A Study on Influence of Coarse Aggregate Size on Fresh Properties of Self-Compacting Concrete (SCC)

by

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

(Dr. Victor Macam)

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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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Elaine

(ELAINE KUSON)

ABSTRACT

Accurate descriptions of the shape and surface texture, or roughness, of aggregate particles need to be determined before the effects of these parameters on the properties of Self-Compacting Concrete (SCC) can be evaluated. In 1980s, SCC is developed in Japan, Sweden and France. SCC has recently been one of the most important developments in building technology, usually used in pre-cast applications or for concrete placed on site. SCC is characterized by extreme fluidity, a moderate viscosity, no bleed water and no blocking may occur during flow. SCC assures compaction in the structure; expecially in confined zones where vibrating compaction is difficult. SCC results in durable concrete structures, reducing costs and improving workmanship as well as working conditions. Most importantly, SCC can reduce or even completely eliminate the need to vibrate which consolidation noise. The previous research has proven that the workability of SCC is better than normal concrete and Researchers also conclude that the aggregate content and size that possible to be added in the concrete mixture, in order to enhance the concrete performance but the studies had not been done to examine the coarse aggregate size that maximizes workability and strength. The project is carried out based on this finding that there is not a systematic study on the SCC that is being produce according to specific range of sizes. This research describes the investigation of the effect of coarse aggregate size towards the fresh properties of SCC and provides a reference on coarse aggregate size that maximizes SCC workability and compressive strength. The analysis focused on the question of how far the coarse aggregate in SCC differs from other aggregate size in term of workability and compressive strength. The Kajima Box test, V-funnel test and slump flow test are used to determine the fresh properties while for the hardened concrete properties, 7 and 28 days compressive strength test are carried out to verify that its strength is achieved. These results provide information on the filling ability, slump flow, flow time, compressive strength at specific size of ranges 3.36 mm – 5 mm, 5 mm – 10 mm, 10 mm – 14 mm and 14 mm – 20 mm. At the end of the project, comparison of fresh properties and compressive strength between coarse aggregate sizes under study revealed the best range size range 3.36 mm – 5 mm. The size of coarse aggregate plays a significant role in determining the fresh properties of SCC. The project may assist in designing optimal SCC performance for construction industry.

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CHAPTER 1

INTRODUCTION

Since the discovery of the Self Compacting Concrete (SCC), research and studies have been conducted to studied on it fresh properties and mechanical properties. SCC is developed to ensure adequate compaction and facilitate placement if concrete in structure with congested reinforcement and in restricted area. However, a survey on its literature revealed that there is not a systematic study on the SCC that being produce according to specific range sizes. It is based on this finding that this project is carrying out.

1.1 Background of Problem

Self Compacting Concrete (SCC) is certainly the way forward for both insitu and precast concrete construction. Its acceptance and use is growing slowly in many countries, which are Japan, Korea, Sweden France and USA in late 1980s. In fact, SCC is characterized by extreme fluidity. Because it spreads readily into place and self-consolidates under its own weight, it contributes to a reduction in labour cost and construction time. Most importantly, SCC eliminates the impact of tamping vibration associated with normal concrete.

Viscosity modifying admixture (VMA) increased the viscosity, yield value and cohesion which also enable production of a stable yet highly flowable concrete to facilitate filing congested reinforced members with minimal vibration and separation. Advantage of the use of VMA is that it reduces the sensitivity of the mix to variations in material supply, such as grading or moisture content of aggregate, reduced the amount of free water available for lubrication of cement paste and reduced risk of separation of heterogeneous constituent of concrete during transport, placement and consolidation. The improved homogeneity of the concrete can enhance bond strength to reinforcement and aggregate, thereby decreasing permeability.

However, the main problem of the SCC is segregation and settlement occurs due to extra fluidity. As the result, the workability and fresh properties are far lower compared to the normal concrete.

1.2 Statement of Problem

Base on the background problems of SCC, it found that segregation and settlement occur during it transportations and placing and causes the workability and fresh properties of SCC to be reduced.

In additions, the previous research has proven that the workability of SCC is better than normal concrete. Researchers also conclude that the aggregate content and size that possible to be added in the concrete mixture, in order to enhance the concrete performance. However, the studies had not been done to examine the coarse aggregate size that maximizes workability and strength.

Therefore, this study is focused on the question of how far coarse aggregate in SCC differ from other aggregate size in term of compressive strength and workability. In other words, with the intention of continuing the research, the Viscosity Modifying Admixtures (VMA) is added into the SCC to evaluate its fresh concrete properties and also compressive strength.

1.3 Purpose of the Study

The objectives of this study are:

i. To experimentally investigate the effect of coarse aggregate size towards the fresh properties of SCC.
ii. To provide a reference on coarse aggregate size that maximizes SCC workability and compressive strength.

1.4 Importance of the Study

The scope of study of this project is more towards concrete technology and coarse aggregate. Size range between 3.36 mm to 5 mm, 5 mm to 10 mm, 10 mm to 14 mm, and 14 mm to 20 mm were carried out. (Refer Appendix I for coarse aggregate). The probability of obtaining coarse aggregate from the vicinity of campus with the size greater than 20 mm is very low. Secondly, the influence of time constrain prevent further investigation on other size range. Therefore, this study mainly focused, addressed and discussed on the ranges within 3.36 mm to 5 mm, 5 mm to 10 mm, 10 mm to 14 mm, and 14 mm to 20 mm.

The fresh properties test that is carried out is Slump Flow, Kajima Box and V-Funnel test. Slump Flow and V-Funnel tests are performed to assess workability. The Slump Flow test determines the flowability and the V-Funnel test the segregation resistance. The Slump Flow is used to evaluate the horizontal free flow (deformability) of SCC in the absence of obstruction.

The V-Funnel test is used to determine the filling ability (flowability) or viscosity of SCC. Kajima Box Method is used to measure the filling ability. In addition, harden properties of SCC namely compressive strength is also determined at 7 and 28 days. Other fresh properties test is not executed due to time constraint and in precast concrete industry, the other test is less significant.

The materials used in producing SCC are water, cement, fine aggregate, coarse aggregate, High Range Water Reducing admixture (HRWR) and Viscosity Modifying Admixture (VMA). VMA produced by local manufacturer was used in all concrete mixtures. Except for size range of coarse aggregate, all ingredients were kept constant.

For all mixes, the water/cement ration was kept constant as 0.45. The aggregates used in all mixes were of saturated surface dry and were sieved. Coarse aggregate size is varied to determine size that maximizes SCC workability and compressive strength.

1.5 Scope of the Study

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CHAPTER 2

LITERATURE REVIEW

2.1 Self Compacting Concrete

Self compacting concrete (SCC) is a mix that flow by its own weight and fills the foamwork properly and encloses the reinforcement without any vibration. In spite of its high flowability, the coarse aggregte is not segregated [1]. SCC is produced by adding superplasticiser and stabilizer to concrete during mixing in order to increase flowability, elastic modulus, flexural strength, improved abrasion resistance and lower permeability.

The concrete has higher density. It has very low water cement ratio of below 0.4 and also a minimal volume of capillary pores [2, 3]. In 1980s, SCC is developed in Japan, Sweden and France. The advantages of this type of concrete are absence of vibration, improved durability, increased workability, better surface finishes, easier placing, and ease of flow around heavy reinforcement, thinner concrete sections and speed up construction as concrete being poured much faster. Furthermore, it reduced wear and tear on formwork, reduced in site manpower and reduced noise levels.

Above all, it will certainly provide greater freedom in design and a safer working environment. [4]. Self-compacting concrete is not restricted to major constructions. There is also considerable interest in precast industry.

Factors affecting self-compacting concrete are water /cement ratio, admixtures, fines aggregate, coarse aggregate.

2.1.1 Water /Cement Ratio

The amount of water per unit volume of concrete is the most important controllable factor affecting shrinkage. Although relationship between change of water content and change of volume is not the same for all paste, shrinkage can be minimized by keeping the water content of the paste as low as possible. The water /cement ratio has influence to workability of concrete. In order to prevent any losses in the water content and maintain the performance of concrete, small amount of paste with same water /cement ratio 0.36, as proposed by manufacturer, is applied to the mixer surface.

2.1.2 Admixtures

Admixtures are added into the concrete mixture to accelerate or retard the initial set, improve workability, reduce water requirement and alter concrete properties. Concrete's strength may also be affected by the addition of admixtures. Admixtures are substances other than the key ingredients or reinforcements, which are added during the mixing process. This makes concrete more workable or fluid without adding excess water. The admixtures such as Viscosity Modifying Admixtures (VMA) increase the viscosity of paste. Furthermore, admixtures decrease the occurrence of segregation and bleeding in SCC. Admixtures do affect concrete strength as the strength increase, the workability increase as well as the density [5]. However, the delay in setting time and decrease in air content are encountered with addition of admixture [6, 7].

2.1.3 Fine Aggregate

Fine aggregate is smaller filler made of sand. It ranges in size from No.4 to No 100 sieves [18]. It is assumed that small aggregate particles will contain less internal flaws and hence produce a higher concrete strength. The fineness of sand influences the workability of concrete and should consist of smooth rounded particles. For fine aggregate grading, Index of Aggregate Particle Size and Texture, IAPST increase while optimum Volume Fraction of Fine Aggregate, VFFA increases [8]. Gradation which is in the range of less than 4mm, 4-8 mm and 8-16 mm have positive and negative effect on strength and density, respectively [9]. Compressive strength will increase but then decrease as specific surface increase. For the grain size between the ranges of 1.5 - 2.0 mm the highest strength is observed. [10].

2.1.4 Coarse Aggregate

Coarse aggregate is classified as such if the size of particle is greater than ¼ in or 6 mm. Properties of the coarse aggregate affect the final strength of the hardened concrete [19]. Sieve analysis will be used to get the desired aggregate size. Aggregate of 15 mm maximum size will be used in this study. It is important to limit aggregate size to 19mm maximum size for strength up to 62MPa. For higher strength, a 12-7- 9.5 mm size should be used. With most natural aggregate, it seems that, for making high performance concrete, 10-12 mm Maximum Size Aggregate (MSA) is probably the safest in the absence of any optimization testing. Aggregate must be in saturated surface dry to avoid water absorption that affect water/cement ratio. A maximum aggregate size of 10-14mm is usually selected although aggregates up to 20mm may be used if they are strong and free of internal flaws or fractures. [18]

2.2 Aggregate

Aggregates are those parts of concrete that constitute the bulk of the finished product. It comprises 60-80 percent of volume of concrete. The entire mass acts as a relatively solid, homogeneous, dense combination with the smaller sizes acting as an inert filler of the voids that exist between the larger particles. Common features of many standards for aggregates include the basic limits on composition, particularly to ensure the quantity of potential deleterious material is within acceptable limits, particle shape, to ensure satisfactory workability and strength in concrete and also grading, to ensure satisfactory cohesion and particle packing within concrete.

Therefore, the geometrical shapes, texture, amount of aggregate, quality and particle size distribution with the cement paste are important parameters in this context.

2.2.1 Size

The greater the particle size yields the higher the stress concentration. Thus, it caused an earlier failure. Hence, it is to be expected that concrete strength will decrease with an increase in maximum particle size. Zhiwu Yu stated that the compressive strength of SCC increases with decrease maximum size of coarse aggregate. Compared with SCC prepared with gravel, the compressive strength of SCC with crushed stone is higher. Effect on maximum size of coarse aggregate on shrinkage of SCC results show that the drying shrinkage of SCC with large maximum size of coarse aggregate is lower than that of SCC with smaller aggregate. This may be the reason that the larger the maximum size of coarse aggregate, the more effective the role to restrict drying shrinkage is.

In order to make drying shrinkage of SCC lower, larger maximum size of coarse aggregate is top priority. However, it can be seen that the workability of SCC will be worse when the maximum size of coarse aggregate is larger than certain size. Combining workability and drying shrinkage requirements, the maximum size of coarse aggregate should be lesser than 20mm [11]. As for Light Weight Concrete (LWC) the drying rate increase as the permeability increases [12].

As for the effect of aggregate maximum size and aggregate type on compressive strength of SCC, the result indicates that the compressive strength of SCC with crushed stone is higher. In addition, compressive strength of SCC increases with age. This result agrees with that of ordinary concrete [11]. On the other hand, the compressive and flexural strength decrease as Waste Concrete Aggregate increases [13].

2.2.2 Texture

For normal high strength concrete, gravel will give better workability and compactability at low water/cement ratio. For extremely high strength concrete, cruched rock of proper angularity is superior but requires intensive vibration to achieve proper compaction. Fine aggregates should be in the coarser ranges since with the rich cement factor usually employed in prestressed concrete, perfect grading is unnecessary. Gap-grading properly applied can often reduce shrinkage and improved strength and modulus of elasticity [14].

Rounded particles are thus preferred to crush rock fines where possible. It is acceptable practice to utilize slightly coarser grading of fine aggregate than is normal for conventional structural concrete. The fineness fraction of the fine aggregate are no longer essential to increase workability or prevent segregation; a coarser grading; (fineness modulus 2.7 to 3.0) is therefore appropriate.

Limestone aggregate requires more water than similar size marble aggregate. Aggregate surface texture influences the bond between the aggregate and the cement paste. In properly mixed concrete, the paste surrounds each aggregate particle and fills all spaces between the particles. The elastic properties of the aggregate influence the elastic properties of the concrete and the paste resistance to shrinkage. Reactions between the cement paste and the aggregate can either improve or harm the bond in concrete quality. [21]

2.2.3 Particle Distribution

The particle shape for coarse aggregate should ideally be equidimensional where it is not elongated or flaky. However it has been reported that in practical concrete mixes, the size and gradation have little effect, as the effect of shrinkage is a function only of the total quantity of the aggregate per unit volume of the concrete. The grading should be smooth with no gaps in the grading between fine and coarse fractions. It is acceptable practice to utilize slightly coarser grading of fine aggregate than is normal for conventional structural concrete. The fineness fraction of the fine aggregate are no longer essential to increase workability or prevent segregation; a coarser grading ;(fineness modulus 2.7 to 3.0) is therefore appropriate. The grading curve of the fine aggregate should once again be smooth and free from of gap grading to optimize the water demand. [18]. A fineness modulus (FM), in the range of 2.5 to 3.2 is recommended for high strength concrete to facilitate workability. Lower value result in decrease workability and a higher water demand. The mixing water demand is dependent on the void ratio in the sand. Grading requirement for aggregates in normal weight concrete are presented is Table 1 and coarse aggregates for aggregate concrete in Table 2.1.

Table 2.1 Grading Requirement for Aggregates in Normal Weight Concrete

	Percent Passing				
	Coarse Aggregate				
U.S. Standard Sieve Size	**No.4 to 2 in**	**No.4 to 1 ½ in.**	**No. 4 to 1 in.**	**No. 4 to ¾ in.**	**Fine Aggregate**
2 in. (50mm)	95-100	100	-	-	-
1 ½ in. (37.5mm)	-	95-100	100	-	-
1 in. (25.0mm)	25-70	-	95-100	100	-
¾ in (19mm)	-	35-70	-	90-100	-
½ in (12.5mm)	10-30	-	25-60	-	-
3/8 in (9.5mm)	-	10-30	-	20-55	100
No. 4 (4.75mm)	0-5	0-5	0-10	0-10	95-100
No.8 (2.36mm)	0	0	0-5	0-5	80-100
No.16 (1.18mm)	0	0	0	0	50-85
No.30 (600*um*)	0	0	0	0	25-60
No.50 (300*um*)	0	0	0	0	10-30
No.100 (150*um*)	0	0	0	0	2-10

Source: Data from Fundamental of High Performance Concrete, Edward G.Nawy

Table 2.2 Grading Requirement for Coarse Aggregates for Aggregate Concrete

	Percent Passing	
Sieve Size	**Grading 1: for 1 ½ in (37.5mm) Maximum-Size aggregate**	**Grading 2 : for 3/4 in (19mm) Maximum-Size aggregate**
Coarse Aggregate		
2 in. (50mm)	100	-
1 ½ in. (37.5mm)	95-100	100-95-100
1 in. (25.0mm)	40-80	40-80
¾ in (19mm)	20-45	40-80
½ in (12.5mm)	0-10	0-15
3/8 in (9.5mm)	0-2	0-2
	Fine Aggregate	
No.8 (2.36mm)	100	-
No.16 (1.18mm)	95-100	100
No. 30(600*um*)	55-80	75-95
No. 50(300*um*)	30-55	45-65
No.100 (150*um*)	10-30	20-40
No.200 (75*um*)	0.10	0.10
Fineness modulus	1.30-2.10	1.00-1.60

Source: Data from Fundamental of High Performance Concrete, Edward G.Nawy

2.2.4 Amount of Aggregate

Effects of content of coarse aggregate on shrinkage of SCC indicate drying shrinkage of SCC decreases with increasing coarse aggregate to fine aggregate ratio. Meanwhile, it can be seen that the effect of coarse aggregate to fine aggregate ratio value the result at later age is more remarkable than early age [11]. In conventional concrete, the larger the proportion of coarse aggregates of large diameter, the larger the mechanical properties of hardened concrete, assuming the total amount of aggregate is the same.

However, for fresh concrete to around obstacles and through reinforcement, it is better to increases the proportion of fine aggregates and to reduce coarse aggregate size. According to discovery made by Yoshida Tokujiro, when studying conventional concrete mixes, was that the optimum proportions for concrete mix should be 1:1:2 to obtain the maximum strength. In addition, if aggregate volume exceeded this ratio, the attainable maximum strength would fall drastically. The proportion of fine to coarse aggregate is kept at 1:1 by volume, which is a big reduction on the conventional coarse aggregate content, but the concrete does suffer from a drastic drop in ultimate strength [15]. The total amount and properties of the aggregate have an influence on shrinkage. By keeping the total aggregate content as high as possible, will help minimized shrinkage

2.2.5 Aggregate Quality

In general, aggregates must be clean. The presence of dust, silt or clay and presence of surface coatings will affect its quality. The mineral coarse aggregate must be clean of organic impurities and must bond well with the cement. A good fine aggregate should always be free of organic impurities, clay or any deleterious materials or excessive filler of size smaller than No.100 sieve [18]. Even a few percent of silt can make the low W/C mixes for prestressed concrete, excessively sticky and difficult to place. Lightweight aggregate are ceramic particles containing numerous air voids.

The air voids are generally disconnected. Hence the aggregate particles, which porous, are also impermeable. Such particles are also available both as coarse aggregate and as fine aggregates. Due to size effects, it is the coarse aggregate particles which contribute most to the reduction in the weight of the finished concrete [14]. As been examined, the use of dirty sand or unwashed coarse aggregate containing clay can cause excessive shrinkage. Shrinkage of structural lightweight concrete varies from equal to about double that of normal concrete weight. Aggregate impurities such as clay and mice which leads to weak, absorptive, expensive, silica which leads to alkali reaction, salt which leads to corrosion and organic shell which leads to weak, impurities must generally be avoided.

2.3 Others

The density is generally considered to distinguished lightweight concrete from normal dense concrete, and concrete below 2000kg/m^3 is therefore considered lightweight. Because lightweight grains are weaker than natural heavy-aggregates grains, crack when they occur tend to go through the grains [20].

Air content in modified Light Weight Aggregate Concrete (LWAC) is higher than unmodified LWAC. Meanwhile, for modified LWAC, it is considered more cohesive and workable than unmodified LWAC [16]. As permeability increase, weight loss increase parallel with age [12]. Air content increases due to size of waste glass aggregate size of more than 0.6mm, which contributes in larger surface area [17]. In Waste Concrete Aggregate (WCA), it is observed that the water absorption is considerably higher whereas the slump flow shows a decrease as well as its workability [13].

In conventional concretes, transition zone is quite large and is characterizes by high porosity. The strength of the paste is a function of its water/cement ratio. This is true also for SCC but it is also the effect of porosity between the paste, the particle size distribution and the presence of unhomogeneities within the hydrated paste.

A reduction in water/cement ratio produced a paste in which the cementitious particles are initially closer together in freshly mixed concrete. This result in less capillary porosity in the hardened paste and hence a greater strength and also favours the formation of fine-textured hydration products that have higher strength equivalents. [18].

CHAPTER 3

METHODOLOGY / PROJECT WORK

After all the relevant data and information gathered during the literature review, the laboratory tests are conducted to test the performance of the SCC. The tests that are performed are:

a. Slump flow test
b. V-funnel test
c. Filling Vessel Test Method (known as Kajima Box Method)
d. Compressive strength test

3.1 Materials Preparation

The aggregates are submerged into the water for one day. The aggregates is taken out and left for another day at room temperature for the water to evaporate. If the aggregates are still very wet, it is left for another day until it become saturated surface dry (SSD). For fine aggregate, the surface layer of sand that was exposed to the hot sun is scrap off.

The fine aggregate of inner part is taken which have certain amount of moisture. Portland cement must not be hardened. Once the packet is opened, the cement is kept in a closed tank to avoid air and water contact. The mix proportion is shown in Table 3.1 and six concrete cylinders are casted for 7 day and 28 day compressive strength test.

3.2 Proposed Mix Proportion

The water/cement (w/c) ratio was selected as 0.45. With reference to research by P.L Domane, almost 80 percent w/c ratio ranged from 0.26 to 0.48. Therefore, 0.45 is suitable for the analysis purposes as it differs according to wide range of application and varying requirement. The w/c ratio has significant effects on both fresh and harden properties of SCC while the powder composition has more significant effect on the hydration processes (and hence strength gain). From the literature review, information as shown in Appendix A was found to determine the SCC mix proportions:

Table 3.1 Mix Proportion

Concrete type	**water**	**sand**	**gravel**	**cement**	**HRWR**	**VMA**
	l/m^3	**kg/m^3**	**kg/m^3**	**kg/m^3**	**l/m^3**	**%/cement**
14 - 20 mm	189	826	826	413	9	8
10 - 14 mm	189	826	826	413	9	8
5 - 10 mm	189	826	826	413	9	8
3.36 - 5 mm	189	826	826	413	9	8

3.3 Procedure Identification

3.3.1 Mixing Concrete

The procedure of mixing the concrete incorporating HRWR and VMA are described. Firstly, all coarse and fine aggregates is poured into the mixer and mixed for 25 seconds to ensure the uniform distribution of both materials. Secondly, half of the water is poured and mixing is continued for 1 minute. The mix is mixed for 8 minutes to let both sand and coarse aggregate to absorb water. Next, all Portland cement is poured into the mixer and is mixed for 1 minute. Another half of the water is poured and HRWR is added and mixed for 3 minutes. Then, VMA is added and mixed for another 2 minutes. Finally, hand mixing is performed until the mix is in uniform stage.

3.3.2 Slump Test

The procedure of mixing slump test is shown. About 6 liters of SCC is needed. The base plate is placed on level stable ground and the slump cone is placed centrally on the base plate and is held down firmly. Next, the cone is filled with the scoop without tamping. Any surplus SCC is removed from around the base of the cone. Furthermore, the cone is raised vertically and the SCC is allowed to flow out freely. The final diameter of the SCC is measured in two perpendicular directions. Finally, the average of the two measured diameters calculate

3.3.3 V-Funnel Test

About 12 liters of SCC is needed. The V-funnel is set on firm ground as shown in Appendix C and the assembly drawing of the apparatus is indicated in Figure G1 in Appendix G. The inside surfaces of the funnel are moistened and the trap door is kept open to allow any surplus water to drain. The trap door is closed and a bucket is placed underneath. The apparatus is filled completely with SCC without compacting or tapping. The bottom outlet is opened within 10 seconds after filling and the SCC is allowed to flow out under gravity. The stopwatch is started when bottom outlet is opened and the time for the discharge to complete or in other words the time of flow from the opening of outlet to the seizure of flow is recorded. Flow time can be associated with a low deformability due to high paste viscosity, high inter-particle friction or blockage of flow. Flow time should be below 6 seconds for the concrete to be considered as SCC.

3.3.4 Filling Vessel Test Method (known as Kajima Box Method)

The test is used to measure the filling ability of SCC with a maximum aggregate size of 20 mm. The apparatus consists of a container with a flat and smooth surface. In the container are 35 obstacles made of PVC with a diameter of 22 mm and a distance center to center of 50 mm as shown in Figure G2 in Appendix G. A filling pipe is located at the top of the apparatus. The pipe has a diameter of 100 mm, a height 500 mm, with a funnel height of 100 mm. About 30L of SCC is needed. The apparatus is set at level on firm ground. The container is filled with SCC through this filling pipe.

When the concrete reaches a level of roughly 220mm in the non reinforced section, pouring is stopped. The A surface and is measured and the cross-sectional area of area A is determined. The filling A / (A+B) ratio is calculated. The difference in height between two sides of the container is a measure of the filling ability. The whole test has to be performed within 8 minutes.

3.3.5 Compressive Strength Test

The concrete is cast into 6 moulds of height 200 mm and diameter 100 mm. After removal of the mould the second day, the cylinder is placed and cured (7 days and 28 days) in a water tank at room temperature for strength development. The highest concrete strength is obtained with specimens continuously cured until the time of testing.

Comparative performance of hardened concrete is investigated by measuring the development of compressive strength with curing age from 7 and 28 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 is taken as the maximum compressive load it can be carry per unit area.

CHAPTER 4

RESULT AND DISCUSSION

4.1 V-Funnel Test

The result of V-Funnel flow time test for coarse aggregate size range is listed in Table 4.1. The results provided a base point for reference in comparison with the coarse aggregate size range 3.36 mm to 5 mm, 5 mm to 10 mm, 10 mm to 15 mm and 15 mm to 20 mm.

Table 4.1 V-Funnel flow time results for coarse aggregate size range

Aggregate Type	Stuck Time, *s*	Tamp with steel rod, *s*	Lumpy Flow, *s*	Smooth Flow, *s*	Total Time, *s*
14-20 mm	60	3	7.12	5.11	75.23
10-14 mm	60	3	8.25	5.19	76.44
5-10 mm	-	-	9.91	4.75	14.66
3.36-5 mm	-	-	8.54	5.23	13.77
Reference	-	-	-	5.00	5.00

Note:
Stuck time is where the cement hardens at the opening of the funnel

Based on the experiments, for size range 14 mm to 20 mm and 10 mm to 14 mm, the stuck time is approximately 60 second as the cement hardens at the opening of the funnel. Hence, duration of 3 seconds is taken to tamp using steel rod with diameter 12 mm to force the stuck harden concrete flow through the inlet and to allow the fresh concrete to flow down. Flow time of 7.12 seconds is recorded where concrete is combined with lumpy aggregate. Then, 5.11 seconds is taken when the flow is smooth and fast. Hence, the total flow time is 75.23 seconds.

Size range 5 mm to 10 mm has a flow time for lumpy concrete of 9.91 seconds and 4.75 seconds is recorded when concrete flows smoothly giving a total flow time of 14.66 seconds.

While for 10 mm to 14 mm size range, the stuck time and duration of tamping with the aid of steel rod are similar to that of size range 14 mm to 20 mm. The flow time taken as the concrete lump begins to drop is around 8.25 seconds. As time goes by, concrete flow smoothly without obstructing the inlet that brings the flow time to around 5.19 seconds. Therefore, total flow time 76.44 seconds is obtained.

The time duration of 8.54 seconds is recorded for concrete with lump for the size range 3.36 mm to 5 mm. Continuously, the concrete with fast yet smooth flow around 5.25 seconds. Therefore, the total flow time is 13.77 seconds. Size range 5 mm to 10 mm and 3.36 mm to 5 mm did not stuck.

The V-funnel test results proved that the flow time is exhibited sinusoidal trends as the aggregate size increased, which shown in Figure 4.1. As the aggregate size increase from 3.36 mm - 5 mm to 5 mm - 10 mm range, the flow time slightly decreased from 5.23 seconds.

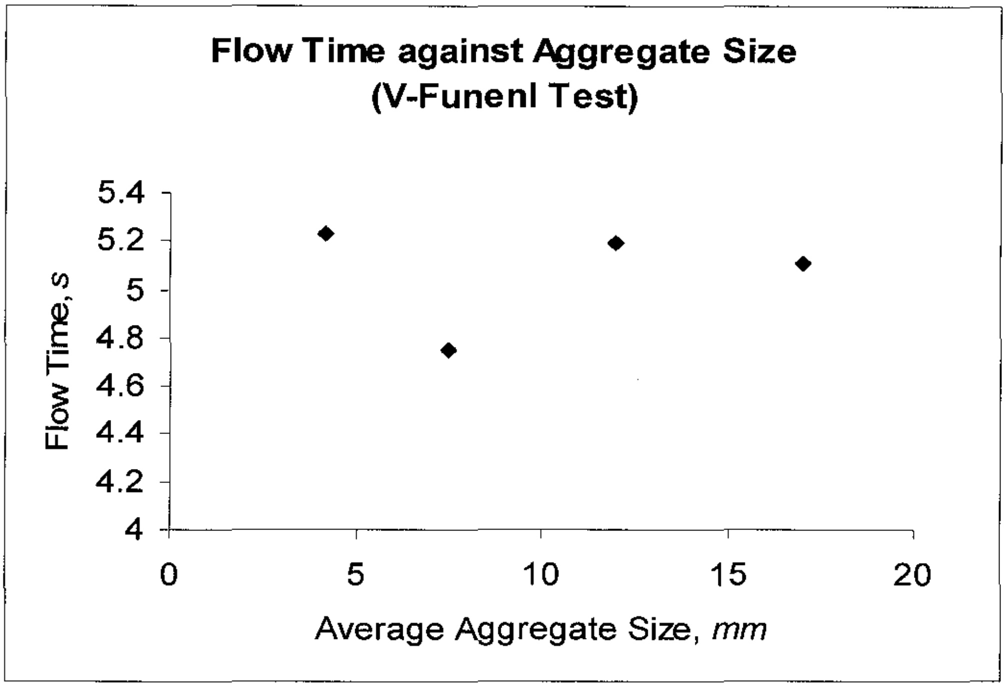

Figure 4.1 Effect of aggregate size against flow time

This is due to the 5 mm - 10 mm range has low segregation, high deformability due to low paste viscosity, low inter-particle friction or blockage of flow. Significant segregation occurred while pouring the concrete into the funnel. This can be seen from the seepage through the gap of the funnel.

Meanwhile, for aggregate size 3.36 mm to 5 mm, the flow time is 4.6 % more than reference. This indicated that the 3.36 mm to 5 mm range have a slightly worse flowability than the reference. Unlike others, the aggregate size 5 mm to 10 mm have improvement 5 % which taken lesser time to flow, which proved that the 5 mm to 10 mm range have a slightly better flowability that the reference.

However, the flow time increase gradually until 5.5 seconds as the aggregate increase from 5 mm - 10 mm to 10 mm - 14 mm to range size. Unstable and low flowable concrete consume longer flow time. Hence, flow time consume for aggregate size 10 mm to 14 mm is longer 3.8 % from the reference.

Again, as the aggregate increase from 10 mm - 14 mm to 14 mm - 20 mm range size, the flow time decreased from 5.19 second to 5.11 second and revealed a 2.2% increment compared to reference. Good flowable and stable concrete would consume a short time to flow out. Therefore, the V-funnel flowability is slightly lower that the reference. Highest segregation occurred in aggregate range from 14 mm to 20 mm causes particle to settle and water rises to the surface.

The V-funnel flow time is associated with a low deformability due to high paste viscosity, high inter-particle friction or blockage of flow. The V-funnel flow time for reference is 5 seconds.

4.2 Kajima Box

Results in Table 4.2 show the effect of aggregate size on filling ability. Figure 4.2 illustrated the filling ability increasing exponentially as the aggregate size increase from 3.36 mm - 5 mm to 5 mm - 10 mm range but drop exponentially from 5 mm - 10 mm to 14 mm - 20 mm aggregate size, which form a maximum quadratic trend line.

Table 4.2 Kajima Box test results for coarse aggregate size range

Aggregate Type	3.36-5 mm	5-10 mm	10-14 mm	14-20mm
Kajima Box Filling Ability (%)	22.50	24.47	23.26	11.02

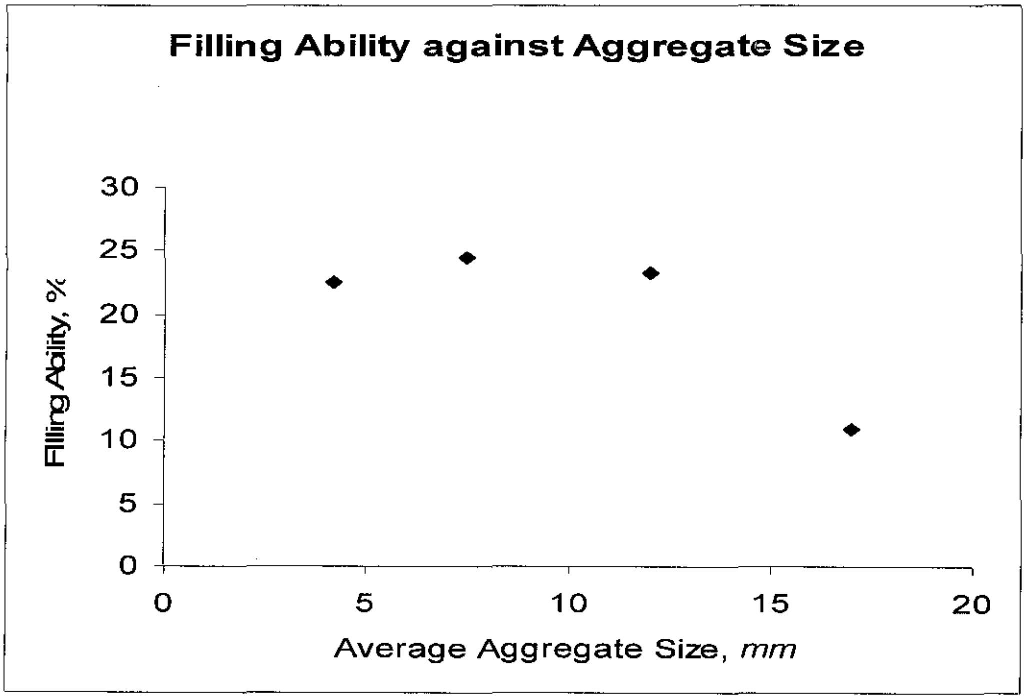

Figure 4.2 Effect of aggregate size on filling ability

As for the size range 3.36 mm to 5 mm give a filling ability of 22.50 % where the calculation is shown in Figure H1 in Appendix H. In SCC, the nearer the filling height is to 100 %, the better the filling ability characteristic. The filling ability of 22.50 % produced too low filling ability as it encountered 65.7 % deviation from the reference (refer to Figure D5 and D6 in Appendix D). As shown in Table 4.2, the filling ability for reference is 65.71 %. In addition, very low segregation occurred in the mix because aggregate size is smaller compared to size range 14 mm to 20 mm, 10 mm to 14 mm and 5 mm to 10 mm. Segregation is observed through visual inspection in the concrete mix as shown in Appendix B.

Then, the filling ability is increased in quadratic trend to 24.47 % at 5 mm - 10 mm aggregate size from the 22.50%, which is 62.7 % lower than the reference (refer calculation in Figure H2 in Appendix H). This indicates low filling ability than reference as the workability is too low as shown in Figure D4 in Appendix D.

Segregation happened in a lower level as the aggregate size smaller compared to size range 14 mm to 20 mm and 10 mm to 14 mm.

Next, for size range 10 mm to 14 mm, the filling ability is 23.26 %, which drop quadratically and resulted in 64.6 % lower value with respect to the reference (refer Figure D3 and H3 in Appendix). The further this test result to the reference, the worse the filling ability characteristics of the SCC. Medium segregation occurred compared to size 14 mm to 20 mm. Segregation in size range 10 mm to 14 mm is smaller than size 14 mm to 20 mm. This is due to the size 10 mm to 14 mm aggregate size is smaller than in size 14 mm to 20 mm.

Lastly, the filling ability for size range 14 mm to 20 mm drop quadratically to 11.02 % (refer diagrams in Appendix Figure D1, D2 and H1). High segregation occurred in the mixture. As the aggregate size increased, total surface area of the aggregate and water content needed is lesser. The segregation occurred due to large maximum particle size; large proportion of large aggregate, mixes was too wet or too dry and high specific gravity of coarse aggregate.

For aggregate size 14 mm to 20mm, a value of 83.2 % deviation in filling ability is experienced compared to the reference. The filling ability for reference is 65.71 %, which proved that the 14 mm to 20 mm range have a slightly too low filling ability than the reference.

4.3 Slump Flow

The result of slump flow is presented in Table 4.3. The slump flow exhibited a minimum quadratic trend line where slump flow decreasing exponentially as the aggregate size increase from 3.36 mm - 5 mm to 5 mm - 10 mm range and increasing exponentially from 5 mm - 10 mm to 14 mm - 20 mm aggregate size as shown in Figure 4.3.

The initial slump flow value is found to decrease up to a level of 460 mm and found to slightly increase dramatically as the aggregate size increases. The slump flow is 555 mm for reference.

Table 4.3 Slump flow test results for coarse aggregate size range

Aggregate Type	Slump Flow		
	X-direction (mm)	Y-direction (mm)	Average (mm)
14-20 mm	500	550	525
10-14 mm	500	450	475
5-10 mm	450	470	460
3.36-5 mm	530	470	500
Reference	550	560	555

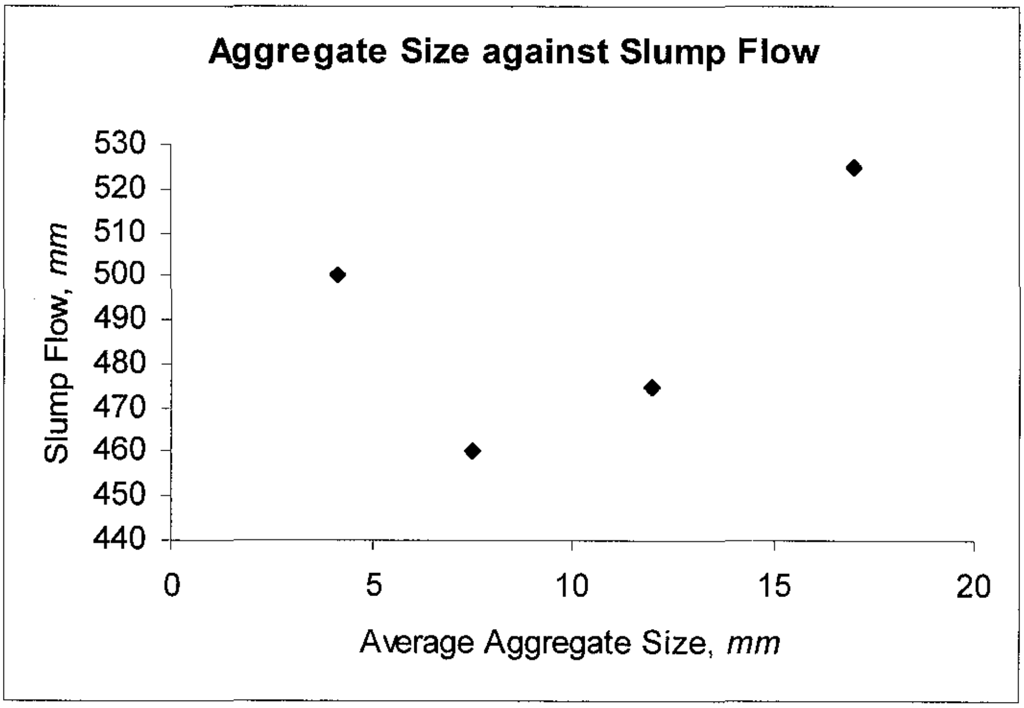

Figure 4.3 Effect of aggregate size against slump flow

As for size range 14 mm to 20 mm, segregation occurred where the aggregate, sand and water exist in several different regions indicated in Appendix Figure E1. The outer diameter and the inner diameter of water are 865 mm and 725 mm. In addition, the sand outer and inner diameters are 725 mm and 525 mm. However, the Self Compacting Concrete (SCC) diameter is approximately 525 mm.

Hence, it is within the standard range of 500 mm to 700 mm and also desirable and good SCC. The slump flow is 4.5 % lower than reference when aggregate size is 14 mm to 20mm, also within acceptable limit. From the result, it indicated slightly poorer workability due to lower slump flow.

Size range of 10 mm to 14 mm shown an average diameter of 475 mm (refer Appendix Figure E2). Medium segregation occurred. The cement is observed to be very lumpy. Therefore, the result is slightly out of specification.

A low segregation occurred for size 5 mm to 10 mm compared to the first and second batch sample and have average diameter is 460 mm (refer Figure E3 in Appendix). Hence, it is not within the standard range because it has thick constituency. However, for aggregate size 5 mm to 10 mm and 10 mm to 14 mm, slump flow difference with the reference has encountered reduction of 17.1 % and 14.4 % respectively. Both the reduction has shown that the workability of SCC is still considered poor.

As for size 3.36 mm to 5 mm, average diameter is 500 mm shown in Appendix Figure E4. It is within the standard range of 500 mm to 700 mm and the fresh SCC has a good constituency. In comparison with the reference, the aggregate size for 3.36 mm to 5mm is lesser 9% but is still within acceptable limit. As obtained from the study, the lower slump flow resulted in poorer workability of SCC.

4.4 Compressive Strength Test

The result of 7-day compressive strength test results for coarse aggregate size range is listed in Table 4.4. For the size range of 3.36 mm to 5 mm, the maximum load for the first sample and third sample are 116.1 kN and 108.3 kN respectively while compressive strength are 14.78 MPa and 13.74 MPa accordingly. Meanwhile for the second sample, which is crack after placing in the curing tank for a 7-day period, the maximum load is 64.5 kN is used to crack the sample and the computed compressive strength is 8.209 MPa. The area of crack sample is 0.005 m^2. The area in crack sample is lesser compared to setting area which is 0.00786 m^2. Therefore, the measured stress for second sample is less than first sample.

Table 4.4 7-day compressive strength test for coarse aggregate size range

Aggregate Size (mm)	Maximum Load (kN)			Average Maximum Load (kN)
	Sample 1	Sample 2	Sample 3	
14 mm –20 mm	57.50	63.30	101.60	74.13
10 mm –14 mm	122.20	119.80	121.70	121.23
5 mm – 10 mm	112.47	66.70	116.80	98.66
3.36 mm – 5 mm	116.10	64.50	108.30	96.30

Aggregate Size (mm)	Stress (MPa)			Average Maximum Stress (MPa)
	Sample 1	Sample 2	Sample 3	
14 mm –20 mm	7.32* (11.00†)	8.06* (9.05†)	12.94	9.44* (11.00†)
10 mm –14 mm	15.56	15.26	15.47	15.43
5 mm – 10 mm	14.32	8.49* (13.20†)	14.81	12.54* (14.11†)
3.36 mm – 5 mm	14.78	8.21* (12.90†)	13.74	12.24* (13.81†)

Note:

* The value obtained from Test Machine.

† The value obtained from analysis performed.

Stress is defined as ratio of applied force over area. Machine computes the stress based on the setting circular area with diameter 100 mm. However, the problem is it will give a lower strength for broken sample if machine calculates based on settings. In others word, a lower strength of crack SCC sample is produced when area is large. Therefore the stress is calculated based on the broken area and the actual strength for the second sample is 12.9 MPa. The difference between strength by first sample as well as third sample and actual strength gives closer difference.

On the other hand, for size range from 5 mm to 10 mm, 112.47 kN is used to compress the first sample to crack and compressive strength is 14.32 MPa. The third sample has a maximum load of 116.8 kN and compressive strength of 14.81 MPa. The second sample experienced crack after placing in the curing tank for a 7-day period. This sample has maximum load of 66.7 kN and compressive strength of

8.494 MPa. The area of the crack sample is 0.0051 m^2. From the analysis, the actual strength is 13.2 MPa and closer with the strength by first sample and third sample.

Size range from 10 mm to 14 mm, 122.2 kN load and 15.56 MPa compressive strength are encountered in first sample. The third sample shows maximum load 121.7 kN load and 15.47 MPa compressive strength. While for second sample, the maximum load and compressive strength are 119.8 kN and 15.26 MPa respectively.

Lastly, the load and compressive strength for the first, second and third sample in the size range from 14 mm to 20 mm are 57.50 kN, 63.3 kN, 101.6 kN and 7.32 MPa, 8.06 MPa, 12.94 MPa respectively. Both first and second samples are crack after placing in the curing tank for a 7-day period. The area of the broken first and second sample is 0.0052 m^2 and 0.0069 m^2 accordingly. Actual strength for first and second sample is 11.0 MPa and 9.05 MPa.

Figure 4.4 illustrated the 7 days compressive strength increasing exponentially as the aggregate size increase from 3.36 mm - 5 mm to 5 mm - 10 mm range but drop exponentially from 10 mm - 14 mm to 14 mm - 20 mm aggregate size, which form a maximum quadratic trend line.

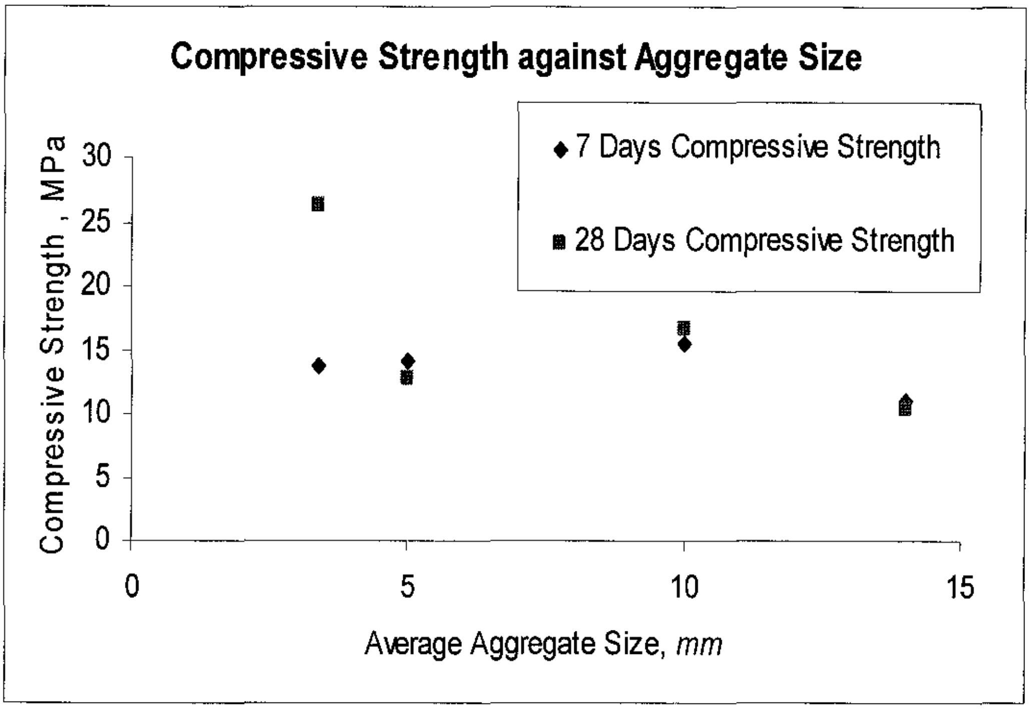

Figure 4.4 Compressive Strength at Different Ages

As the aggregate size increase from 3.36 mm - 5 mm to 5 mm - 10 mm range and 10 mm to 14 mm, the compressive strength increased to 15.43 MPa from 13.81 MPa. The compressive strength increased due to higher bond between the mortar and the coarse aggregate where it has the more contact point between aggregate. In addition, higher strength in aggregate particle such as increase in the ability to resist stress applied to it also contributed to the increase in compressive strength.

However, the compressive strength decrease quadratically until 11.00 MPa for aggregate size of 14 mm - 20 mm from 15.43 MPa. The reduction in compressive strength is due to lower bond between the mortar and the coarse aggregate where it has the least contact point between aggregate. In addition, the lesser strength in aggregate particle such as the lesser the ability to resist stress applied to it also contributed to the decrease in compressive strength.

On the other hand, the result of 28-day compressive strength test is shown in Table 4.5. From the result of size range from 3.36 mm to 5 mm, the maximum load for the first sample, second sample and third sample are 227.6 kN, 181.9 kN and 209.7 kN respectively while 28-day compressive strength are 28.98 MPa, 23.16 MPa and 26.7 MPa accordingly. The range from 3.36 mm to 5 mm require more aggregate to fill the mould, which leads to more point of contact between each aggregate. The range from 3.36 mm to 5 mm has the largest compressive strength as mentioned above compared to size range from 5 mm to 10 mm, size range from 10 mm to 14 mm and size range from 14 mm to 20 mm.

On the other hand, for size range from 5 mm to 10 mm, the first and second samples have maximum load of 82.1 kN and 98.6 kN whereas the 28-day compressive strength of 10.45 MPa and 12.55 MPa, respectively. The first sample experienced crack after placing in the curing tank for a 28-day period. The area in crack sample is 0.0065 m^2. The area is lesser in crack sample which yield the measured stress is lesser than second and third sample. From the analysis, the actual strength is 12.63 MPa and closer with the strength by second sample and third sample. However, the third sample has a maximum load of 117.6 kN and 28-day compressive strength of 14.98 MPa. The reason of compressive strength being slightly lower than size range 3.36 mm to 5 mm is due to the contact point between aggregate are much lesser as the volume needed to fill up the mould is also lesser.

Table 4.5 28-day compressive strength test for coarse aggregate size range

Aggregate Size (mm)	Maximum Load (kN)			Average Maximum Load (kN)
	Sample 1	Sample 2	Sample 3	
14 mm –20 mm	73.30	85.90	83.60	80.93
10 mm –14 mm	123.20	124.80	143.80	130.60
5 mm – 10 mm	82.10	98.60	117.60	99.43
3.36 mm – 5 mm	227.60	181.90	209.70	206.40

Aggregate Size (mm)	Stress (MPa)			Average Maximum Stress (MPa)
	Sample 1	Sample 2	Sample 3	
14 mm –20 mm	9.33* ($12.21^{\dagger}$)	10.94	10.64	10.30* ($11.26^{\dagger}$)
10 mm –14 mm	15.69	15.89	18.31	16.63
5 mm – 10 mm	10.45* ($12.63^{\dagger}$)	12.55	14.98	12.66* ($13.39^{\dagger}$)
3.36 mm – 5 mm	28.98	23.16	26.70	26.28

Note:

* The value obtained from Test Machine.

† The value obtained from analysis performed.

In addition, as for size range from 10 mm to 14 mm, 123.2 kN load and 15.69 MPa 28-day compressive strength are encountered in first sample. While for second sample, the maximum load and compressive strength are 124.8 kN and 15.89 MPa respectively. The third sample shows maximum load of 143.8 kN and 18.31 MPa compressive strength. Similarly, the size range from 10 mm to 14 mm showed lower compressive strength than size range 3.36 mm to 5 mm.

Lastly, the load and 28-day compressive strength for the first, second and third sample in the size range from 14 mm to 20 mm are 73.3 kN, 85.9 kN, 83.6 kN and 9.33 MPa, 10.94 MPa, 10.64 MPa respectively. The first sample has crack after placing in the curing tank for a 28-day period. The crack sample has an area of $0.006 m^2$. The area is lesser in crack sample compared to setting area, which is $0.00786\ m^2$. Therefore, the measured stress for second sample is less than first sample. From the analysis, the actual strength is 12.21 MPa.

The difference between strength by second sample as well as third sample and actual strength gives closer difference. In size range from 14 mm to 20 mm, the volume of aggregate required to fill up the mould is lesser compared to range from 3.36 mm to 5 mm. In large aggregate such as for size range from 14 mm to 20 mm, the gap between the aggregate is big. It is the sand and cement that fill up the gap as well as with addition of adhesive, SCC experience bonding and become as one. The least contact point is experienced for size range from 14 mm to 20 mm. Therefore, the range from 14 mm to 20 mm has lowest compressive strength compared to range from 3.36 mm to 5 mm, size range from 5 mm to 10 mm and size range from 10 mm to 14 mm.

Figure 4.4 illustrated 28 days compressive strength decreasing exponentially as the aggregate size increase from 3.36 mm - 5 mm to 5 mm - 10 mm range but rise exponentially from 10 mm - 14 mm and slightly decrease from 14 mm - 20 mm aggregate size, which forms a maximum quadratic trend line.

As the aggregate size decrease from 3.36 mm - 5 mm, the compressive strength decreased to 13.39 MPa from 26.28 MPa. The 3.36 mm to 5 mm aggregate size encountered lower compressive strength, which is 19.7 % lower than the reference. A lower bond between the mortar and the coarse aggregate where it has the least contact point between aggregate caused the compressive strength to reduce. Besides, the compressive strength decrease due to the lesser strength in aggregate particle such as the lesser the ability to resist stress applied to it.

However, the compressive strength increase quadratically until 16.63 MPa for aggregate size of 5 mm - 10 mm to 10 mm - 14 mm, where 59.08 % and 49. 19 % lower that the reference, respectively. It further reduced to 11.26 MPa for aggregate range 14 mm to 20 mm, 65.6 % lower than reference. The reduction in compressive strength is due to lower bond between the mortar and the coarse aggregate where it has the least contact point between aggregate. In addition, the lesser strength in aggregate particle such as the lesser the ability to resist stress applied to it also contributed to the decrease in compressive strength. In reference, the 28 days compressive strength is 32.73 MPa.

Figure 4.4 compare the 7 days to 28 days compressive strength. 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. Generally, the smallest aggregate size, which is 3.36 mm to 5 mm, gives the highest 7 days and 28 days compressive strength. On the contrary, the lowest compressive strength is obtained in 15 mm to 20 mm aggregate size.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The size of aggregate plays a contributing role in determining the fresh properties of SCC. As for V-Funnel result, it is found out that the flow time produce a sinusoidal graph as the aggregate size increased. With constant size of aggregate, filling ability decreases with the increase of aggregate size. The workability obtained from this study is 460 mm to 525 mm, compared with literature range from 500 to 700 mm for self-compacting concrete.

The range from 3.36 mm to 5 mm has the largest 28-days compressive strength compared to size range from 5 mm to 10 mm, size range from 10 mm to 14 mm and size range from 14 mm to 20 mm. As for size 3.36 mm to 5 mm, average diameter for slump flow is 500 mm. It is within the standard range of 500 mm to 700 mm and the fresh SCC has a good constituency.

The size of coarse aggregate plays a significant role in determining the fresh properties of the SCC. The best range is aggregate size from 3.36 mm to 5 mm as it has the largest 28-days compressive strength and average diameter for slump flow is 500 mm and highest filling ability compared to 5 mm to 10 mm, 10 mm to 14 mm and 14 mm to 20 mm.

5.2 Suggestion for Further Study

There are several suggestions for further studies. First, it is vital to reduce segregation by variation in mix proportion especially cement content, coarse aggregate, fine aggregate and water. The possible impact to this study is to achieve a good and workable SCC in fresh concrete properties.

Another possible field of study is to increase the sizes to a wider range and to perform more batches. The reason for doing only four coarse aggregate sizes in this study is particularly due to time constrain.

Thirdly, it is recommended that more mixture have to be done and also incorporate a mixture of well-grade aggregate size with appropriate mix design in future. Besides, suggestion to improve compressive strength test sample is to lay a sheet of paper in the cylinder mould. Instead of applying grease, wet the mould before placing the paper to prevent it from absorbing the water. An important reminder would be to ensure the cylinders have hardened prior to placement into curing tank.

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APPENDIX A

CALCULATION OF 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 was obtained:

Sand = 826 kg/m^3

Coarse Aggregate = 826 kg/m^3

Cementitious Content = 413 kg/m^3

Water = 189 kg/m^3

Volume of cylinder

Size of 1 cylinder: Diameter = 100mm, Length = 200mm

Volume of 1 cylinder = $\frac{0.1^2\pi}{4}x0.2$ = 0.001571m^3

Volume of 6 cylinder = 0.001571 x 6 = 0.009426m^3

Volume of air content test

Size of the cylinder: Diameter = 250mm, Length = 250mm

Volume of cylinder = $(0.25^2 \times 3.142)/4 = 0.012272m^3$

Volume of concrete = $0.009426 + 0.012272 = 0.021698m^3$

Total volume needed

Allowable waste is assumed as 10% of concrete volume = 0.1 x 0.021698 = $0.0021698m^3$

Volume of concrete + assumed wastage = $0.021698 + 0.0021698 = 0.0238678m^3$

Thus, the amount of concrete needed is $0.024m^3$

Reference Concrete needed for $0.024m^3$

Cement	= 413x 0.024 = 9.912 kg
Sand	= 826 x 0.024 = 19.824 kg
Coarse aggregates	= 826 x 0.024 = 19.824 kg
Water	= 189 x 0.024 = 4.536 L
Adva (HRWR)	= 9 x 0.024 = 0.216 L
Vismocrete(VMA)	= 8 % x 9.912 = 0.793 kg

Table A.1 Mix Proportion

Concrete type	water	sand	gravel	cement	HRWR	VMA
	l	kg	kg	kg	l	kg
14 - 20 mm	4.536	19.824	19.824	9.912	0.216	0.793
10 - 14 mm	4.536	19.824	19.824	9.912	0.216	0.793
5 - 10 mm	4.536	19.824	19.824	9.912	0.216	0.793
3.36 - 5 mm	4.536	19.824	19.824	9.912	0.216	0.793

APPENDIX B

CONCRETE MIX

Figure B.1 High segregation occurred in mixture of size range 14 mm - 20 mm

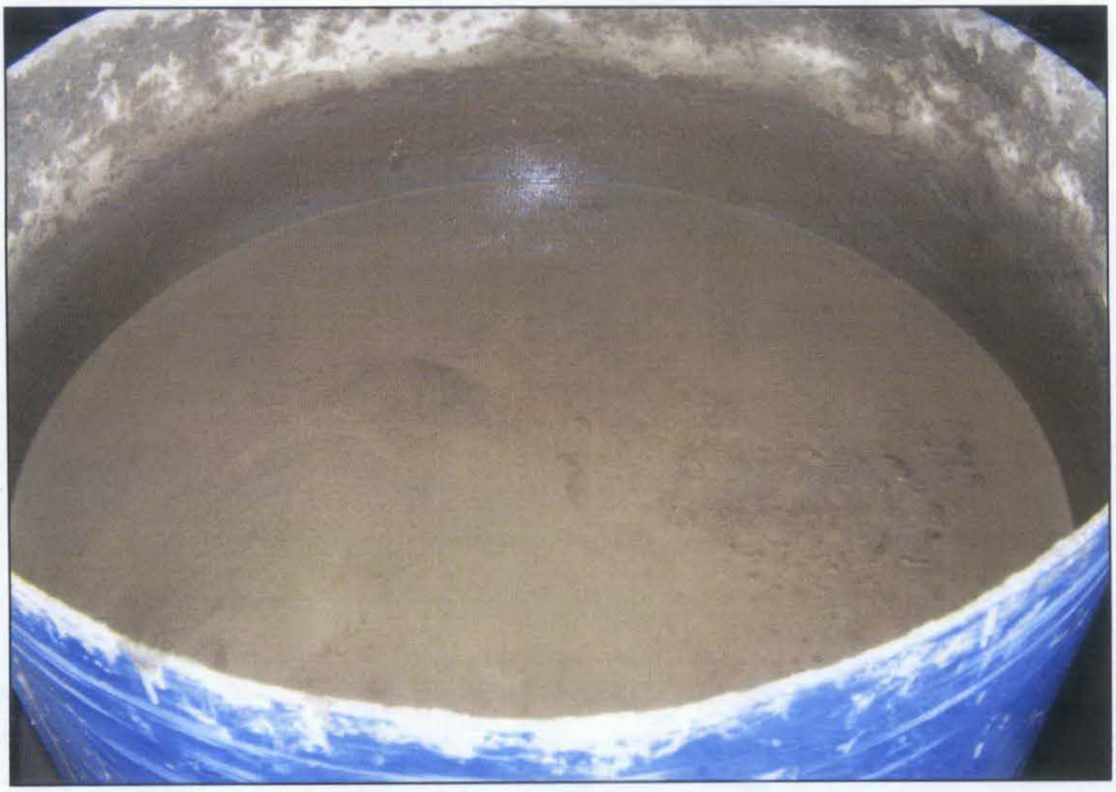

Figure B.2 Medium segregation occurred in mixture of size range 10 mm - 14 mm

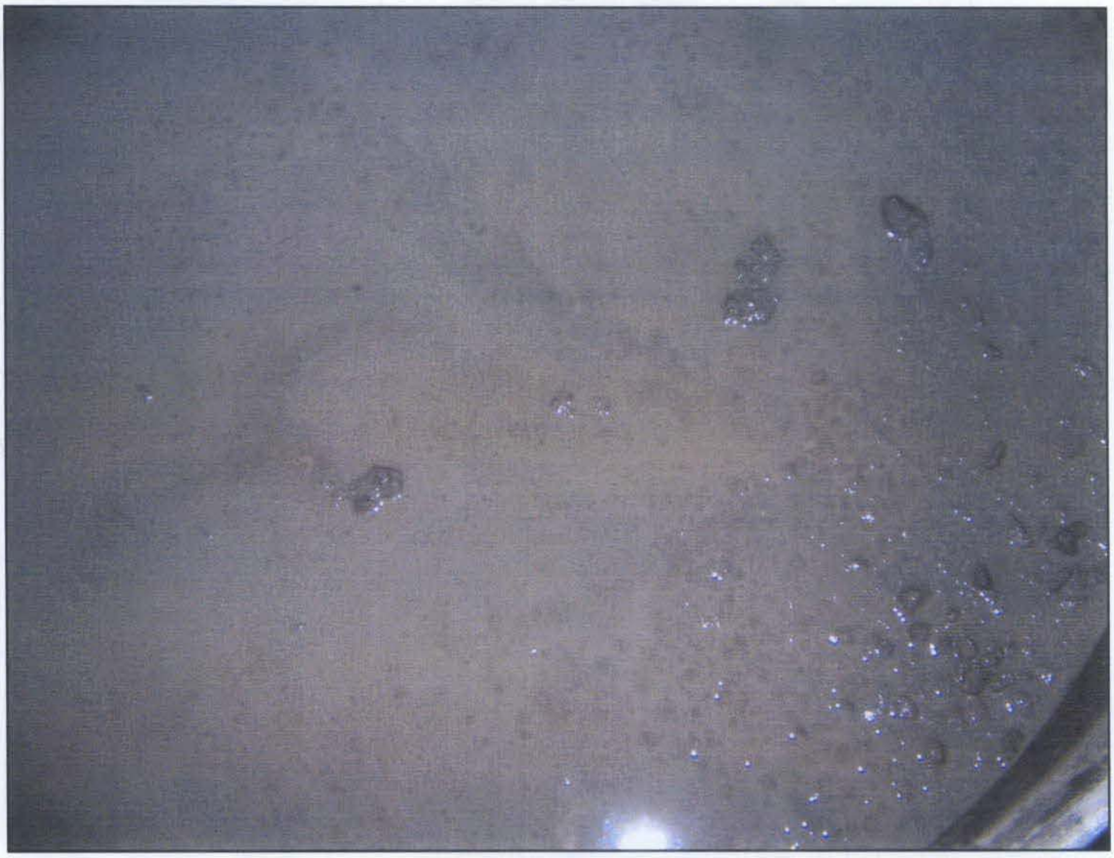

Figure B.3 Lower level segregation occurred in mixture of size range 5 mm - 10 mm

Figure B.4 Low segregation occurred in mixture of size range 3.36 mm – 20 mm

APPENDIX C

V-FUNNEL TEST

Figure C.1 V-Funnel test

APPENDIX D

KAJIMA BOX TEST

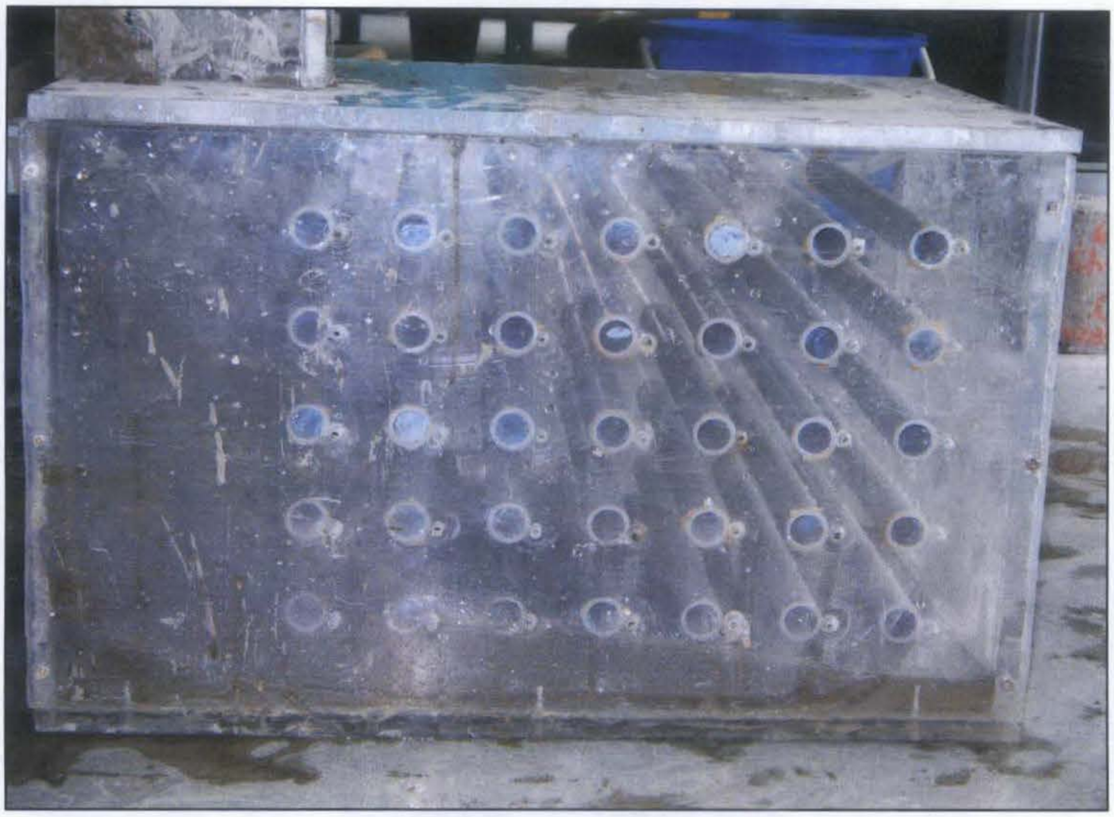

Figure D.1 Filling ability for size range 14 mm - 20 mm is 11.02 %

Figure D.2 Top view in Kajima Box of size range 14 mm – 20 mm

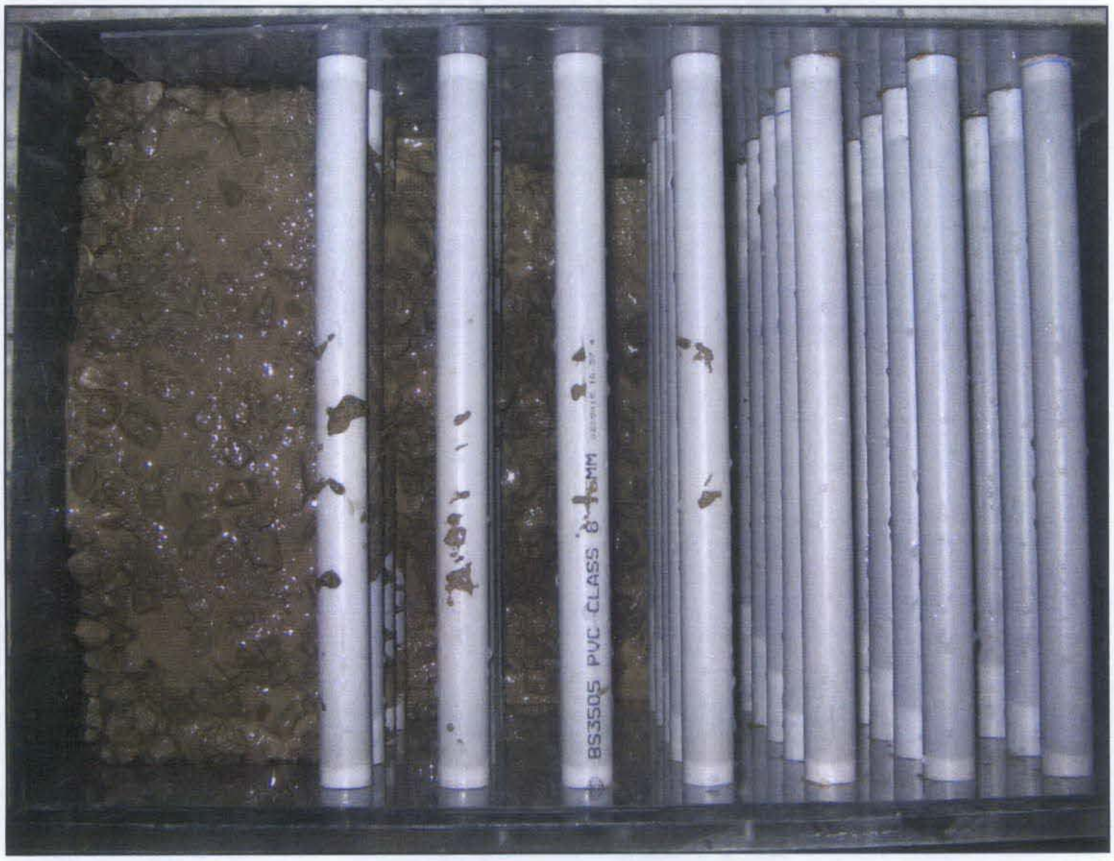

Figure D.3 Top view in Kajima Box of size range 10 mm – 14 mm and its filling ability is 23.26 %.

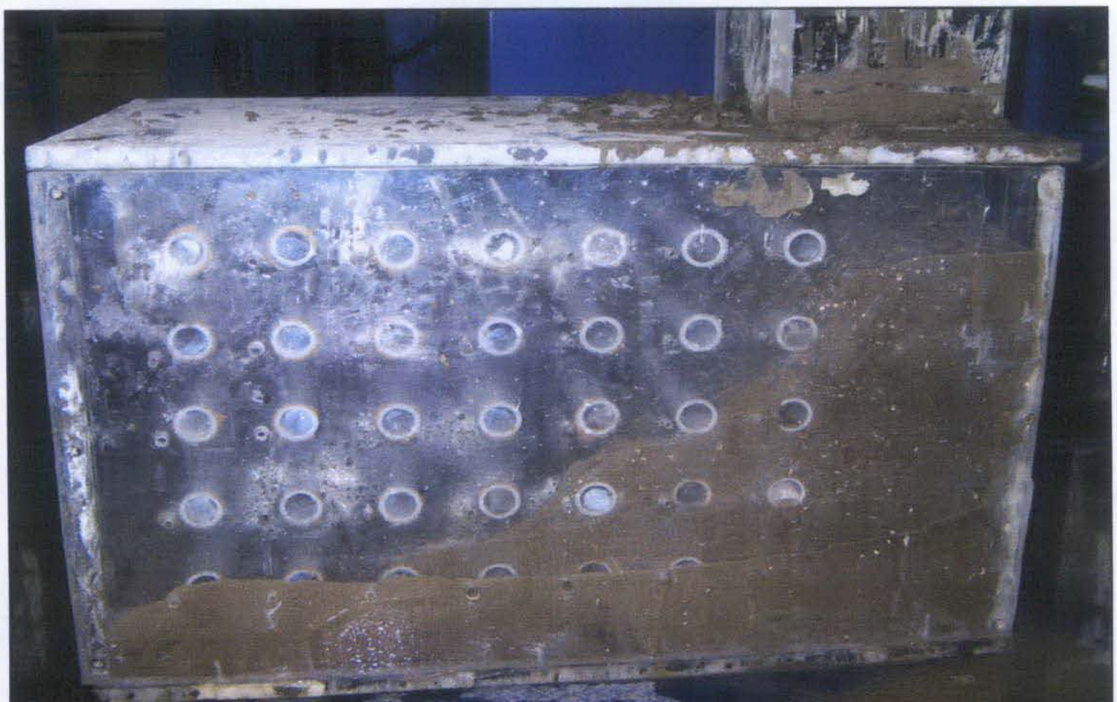

Figure D.4 Filling ability for size range 5 mm - 10 mm is 24.47 %

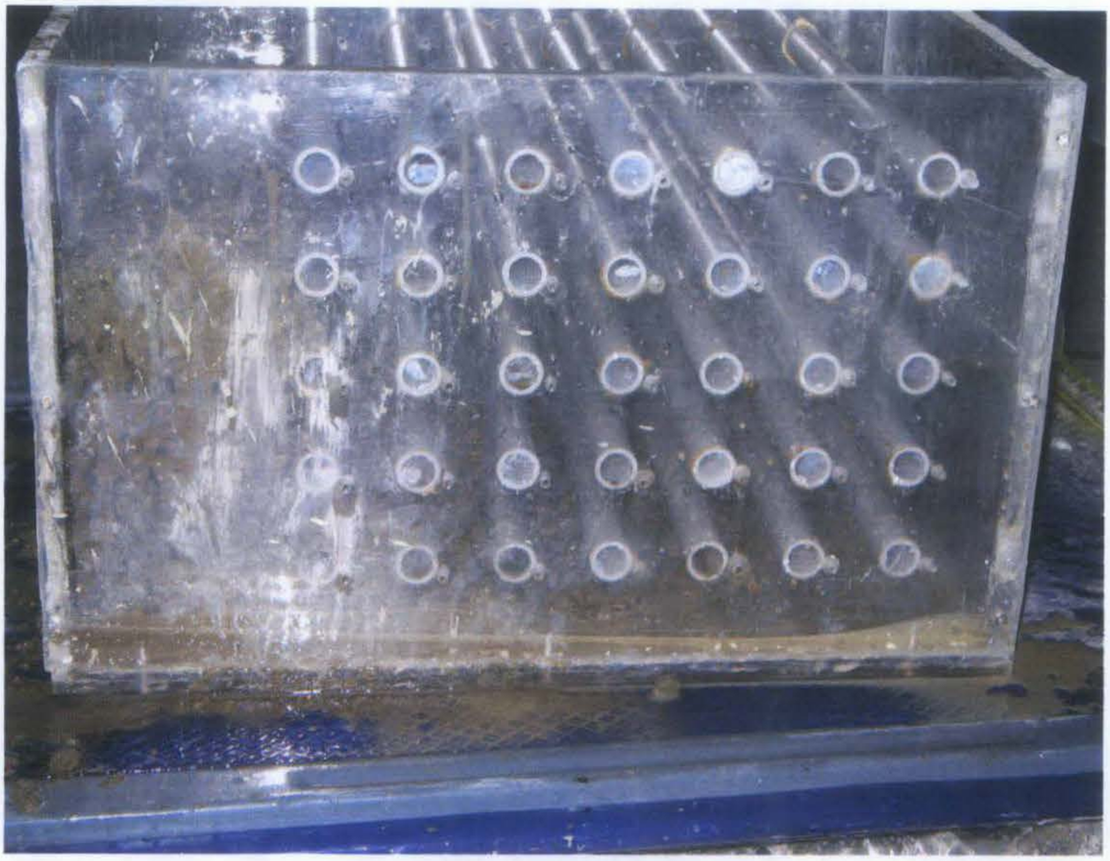

Figure D.5 Filling ability for size range 3.36 mm - 5 mm is 22.50 %

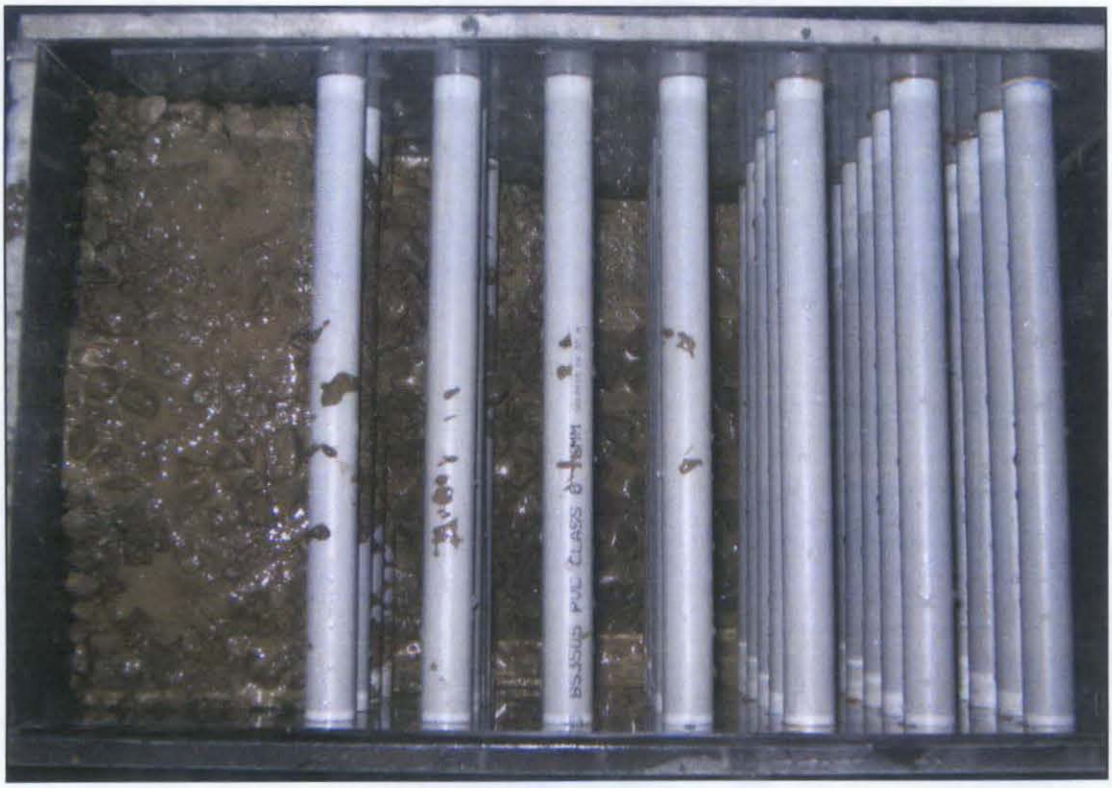

Figure D.6 Top view in Kajima Box of size range 3.36 mm - 5 mm

APPENDIX E

SLUMP FLOW TEST

Figure E.1 Slump flow inner diameter 525 mm of size range 14mm – 20 mm

Figure E.2 Slump flow inner diameter 475 mm of size range 10mm – 14 mm

Figure E.3 Slump flow inner diameter 460 mm of size range 5mm – 10 mm

Figure E.4 Slump flow inner diameter 500 mm of size range 3.36 mm – 5 mm

APPENDIX F

28 DAYS COMPRESSIVE STRENGTH TEST

Figure F.1 Before compressive strength test of size range 14 mm - 20 mm

Figure F.2 After compressive strength test of size range 14 mm - 20 mm

Figure F.3 Before compressive strength test of size range 10 mm - 14 mm

Figure F.4 After compressive strength test of size range 10 mm - 14 mm

Figure F.5 Before compressive strength test of size range 5 mm - 10 mm

Figure F.6 After compressive strength test of size range 5 mm - 10 mm

Figure F.7 Before compressive strength test of size range 3.36 mm - 5 mm

Figure F.8 After compressive strength test of size range 3.36 mm - 5 mm

APPENDIX G

ASSEMBLY DRAWING

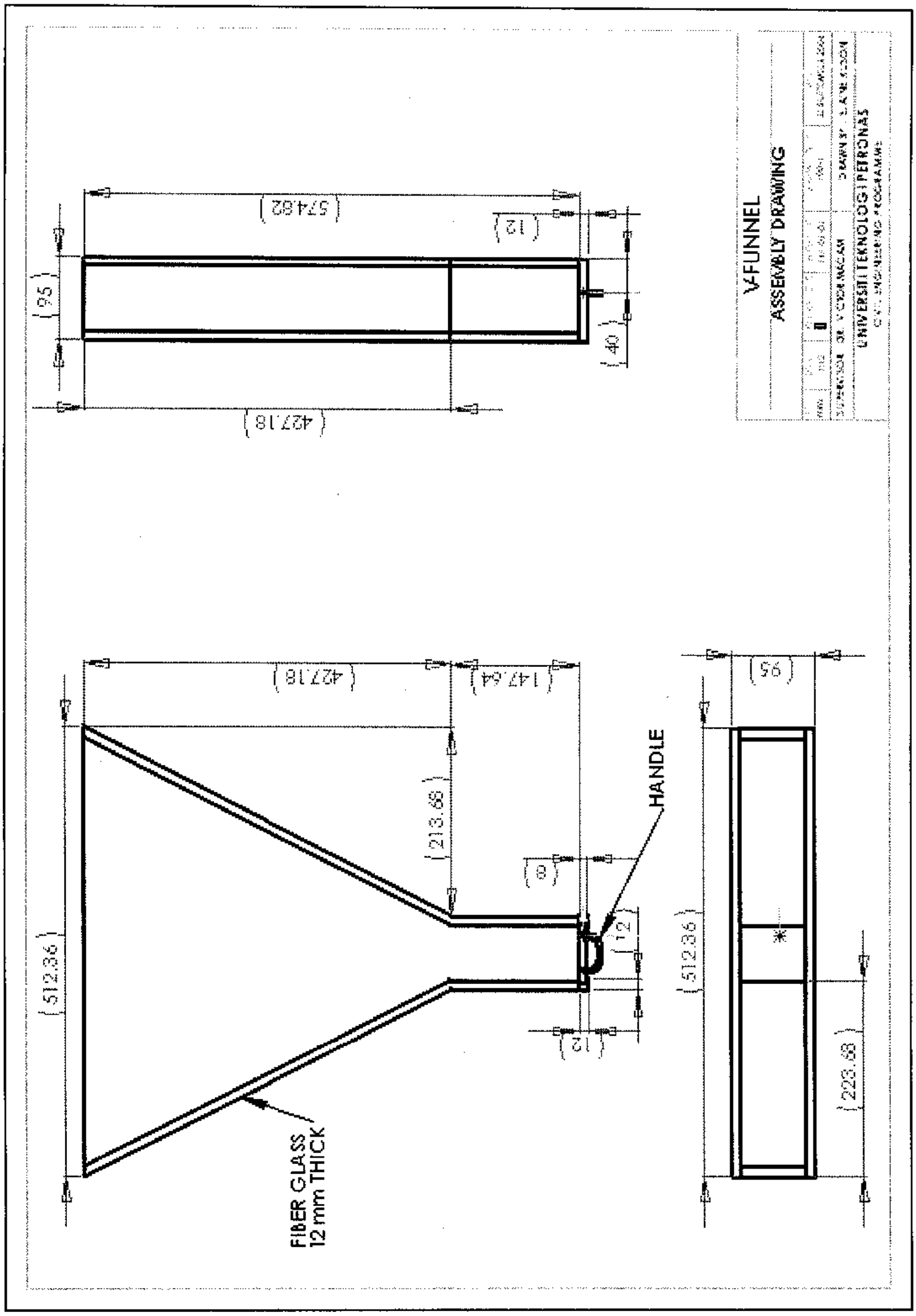

Figure G.1 Assembly drawing of V-Funnel

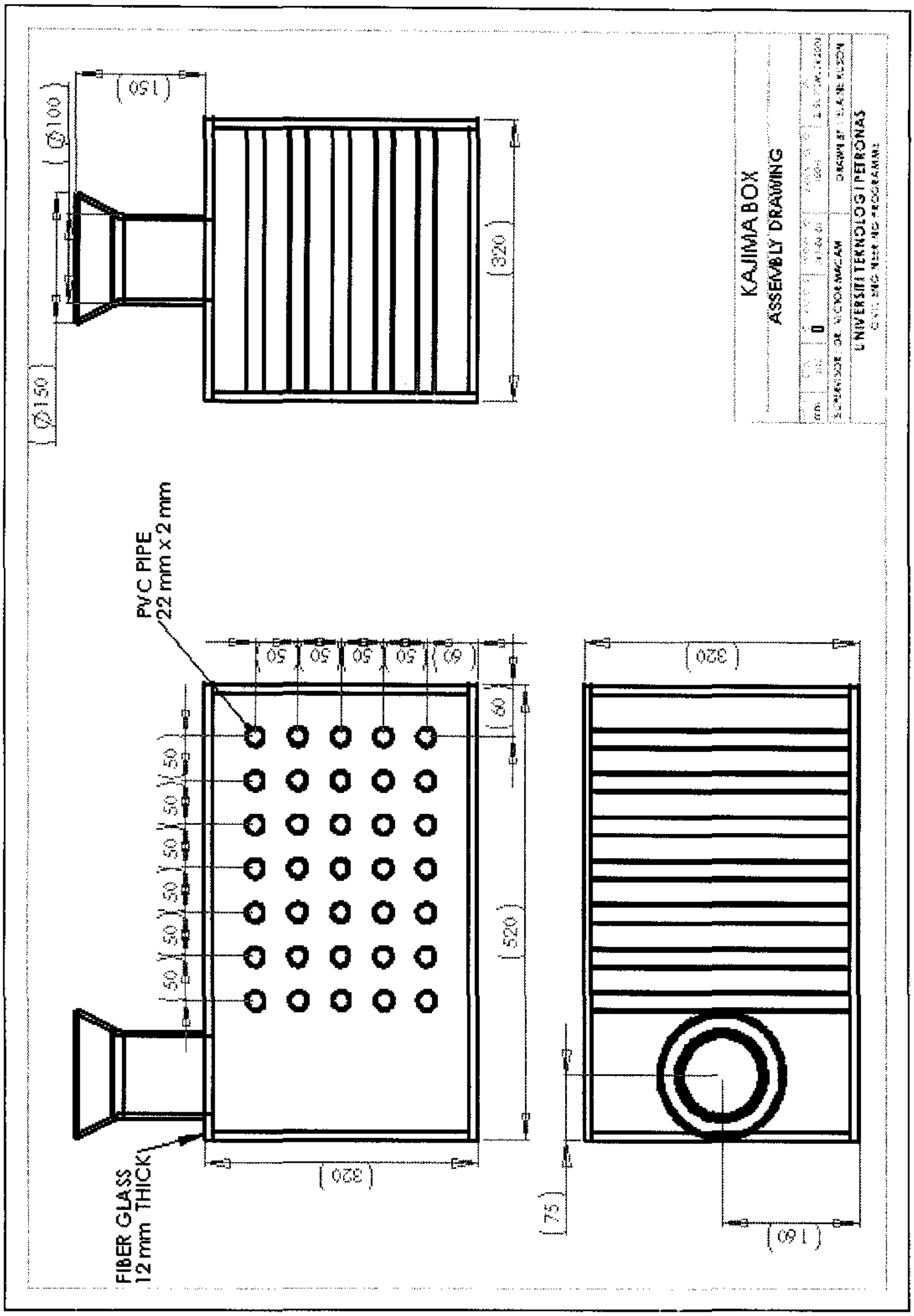

Figure G.2 Assembly drawing of Kajima Box

APPENDIX H

KAJIMA BOX TEST RESULTS

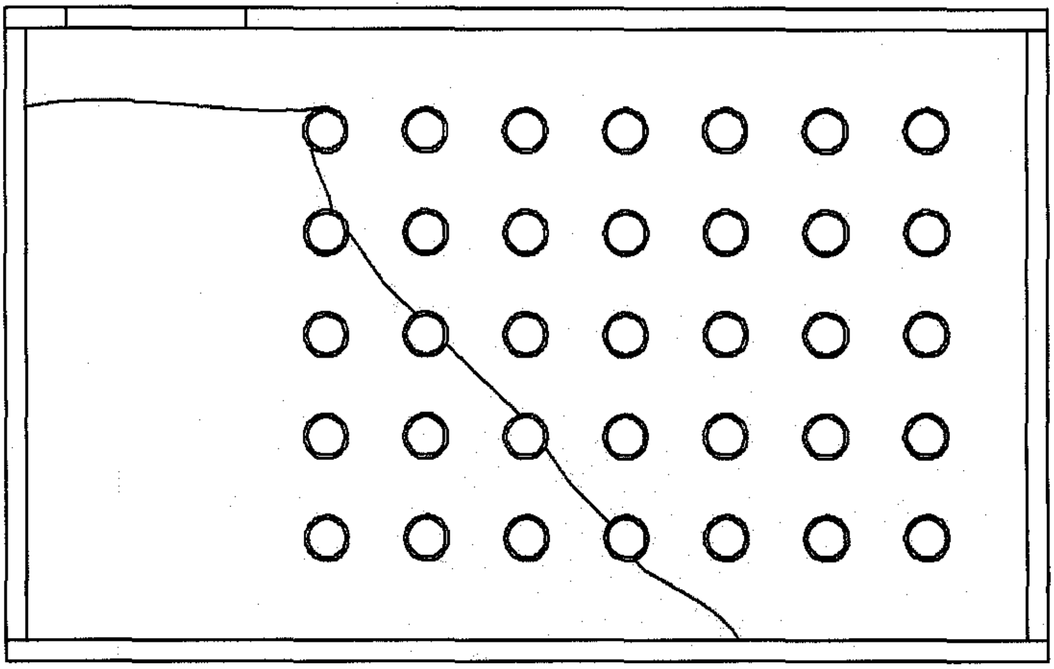

Figure H.1 Kajima box test result for size range 3.36 mm – 5 mm
Percentage of filling ability = (5550 + 15000) / 91354 * 100 = 22.495 %

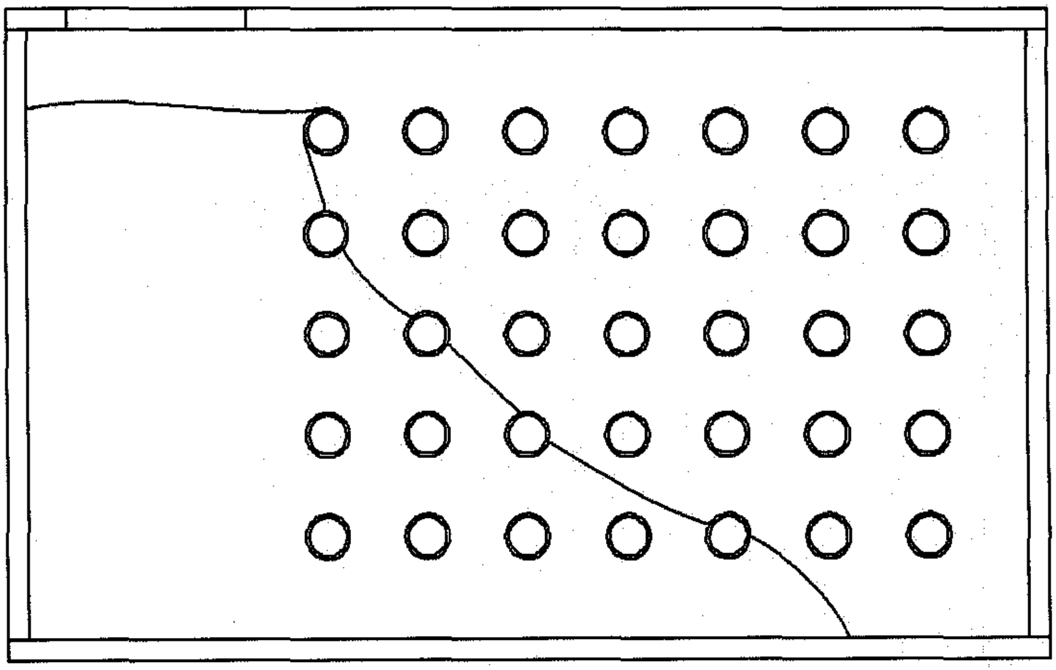

Figure H.2 Kajima box test result for size range 5 mm – 10 mm
Percentage of filling ability = (8325 + 5275 + 8750) / 91354 * 100 = 24.47 %

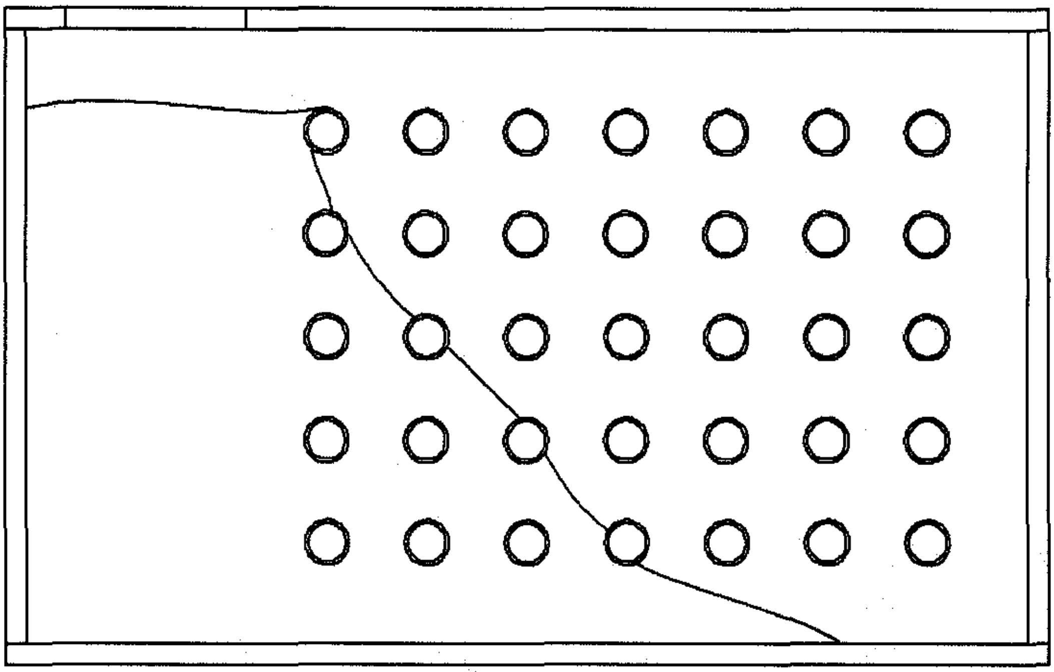

Figure H.3 Kajima box test result for size range 10 mm – 14 mm
Percentage of filling ability = (2500 + 18750) / 91354 * 100 = 23.26 %

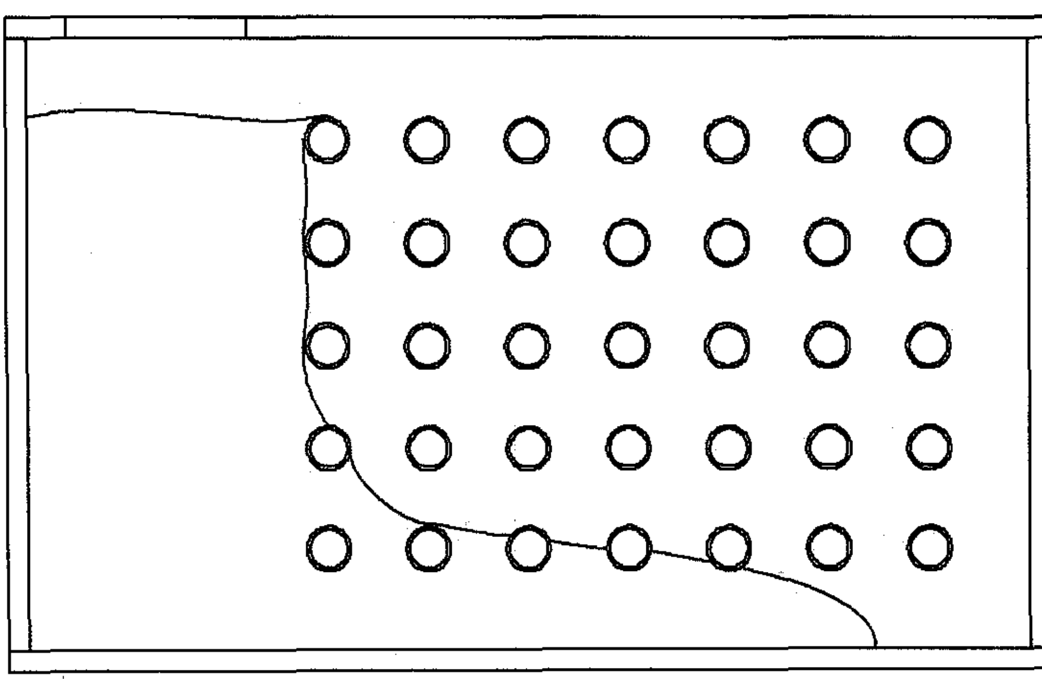

Figure H.4 Kajima box test result for size range 14 mm – 20 mm
Percentage of filling ability = (5764.5 + 4300) / 91354 * 100 = 11.017 %

APPENDIX I

COARSE AGGREGATE

Figure I.1 Coarse aggregate of size range 14 mm - 20 mm

Figure I.2 Coarse aggregate of size range 10 mm - 14 mm

Figure I.3 Coarse aggregate of size range 5 mm - 10 mm

Figure I.4 Coarse aggregate of size range 3.36 mm – 5 mm