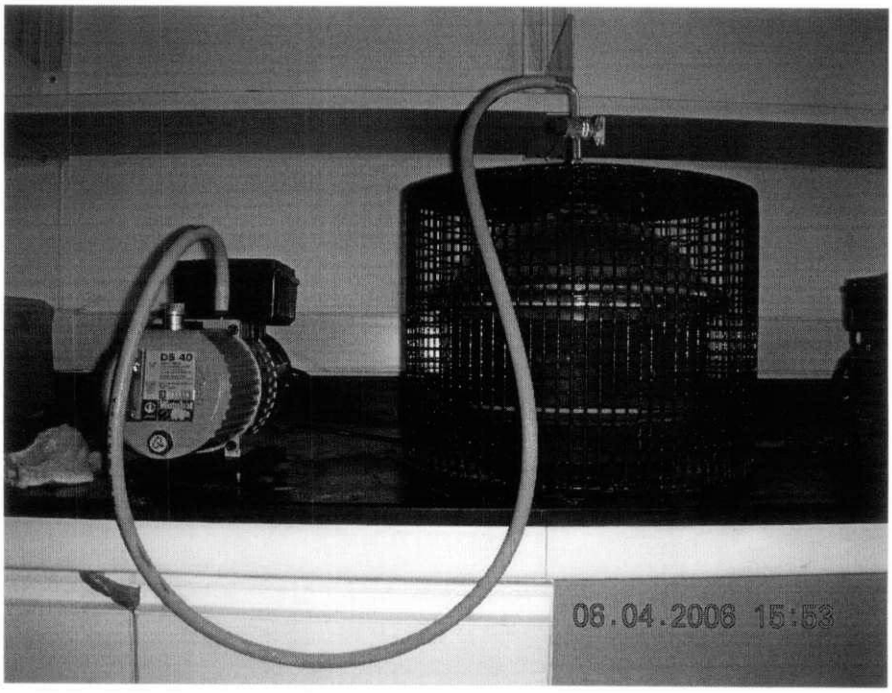

Figure 13: Vacuum saturation apparatus

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Mix Proportion by Manufacturer

The performance of new developed VMA (Vismocrete), which is supplied by the manufacturer, has not been determined. However, Reference concrete and test concrete 1 in table below show the mix proportion proposed by the manufacturer and it is believed to have best performance. However, the amount of HRWR in test concrete 2 will be increased to 1000ml/100kg of cement.

Table 1: Mix proportion by manufacturer

Mixture Type	Cement (kg/m^3)	Sand (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (l/m^3)	Adva (HRWR) (ml)	Vismocrete (VMA) (ml)
Reference Concrete	525	865	750	190	500/100kg of cement	-
Test Concrete 1	525	865	750	190	500/100kg of cement	950/100kg of cement
Test Concrete 2	525	865	750	190	1000/100kg of cement	950/100kg of cement

4.1.2 Result and Discussion

Slump Flow Test

Table 2: Slump flow test result for manufacturer's mix proportion

Concrete Type	Slump Flow (mm)		Average slump Flow (mm)
	x-direction	y-direction	
Reference Concrete	240	250	**245**
Test Concrete 1	380	410	**395**
Test Concrete 2	560	600	**580**

Result shows that test concrete 2 had higher slump flow, 580 mm, followed by test concrete 1, 395 mm, as compared to reference concrete. In another way, concrete incorporating greater HRWR has higher workability in the absence of obstructions. The reference concrete showed little horizontal free flow properties as the average slump flow is only 245 mm. Based on the literature review, Nagasaki and Fujiwara suggested a slump flow value ranging from 500 to 700 mm for a concrete to be self-compacted. At > 700 mm, the concrete might segregate, and at < 500 mm, the concrete might have insufficient flow to pass through highly congested reinforcement. Result indicates that only test concrete 2 fit into the allowable range. This proved that the addition of HRWR has generally increased the workability to the SCC range. However, segregation could be observed in this test.

V-funnel Test

Table 3: V-funnel test for manufacturer's mix proportion

Concrete Type	V-funnel (s)
Reference Concrete	-
Test Concrete 1	**5.35**
Test Concrete 2	**4.08**

The deformability through restricted areas can be evaluated using V-funnel test. Flow time can be associated with a low deformability due to high paste viscosity, high interparticle friction or blockage of flow. From literature review, Flow time should be below 6 s for the concrete to be considered as SCC. In this test, no result was shown for reference concrete because the concrete could not pass through the contraction part of V-funnel. However, the time for test concrete 1 and 2 to flow through the contraction part was recorded as 5.35s and 4.08s respectively. The test concrete performed well with no significant segregation and jamming of aggregate at the contraction and it fulfilled the requirements of allowable flow time for SCC. However, significant segregation occurred while pouring the concrete into the V-funnel. This could be seen from the seepage of cement paste through the gap in the funnel.

Segregation Test

Table 4: Segregation test result for manufacturer's mix proportion

Concrete Type	Weight of concrete (kg)	Weight of mortar (kg)	Segregation Index (%)
Reference concrete	-	-	-
Test concrete 1	3.08	0.1	**3.25**
Test concrete 2	3.25	0.84	**25.85**

The segregation index (SI) is taken as the ratio of the mortar passing to that contained in the original concrete sample. No result was shown for reference concrete since mortar did not pass through 5-mm mesh. From the literature review, a stable concrete should have a SI value of <5 %. The test concrete 1 with SI of 3.25 % fulfilled the required criteria. The SI of 25.85 % for test concrete 2 was extremely high. There was a significant segregation where all aggregates remained at the 5-mm mesh whereas almost all cement paste passed through the mesh and retained on the pan.

Kajima Box Test

Table 5: Kajima box test result for manufacturer's mix proportion

Concrete Type	Kajima Box Test (%)
Reference Concrete	-
Test Concrete 1	**17.86**
Test Concrete 2	**46.4**

If the SCC flows as freely as water at rest, it will be horizontal resulting in average filling percentage equals to 100 %. Therefore, the nearer this test value, the 'filling height' is to 100 %, the better the filing ability characteristics of the SCC. The reference concrete showed no sign of filling ability, as the workability was too low. Table above presents the filling ability of test concrete at the presence of obstacles and the calculations are shown in Appendix 3. Filling ability of test concrete 2, 46.4 %, was better than the test concrete 1, 17.86%, in the presence of obstructions. However, segregation occurred obviously while conducting the test. Cement paste would first pass through those obstacles before the aggregates. Some aggregates even trapped between those obstacles.

Compressive Strength Test

Table 6: Compressive strength test result for manufacturer's mix proportions

	Concrete Type	Reference Concrete		Test Concrete 1		Test Concrete 2
		3 days	7 days	3 days	7 days	7 days
1	Maximum load (kN)	104.5	103.7	119.7	158.7	257.3
	Stress (MPa)	13.30	13.21	15.24	20.21	250.3
2	Maximum load (kN)	91.9	123.8	135.7	110.7	240.9
	Stress (MPa)	11.71	15.77	17.27	14.09	32.76
3	Maximum load (kN)	89.7	107.7	158.0	92.9	31.86
	Stress (MPa)	11.42	13.71	20.11	11.83	30.67
	Maximum load (kN)	95.4	111.73	137.8	120.77	249.5
	Stress (MPa)	**12.14**	**14.23**	**17.54**	**15.37**	**31.76**

Comparative performance of hardened concrete was investigated by measuring the development of compressive strength with curing age ranging from 1 to 28 days. However, due to time constraint, hardened concrete test were performed only on the third day and seventh day. The concrete mixes were required to test the compressive strength since the supplier of VMA and HRWR proposes the mix proportion and it was unknown. The compressive strength result of test concrete 2 shows that both the maximum load and stress are very much higher than the reference concrete and test concrete 1. This might be due to better workability of concrete whereby it flowed smoothly and filled all voids in the cylinder mould resulting in better bonding between particles. As for reference concrete and test concrete 1, since it had lower slump flow test, poorer workability might result in voids and honeycomb where it would weaken the concrete. Thus, the compressive strength was lower.

4.2 Proposed Mix Proportion

The water/cement (w/c) ratio was selected as 0.45. From the literature review, information below was found to determine the SCC mix proportions:

Cementitious content/Aggregate ratio (C/A): 0.25

Sand/Gravel ratio (S/G): 1.0

Concrete Density: 2250 kg/m^3

W/C = 0.45

C/A = 0.25

S/G = 1.00

Density = 2250 kg/m^3

Water + Cementitious Content + Sand + Gravel = Density

Since S/G = 1.00, assume that S = G ....(1)

0.45*C + C + S + G = 2250.........(2)

Substitute (1) into (2)

1.45C + 2S = 2250.......(3)

Since C/A = 0.25, thus C = 0.25*2S.......(4)

Substitute (4) into (3)

1.45(0.5S) +2S = 2250

By mathematical calculations, information below were obtained:

Sand = 826 kg/m^3

Coarse Aggregate = 826 kg/m^3

Cementitious Content = 413 kg/m^3

Water = 189 kg/m^3

As determined previously, concrete volume needed to perform the prescribe tests was $0.03m^3$. Nine mixtures with HRWR and VMA were prepared. Table below presents the composition and labeling of mixtures prepared with consistent amount of aggregate, sand, water and HRWR and VMA. Since the variables of the compositions were HRWR and VMA, the mixtures were labeled such that the identified ingredients as shown in the table. For example, the mixture HRWR-3 contained 3 l/m^3 of HRWR; the mixture VMA-1 contained 9 l/m3 of HRWR and 1 % of VMA.

Table 7: Proposed mix proportion

Concrete Type	Cement (kg/m^3)	Aggregate (kg/m^3)	Sand (kg/m^3)	Water (l/m^3)	HRWR (l/m^3)	VMA (%)
HRWR-3	413	826	826	189	3	0
HRWR-6	413	826	826	189	6	0
HRWR-9	413	826	826	189	9	0
HRWR-12	413	826	826	189	12	0
VMA-1	413	826	826	189	9	1
VMA-2	413	826	826	189	9	2
VMA-4	413	826	826	189	9	4
VMA-6	413	826	826	189	9	6
VMA-8	413	826	826	189	9	8

4.2.1 Results

Table 8: Summary of fresh concrete test results for proposed mix proportion

Concrete Type	Slump Flow			V-Funnel	Segregation Index (SI)			Kajima Box
	X-direction (mm)	Y-direction (mm)	Average (mm)	(s)	Mortar (kg)	Concrete (kg)	SI (%)	Filling Ability (%)
HRWR-3	-	-	-	-	-	-	-	-
HRWR-6	510	480	**495**	-	2.06	0.09	**4.37**	-
HRWR-9	570	580	**575**	**23**	3.53	0.43	**12.18**	**20**
HRWR-12	660	620	**640**	**34**	2.02	0.28	**13.86**	**25.71**
VMA-1	630	620	**625**	**32**	2.04	0.37	**18.14**	**41.43**
VMA-2	620	650	**635**	**16**	2	0.3	**15.00**	**48.57**
VMA-4	610	580	**595**	**6**	2.02	0.3	**14.85**	**52.86**
VMA-6	630	640	**635**	**6**	2.06	0.23	**11.17**	**55.71**
VMA-8	550	560	**555**	**5**	1.99	0.14	**7.04**	**65.71**

Table 9: Compressive strength test results for proposed mix proportion

Concrete Type	7-day Compressive Strength (MPa)				28-day Compressive Strength (MPa)			
	1	2	3	Average	1	2	3	Average
HRWR-3	24.21	20.38	21.62	**22.07**	31.33	33.14	32.57	**32.34**
HRWR-6	20.15	19.72	16.08	**18.65**	22.01	25.92	24.18	**24.04**
HRWR-9	18.88	18.17	15.07	**17.37**	22.09	20.53	22.99	**21.87**
HRWR-12	17.70	16.72	20.97	**18.46**	20.88	22.56	15.75	**19.73**
VMA-1	24.07	25.19	20.27	**23.18**	34.21	34.98	33.04	**34.08**
VMA-2	22.36	25.37	25.87	**24.53**	35.19	34.17	33.77	**34.38**
VMA-4	24.26	22.67	23.26	**23.40**	35.77	35.09	35.29	**35.38**
VMA-6	19.07	22.28	19.80	**20.38**	32.69	31.61	35.07	**33.13**
VMA-8	18.35	20.53	21.01	**19.96**	32.41	32.18	33.60	**32.73**

Table 10: 7-day porosity test result for proposed mix proportion

Concrete Type	Weight in Air (g)			Weight in Water (g)			Oven-dry Weight (g)			Porosity (%)			
	1	2	3	1	2	3	1	2	3	1	2	3	Average
HRWR-3	336.5	329.5	330.6	159.5	149.6	152.6	320.0	312.2	315.3	9.32	9.62	8.60	**9.18**
HRWR-6	270.7	267.4	269.5	120.8	118.4	119.9	253.7	250.0	252.7	11.34	11.66	11.24	**11.42**
HRWR-9	323.1	325.4	317.4	150.5	152.2	147.1	303.8	306.6	298.2	11.19	10.87	11.29	**11.11**
HRWR-12	241.6	238.2	244	100.2	99.7	103.1	225.4	222.2	229.6	11.46	11.59	10.24	**11.10**
VMA-1	308.3	305.8	311.9	140.8	139	143.5	290.3	287.5	294.4	10.72	10.97	10.39	**10.69**
VMA-2	322.6	316.4	312.2	154.2	146.9	135.8	304.1	298.9	293.4	11.02	10.32	10.67	**10.67**
VMA-4	253.3	254.7	255.9	111.9	113.2	114.2	238.5	239.3	240.2	10.49	10.91	11.08	**10.83**
VMA-6	315	306.2	308.5	141.3	134.8	136.7	297.1	289.0	290.6	10.33	10.03	10.44	**10.27**
VMA-8	257.9	257.5	255.7	115	106.8	107.6	242.4	242.7	240.7	10.86	9.85	10.16	**10.29**

Table 11: 28-day porosity test result for proposed mix proportion

Concrete Type	Weight in Air (g)			Weight in Water (g)			Oven-dry Weight (g)			Porosity (%)			
	1	2	3	1	2	3	1	2	3	1	2	3	Average
HRWR-3	305.8	297.3	310.5	139.4	133.2	140.9	292.5	282.6	296.8	7.99	8.96	8.08	**8.34**
HRWR-6	320.9	321.7	317	148.6	148.1	144.1	302.7	303.2	299.4	10.56	10.66	10.18	**10.47**
HRWR-9	308.8	313.8	301.5	142.6	144.8	135.6	291.6	294.3	284.2	10.35	11.54	10.43	**10.77**
HRWR-12	238.5	241.2	240.5	99.8	99.6	101.1	223.9	226.8	225.6	10.53	10.17	10.69	**10.46**
VMA-1	288	290.1	287.5	125.2	127.6	125.2	272.5	274.2	271.3	9.52	9.78	9.98	**9.76**
VMA-2	310.2	308.2	304.2	141.2	139.9	137.2	293.4	293.8	287.2	9.94	8.56	10.18	**9.56**
VMA-4	263.4	264.1	263.1	114.6	113.8	114.2	248.3	248.7	249.2	10.15	10.25	9.34	**9.91**
VMA-6	310.4	312.3	295.7	139.3	141.5	131.8	295.2	296.7	280.1	8.88	9.13	9.52	**9.18**
VMA-8	242.8	241.8	252	100.5	100.2	103.4	228.2	226.4	238.9	10.26	10.88	8.82	**9.98**

4.2.2 Discussion

Fresh Concrete Properties

Table 8 presents the fresh properties of all mixtures. Included in that table are the calculated average slump flow (mm), the measured V-funnel time (s), the calculated segregation index (%), and the filling ability (%).

The effect of HRWR and VMA on segregation is presented in Figure 14 and 15. As seen in Figure 14, the segregation is found to increase with the increase of HRWR amount. Although the increase of HRWR improved the workability, it caused serious separation between mortar and coarse aggregate. As can be seen in Appendix 7, there would be more mortar passing through the 5-mm mesh for higher HRWR as compared to lower one. As for the case shown in Figure 15, with constant amount of HRWR, segregation decreases with the increase of VMA amount. Most of the concrete mixtures do not satisfy the requirement of SI value of < 5 % [20] except for HRWR-6. However, the limit of 5% is considered too severe and a limit of 10% appears more realistic [22].

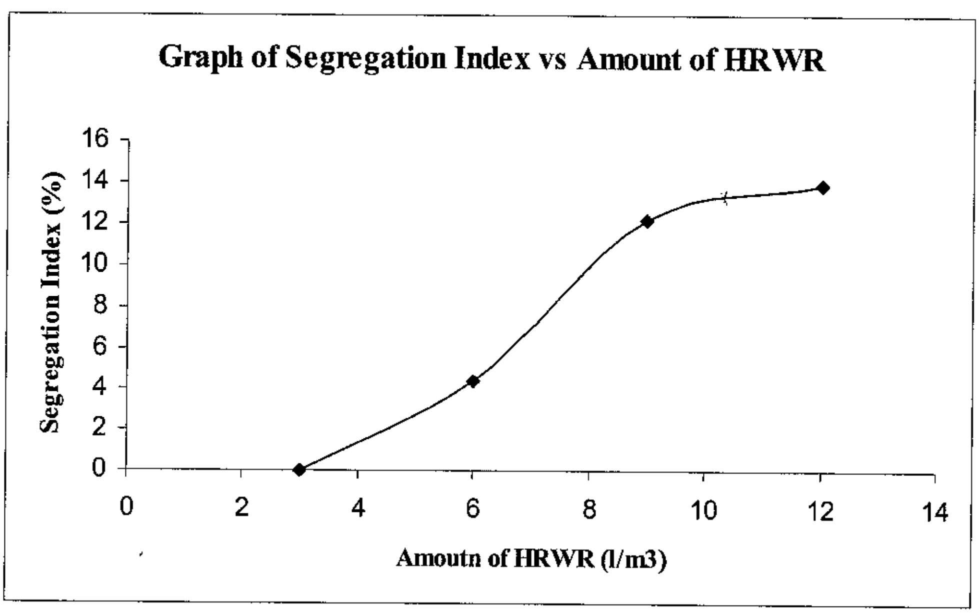

Figure 14: Effect of HRWR amount on segregation index

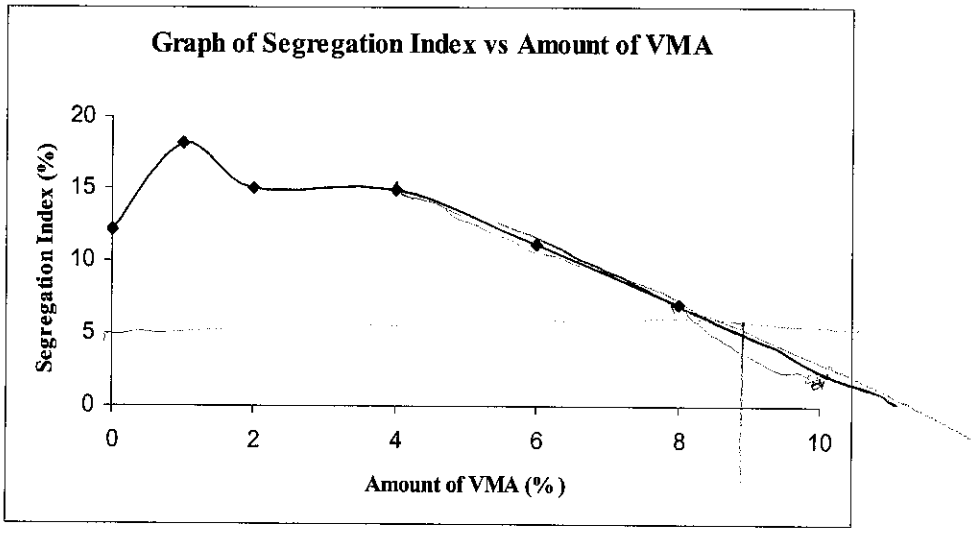

Figure 15: Effect of VMA amount on segregation index

The increase in slump flow incorporating HRWR is presented in Figure 16. There was no record for HRWR-3 because it was not flowable at all. The initial slump flow value is found to slightly increase dramatically as the amount of HRWR increases. Slump flow maintains at a certain level when average slump flow value of 600 is reached. Thus, there is no significant increase in slump flow for HRWR-9 and HRWR-12 as they maintain in the acceptable range of 500 to 700 [19]. During the experiment, it was observed that serious segregations occurred in concretes without VMA.

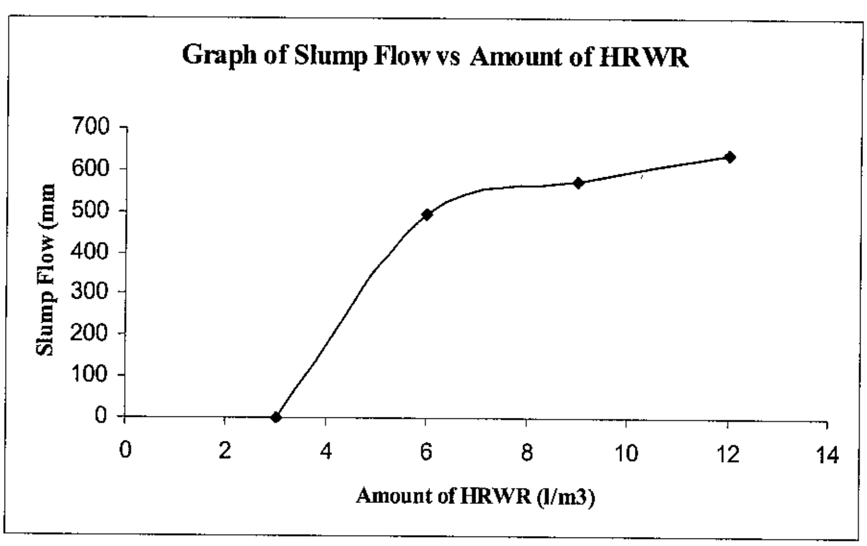

Figure 16: Effect of HRWR amount on slump flow

Result in Table 8 shows that segregation index decreases as the amount of VMA increases. However, as seen in Figure 17, there is no significant effect of segregation index on slump flow as all mixtures' workability vary between 500 and 700. Therefore, it shows that HRWR dominates the workability of fresh concrete.

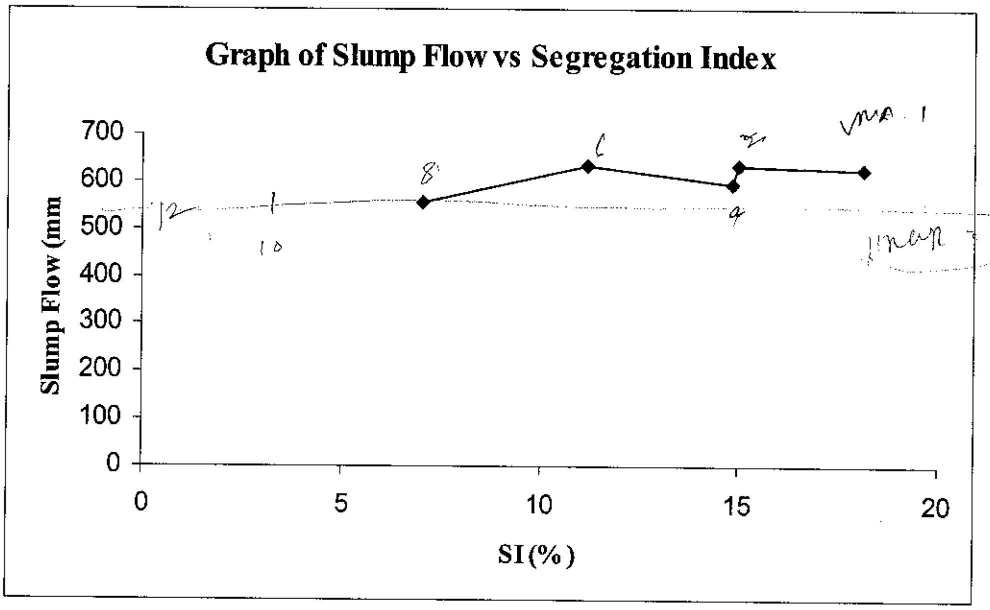

Figure 17: Effect of segregation on slump flow

The V-funnel flow time can be associated with a low deformability due to high paste viscosity, high interparticle friction or blockage of flow. Table 8 shows that flow time decreases with the increase of VMA up to a level where average flow time of <6s is maintained. Based on the result, the flow time of HRWR-9, VMA-1 and VMA-2 are not in the acceptable range whereas flow time of concretes with 4, 6 and 8 % of VMA perform well with no jamming of concrete at the contraction. Figure 18 presents the effect of segregation on V-funnel flow for concretes with VMA. It shows that v-funnel time decreases as segregation index decreases. The threshold of v-funnel flow time is < 6s in which segregation index must be less than 15%.

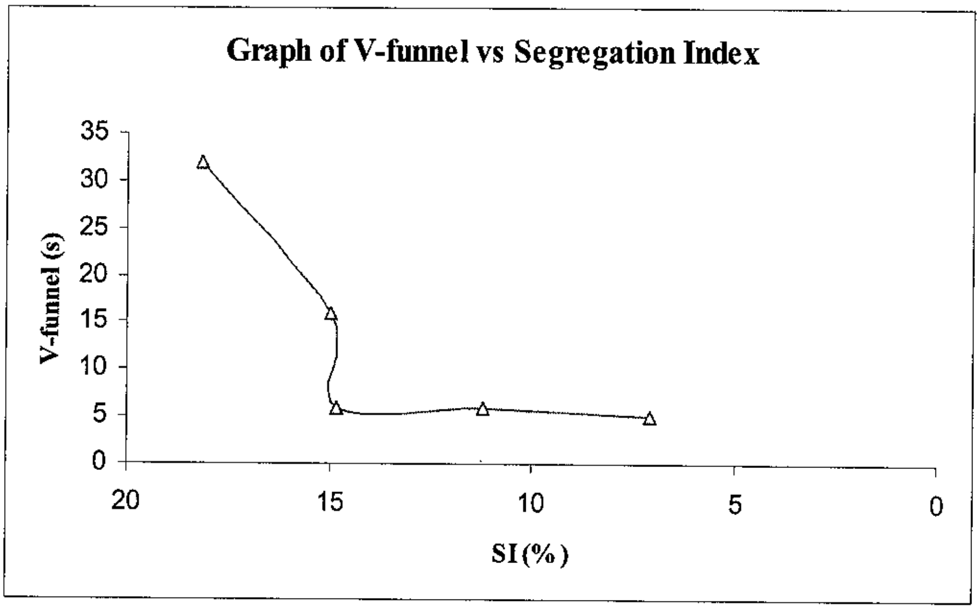

Figure 18: Effect of segregation on v-funnel time

As for the case of filling ability, the results are presented in Table 8 and calculations are shown in Appendix 4. The filling ability increases as the VMA amount increases. There were no records for HRWR-3 and HRWR-6 because these two mixtures were not flowable. A significant increase of filling ability occurs from 0% to 1 % of VMA and the increment goes gradually starting from 1% of VMA onwards. When the concrete was incorporating with only HRWR, serious segregation occurred whereby only mortar flowing through the obstacles and coarse aggregate jammed at the first row of obstacles. It tends to remain the workability, increase the viscosity, and resulting in no jamming at the obstacles side only when VMA were added into the concrete. Therefore, concrete could be easily flowed through the obstacles.

As presented in figure 19 and 20, filling ability increases when segregation index decreases. In order to get the best result, two graphs with linear trend line and power trend line each were plotted to get the equation and to compare the R^2 value. The closer the R^2 value is to 1.0, the better the result is. As in this case, R^2 for linear trend line is closer than the R^2 value for power trend line and thus, linear trend line is chosen:

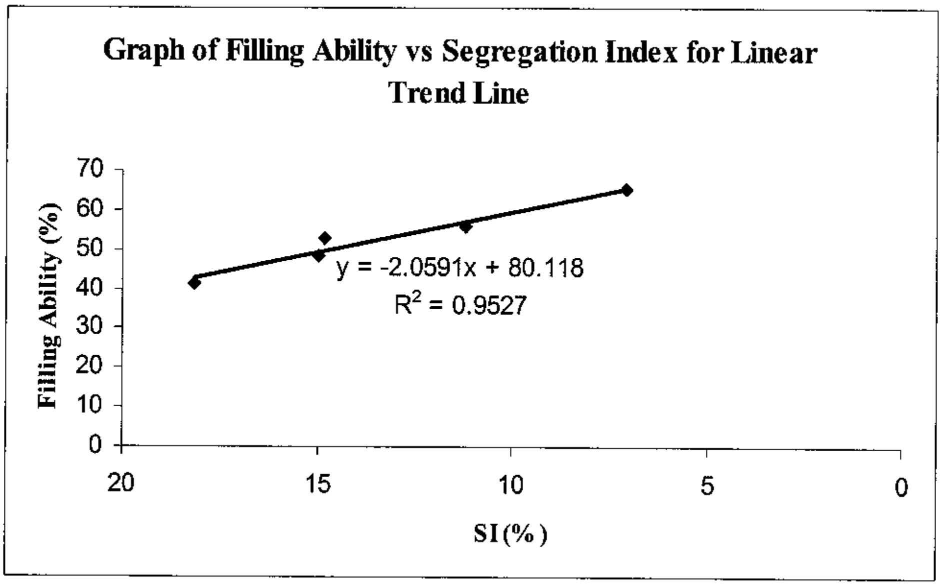

Figure 19: Linear trend line for filling ability

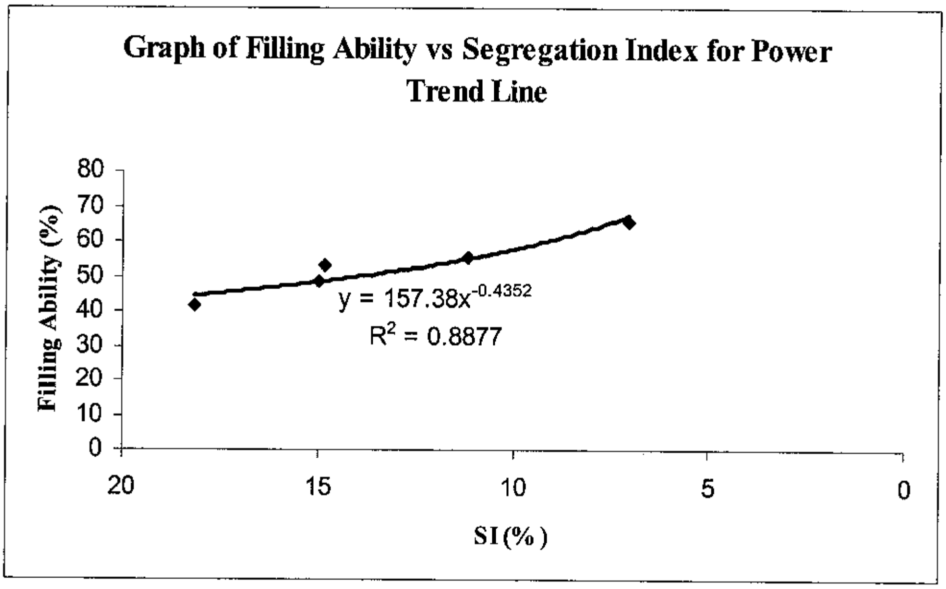

Figure 20: Power trend line for filling ability

However, the highest value that obtained from filling ability is only 66%. If the equation of $y = -2.0591x + 80.118$ in which,

Y = filling ability

X = segregation index

were to be used to indicate the relationship between filling ability and segregation, negative x value would be obtained in order to achieve the filling ability of 100%.

Therefore, an assumption was made that 100% of filling ability will be achieved by 0% of segregation index. The trend line is re-plotted with this assumption and another trend line with equation of y = -3.063x+ 94.508 will be obtained as shown in Figure 21.

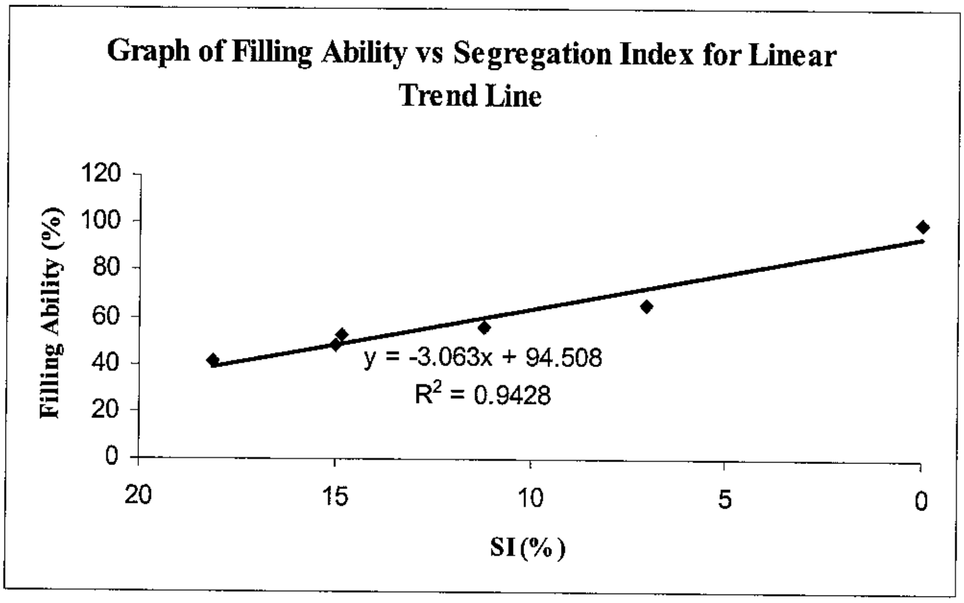

Figure 21: Re-plotted Linear Trend Line for Filling Ability

Hardened Concrete Properties

The compressive strength of concrete mixtures having the same W/C ratio depends mainly on the pore volume, pore-size distribution, and degree of hydration. As presented in Table 9, the compressive strength values varied between 17 and 25 MPa at 7 days and 19 and 36 MPa at 28 days. The highest compressive strength at 7 and 28 days were obtained with VMA-1, VMA-2 and VMA-4. These strength values were between 23 and 24 at 7 days, 34 and 35 at 28 days. These concrete contained HRWR and VMA and thus resulting in higher viscosity and lower porosity that have marked influence on strength (Table 10 and 11). The lowest compressive strength at 7 and 28 days were obtained with HRWR-6, HRWR-9 and HRWR-12. These strength values were obtained between 17 and 18 at 7 days, 19 and 24 at 28 days. These concrete contained only HRWR resulting in great segregation. Therefore, the concrete mixtures had the higher porosity as seen in Table 10 and 11. As presented in Figure 21, the rate of hydration is higher for concrete containing both HRWR and VMA as compared to that containing only HRWR.

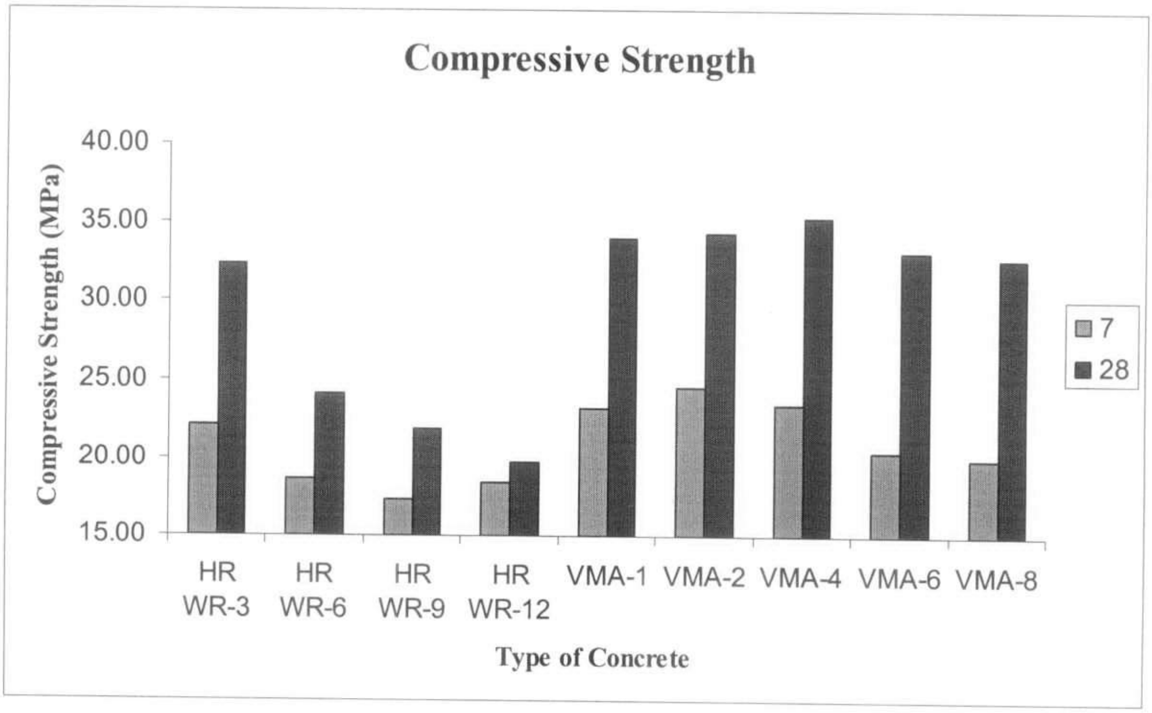

Figure 22: Compressive strength of all mixtures at different ages

The porosity of concrete depends on factors such as saturation of concrete, shape and surface roughness of concrete, water cement ratio and degree of hydration. The results of porosity are presented in Figure 22. It indicates that porosity decreases as ages increases. The porosity values varied between 9 to 12 at 7 days and 8 to 11 at 28 days. Generally, the porosity of all mixtures decrease only 1 % from 7 day to 28 day. Concrete with low workability and low segregation had lowest porosity, which is 9.18 % at 7 day and 8.34 % at 28 day as seen in HRWR-3 whereas concrete with high workability and high segregation had the highest porosity, which is 11++% at 7 day and 10++ at 28 day. As for concrete with high workability and low segregation, the porosity values are calculated at about 10++% at 7 day and 9++ % at 28 day. Besides, when comparing Figure 21 and 22, conclusion can be made that higher rates of hydration result in higher decrease in porosity.

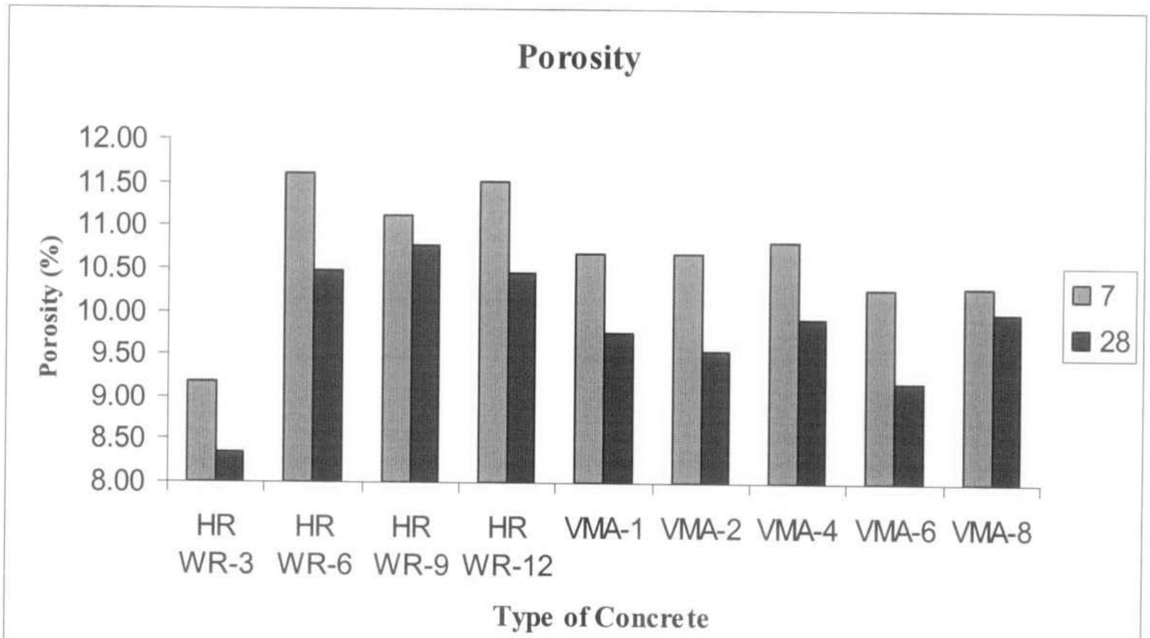

Figure 23: Porosity of all mixtures at different ages

Aggregate Grading and Particle Shape

Grading is the particle-size distribution of aggregate as determined by a sieve analysis in accordance with CSA Standards A23.2-2A and A23.2-5A (ASTM C 136). There are several reasons for specifying grading limits and maximum aggregate size. The grading and maximum size of aggregate affect relative aggregate proportions as well as cementing materials and water requirements, workability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine sands are often uneconomical; very coarse sands and coarse aggregate can produce harsh, unworkable mixes. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.

The coarse aggregate grading requirements of CSA A23.1 (ASTM C 33) permit a wide range in grading and a variety of grading sizes (kindly refer to Appendix 5). The grading for a given maximum-size coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirements of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. Usually more paste, water, and cement is required for small-size aggregates than for large sizes, due to an increase in total aggregate surface area. Figure 23 compares the grading curve of the coarse aggregate sample to high and low specification of ASTM C33. The grading curve of aggregate sample does not fit into the requirement zone. This might be affected by the aggregate size limitations on this experiment whereby only coarse aggregate of 5 to 20 mm are allowed. Therefore, the distribution of coarse aggregate is coarser than normal distribution.

Furthermore, coarser distribution of aggregates may give slightly lower slump flow and concrete strengths for the same water-cementing materials ratio. However, the optimum maximum size of coarse aggregate for higher strength depends on factors such as relative strength of the paste, cementing materials-aggregate bond, and strength of the aggregate particles.

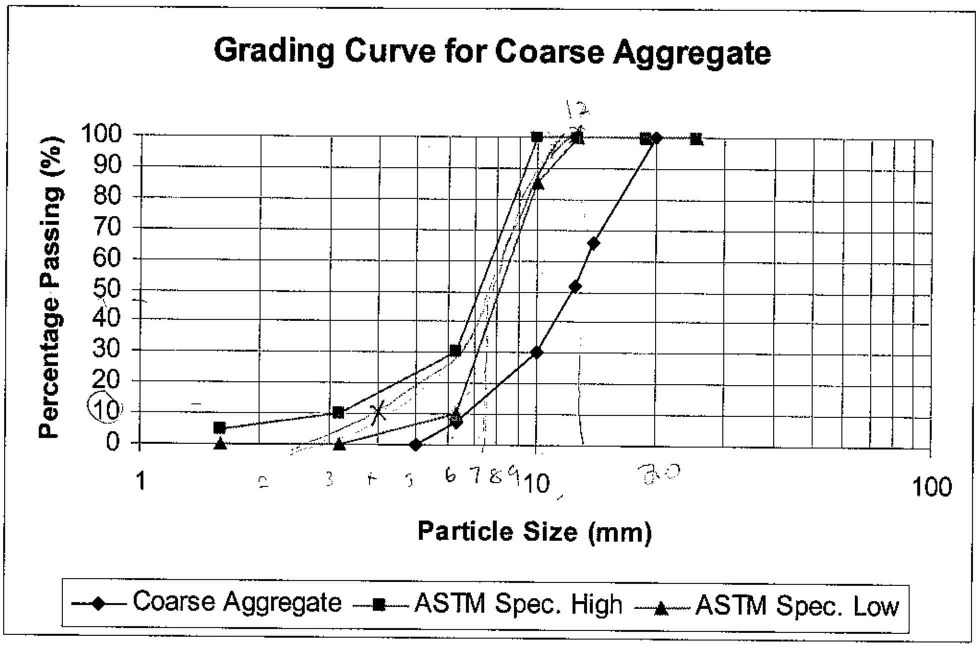

Figure 24: Grading curve for coarse aggregate

Requirements of CSA A23.1 (ASTM C 33) permit a relatively wide range in fine-aggregate gradation (kindly refer to Appendix 5), but specifications by other organizations are sometimes more restrictive. The most desirable fine-aggregate grading depends on the type of work, the richness of the mixture, and the maximum size of coarse aggregate. In general, if the water-cementing materials ratio is kept constant and the ratio of fine-to-coarse aggregate is chosen correctly, a wide range in grading can be used without measurable effect on strength. Standard also notes that:

- For high-strength concrete, it is desirable to limit the amount of material passing the 160-µm sieve to a maximum of 2%.
- Workability problems have been experienced when the percentage passing the 315-µm sieve is less than 10.

Figure 23 compares the grading curve of the fine aggregate sample to high and low specification of ASTM C33. There is a small portion falling outside the limits. However, the amount of material passing the 160-µm sieve and 315-µm is more than the percentage specified above. Therefore, the concrete is said to have less workability problems and low compressive strength.

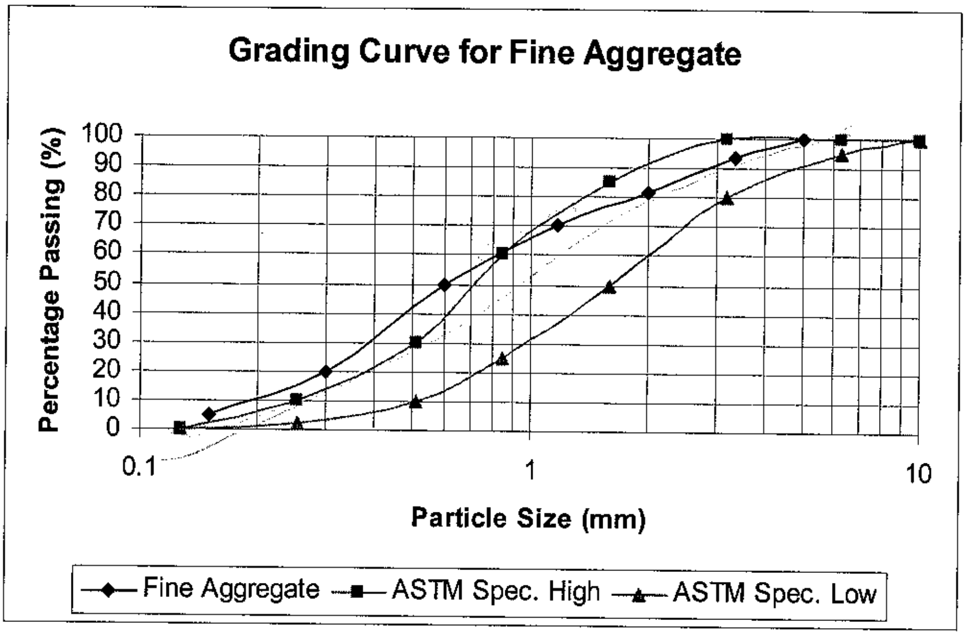

Figure 25: Grading curve for fine aggregate

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. The crushed aggregates of this experiment have a very rough surface and thus, resulting in lower workability whereby friction generated between the rough surfaces, as compared to river rocks. However, this is not the main problem as the workability will be improved by HRWR.

The fineness modulus (FM) of either fine or coarse aggregate according to ASTM C 125 is calculated by adding the cumulative percentages by mass retained on each of a specified series of sieves and dividing the sum by 100. The fineness modulus of coarse aggregate and fine aggregate are calculated as 3.45 and 2.79 respectively. The calculation was shown in Appendix 5. The FM is an index of the fineness of an aggregate - the higher the FM, the coarser the aggregate. If a fineness modulus less than 2.5 is employed, the resultant mixture may be "sticky", resulting in poor workability and a higher water demand [23].

CHAPTER 5.0
CONCLUSION AND RECOMMENDATION

The objective of this project, which is to investigate the performance of VMA and HRWR based on various tests of rheology properties, is successfully achieved. The workability of SCC depends mainly on the HRWR regardless the dosage of VMA where the slump flow value range varied from 500 to 700mm. With constant HRWR amount, segregation decreases as the VMA amount increases. As for V-funnel test and filling ability test, the combination of HRWR and VMA is found to have better result as compared to concrete mixtures with only HRWR. Serious segregation occurs in the latter whereby coarse aggregates stuck at the obstacles and the contraction area whereas only cement pastes pass through the obstacles and the contraction area. With the help of VMA, such condition can be improved as segregation reduces.

The second objective, which is to investigate the relationship between all fresh and hardened concrete properties, is also successfully achieved. There is no significant effect of segregation on slump flow. The workability will remain consistent at 500 to 700 even though segregation continues to decrease. As for V-funnel result, it is found out that flow time decreases with the decrease of segregation. However, the threshold of flow time is < 6s although segregation continues to decrease. The filling ability increases as the segregation decreases. Based on the result, filling ability can be expressed as a function of segregation with the equation of $y = 157.38x^{-0.4352}$. In order to get 100% of filling ability, the segregation index can theoretically be estimated at 1.18%.

There are somehow, errors occur during the experiment whereby unknown factors might affect the result. In order to reduce the possible errors, it is recommended that the mixing process and fresh concrete testing must be conducted in an error-free condition. Although it is impossible, effort must be done to at least reduce the significant factors such as variation of water/cement ratio. Besides, in order to further the research regarding this topic, more experiments with different dosage of HRWR and VMA are recommended in order to get the optimum dosage.

Water/cement ratio is very important in determining properties of either freshly mixed concrete or hardened concrete. It is recommended that all materials that planned for different mix proportion for different testing must be prepared at the same day and sealed with plastic bag even if the materials are not being used at the same time. This is to ensure the uniformity of moisture content of the materials since even minor variation in moisture content may change the properties of concrete. Besides, it is also recommended that the mixer is to be applied with the same water/cement ratio of cement paste before mixing process takes place.

Concrete admixtures are still too often perceived as mysterious ingredients for making concrete. Since some admixtures were originally industrial by-products and only marginally beneficial, more and more modern products are specially prepared or synthesized for the concrete industry. Their action is more specific and more engineered, making them more efficient. Thus, it is believed that the most recent and future technological developments in concrete technology rely on enhanced admixture efficiency rather than on improvements in cement manufacturing.

CHAPTER 6.0

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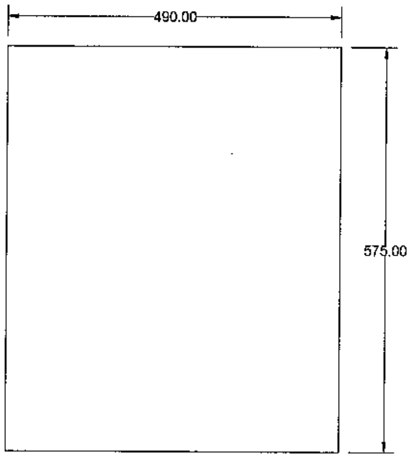
APPENDIX 1

Figure below shows the steps of manufacturing V-funnel equipment:

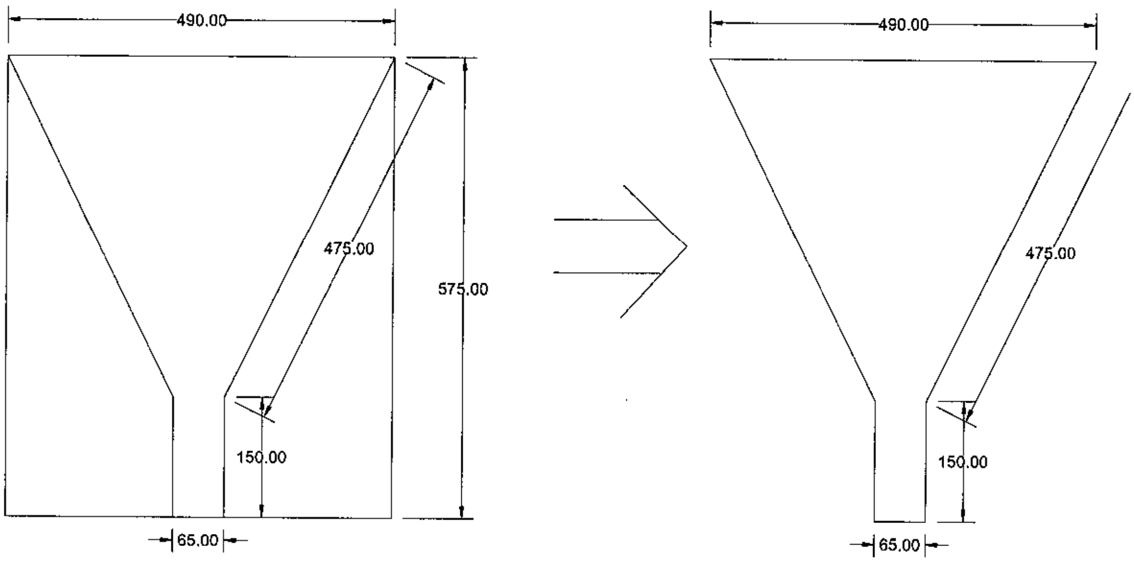
Step 1:

Cut the fiber glass into 2 small rectangular pieces with size 490 x 575.



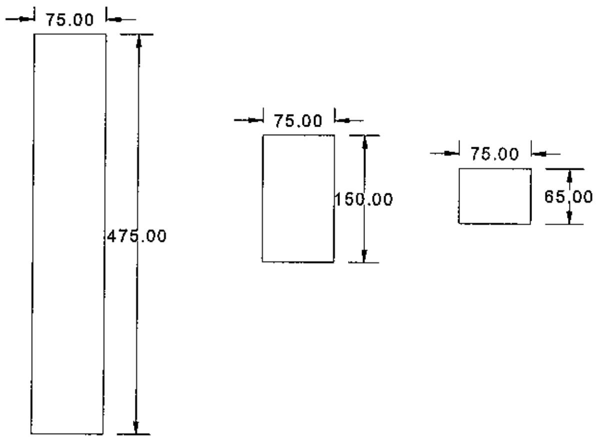
Step 2:

Mark the dimension of V-funnel shape on the rectangular fiber glasses and cut them into the desired shape.



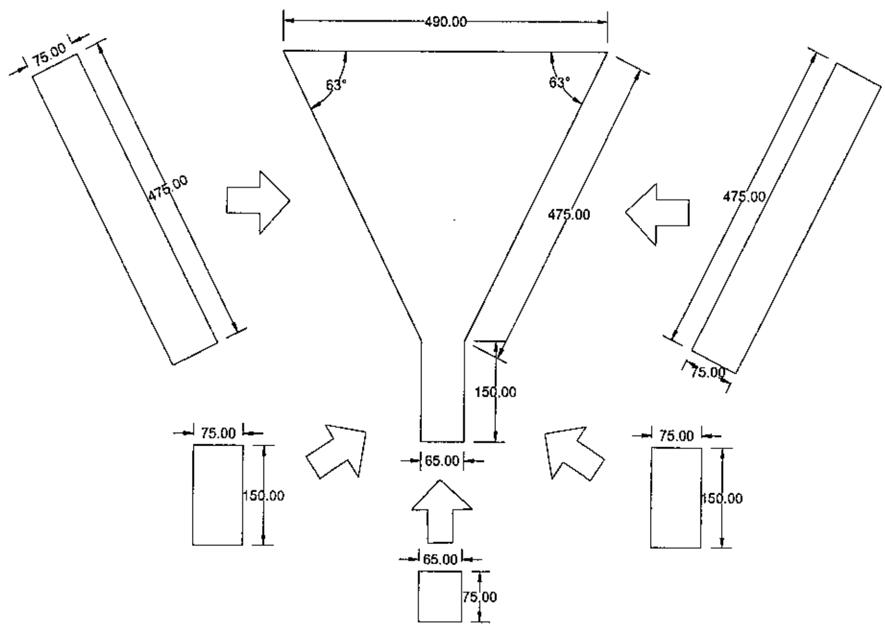
Step 3:

Again, cut the fiber glass into 2 pieces of 475 x 75 rectangle, 2 pieces of 150 x 75 rectangle and 1 piece of 65 x 75 rectangle.

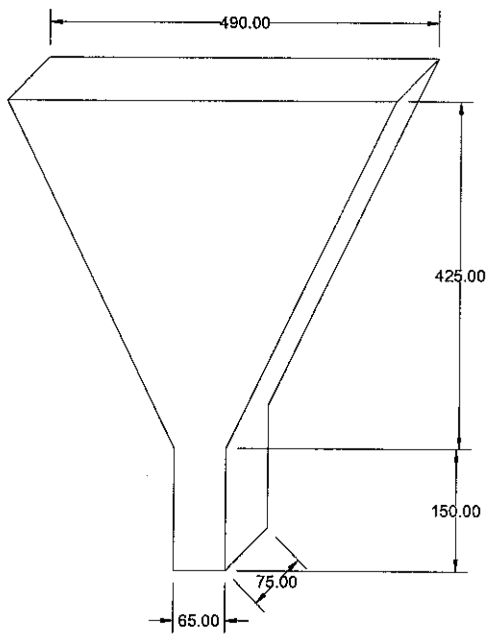


Step 4:

Assemble the equipment by using glue.



The final product of V-funnel equipment is shown as below:

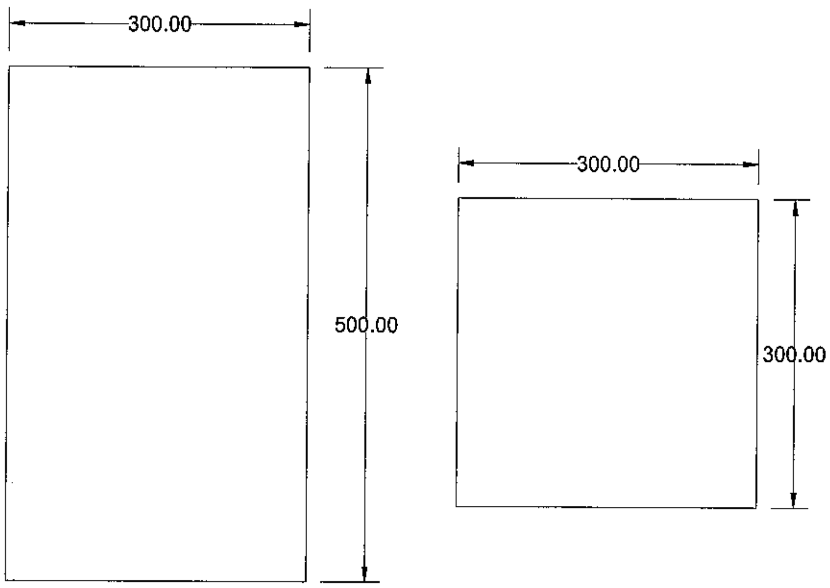


APPENDIX 2

Below shows the steps of manufacturing the Kajima Box:

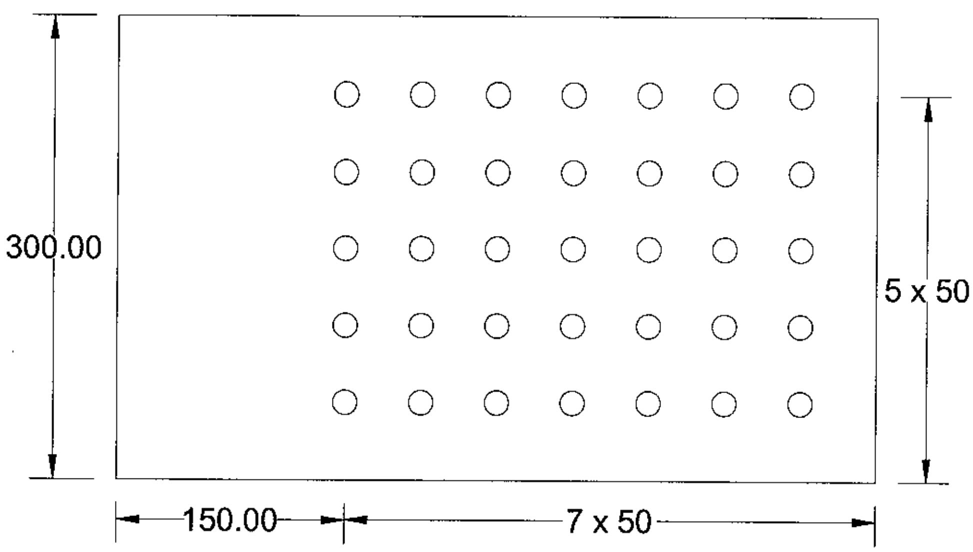
Step 1:

Cut the fiber glass into 4 pieces of 300 x 500 rectangle and 2 pieces of 300 x 300 rectangle.



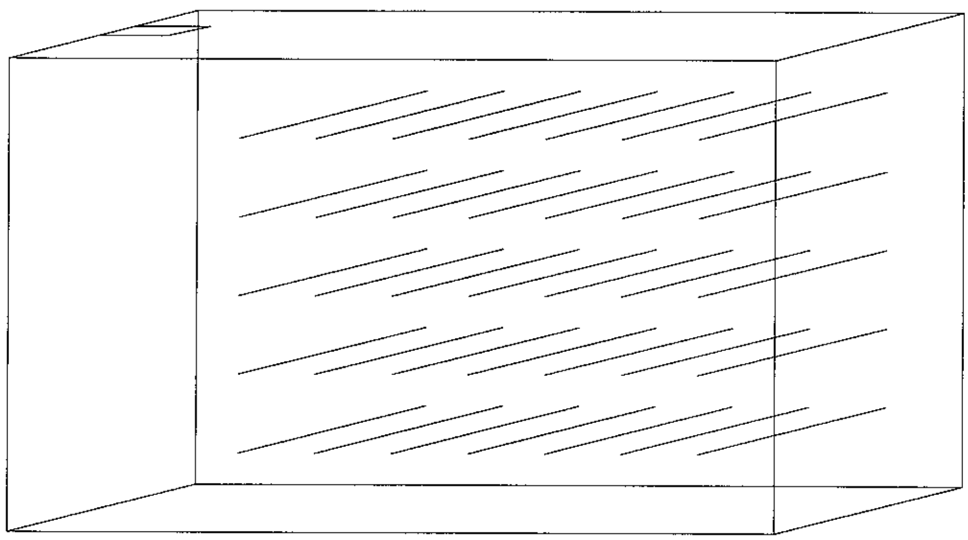
Step 2:

Drill 35 holes on the 300 x 500 rectangle as shown below.



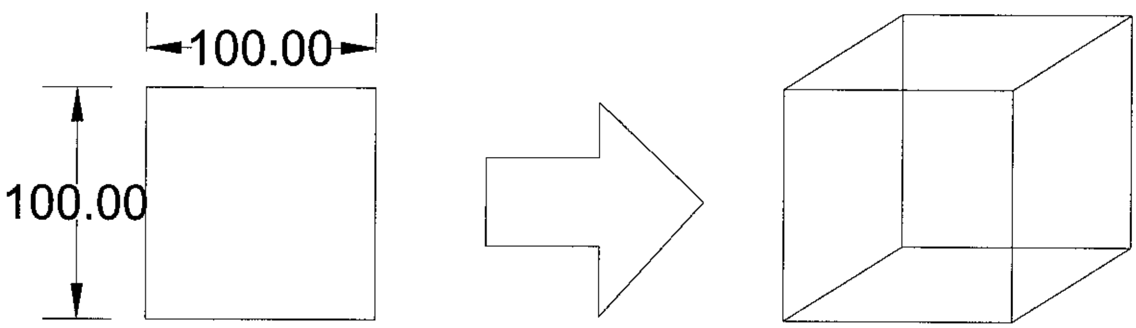
Step 3:

Prepare 35 numbers of 16 mm woods with 300 mm long and stick them to the holes drilled. Assemble the box by using glue and leave one 100 mm square hole for filling channel.



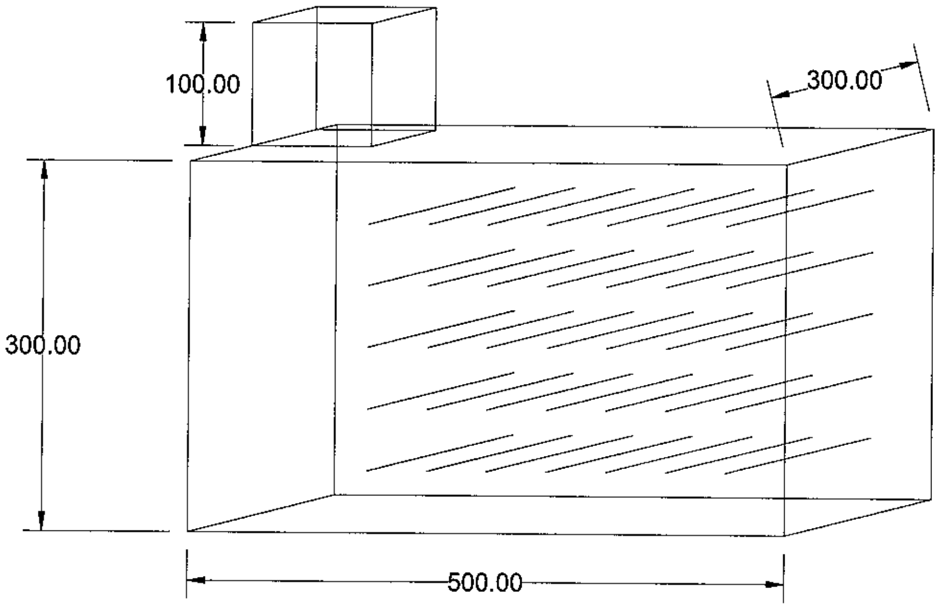
Step 4:

Cut 4 pieces of 100 x 100 mm fiber glasses and assemble it as shown below without top and bottom.

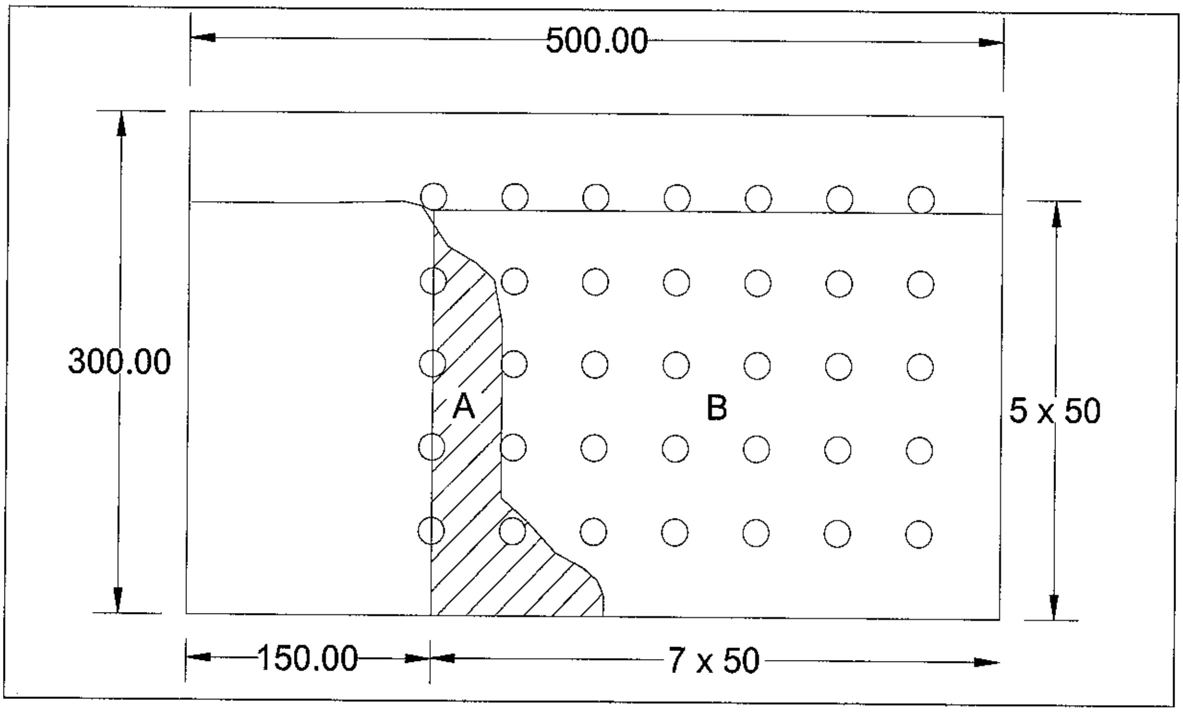


Step 5:

Stick the small box on top of the hole of large box.



APPENDIX 3



Filling Ability in the Presence of Obstruction for First Trial Mix

A = Area filled by concrete

B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.2 x 0.05 + 0.05^2 = 0.0125 m^2

Total area = 0.2 x 0.35 = 0.07 m^2

Thus, the filing capacity (%) = 0.0125/0.07 x 100 = 17.86 %

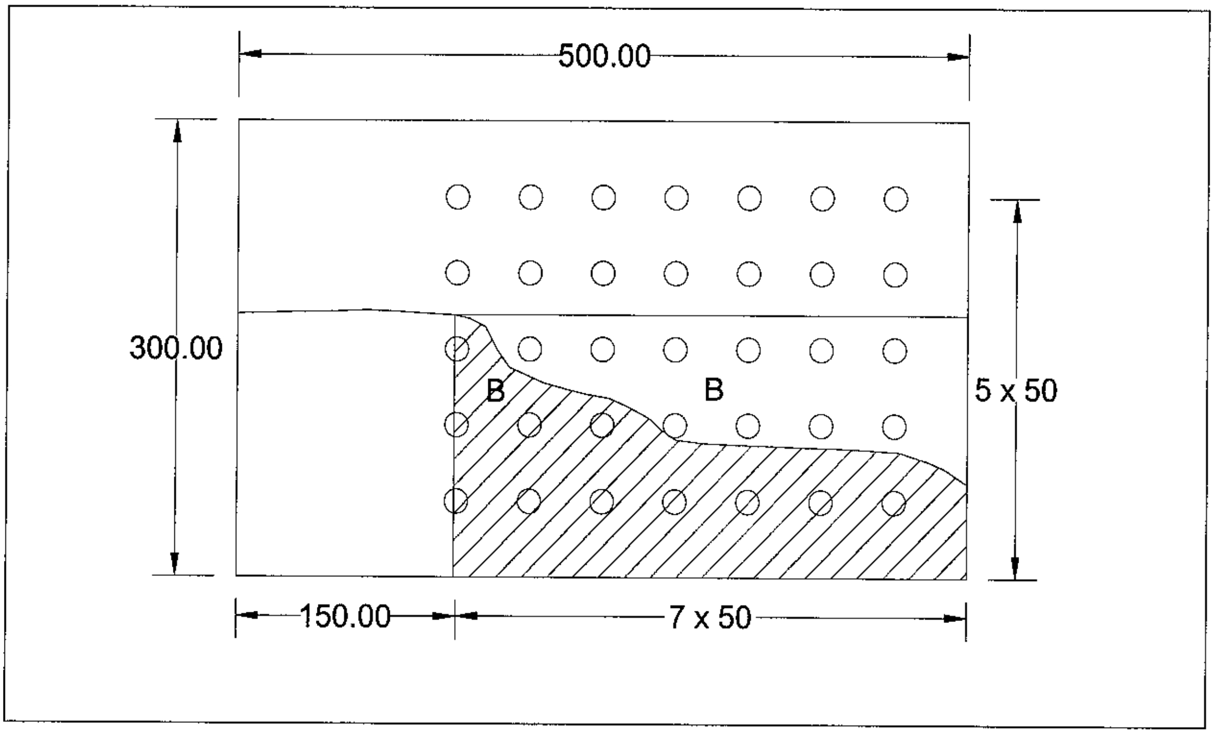


Figure 1: Filling Ability in the Presence of Obstruction for Second Trial Mix

A = Area filled by concrete

B = Empty area

Filling capacity (%) = A/(A+B)

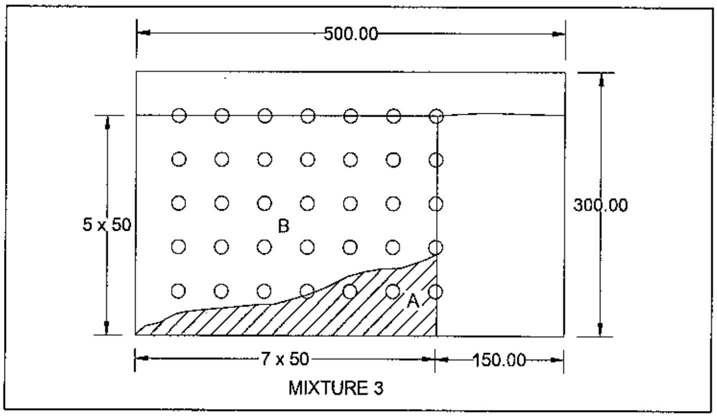
A = 0.15 x (0.1+0.175)/2 + 0.2 x 0.1 = 0.0406 m^2

Total area = 0.175 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.0406/0.0613 x 100 = 46.4 %

APPENDIX 4

Filing Ability Calculation



A = Area filled by concrete

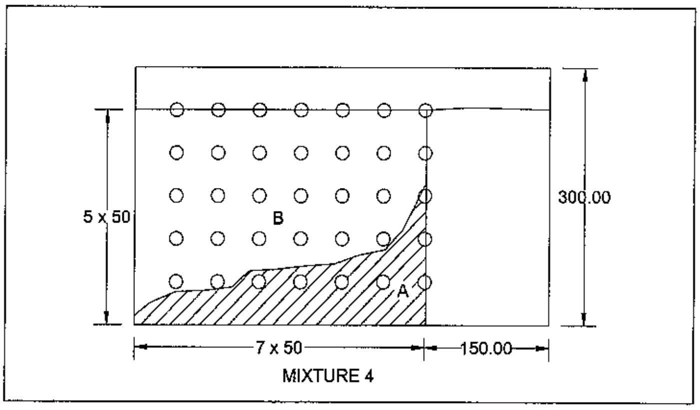
B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.5 x 0.35 x 0.1 = 0.0175 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.0175/0.0875 x 100 = 20 %



A = Area filled by concrete

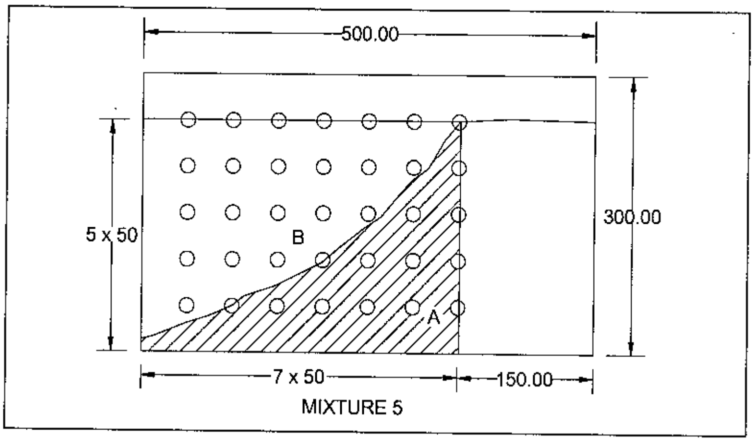
B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.05 x 0.35 + 0.1 x 0.05 = 0.0225 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.0225/0.0875 x 100 = 25.71 %



A = Area filled by concrete

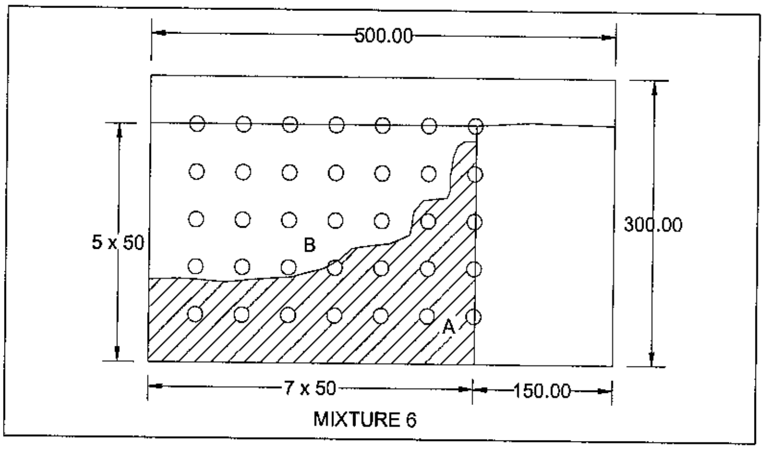
B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.15 x 0.1 + 0.5 x 0.15 x 0.15 + 0.5 x 0.1 x 0.2 = 0.03625 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.03625/0.0875 x 100 = 41.43 %



A = Area filled by concrete

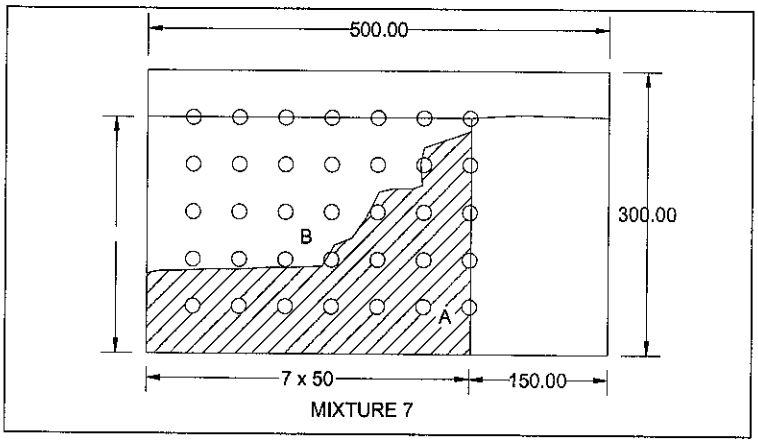
B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.1 x 0.35 + 0.15 x 0.05 = 0.0425 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.0425/0.0875 x 100 = 48.57 %



A = Area filled by concrete

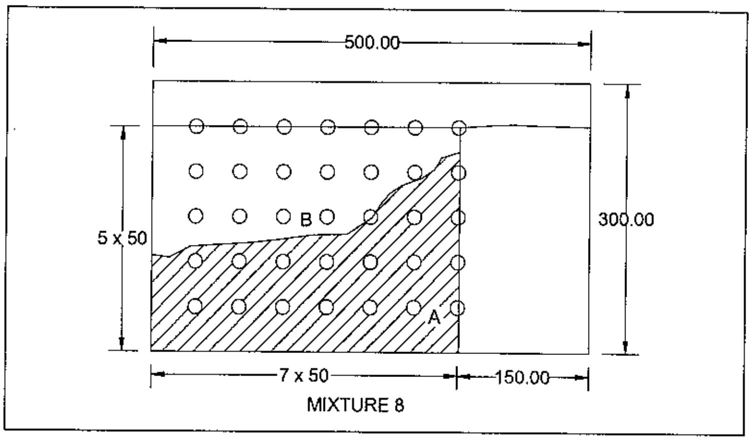
B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.1 x 0.35 + 0.5 x 0.15 x 0.15 = 0.04625 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.04625/0.0875 x 100 = 52.86 %



A = Area filled by concrete

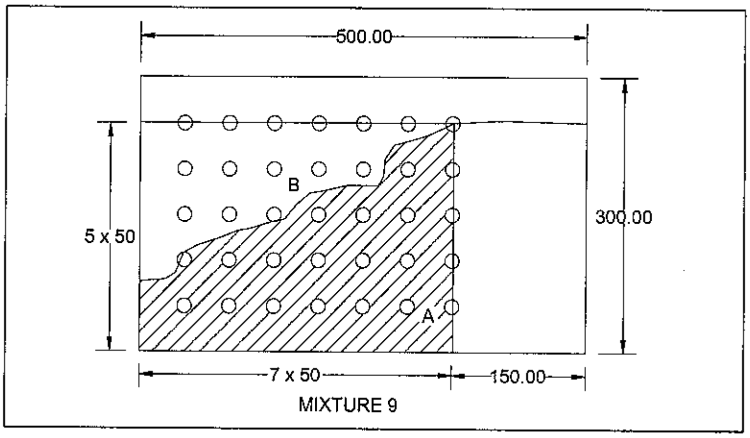
B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.125 x 0.35 + 0.1 x 0.05 = 0.04875 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.04875/0.0875 x 100 = 55.71 %



A = Area filled by concrete

B = Empty area

Filling capacity (%) = A/(A+B)

A = 0.1 x 0.35 + 0.5 x 0.15 x 0.3 = 0.0575 m^2

Total area = 0.25 x 0.35 = 0.0875 m^2

Thus, the filing capacity (%) = 0.0575/0.0875 x 100 = 65.71 %

APPENDIX 5

Sieve Analysis for Coarse Aggregate

Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative Percentage Passing (%)	Cumulative Percentage Retained (%)
20	0	0	100	0
14	1699	33.98	66.02	33.98
12.5	705	14.1	51.92	48.08
10	1097	21.94	29.98	70.02
6.3	1143	22.86	7.12	92.88
5	356	7.12	0	100

ASTM C33 Coarse Aggregate Specification

Sieve Size (in)	Cumulative Percentage Passing (%)	
	High	Low
1	100	100
¾	100	100
½	100	100
3/8	100	85
No. 4	30	10
No.8	10	0
No. 16	5	0

Fineness Modulus (FM)

FM for coarse aggregate = (0 + 33.98 + 48.08 + 70.02 + 92.88 + 100)/100

= 3.45

Sieve Analysis for Fine Aggregate

Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative Percentage Passing (%)	Cumulative Percentage Retained (%)
5	0	0	100	0.00
3.35	32.52	6.50	93.50	6.50
2	57.91	11.58	81.91	18.09
1.18	58.97	11.79	70.12	29.88
0.6	102.45	20.49	49.63	50.37
0.3	147.14	29.43	20.20	79.80
0.15	74.95	14.99	5.21	94.79
0.075	26.06	5.21	0.00	100.00

ASTM C33 Fine Aggregate Specification

Sieve Size (in)	Cumulative Percentage Passing (%)	
	High	Low
3/8	100	100
No. 4	100	95
No.8	100	80
No. 16	85	50
No. 30	60	25
No. 50	30	10
No. 100	10	2

Fineness Modulus (FM)

FM for fine aggregate $= (0 + 6.50 + 18.09 + 29.88 + 50.37 + 79.80)/100$

$= 2.79$

APPENDIX 6

Designation: C 39/C 39M – 01

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C 39/C 39M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 50 lb/ft^3 [800 kg/m^3].

1.2 The values stated in either inch-pound or SI units are to be regarded separately as standard. The SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 The text of this standard references notes which provide explanatory material. These notes shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 873 Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds[2]

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[2]

C 1231 Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders[2]

E 4 Practices for Force Verification of Testing Machines[3]

E 74 Practice for Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines[3]

Manual of Aggregate and Concrete Testing[2]

2.2 *American Concrete Institute:*

CP-16 Concrete Laboratory Testing Technician, Grade I[4]

3. Summary of Test Method

3.1 This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

4. Significance and Use

4.1 Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

4.2 This test method is used to determine compressive strength of cylindrical specimens prepared and cured in accordance with Practices C 31, C 192, C 617 and C 1231 and Test Methods C 42 and C 873.

4.3 The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures and similar uses.

4.4 The individual who tests concrete cylinders for acceptance testing shall have demonstrated a knowledge and ability to perform the test procedure equivalent to the minimum guidelines for certification of Concrete Laboratory Technician, Level I, in accordance with ACI CP-16.

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[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing Concrete for Strength.

Current edition approved Feb. 10, 2001. Published March 2001. Originally published as C 39 – 21 T. Last previous edition C 39 – 99.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] Available from American Concrete Institute, P.O. Box 9094, Farmington Hills, MI 48333-9094.

*A Summary of Changes section appears at the end of this standard.

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NOTE 1—The testing laboratory performing this test method should be evaluated in accordance with Practice C 1077.

5. Apparatus

5.1 *Testing Machine*—The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading prescribed in 7.5.

5.1.1 Verification of calibration of the testing machines in accordance with Practices E 4 is required under the following conditions:

5.1.1.1 After an elapsed interval since the previous verification of 18 months maximum, but preferably after an interval of 12 months,

5.1.1.2 On original installation or relocation of the machine,

5.1.1.3 Immediately after making repairs or adjustments that affect the operation of the force applying system of the machine or the values displayed on the load indicating system, except for zero adjustments that compensate for the mass of bearing blocks, or specimen, or both, or

5.1.1.4 Whenever there is reason to doubt the accuracy of the results, without regard to the time interval since the last verification.

5.1.2 *Design*—The design of the machine must include the following features:

5.1.2.1 The machine must be power operated and must apply the load continuously rather than intermittently, and without shock. If it has only one loading rate (meeting the requirements of 7.5), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand operated.

NOTE 2—High-strength concrete cylinders rupture more intensely than normal strength cylinders. As a safety precaution, it is recommended that the testing machines should be equipped with protective fragment guards.

5.1.2.2 The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device which is of sufficient capacity to cover the potential loading range of the testing machine and which complies with the requirements of Practice E 74.

NOTE 3—The types of elastic calibration devices most generally available and most commonly used for this purpose are the circular proving ring or load cell.

5.1.3 *Accuracy*—The accuracy of the testing machine shall be in accordance with the following provisions:

5.1.3.1 The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0 % of the indicated load.

5.1.3.2 The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one third of the difference between the maximum and minimum test loads.

5.1.3.3 The test load as indicated by the testing machine and the applied load computed from the readings of the verification device shall be recorded at each test point. Calculate the error, E, and the percentage of error, E_p, for each point from these data as follows:

$$E = A - B \quad (1)$$

$$E_p = 100(A - B)/B$$

where:

A = load, lbf [kN] indicated by the machine being verified, and

B = applied load, lbf [kN] as determined by the calibrating device.

5.1.3.4 The report on the verification of a testing machine shall state within what loading range it was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall the loading range be stated as including loads below the value which is 100 times the smallest change of load estimable on the load-indicating mechanism of the testing machine or loads within that portion of the range below 10 % of the maximum range capacity.

5.1.3.5 In no case shall the loading range be stated as including loads outside the range of loads applied during the verification test.

5.1.3.6 The indicated load of a testing machine shall not be corrected either by calculation or by the use of a calibration diagram to obtain values within the required permissible variation.

5.2 The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note 4), one of which is a spherically seated block that will bear on the upper surface of the specimen, and the other a solid block on which the specimen shall rest. Bearing faces of the blocks shall have a minimum dimension at least 3 % greater than the diameter of the specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.001 in. [0.02 mm] in any 6 in. [150 mm] of blocks 6 in. [150 mm] in diameter or larger, or by more than 0.001 in. [0.02 mm] in the diameter of any smaller block; and new blocks shall be manufactured within one half of this tolerance. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than 0.5 in. [13 mm], concentric circles not more than 0.03 in. [0.8 mm] deep and not more than 0.04 in. [1 mm] wide shall be inscribed to facilitate proper centering.

NOTE 4—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than 55 HRC.

5.2.1 Bottom bearing blocks shall conform to the following requirements:

5.2.1.1 The bottom bearing block is specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions (Note 5). The top and bottom surfaces shall be parallel to each other. If the testing machine is so designed that the platen itself is readily maintained in the specified surface condition, a bottom block is not required. Its least horizontal dimension shall be at least 3 % greater than the diameter of the specimen to be tested. Concentric circles as described in 5.2 are optional on the bottom block.

NOTE 5—The block may be fastened to the platen of the testing machine.

5.2.1.2 Final centering must be made with reference to the upper spherical block. When the lower bearing block is used to assist in centering the specimen, the center of the concentric rings, when provided, or the center of the block itself must be directly below the center of the spherical head. Provision shall be made on the platen of the machine to assure such a position.

5.2.1.3 The bottom bearing block shall be at least 1 in. [25 mm] thick when new, and at least 0.9 in. [22.5 mm] thick after any resurfacing operations.

5.2.2 The spherically seated bearing block shall conform to the following requirements:

5.2.2.1 The maximum diameter of the bearing face of the suspended spherically seated block shall not exceed the values given below:

Diameter of Test Specimens, in. [mm]	Maximum Diameter of Bearing Face, in. [mm]
2 [50]	4 [105]
3 [75]	5 [130]
4 [100]	6.5 [165]
6 [150]	10 [255]
8 [200]	11 [280]

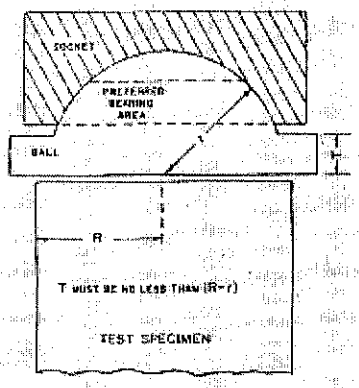
NOTE 6—Square bearing faces are permissible, provided the diameter of the largest possible inscribed circle does not exceed the above diameter.

5.2.2.2 The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 % of the radius of the sphere. The diameter of the sphere shall be at least 75 % of the diameter of the specimen to be tested.

5.2.2.3 The ball and the socket must be so designed by the manufacturer that the steel in the contact area does not permanently deform under repeated use, with loads up to 12 000 psi [85 MPa] on the test specimen.

NOTE 7—The preferred contact area is in the form of a ring (described as preferred "bearing" area) as shown on Fig. 1.

5.2.2.4 The curved surfaces of the socket and of the spherical portion shall be kept clean and shall be lubricated with a petroleum-type oil such as conventional motor oil, not with a pressure type grease. After contacting the specimen and application of small initial load, further tilting of the spherically seated block is not intended and is undesirable.



NOTE 1—Provision shall be made for holding the ball in the socket and for holding the entire unit in the testing machine.

FIG. 1 Schematic Sketch of a Typical Spherical Bearing Block

5.2.2.5 If the radius of the sphere is smaller than the radius of the largest specimen to be tested, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen. The least dimension of the bearing face shall be at least as great as the diameter of the sphere (see Fig. 1).

5.2.2.6 The movable portion of the bearing block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted at least 4° in any direction.

5.3 *Load Indication*:

5.3.1 If the load of a compression machine used in concrete testing is registered on a dial, the dial shall be provided with a graduated scale that is readable to at least the nearest 0.1 % of the full scale load (Note 8). The dial shall be readable within 1 % of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment located outside the dialcase and easily accessible from the front of the machine while observing the zero mark and dial pointer. Each dial shall be equipped with a suitable device that at all times until reset, will indicate to within 1 % accuracy the maximum load applied to the specimen.

NOTE 8—Readability is considered to be 0.02 in. [0.5 mm] along the arc described by the end of the pointer. Also, one half of a scale interval is readable with reasonable certainty when the spacing on the load indicating mechanism is between 0.04 in. [1 mm] and 0.06 in. [2 mm]. When the spacing is between 0.06 and 0.12 in. [2 and 3 mm], one third of a scale interval is readable with reasonable certainty. When the spacing is 0.12 in. [3 mm] or more, one fourth of a scale interval is readable with reasonable certainty.

5.3.2 If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 % of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 % for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1 % system accuracy the maximum load applied to the specimen.

6. Specimens

6.1 Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 %.

NOTE 9—This may occur when single use molds are damaged or deformed during shipment, when flexible single use molds are deformed during molding or when a core drill deflects or shifts during drilling.

6.2 Neither end of compressive test specimens when tested shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to 0.12 in 12 in. [3 in 300 mm]). The ends of compression test specimens that are not plane within 0.002 in. [0.050 mm] shall be sawed or ground to meet that tolerance, or capped in accordance with either Practice C 617 or Practice C 1231. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.01 in. [0.25 mm] by averaging two diameters measured at right angles to each other at about midheight of the specimen.

6.3 The number of individual cylinders measured for determination of average diameter is not prohibited from being reduced to one for each ten specimens or three specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reusable or single-use molds which consistently produce specimens with average diameters within a range of 0.02 in. [0.5 mm]. When the average diameters do not fall within the range of 0.02 in. [0.5 mm] or when the cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculation of the unit compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

6.4 The length shall be measured to the nearest 0.05 D when the length to diameter ratio is less than 1.8, or more than 2.2, or when the volume of the cylinder is determined from measured dimensions.

7. Procedure

7.1 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from moist storage.

7.2 Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

7.3 All test specimens for a given test age shall be broken within the permissible time tolerances prescribed as follows:

Test Age	Permissible Tolerance
24 h	± 0.5 h or 2.1 %
3 days	2 h or 2.8 %
7 days	6 h or 3.6 %
28 days	20 h or 3.0 %
90 days	2 days 2.2 %

7.4 *Placing the Specimen*—Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen and place the test specimen on the lower bearing block. Carefully align the axis of the specimen with the center of thrust of the spherically seated block.

7.4.1 *Zero Verification and Block Seating*—Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator (Note 10). As the spherically seated block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

NOTE 10—The technique used to verify and adjust load indicator to zero will vary depending on the machine manufacturer. Consult your owner's manual or compression machine calibrator for the proper technique.

7.5 *Rate of Loading*—Apply the load continuously and without shock.

7.5.1 For testing machines of the screw type, the moving head shall travel at a rate of approximately 0.05 in. [1 mm]/min when the machine is running idle. For hydraulically operated machines, the load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a loading rate on the specimen within the range of 20 to 50 psi/s [0.15 to 0.35 MPa/s]. The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase of the testing cycle.

7.5.2 During the application of the first half of the anticipated loading phase a higher rate of loading shall be allowed.

7.5.3 Make no adjustment in the rate of movement of the platen at any time while a specimen is yielding rapidly immediately before failure.

7.6 Apply the load until the specimen fails, and record the maximum load carried by the specimen during the test. Note the type of failure and the appearance of the concrete.

8. Calculation

8.1 Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Section 6 and express the result to the nearest 10 psi [0.1 MPa].

8.2 If the specimen length to diameter ratio is less than 1.8, correct the result obtained in 8.1 by multiplying by the appropriate correction factor shown in the following table:

L/D:	1.75	1.50	1.25	1.00
Factor:	0.98	0.96	0.93	0.87 (Note 11)

NOTE 11—These correction factors apply to lightweight concrete weighing between 100 and 120 lb/ft^3 [1600 and 1920 kg/m^3] and to normal weight concrete. They are applicable to concrete dry or soaked at the time of loading. Values not given in the table shall be determined by interpolation. The correction factors are applicable for nominal concrete strengths from 2000 to 6000 psi [15 to 45 MPa].

9. Report

9.1 Report the following information:

9.1.1 Identification number,

9.1.2 Diameter (and length, if outside the range of 1.8D to 2.2D), in inches [millimetres],

9.1.3 Cross-sectional area, in square inches [square millimetres],

9.1.4 Maximum load, in pounds-force [kilonewtons],

9.1.5 Compressive strength calculated to the nearest 10 psi [0.1 MPa],

9.1.6 Type of fracture, if other than the usual cone (see Fig. 2),

9.1.7 Defects in either specimen or caps, and,

9.1.8 Age of specimen.

10. Precision and Bias

10.1 *Precision*—The single operator precision of tests of individual 6 by 12 in. [150 by 300 mm] cylinders made from

A2.0 SLUMP FLOW TEST AND VSI (VISUAL STABILITY INDEX) TEST METHOD

A2.1 Introduction

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan (Reference 1, page 80) for use in assessment of underwater SCC. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the flowability of the SCC.

A2.2 Assessment of Test

This is a simple, rapid test procedure. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the SCC to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably used to assess the consistency of supply of mixed SCC to a site from load to load.

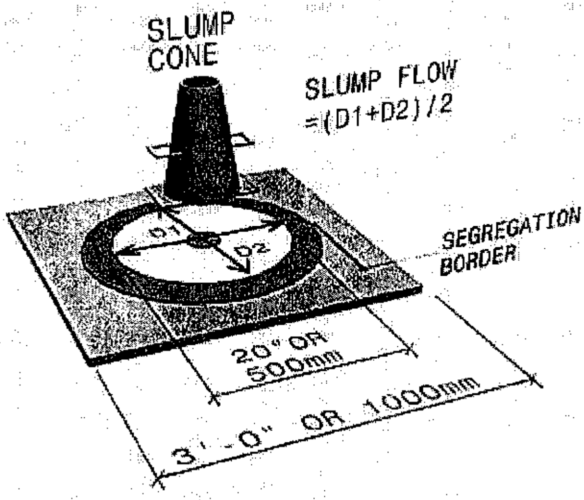


Figure 2.1 - Method A Upright Slump Cone

The slump cone can also be used in the inverted position to perform the sump flow test. Values of sump flow are nearly the same as determined by either the upright or inverted slump cone. Either the inverted or upright slump cone should be used consistently in controlling SCC production (don't switch from one method to the other).

A2.3 Equipment

The apparatus is shown in Figure 2.1.

a. Mold in the shape of a truncated cone with the internal dimensions 8-inch diameter (200 mm) at the base, 4-inch diameter (100 mm) at the top, and a height of 12 inches (300 mm)

b. Base plate of a stiff non-absorbing material, at least 28 inches square (700 mm square), marked with a circle marking the central location for the slump cone, and a further concentric circle of 20-inch diameter (500 mm)

c. Trowel

d. Scoop

e. Ruler

A2.4 Procedure

a. About 0.2 ft^3 (6 L) of SCC is needed to perform the test, sampled normally.

b. Moisten the base plate and inside of slump cone.

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

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

e. Remove any surplus SCC from around the base of the cone.

f. Raise the cone vertically and allow the SCC to flow out freely.

g. Measure the final diameter of the SCC in two perpendicular directions.

h. Calculate the average of the two measured diameters (this is the slump flow in inches [mm]).

i. Rate the stability of the mixture in 0.5 increments by visual examination using the following guidelines. (See 13.0 for details of VSI rating test.)

Rating	Criteria
0	No evidence of segregation in slump flow patty or in mixer drum or wheelbarrow.
1	No mortar halo or aggregate pile in the slump flow patty but some slight bleed or air popping on the surface of the concrete in the mixer drum or wheelbarrow.
2	A slight mortar halo (< 10 mm) (3/8 inch) and/or aggregate pile in the slump flow patty and highly noticeable bleeding in the mixer drum and wheelbarrow.
3	Clearly segregating by evidence of a large mortar halo (> 10 mm) (3/8 inch) and/or large aggregate pile in the center of the concrete patty and a thick layer of paste on the surface of the resting concrete in the mixer drum or wheelbarrow.

See A11.0 for photos showing the range of VSI ratings.

A2.5 Interpretation of Result

The higher the slump flow value, the greater its ability to fill formwork under its own weight. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ±50 mm (±2 inches) may be appropriate.

In case of severe segregation, most coarse aggregate will remain in the center of the pool of SCC and mortar and cement paste at the SCC periphery. In case of minor segregation, a border of mortar without coarse aggregate can occur at the edge of the pool of SCC. Because the slump flow patty has no significant depth through which settlement of aggregate can occur, a visual inspection of the concrete in the wheelbarrow or mixer should be part of the process in determining the VSI rating. The VSI does not quantify a property of the concrete mixture, however, it is useful for quality control/consistency testing.

A7.0 V-FUNNEL TEST AND V-FUNNEL TEST AT T = 5 MINUTES

A7.1 Introduction

The equipment consists of a V-shaped funnel, shown in Figure 7.1. An alternative type of V-funnel, the O-Funnel, with a circular section, is also used in Japan but is not described in this test method.

The described V-Funnel test is used to determine the filling ability (flowability) of the SCC with a maximum aggregate size of 20 mm (3/4 inch). The funnel is filled with about 12 liters of SCC and the time taken for it to flow through the apparatus measured.

After this, the funnel can be refilled with SCC and left for 5 minutes to settle. If the SCC shows segregation, then the flow time will increase significantly. If the SCC mixture has thixotropic properties, it will also indicate an increased flow time.

A7.2 Assessment of Test

Though the test is designed to measure flowability, the result is affected by SCC properties other than flow. The inverted cone shape will cause any tendency of the SCC to block to be reflected in the result - if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high interparticle friction.

While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of SCC is not clear.

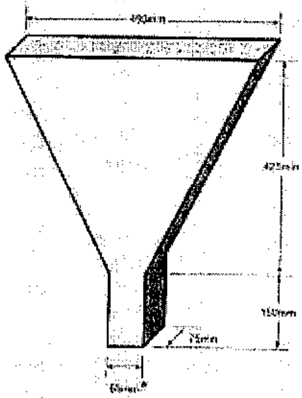


Figure 7.1 – V-Funnel Apparatus

A7.3 Equipment

a. V-Funnel
b. Bucket (± 0.4 ft^3, ± 12 liters)
c. Trowel
d. Scoop
e. Stopwatch

A7.4 **Procedure Flow Time**

a. About 0.4 ft^3 (12 L) of SCC is needed to perform the test, sampled normally.

b. Set the V-Funnel on firm ground.

c. Moisten the inside surfaces of the funnel.

d. Keep the trap door open to allow any surplus water to drain.

e. Close the trap door and place a bucket underneath.

f. Fill the apparatus completely with SCC without compacting or tapping, simply strike off the SCC level with the top with the trowel.

g. Open the trap door within 10 seconds after filling and allow the SCC to flow out under gravity.

h. Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time). This is taken to be when light is seen from above through the funnel.

i. The whole test has to be performed within 5 minutes.

A7.5 **Procedure Flow Time at T-5 Minutes**

a. Performed subsequent to the flow time test.

b. Do NOT clean or moisten the inside surfaces of the funnel again.

c. Close the trap door and refill the V-Funnel immediately after measuring the flow time.

d. Fill the apparatus completely with SCC without compacting or tapping, simply strike off the SCC level with the top with the trowel.

e. Place a bucket underneath.

f. Open the trap door 5 minutes after the second fill of the funnel and allow the SCC to flow out under gravity

g. Simultaneously start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time at T-5 minutes). The record time is to be when light is seen from above through the funnel.

A7.6 **Interpretation of Result**

This test measures the ease of flow of the SCC; shorter flow times indicate greater flowability. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking.

After 5 minutes of settling, segregation of SCC (if any) will cause the flow time to increase. As noted above, the flow time will also increase if the SCC has thixotropic properties.

A10.0 FILLING VESSEL TEST METHOD (ALSO KNOWN AS KAJIMA BOX METHOD)

A10.1 Introduction

The test is used to measure the filling ability of SCC with a maximum aggregate size of 3/4 inch (20 mm). The apparatus consists of a container (transparent Plexiglas) with a flat and smooth surface. In the container are 35 obstacles made of PVC with a diameter of 3/4 inch (20 mm) and a distance center to center of 2 inches (50 mm). A filling pipe is located at the top of the apparatus. The pipe has a diameter of 4 inches (100 mm), a height 20 inches (500 mm), with a funnel height of 4 inches (100 mm). The container is filled with SCC through this filling pipe and the difference in height between two sides of the container is a measure of the filling ability.

A10.2 Assessment of Test

This is a test that is difficult to perform on site due to the complex structure of the apparatus and large weight of the SCC (see Figure 10.1). It gives a good impression of the self-consolidating characteristics of the SCC. Even a SCC mix with a high-filling ability will perform poorly if the passing ability and segregation resistance are poor.

A10.3 Equipment

a. Fill box of a stiff, transparent, non-absorbing material
b. Scoop (64 oz - 1.5 to 2 liters)
c. Ruler
d. Stopwatch

A10.4 Procedure

a. About 1.5 ft^3 (45 L) of SCC is needed to perform the test, sampled normally.

b. Set the apparatus level on firm ground.

c. Moisten the inside surfaces of the apparatus, remove any surplus water.

d. Fill the apparatus with the SCC sample.

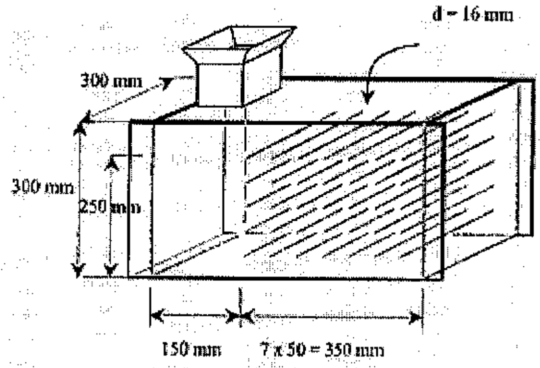
e. Pour the concrete through the funnel at a constant rate of 0.2 liter per second.

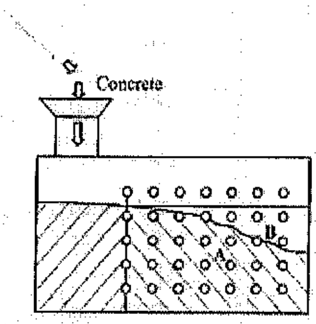
f. Stop pouring when the concrete reaches a level of 220 mm (8-5/8 inches) in the nonreinforced section of the vessel.

g. Measure the A surface and determine the cross-sectional area of Area A.

h. Calculate the filling capacity A/(A+B) ratio.

i. The whole test has to be performed within 8 minutes.





Filling capacity (%) = A/(A+B)

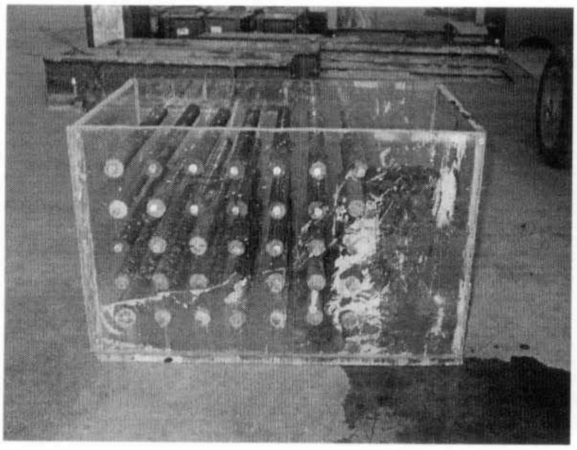
Figure 10.1 – Filling Vessel Test Apparatus

A10.5 Interpretation of result

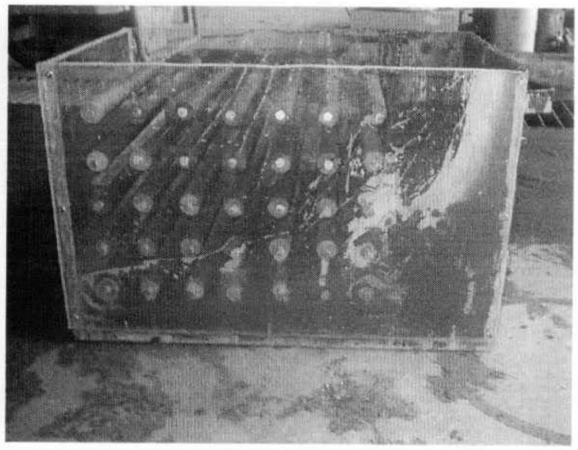
If the SCC flows as freely as water, at rest, it will be horizontal, so average filling percentage = 100 percent. Therefore, the nearer this test value, the 'filling height,' is to 100 percent, the better the filling ability characteristics of the SCC.

APPENDIX 7

Filling Ability Test

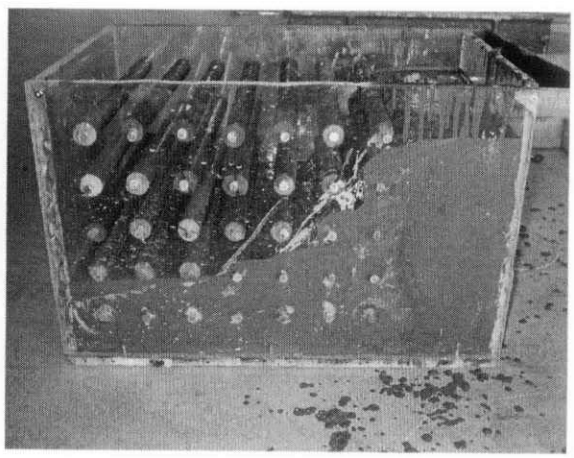


HRWR-6

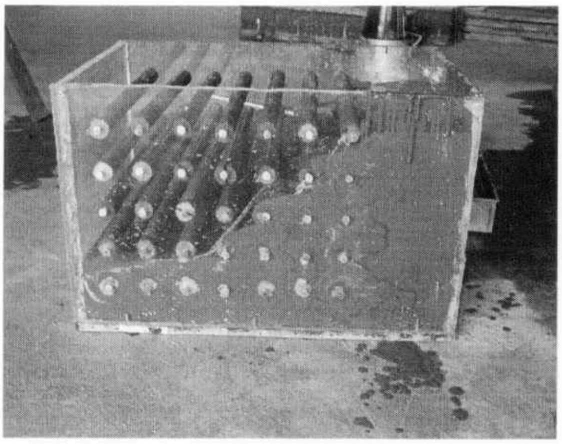


HRWR-9

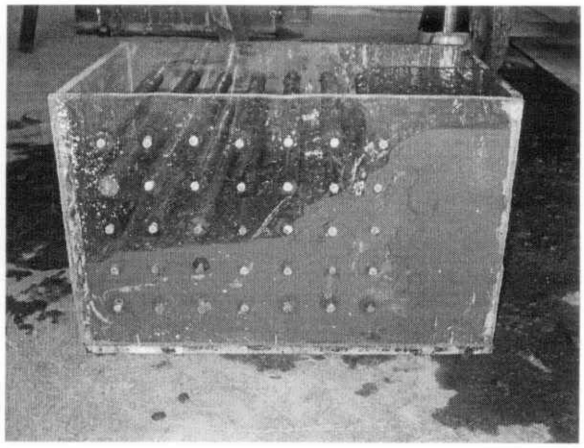
VMA-1



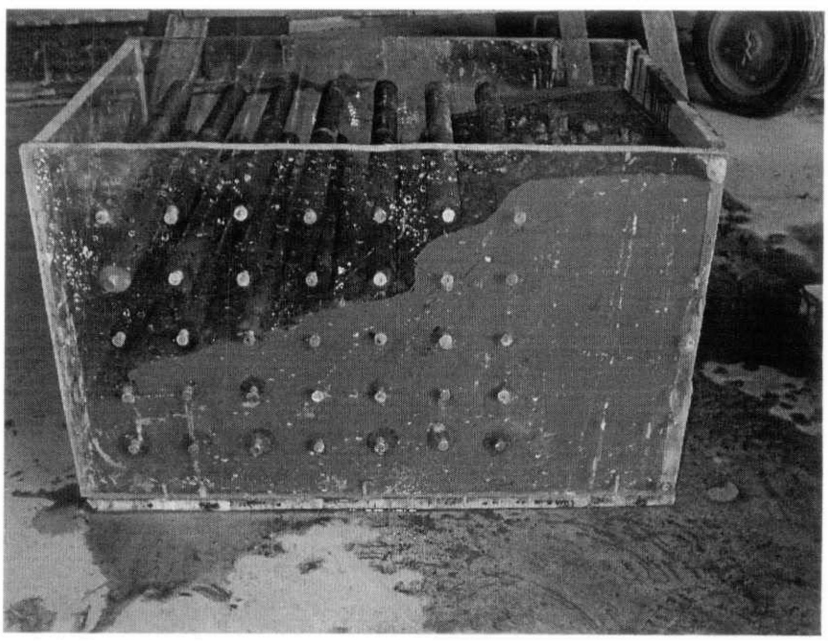
VMA-2



VMA-4

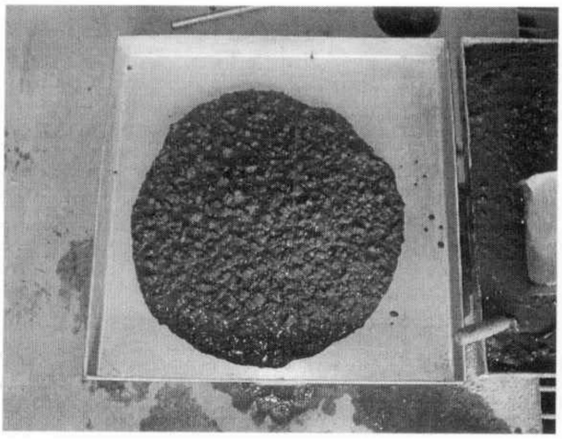


VMA-6

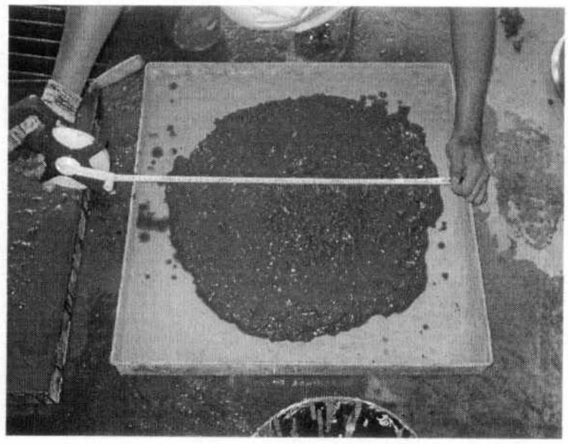


VMA-8

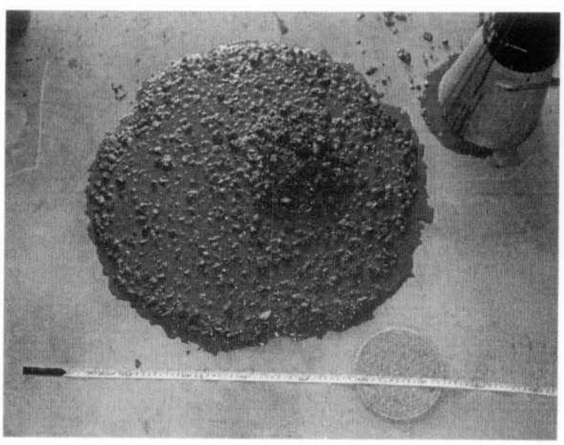
Slump Flow Test



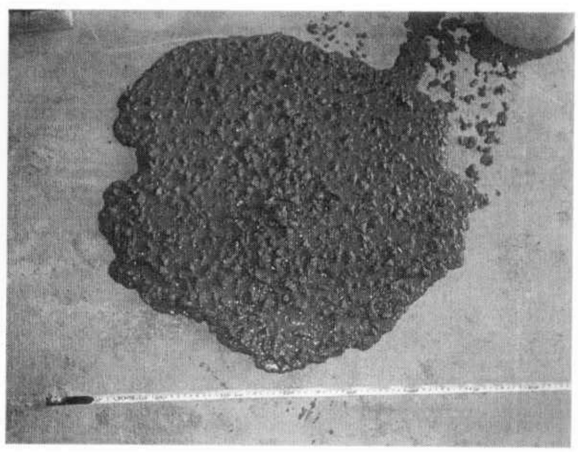
HRWR-6



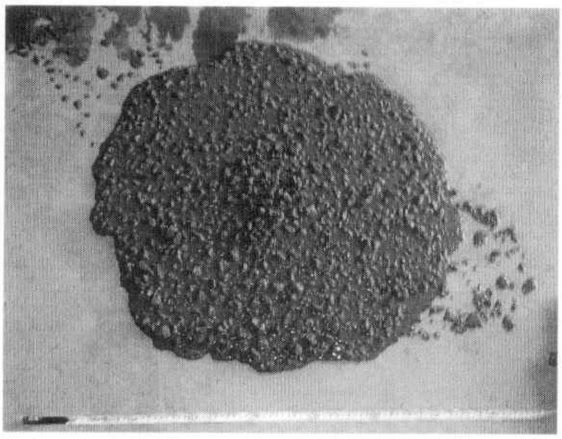
HRWR-9



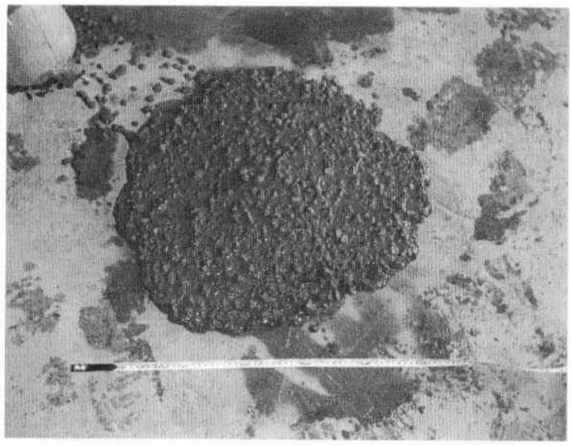
HRWR-12



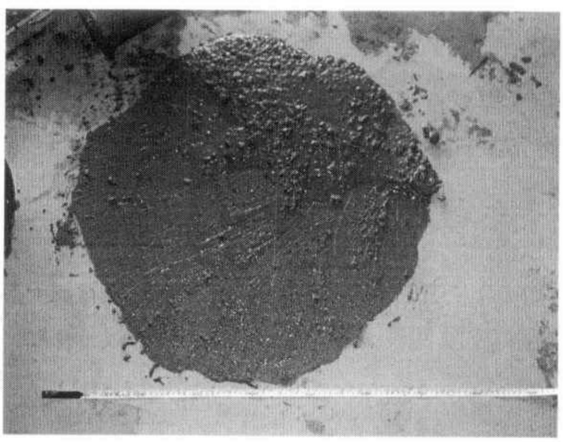
VMA-1



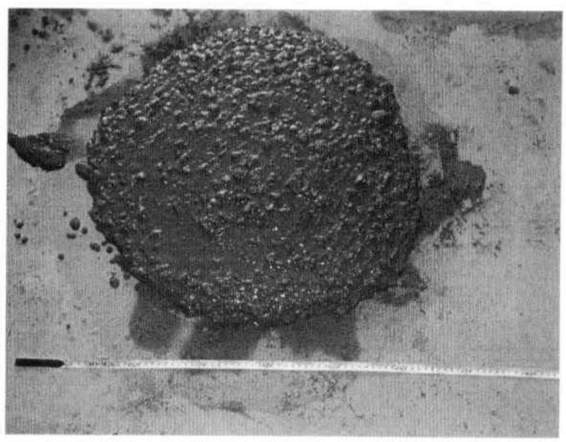
VMA-2



VMA-4

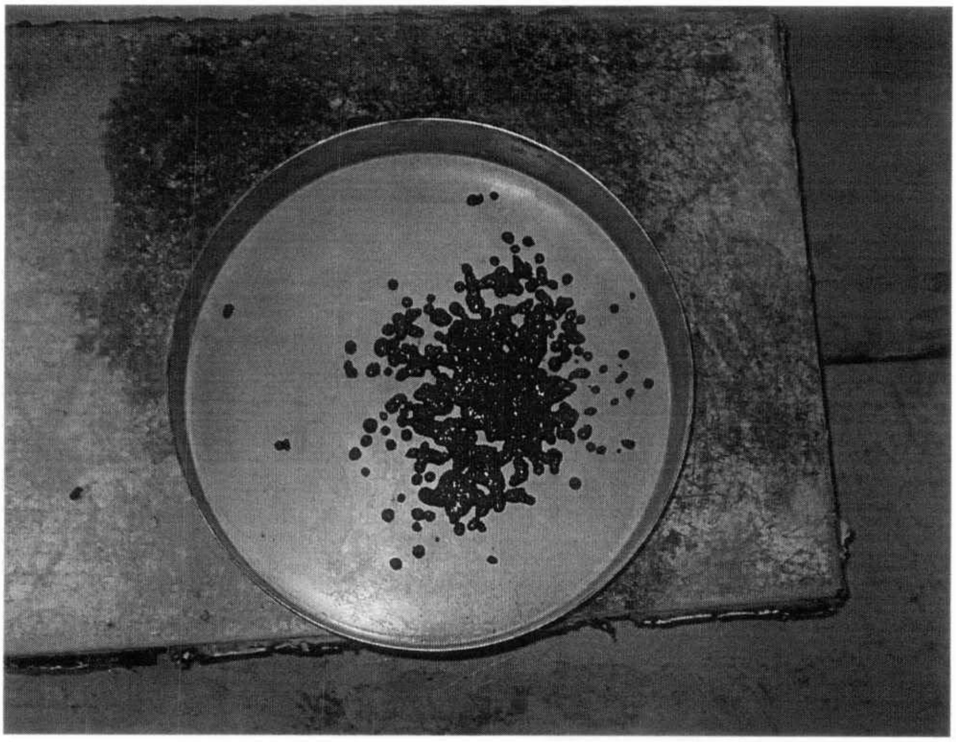


VMA-6

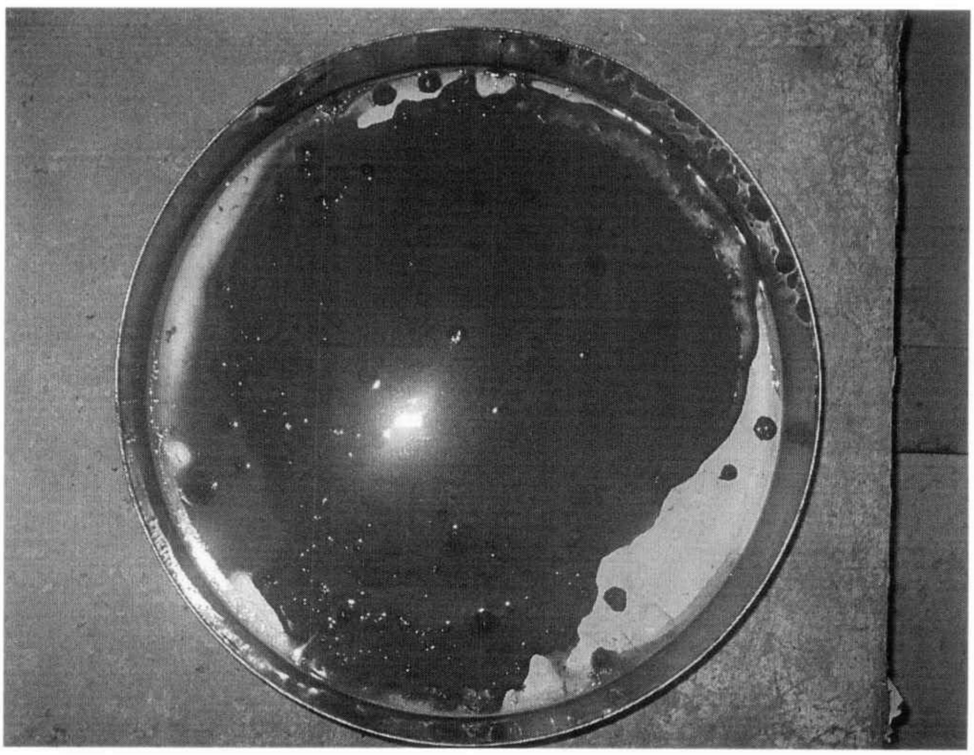


VMA-8

Segregation Index Test



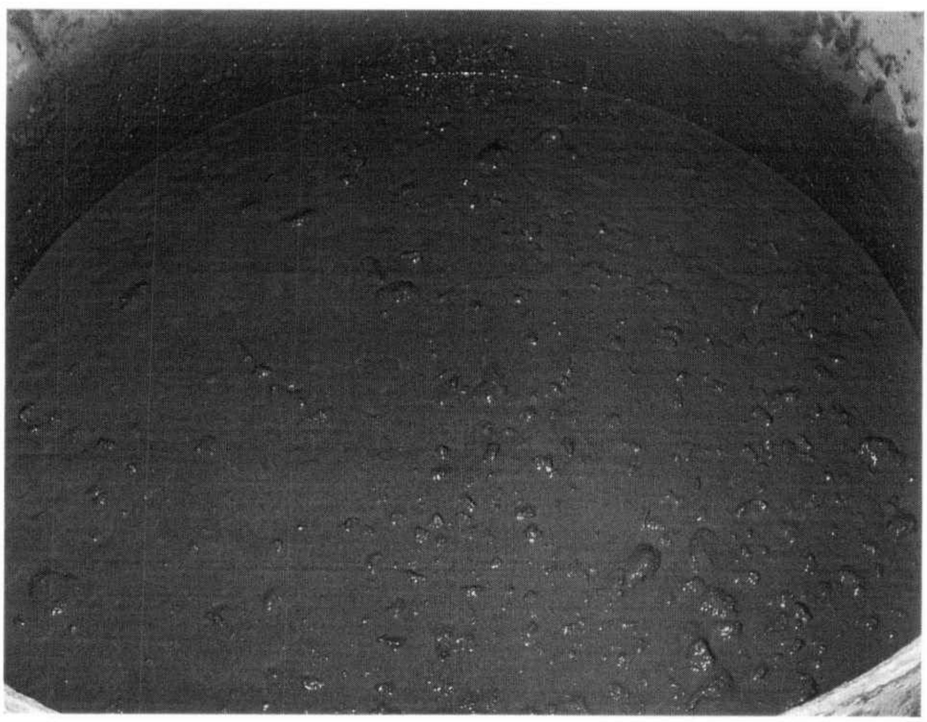
Less segregation: Small amount of mortar pass through the mesh and retain on the pan



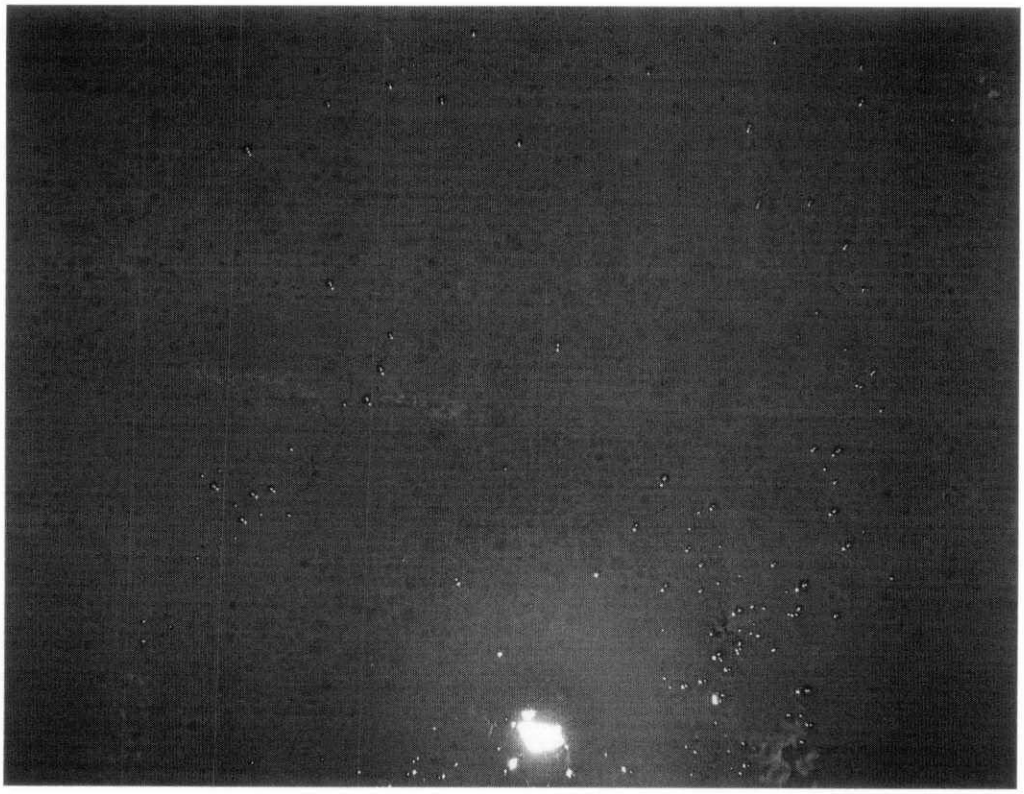
Serious segregation: Large amount of mortar pass through the mesh and retain on the pan

Fresh Concrete

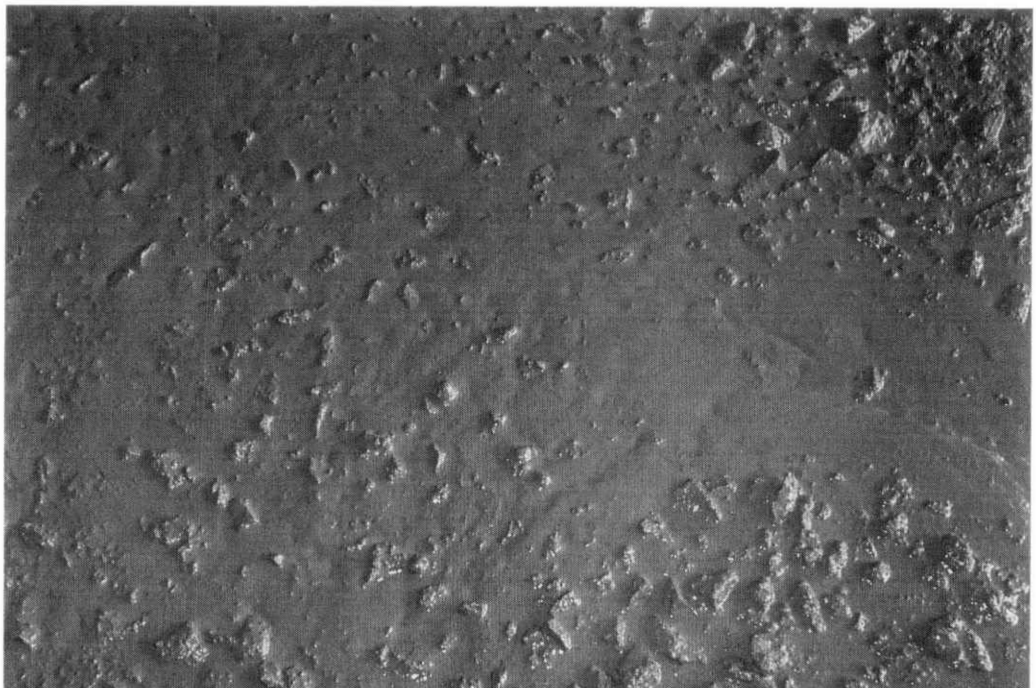
Concrete without HRWR



Concrete with HRWR

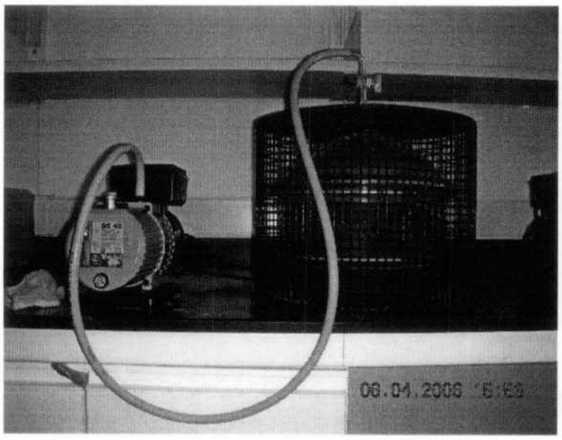


Concrete with serious segregation

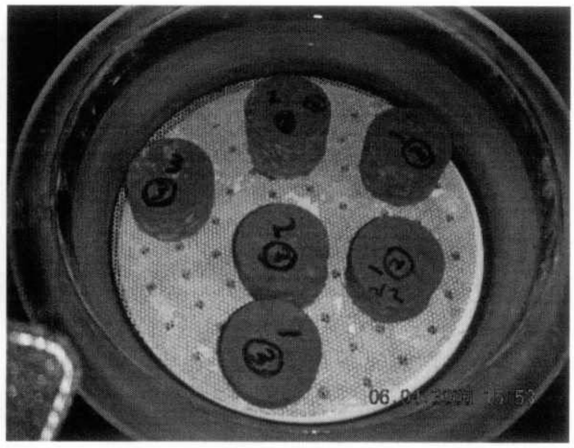


Concrete with less segregation

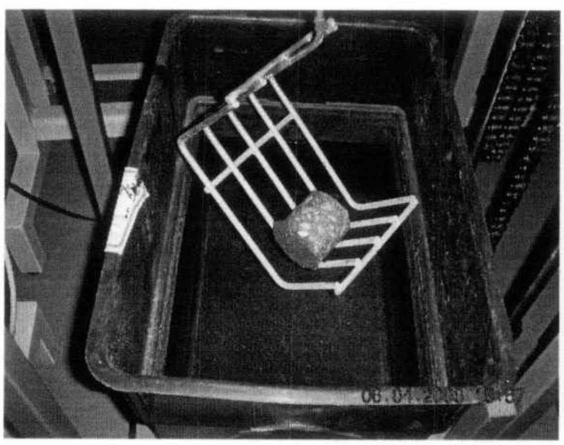
Porosity Test



Vacuum Saturation Apparatus



Sample submerged into water for saturation



Weigh in air

Weigh in water