EFFECTS OF PULVERIZED FUEL ASH (PFA) ON THE BOND STRENGTH OF SELF COMPACTING CONCRETE (SCC) WITH DIFFERENT DIAMETER OF EMBEDDED STEEL BARS

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By

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Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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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 here in have not been undertaken or done by unspecified sources or persons.

Dominic Juhirin Kantis

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ABSTRACT

This project was done to determine the effects of Pulverized Fuel Ash (PFA) on the bond strength of Self Compacting Concrete (SCC) with different diameter of embedded steel bars. PFA act as cement replacement material used at different percentages such as 5%, 10% and 15% and there were three sizes of steel bars diameter used in this project such as 10 mm, 12 mm and 16 mm. To establish the bond strength or stress of SCC to the steel bar, 9 samples of cylinder for each mix with single bar embedded inside will undergo the pull-out test. Two sets of sample were cast which set 1 has a constant embedded area while set 2 with embedded length of steel bars equal to 15 times the diameter of bar. The experimental bond strength value is given by pull out force divided by the effective embedded area of the steel bar while the theoretical value is determined by 0.5 times the square root of the compressive strength data. The results for slump flow are taken to determine the flow ability of the SCC. Based on the results, addition of more PFA to SCC did not affecting significantly to the bond strength at 28 days but have effects on the slump flow of SCC. Addition of PFA improves the slump flow of SCC. By using 12 mm steel bar, the bond strength value for both set are steadier compared to 10 mm and 16 mm bars. For set 1 with constant embedded steel bar area, bigger bar diameter gives better bond strength while for set 2 with embedded length of steel bar equal to 15 times the bar diameter, 12 mm bar gives better bond strength.

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CHAPTER 1
INTRODUCTION

1.1 Background of study.

Self compacting concrete was previously known as non-vibrated concrete or self placing concrete. It was first developed in Japan in 1986 as a result of the problems that conceiving concrete durability and high demands of the skilled workers in the construction industry.

The major difference of self compacting concrete characteristic compared to normal concrete is the ability of self compacting concrete to be compacted by its own weight without the use of any vibration machine to consolidate it. In addition, self compacting concrete can also be poured into congested areas with reinforcement and tight section because of its flow ability that is slightly higher than the normal concrete. It can also resist segregation and allow air bubbles to escape.

This new type of concrete can be made by adjusting the aggregate content, using some chemical admixture and cement replacement material. The usage of High Range Water Reducing (HRWR) admixture or super plasticizer can make the self compacting concrete more flow able, easier to pour and therefore increase its workability.

The usage of filler materials or cement replacement materials like pulverized fuel ash (PFA) is likely to enhance the viscosity of the self compacting concrete mixture, therefore reducing the aggregate segregation and bleeding. By its nature, self compacting concrete is a new type of concrete which is flow able, easy to place and does not need vibration effort to consolidate.

1.2 Problem statement.

Congested area with reinforcement and also tight section makes the work of placing the concrete very uneasy. With this condition, we can not compact or vibrate the concrete to make it consolidated as it is very hard to bring the vibrator machine to the specific place.

Therefore, self compacting concrete need to be introduced as this concrete did not need any compaction or vibration effort to consolidate. This type of concrete can consolidate by its own weight, has good flow ability through congested area with reinforcement and also tight section.

By eliminating vibration, the cost of project can be reduced as we not need to hire workers for that kind of work anymore. Also, we can speed up the construction progress as there is no more vibration process to be done during the construction. Using self compacting concrete in construction also reduce the noise hazard as vibration process produce unwanted noise that can be harmful to human hearings.

But, when compaction or vibration process is eliminated the strength of the concrete and also the bond strength of the self compacting concrete on the reinforcement may be affected. Therefore, this study was conducted.

1.3 Objectives.

The objectives of this study are:

1. To investigate the effects of Pulverized Fuel Ash (PFA) on the bond strength of Self Compacting Concrete (SCC).
2. To investigate the effects of different diameter of bars on bond strength of Self Compacting Concrete (SCC). (With constant embedded area and/or the embedment length equals to 15 times the diameter of bars.)

1.4 Scope of study.

The scope of this study is to determine the bonding strength of self compacting concrete to the reinforcement. In this study, the usage of cement replacement material like Pulverized Fuel Ash (PFA) is known to enhance the properties of self compacting concrete.

This study investigates the effects of different percentages of PFA used in the mix design to the workability of self compacting concrete, compressive strength and also its bonding strength to the reinforcement.

CHAPTER 2
LITERATURE REVIEW

2.1 The history of self compacting concrete (SCC).

According to N. Su et. al (2001), the history of Self Compacting Concrete (SCC) began in the Japanese construction industry in 1986 [1]. This new kind of concrete was designed at that time for two reasons.

Firstly the durability of the concrete was compromised as too much vibration increases the risk of segregation and occurrence of bleeding. Therefore this type of concrete was introduced in the construction to overcome segregation and bleeding that occur during vibrating the concrete. In this concrete casting process, the vibration process is eliminated and that is why this concrete is called self compacting concrete as it will be compacted and consolidate by its own weight.

Secondly, the self compacting concrete would overcome the problem in high demand of skilled workers in the construction at that time. Skilled workers are needed for process in the concrete casting for example like vibration process and they need to be paid more, therefore increased the cost of operation.

2.2 Self Compacting Concrete (SCC) as High Performance Concrete (HPC).

In 1988, the first self compacting concrete was produced and its properties in terms of compressive strength, hardening rate and durability were fully satisfied. This makes the self compacting concrete to be included as High Performance Concrete (HPC) because of its good deformability and it can resist segregation. The only difference of self compacting concrete and high performance concrete are in terms of high strength and durability. High Performance Concrete (HPC) is same like Self Compacting Concrete (SCC) in terms of fluidity and is easy for placing but can not fills in the gaps between the reinforcement and tight section of the mould freely. Therefore, High Performance Concrete (HPC) still needs vibration effort compared to Self Compacting Concrete (SCC).

According to P. Kumar Mehta, ACI defines High Performance Concrete (HPC) as a specially engineered concrete, which some of its characteristics have been enhanced through the selection of component materials and mix proportions.[2] The most significant properties of HPC are high workability, very high early strength (e.g. 30-40 MPa of compressive strength in 24 hours), high toughness, and high durability in any conditions.

2.3 Advantages of using Self Compacting Concrete in construction.

H. Okamura et. al (2003) stated that many intensive research was done after the development of the self compacting concrete prototype at University of Tokyo especially by larger construction companies with a research institute[3]. This made the new kind of concrete to be used in construction of so many structures around the world.

The application of this type of concrete in Japan, begin in June 1990, as the main material for a building and then in 1991, used in as towers for a pre-stressed concrete cable-stayed bridge named Shin-kiba Ohashi bridge. In 1992, lightweight self compacting concrete was used as main girder for of a cable stayed bridge.

Since then, self compacting concrete was used massively in Japan construction industry due to several advantages that it can give to add value for economic, time of construction and safety. The summaries of why most construction company implemented self compacting concrete are:

1. To cut the construction period.
2. To make sure compaction is not a problem especially in difficult area of construction where vibrating machine can not present.
3. To eliminate the unwanted noise due to vibration.

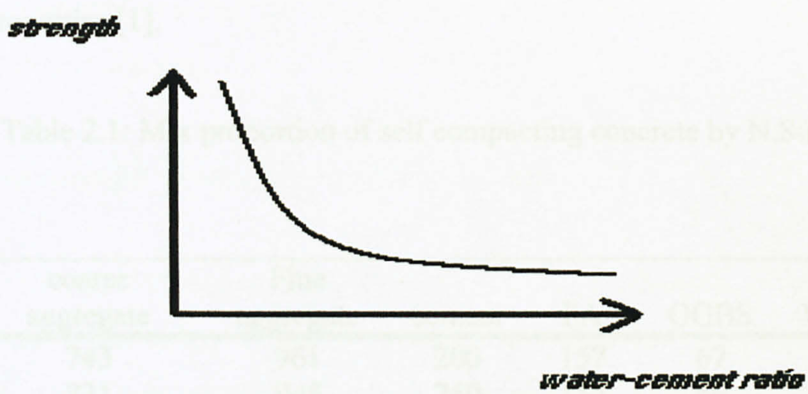
2.4 Production of Self Compacting Concrete (SCC).

To produce self compacting concrete, designing the suitable mix proportion and to determining its properties is very hard to understand. In general, self compacting concrete has a high fluidity properties compared to normal concrete.

By general understanding, designing self compacting concrete will actually require a lot of water because, one of the nature of self compacting concrete is to be a flow able concrete. Therefore this situation should be taken into consideration more seriously as too much water in the self compacting design will reduce its strength.

The relationship of water usage in the mix design and the strength of concrete are similar to the normal concrete. The figure below shows the relationship of water-cement ratio against the strength of concrete. As the water cement ratio increases the strength will reduce significantly.

Figure 2.1: Water-cement ratio relationship.



To enhance some of the self compacting properties, addition of some pozzolans will be very important. By adding Pulverized Fuel Ash (PFA) for example, the flow ability and workability of the self compacting concrete will improve.

According to a study conducted by E.Ozbay et.al (2009), there are some parameters need to be considered during the process of finding the mix proportions of self compacting concrete [4]. These parameters are affecting the characteristics of the self compacting concrete, in terms of flow ability, workability, compressive strength and durability. The parameters are such as:

- Water to cementitious materials ratio (W/C).
- Water content.
- Fine aggregate to total aggregate percent (s/a).
- Fly Ash content (FA).
- Air entraining agent content (AE).
- Superplasticizers content (SP).

The following mix design of self compacting concrete was carried out by N. Su et.al to study its properties [1].

Table 2.1: Mix proportion of self compacting concrete by N.Su et.al.

f'c (Mpa)	coarse aggregate	Fine aggregate	cement	FA	GGBS	Water	SP
27.5	743	961	200	157	67	176	7.6
34.3	731	945	250	154	66	173	8.5
41.2	718	928	300	148	63	172	8.2
48	706	912	350	142	61	170	8.8

FA :fly ash
GGBS :ground granular blast furnace slag
SP :super plasticizer

From the mix design, it shows that the compressive strength is increased when the cement content is increased. The water used in the mix design is also reduced when more super plasticizer is used to enhance the workability of the self compacting concrete. The usage of fly ash and ground granular blast furnace slag is to replace the cement content in the mix design.

This can be verified according to P.L Domone (2007), that to achieve satisfactory fluidity and stability, self compacting concrete need high volume of powder at low water / powder ratio require some quantities of super plasticizer. The powder materials usually consist of a combination of Portland cement with one or more addition of pulverized fly ash (PFA), granulated blast furnace slag (GGBS) and silica fume (SF). [5]

The addition of some of this cement replacement material especially pulverized fly ash (PFA) or simply said as fly ash can enhance some of the properties of concrete. According to research by M.H Shehata et.al (2000), another important aspect that needs to be considered when adding this material in concrete is that it can control the expansion due to alkali-silica-reaction or ASR at percentage of 25%.[6]

For high volume fly ash concrete, 25%-35% volume of fly ash is used in the concrete. But, for commercial practice, the dosage of fly ash limited to 15%-20% by mass of the total cementitious material.

2.5 Bonding strength of concrete to reinforcement.

According to M. Valcuende et.al (2009), the bond strength of concrete on the reinforcement is due to the friction of concrete and the rebar. This phenomenon known when the forces are transferred between the materials by two kinds of actions, first by adhesion and the other by friction and bearing action. [7]

For normal concrete, according to F. Dehn et al.(2000), the bond strength of concrete on rebar influenced by several factors such as surface area of the rebar, the number of load cycles, the mix design, the direction of concreting as well as the geometry of the test specimen.[8]

Bonding strength of the concrete to reinforcement is basically taken as the pull out force divided by the effective area of the embedded reinforcement inside the concrete. As stated in the BS 8110: Part 1, the bonding strength or bond stress is determined by the following equation: [9, 10]

$$fb = \frac{Fs}{\pi D L}$$

Where;

fb = bond stress;

Fs = force in the bar;

L = anchorage length;

D = size of bar.

The value of the design ultimate anchorage bond stress obtained from the BS 8110 code, is given by the following equation: [9]

$$fb = B \sqrt{fcu}$$

Where;

fbu = the design ultimate anchorage bond stress;

B = the coefficient dependent on the type of bar.

From Table 3.26 in the BS 8110 code, the B values are shown as:

Table 2.2: Values of bond coefficient, B.

Table 3.26 Values of bond coefficient, B		
	B	
Bar type	Bars in tension	Bars in compression
Plain Bars	0.28	0.35
Type 1: deformed bars	0.40	0.50
Type 2: deformed bars	0.50	0.63
Fabric	0.65	0.81

2.6 Previous work done:

The study of "Bond-slip characteristics of steel fibers in high reactivity metakaolin (HRM) modified cement-based matrices" by N. Banthia et al. (1996) is one of the previous work that have been done to determine the effects of adding High Reactivity Metakaolin (HRM) and silica fume by different percentages (i.e 5% and 10%). [11] By addition of 10% HRM, the bond–slip behavior of the deformed steel bars seem to be improving compared to addition of similar percentage of silica fume.

In this project, results as pull-out vs. pull-out displacement curves were analyzed to find the peak load or maximum load, average bond strength, energy absorbed to a displacement of 9.75mm, the peak stress in the fiber as the percentage of the ultimate strength, and also the fiber failure mode. The specimens were tested at 7 days and 28 days.The results from the project indicated that the high average bond strength for all the matrices is caused by the very low water / binder ratio of 0.35. The general improvement in the bond strength by adding silica fume or HRM can be determined at 7 and 28 days respectively. At 7 days, the HRM seems to be less effective compared to silica fume but after 28 days, it exceeds the silica fume.

CHAPTER 3

METHODOLOGY

3.1 Project stages:

The methodology of this study is first to gather information about self compacting concrete through reading some publications such as books, journals etc. This is followed by preparing a mix design of the self compacting concrete.

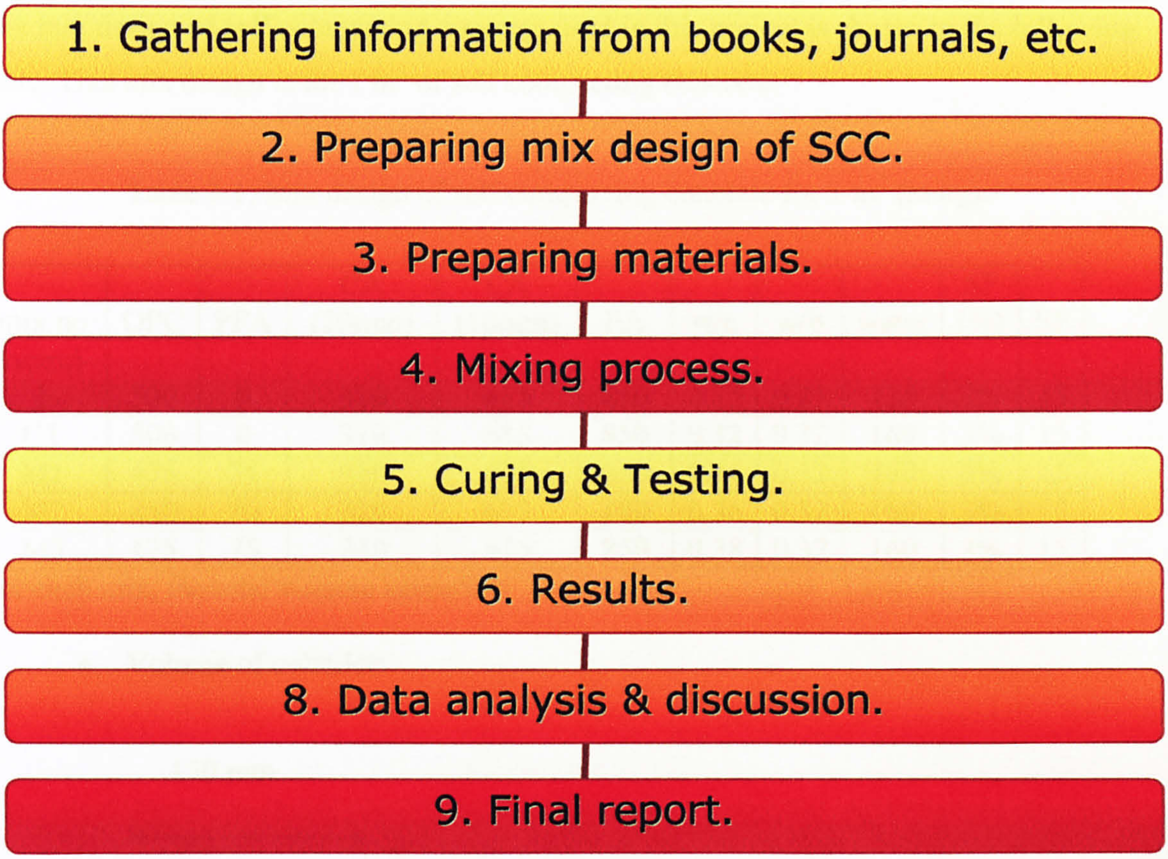
The self compacting concrete designed for this study has been added with cement replacement material, such as pulverized fuel ash or PFA, to enhance its properties. The usage of super plasticizer also improves the workability and flow ability of self compacting concrete so that the self compacting concrete is easy to place and flow.

The materials used to produce self compacting concrete need to be prepared in advance. Materials such as cement, pulverized fly ash (PFA), coarse aggregate of 10mm and 20mm, fine aggregate or sand, super plasticizer and water need to be weighed according to the mix design before casting.

The reinforcement used in this study also needs to be prepared according to its required lengths and diameters. After all materials are ready, the mixing process can proceed.

Then, after each mix the samples are cured inside the curing tank until the date of testing. The data from the test was then analyzed and discussed. Figure 3.1 overleaf is a flow chart of the stages in the project.

Figure 3.1: Flow chart of project stages.



3.2 Mix design of self compacting concrete.

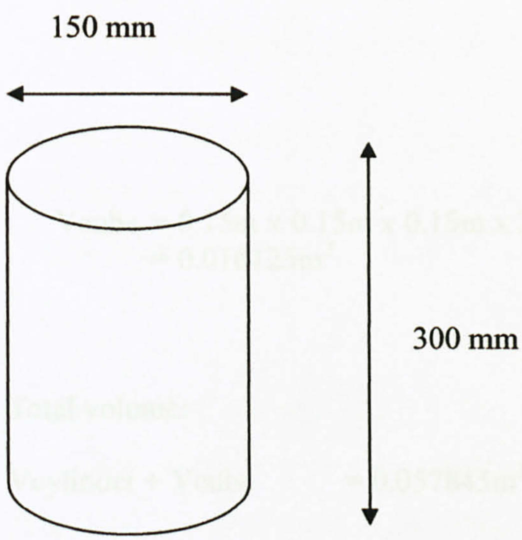
The mix design of self compacting concrete used in this project is shown in the following table. This mix design is for 1 m^3 of self compacting concrete.

Table 3.1: Mix design of self compacting concrete for 1 m^3 (in kg).

mix no	OPC	PFA	CA (20mm)	CA (10mm)	FA	w/c	w/b	water	SP (%)	SP
control-1	500	0	310	615	850	0.25	0.25	125	3%	15
CT	500	0	310	615	850	0.32	0.32	160	3%	15
M1	475	25	310	615	850	0.34	0.32	160	3%	15
M2	450	50	310	615	850	0.36	0.32	160	3%	15
M3	425	75	310	615	850	0.38	0.32	160	3%	15

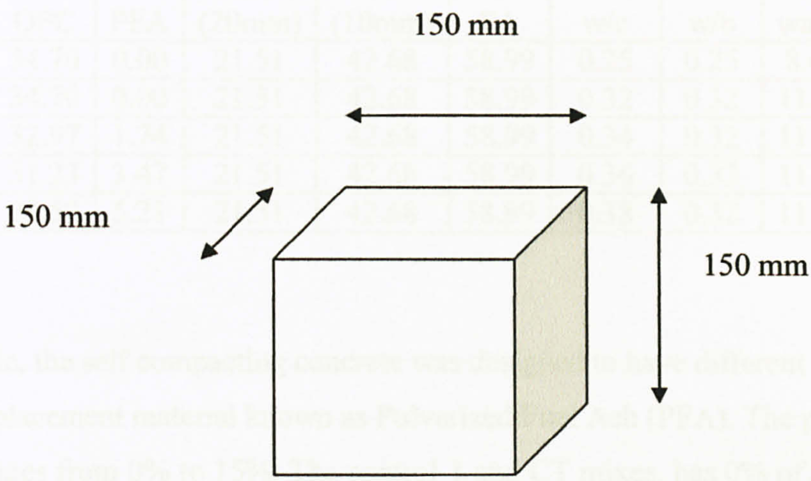
For each mix, the total volume needed is:

- Volume of cylinder:



Vcylinder $= 3.142 \times (0.15 / 2)^2 \times 0.3 \times 9$ samples
$= 0.04772\ m^3$

- Volume of cubes:



$$V_{cube} = 0.15m \times 0.15m \times 0.15m \times 3$$
$$= 0.010125m^3$$

- Total volume:

  $V_{cylinder} + V_{cube} \quad = 0.057845m^3$

- Due to some spillage during mixing process, the total volume increased by 20%:

  $120\% \times 0.057845m^3 \quad = 0.0694m^3$

Therefore for each mix, $0.0694m^3$ of self compacting concrete is needed. The mix design for this volume is shown in the following table:

Table 3.2: Mix design of self compacting concrete for $0.0694m^3$ (in kg).

mix no	OPC	PFA	CA (20mm)	CA (10mm)	FA	w/c	w/b	water	SP	SP	poz
control-1	34.70	0.00	21.51	42.68	58.99	0.25	0.25	8.68	3%	1.04	0%
CT	34.70	0.00	21.51	42.68	58.99	0.32	0.32	11.10	3%	1.04	0%
M1	32.97	1.74	21.51	42.68	58.99	0.34	0.32	11.10	3%	1.04	5%
M2	31.23	3.47	21.51	42.68	58.99	0.36	0.32	11.10	3%	1.04	10%
M3	29.50	5.21	21.51	42.68	58.99	0.38	0.32	11.10	3%	1.04	15%

In this table, the self compacting concrete was designed to have different percentages of a cement replacement material known as Pulverized Fuel Ash (PFA). The percentage of the PFA is ranges from 0% to 15%. The control-1 and CT mixes, has 0% of PFA and will be acting as a benchmark for all mixes of the self compacting concrete. Mix design 2 has 5% of PFA and this increasing 5% incrementally for mix 3 and mix 4.

The water-cement ratio for each mix is different from each other and ranging from 0.25 to 0.38. To get this value, the total amount of water has to be divided by the total amount of cement. As for water-binder ratio, control-1 mix has 0.25 w/b compared to the other mixes with 0.32.

Water binder ratio (w / b) is different from water cement ratio (w / c) because it is the total amount of water divided by the total amount of binder used in this project. Binders that have been used in this project were Ordinary Portland Cement (OPC) and also Pulverized Fuel Ash (PFA).

In this project, super plasticizer was used to enhance the workability of self compacting concrete. By adding this chemical substance in the concrete, the flow ability of concrete also improving and this enhance the performance of SCC. The percentage of super plasticizer is about 3% of the total binders used for each mix.

By calculation, the percentage of coarse aggregates (20mm and 10mm) from the total aggregates content (20mm + 10mm + sand) is about 52% while the percentage of fine aggregate (sand) from the total aggregate content is about 48%. The percentage of larger coarse aggregate (20mm) over the total aggregate content is about 17% compared to the percentage of smaller coarse aggregate (10mm) over the total aggregate content of 35%.

3.3 Material preparation:

Before the mixing process begins, the materials to be used in this project have to be prepared. The aggregates, cement, water, super plasticizer, mould and mixer should be ready to use.

There are two types of coarse aggregates used in this project such as the 10mm and also the 20mm aggregates. These coarse aggregates are crushed granite rock. Before mixing, the aggregates need to be washed to remove the dirt and dust on the surface.

This is because dirt and dust can affect the quality of the self compacting concrete. The fine aggregate is sand; the cement is ordinary Portland cement (OPC) and obtained from local cement producer. All the materials need to be prepared by weighing it according to the mix design.

3.4 Mixing process.

After all materials have been prepared and weighed according to the specified weight in the mix design, the mixing process can begin according to the standard procedure of concrete mixing. The first step to do in the mixing process is to wet the concrete mixer machine.

This is to ensure that when mixing the materials in the mixer, the materials will not stick onto the inside surface of the mixer. Another reason why we need to wash the mixer before using it is to make sure the surface of the mixer is free from unwanted dirt that can affect the mixing process and also the quality of the self compacting concrete.

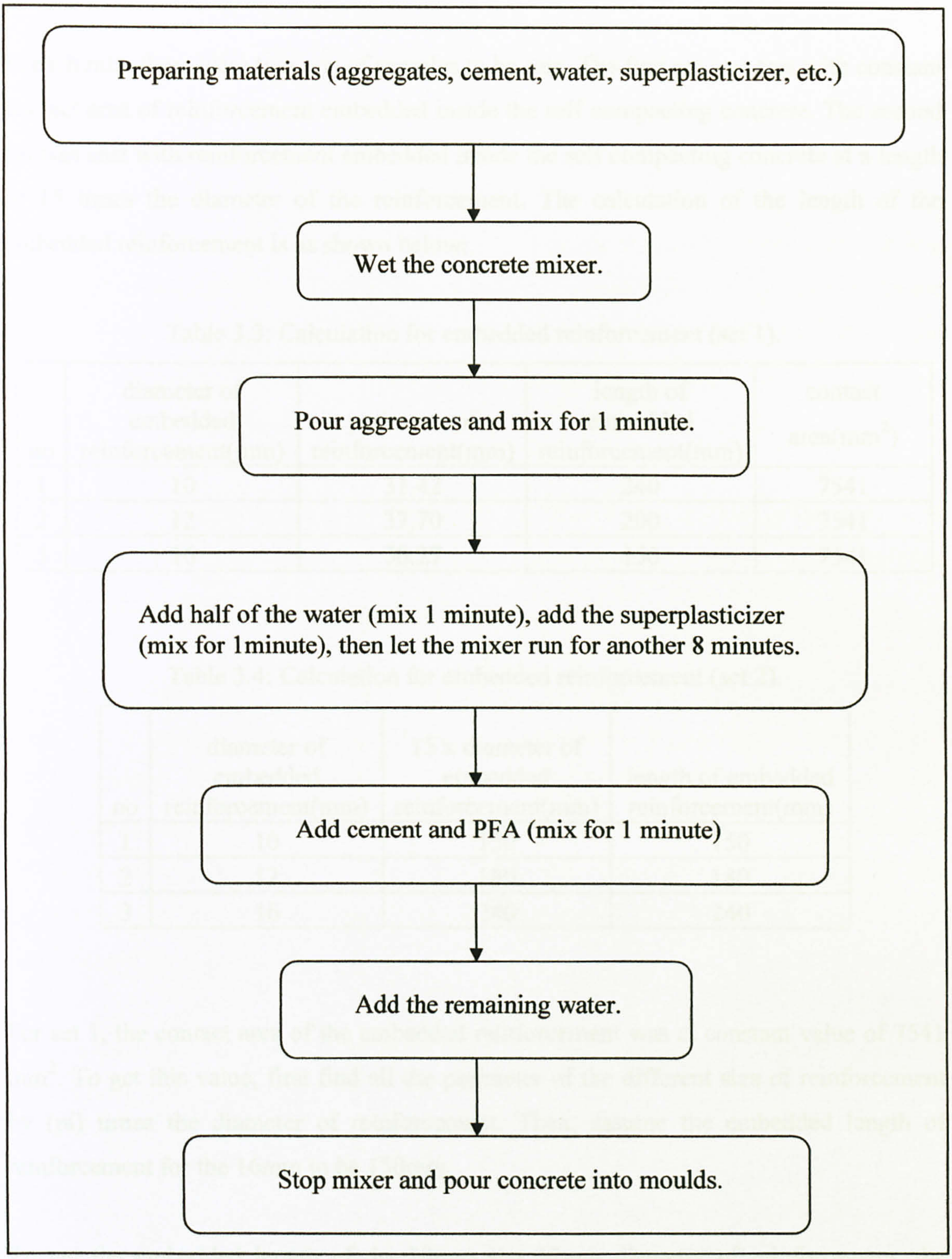
After that, the aggregates that have been weighed before were put into the mixer and mixed for about 1 minute. This is to make sure that all the aggregates are mixed together.

Then, half of the water used in the mix was put into the mixer and continue to mix for about another 1 minute. After that, the super plasticizer was put into the mixer and mixed for about another 8 minutes. The remaining materials such as cement and PFA then mixed together inside the mixer for another 1 minute before adding the remaining water.

Figure 3.2: Concrete mixing in progress.

The self compacting concrete poured into the moulds after that. The whole mixing processes are shown as in the following figure.

Figure 3.3: Flow of mixing process.



3.5 Reinforcement to be used:

In each mix, there were two sets of samples to be cast. The first set was cast with constant contact area of reinforcement embedded inside the self compacting concrete. The second set was cast with reinforcement embedded inside the self compacting concrete at a length of 15 times the diameter of the reinforcement. The calculation of the length of the embedded reinforcement is as shown below:

Table 3.3: Calculation for embedded reinforcement (set 1).

no	diameter of embedded reinforcement(mm)	perimeter of reinforcement(mm)	length of embedded reinforcement(mm)	contact area(mm^2)
1	10	31.42	240	7541
2	12	37.70	200	7541
3	16	50.27	150	7541

Table 3.4: Calculation for embedded reinforcement (set 2).

no	diameter of embedded reinforcement(mm)	15 x diameter of embedded reinforcement(mm)	length of embedded reinforcement(mm)
1	10	150	150
2	12	180	180
3	16	240	240

For set 1, the contact area of the embedded reinforcement was at constant value of 7541 mm^2. To get this value, first find all the perimeter of the different size of reinforcement by (pi) times the diameter of reinforcement. Then, assume the embedded length of reinforcement for the 16mm to be 150mm.

To get the embedded length of the 10mm and 12mm diameter of reinforcement, the constant contact area need to be divided by the perimeter of the respective size of reinforcement. After finding all the embedded length of the reinforcement, the total length of steel bar that need to be prepared was calculated. The total length should be at length of 400mm plus the embedded length in the concrete so that it can fit to the Universal Testing Machine for pull out test.

3.6 Concrete testing.

The fresh concrete test conducted in this project was the slump flow test. This test was conducted to determine the filling ability of the self compacting concrete according to the Guidelines for Testing Fresh Self Compacting Concrete by G.De Schutter (2005) for the European Research Project to measure the properties of fresh self compacting concrete.[12]

The key rheological parameters as stated in the guidelines such as "plastic viscosity" and "yield value" will mainly determine the filling ability. Slump flow test is the best method to determine this combined by the T50 test.

To measure slump flow of the self compacting concrete, the simple slump test was conducted except that the tamping process was neglected to make sure the concrete was self compacted. The testing materials used in slump flow test are much similar to the normal slump test. The difference between slump flow test and normal slump test is the data that need to be obtained. For slump flow test, the diameter of the spread self compacting concrete will be determined while for normal slump test, the height of the concrete will be determined.

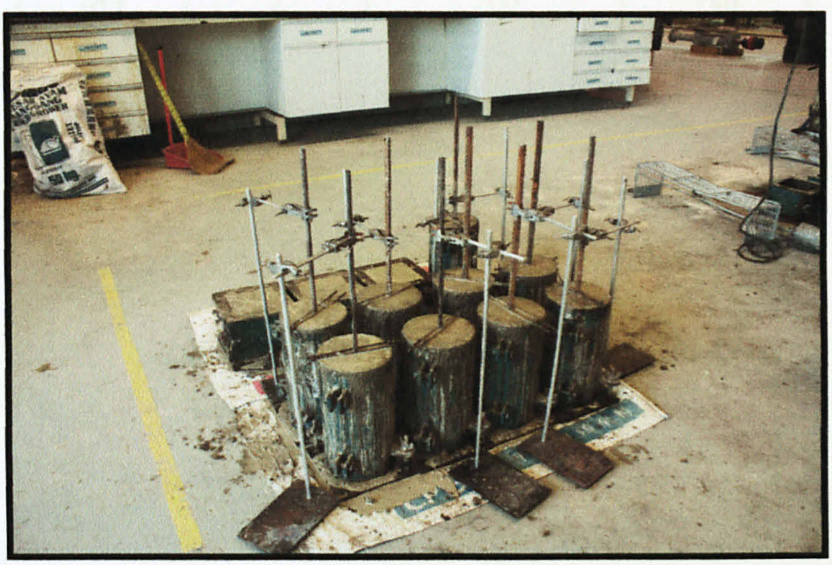
The maximum diameter will be the slump flow of the self compacting concrete which can tell us about its filling ability.

Figure 3.4: Slump flow test.

Figure 3.5: Determining the diameter of the concrete slump flow.

Figure 3.6: Pouring concrete into mould.

Figure 3.7: Self compacting concrete with reinforcement embedded inside.



After the concrete hardened for 24 hours, the concrete will be de-mould and then cured in the water pond for 28 days before tested for Pull-Out test.

CHAPTER 4
RESULTS AND DISCUSSIONS

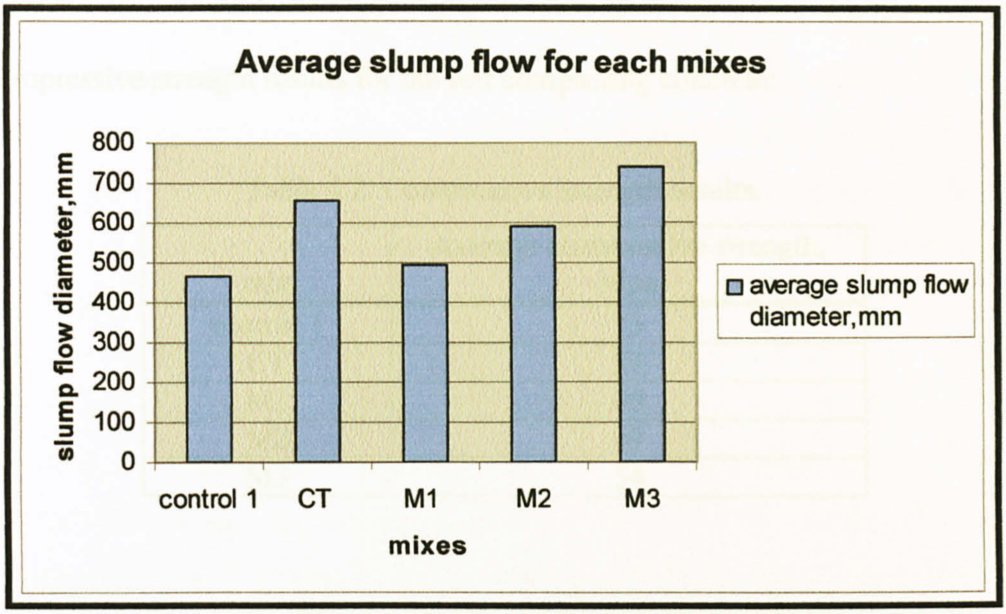
4.1 Slump flow results:

The slump flow results for each mixes can be reviewed as shown below:

Table 4.1: Results of slump flow.

mix no	Set	diameter,mm	average,mm
control-1	1	480	**465**
	2	450	
CT	1	600	**655**
	2	710	
M1	1	400	**495**
	2	590	
M2	1	600	**590**
	2	580	
M3	1	780	**740**
	2	700	

Figure 4.1: Average slump flow for each mixes.



From the slump flow result, it showed that the increased in the water-binder ratio (w/b) will increased the slump flow of the concrete. For control-1, the w/b ratio is 0.25 while for CT; the w/b ratio is 0.32. This is about 14% of water increase compared to the previous one. The reason why the w/b ratio was changed from 0.25 to 0.32 is to make the concrete more flow able and has a high workability as control-1 mix was to stiff and very hard to work on. By changing the w/b ratio to 0.32, the flow ability and the workability of the concrete improved and this has been fixed at constant for the rest of the mix design. From mix 1 (M1) to mix 3 (M3), there is a trend of increasing slump flow result. This is because of the effect of adding some pulverized fuel ash (PFA) into the concrete.

The percentage of PFA added into the concrete is increasing incrementally at 5%. Therefore, 5% of PFA added into mix 1 (M1), 10% for mix 2 (M2) and lastly 15% for mix 3 (M3). The flow ability and workability of the self compacting concrete is improving from M1 to M3 and in the range of the self compacting concrete requirement. In general, increasing 5% of PFA into self compacting concrete will improve the slump flow diameter about 19% to 24%.

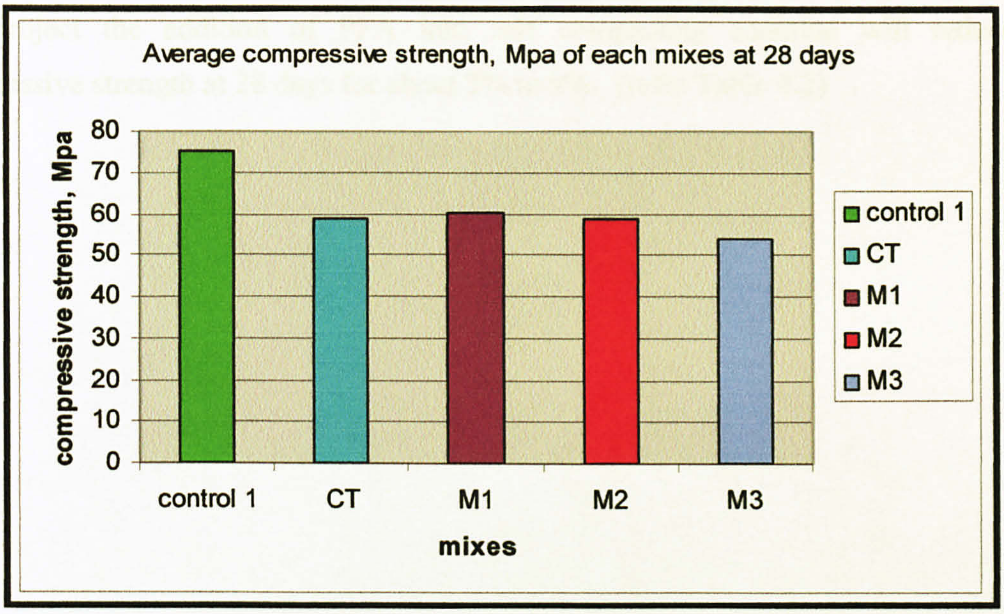
4.2 Compressive strength results:

The compressive strength results for the self compacting concrete:

Table 4.2: Compressive strength results.

mix	Average compressive strength, Mpa
control 1	75
CT	59
M1	60
M2	59
M3	54

Figure 4.2: The compressive strength results at 28 days.



From the graph, the highest average compressive strength for each mixes after 28 days is control 1 at 75 Mpa. For CT, the compressive strength is 59 Mpa while in mix 1 (M1), the compressive strength is 60 Mpa. For M2, the compressive strength is 59 Mpa while M3 is 54 Mpa. In general, the self compacting concrete compressive strength is affected by the amount of cement content in each mix. For control 1 and CT mixes, the total amount of cement in 1 m^3 is 500 kg, while for M1 is 475 kg, M2 is 450 kg and M3 is 425 kg. From the mix design we can see that the amount of cement was reducing and affected the compressive strength. The addition of Pulverized Fuel Ash (PFA) in the concrete did not affecting the compressive strength significantly but contributing to the flow ability and workability of self compacting concrete. The effect of adding PFA into the compressive strength of concrete could not be determine clearly as more compressive strength data should be taken on different age i.e 7 days, 28 days, 56 days. In general, for this project the addition of PFA into self compacting concrete will reduce the compressive strength at 28 days for about 2% to 9%. (refer Table 4.2)

4.3 Pull-out results and bond strength calculation:

Table 4.3: Pull-out results.

Mix	set	dia (mm)	L (mm)	P (kN)	fb (Mpa)
control-1	1	10	240	50.38	6.7
		12	200	81.70	10.8
		16	150	99.46	13.2
	2	10	150	47.19	10.0
		12	180	80.28	11.8
		16	240	121.97	10.1
CT-1	1	10	240	50.00	6.6
		12	200	77.54	10.3
		16	150	74.21	9.8
	2	10	150	50.49	10.7
		12	180	76.85	11.3
		16	240	119.78	9.9
M1	1	10	240	49.37	6.5
		12	200	80.60	10.7
		16	150	85.28	11.3
	2	10	150	49.14	10.4
		12	180	78.24	11.5
		16	240	81.53	6.8
M2	1	10	240	49.92	6.6
		12	200	69.45	9.2
		16	150	73.26	9.7
	2	10	150	49.29	10.5
		12	180	78.79	11.6
		16	240	96.43	8.0
M3	1	10	240	49.51	6.6
		12	200	67.31	8.9
		16	150	93.57	12.4
	2	10	150	49.53	10.5
		12	180	74.40	11.0
		16	240	117.68	9.8

4.4 Bond strength of self compacting concrete on the reinforcement:

Figure 4.3: Bond strength for 16mm reinforcement.

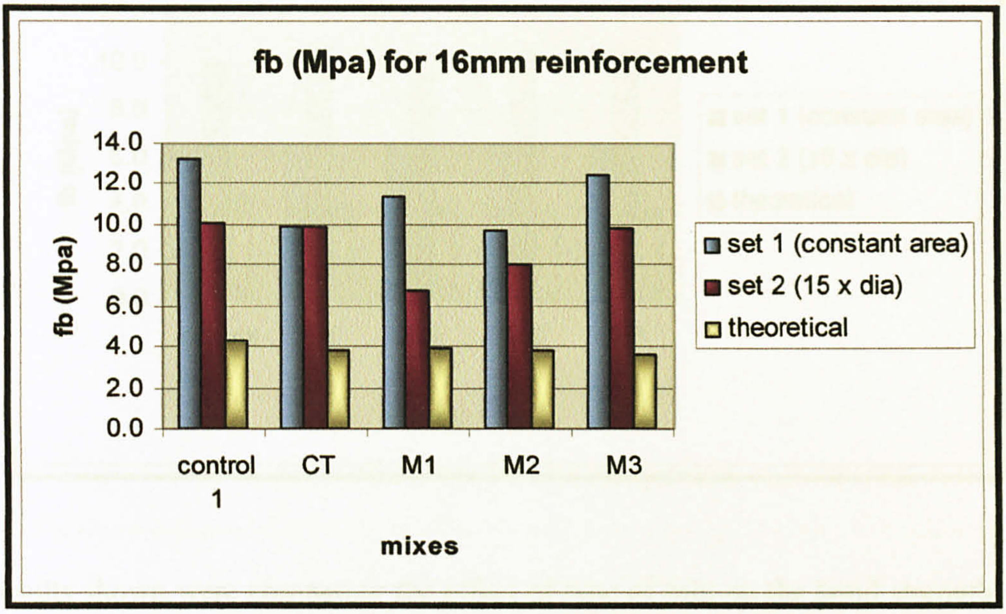


Figure 4.4: Bond strength for 12mm reinforcement.

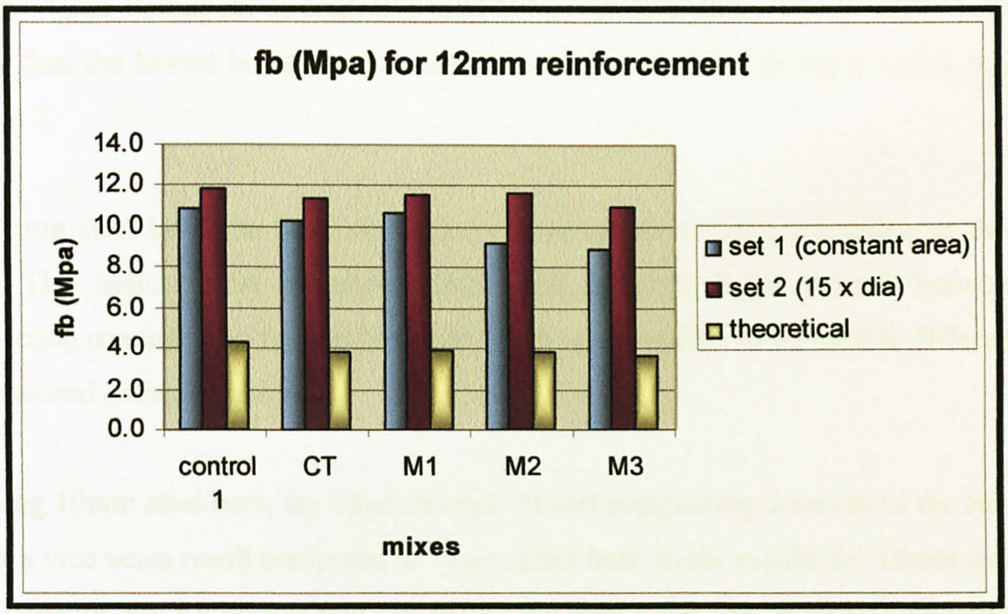
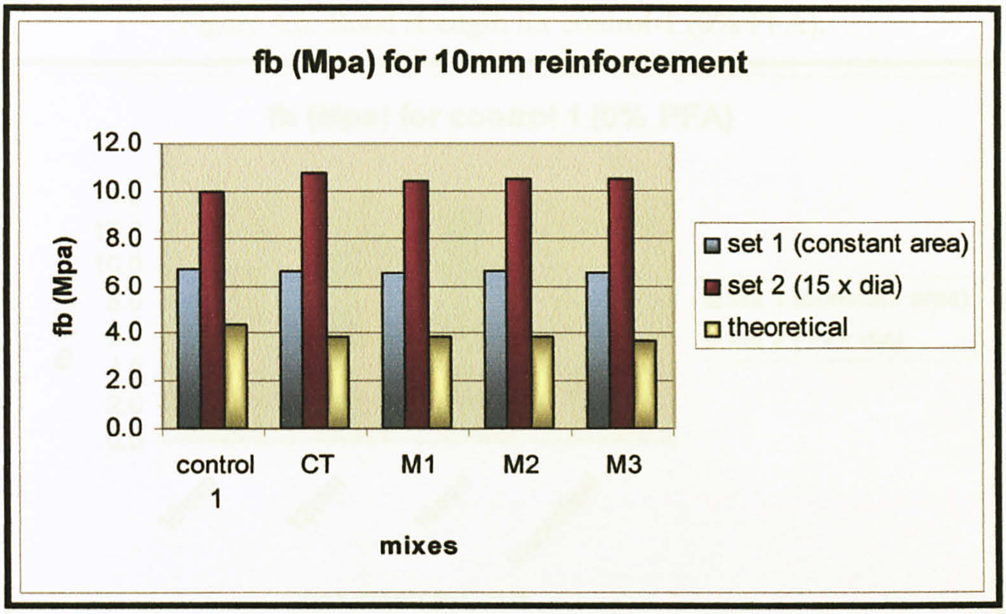


Figure 4.5: Bond strength for 10mm reinforcement.



The results shown were comparing the effect of type of mix on the bond strength of self compacting concrete to the steel bars. For 12mm and 10mm steel bars diameter, set 2 gives better bond strength compared to set 1. For 16mm steel bar, the highest bond strength value was in set 1, control 1 mix, for about 13.2 Mpa. This is about two times higher than the lowest bond strength value for 16mm steel bar diameter which is in mix M1, set 2.

For 12mm steel bars, the bond strength for each mixes and sets are nearly at the same value. This indicate that by using 12mm steel bars, the bond strength between self compacting concrete and the steel bars are much more reliable to be used in different type of mixes and embedment length.

By using 10mm steel bars, the bond strength of self compacting concrete to the steel bars giving a vice versa result compared to 16mm steel bars. In the results for 16mm steel bars bond strength, set 1 with the constant embedded area gives the better value compared to set 2. But in the results for 10mm steel bars, set 2 gives the better bond strength compared to set 1. The bond strength in set 2 gives values around 10.2 Mpa to 10.7 Mpa which were around 60% higher than the bond strength of set 1.

Figure 4.6: Bond strength for control-1 (0% PFA).

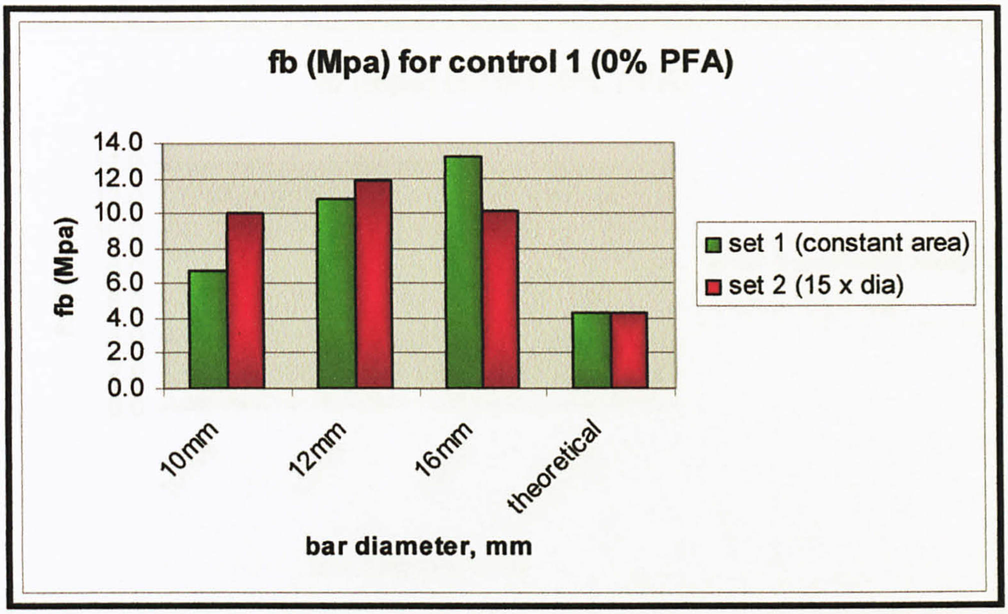


Figure 4.7: Bond strength for CT (0% PFA).

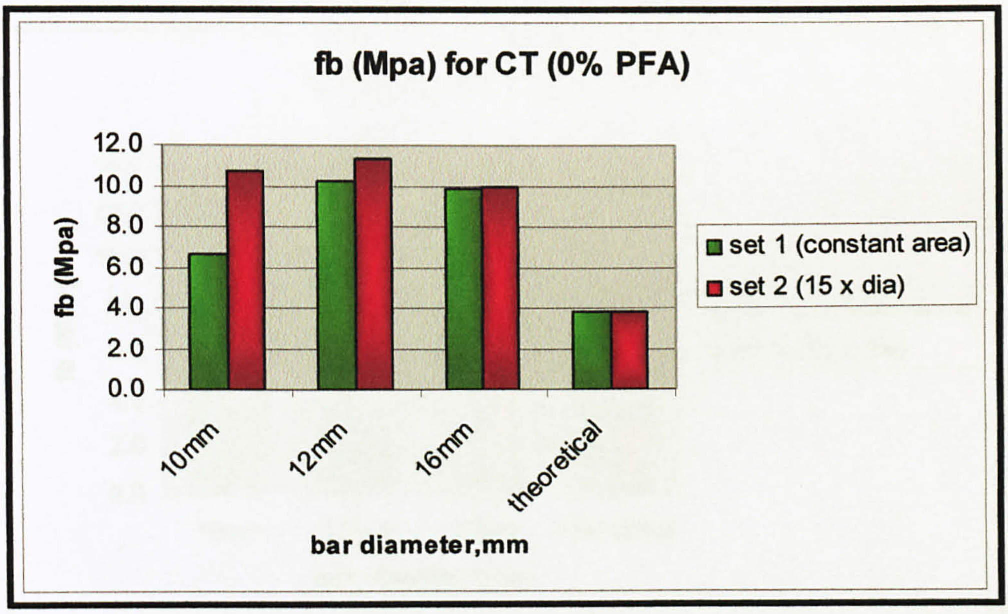


Figure 4.8: Bond strength for M1 (5% PFA).

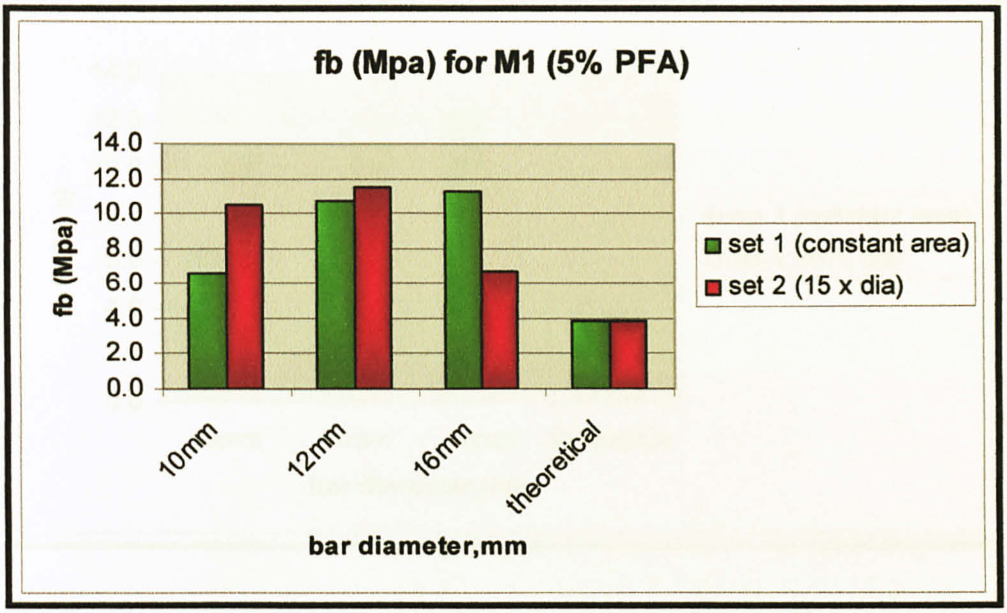


Figure 4.9: Bond strength for M2 (10% PFA).

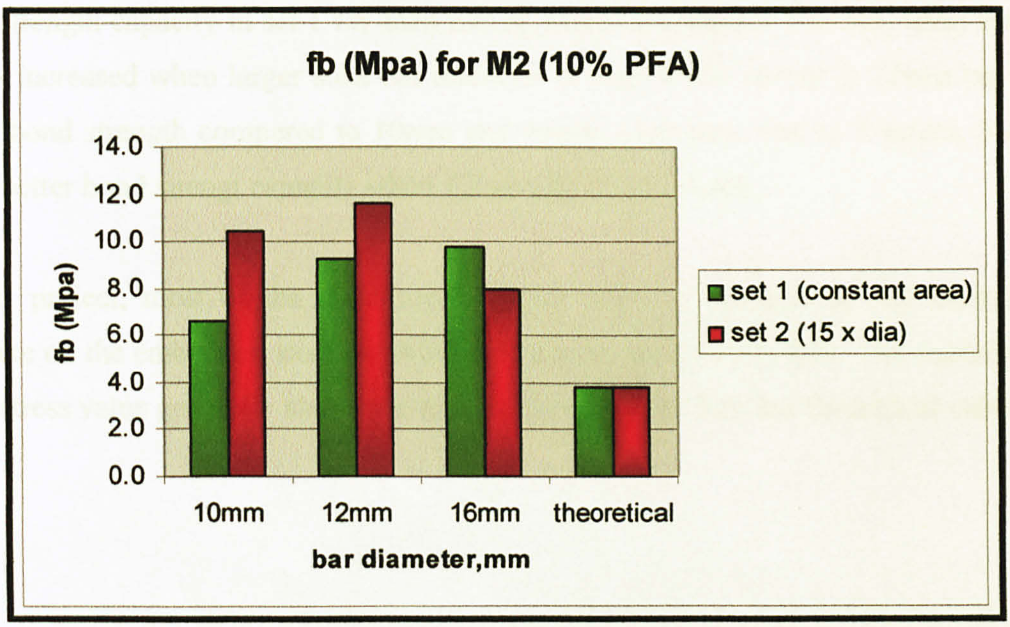
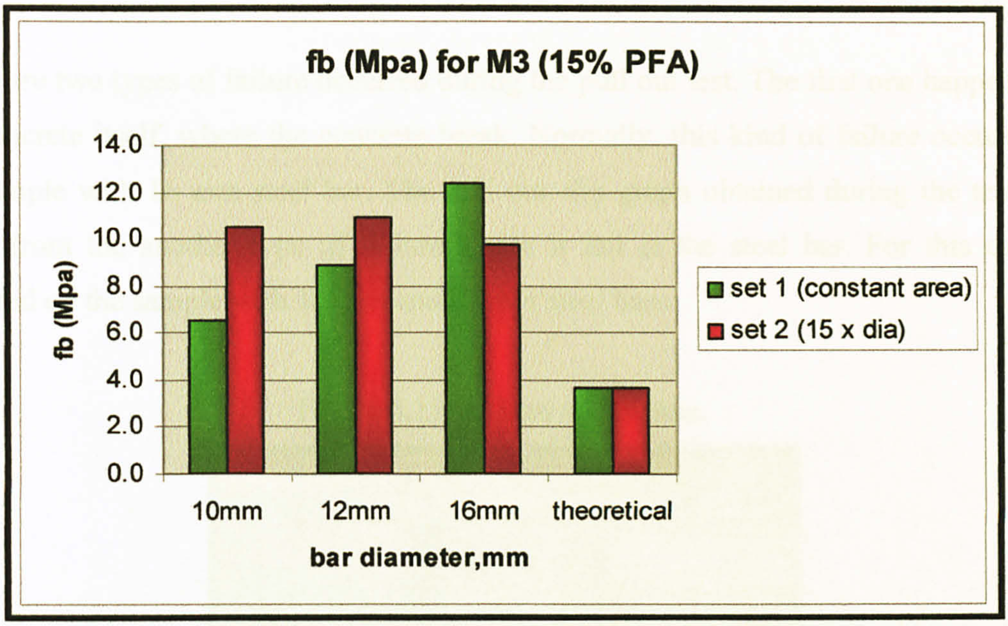


Figure 4.10: Bond strength for M2 (15% PFA).



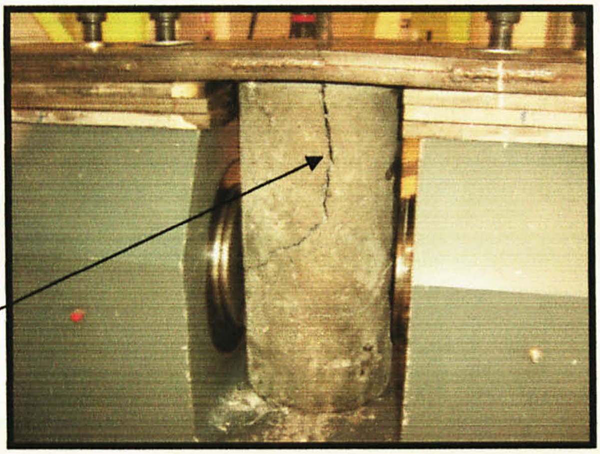
Based on the results, by comparing the effects of bar diameter on the bond strength of self compacting concrete to the steel bars in each mixes, there is a trend of increasing bond strength capacity in set 1 for each mixes. From mix control 1 to M3, bond strength values increased when larger steel bar diameter is used.While for set 2, 12mm bar gives better bond strength compared to 10mm and 16mm steel bars. Out of 5 mixes, 3 mixes gives better bond strengt capacity when 12mm steel bars is used.

In this project, most of the experimental bond stress or strength of self compacting concrete on the embedded steel bar is higher than the theoretical value. The experimental bond stress value generally about two to three times higher than the theoretical value.

4.5 Types of failures:

There are two types of failure occurred during the pull out test. The first one happened to the concrete itself, where the concrete break. Normally, this kind of failure occurred to the sample with 16 mm steel bar. The pull out slip graph obtained during the test also differ from the another type of failure where it fail at the steel bar. For this case, it occurred on the sample with 10 mm and 12 mm steel bars.

Figure 4.11: Failure at concrete.



Failure at concrete

Figure 4.12: Pull out slip graph for failure on concrete.

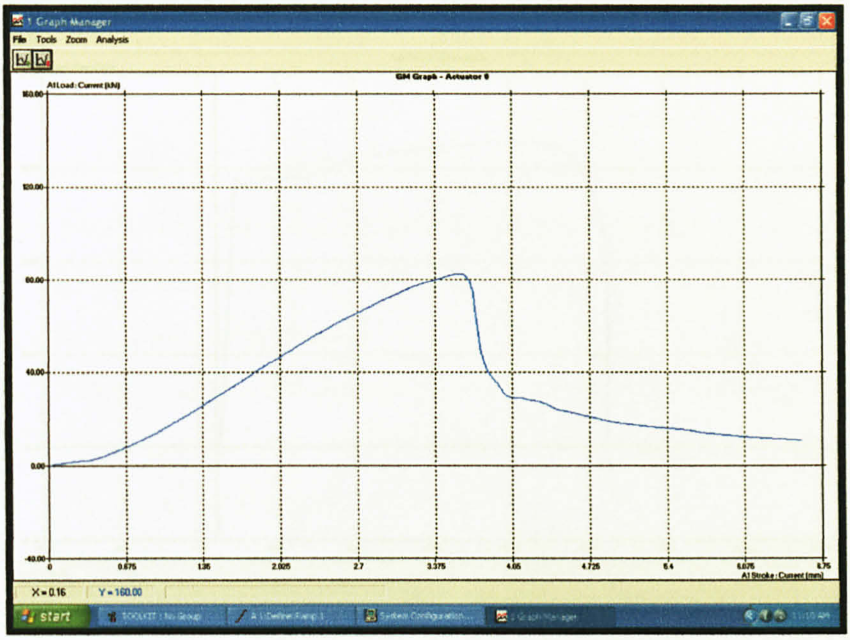
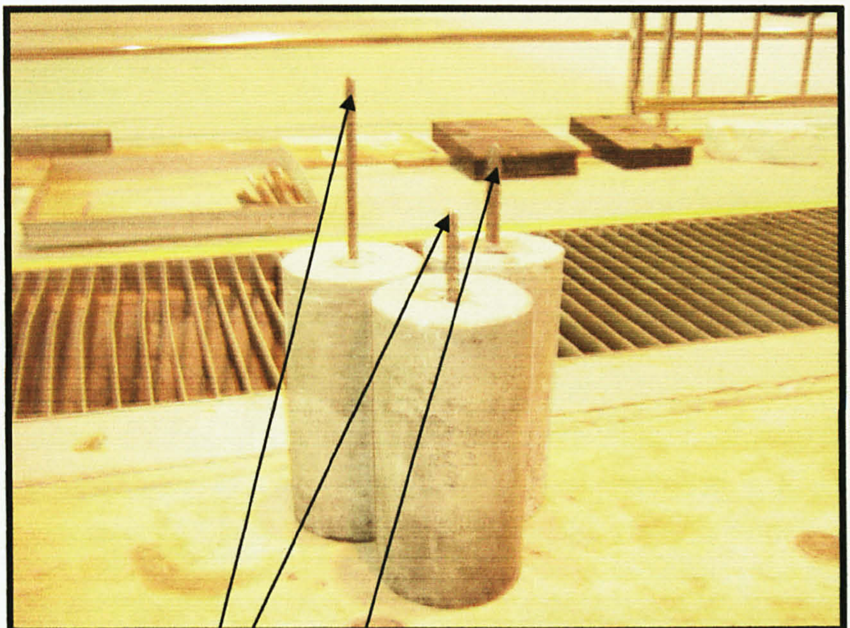
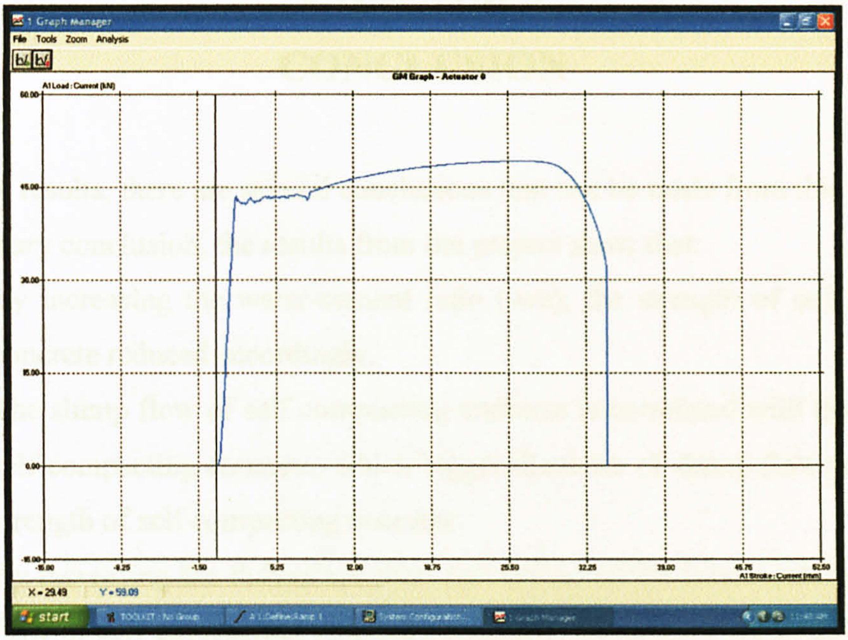


Figure 4.13: Failure at the steel bar.



Failure at steel bars

Figure 4.14: Pull out slip graph for failure at the steel bars.



CHAPTER 5

CONCLUSION

Based on the results, there are several conclusions that can be made from this project. But as a preliminary conclusion, the results from the project show that:

1. By increasing the water-cement ratio (w/c), the strength of self compacting concrete reduced accordingly.
2. The slump flow of self compacting concrete is correlated with the strength of self compacting concrete, which bigger diameter of slump flow will give low strength of self compacting concrete.
3. By increasing the Pulverized Fuel Ash (PFA) of 5% incrementally, the slump flow of self compacting concrete increasing for about 19% to 25%. (mix M1 to M3).
4. The compressive strength of self compacting concrete is correlated to the amount of cement in the mix design which higher strength of concrete obtained when higher amount of cement is used.
5. Pull-out force is higher when 16 mm steel bar is used.
6. Pull-out force is lower when 10 mm steel bar is used.
7. The sample (with constant contact area) which used 16mm steel bars give higher bond strength.
8. The sample (with embedded steel bar length equal to 15 times the diameter of the steel bar) which used 12 mm steel bars gives the higher bond strength.
9. Steel bar of 12 mm diameter gives better bond strength in both set (1 and 2).
10. The experimental bond strength value is about two to three times higher compared to the theoretical bond strength value calculated.

CHAPTER 6

RECOMMENDATIONS

There are several recommendations that can be done to improve the study on the bond strength of self compacting concrete (SCC) to the embedded steel bars and also its performance. The recommendations are:

1. Since the experimental data obtained in this project are two to three times higher compared to the theoretical, therefore there is a need to do extensive research on the formula used in the BS8110: part 1 code. The formula was used to determine the bonding strength of normal concrete and thus for self compacting concrete (SCC), there is a possibility to establish another relationship or formula on its bonding capacity to the embedded steel bar.
2. Using different percentage of Superplasticizer (SP).
3. Different size or type of aggregate can be used to investigate its impact on SCC.
4. By using another type of pozzolan for example silica fume (SF), Rice Husk Ash (RHA), GGBS etc. to compare the significant effects on SCC.
5. The testing age should be in another older age rather than 28 days only. Therefore, to get more accurate results the test can be extended to 56 days, 90 days etc.
6. To use several numbers of embedded steel bars inside the concrete instead of using a single bar.

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APPENDICES

APPENDIX 1: SUMMARY OF RESULTS-PULL OUT TEST

mix	set	diameter, mm	sample	pull out force, kN	average, kN
			1	52.01	
			2	50.6	
		10	3	50.15	**50.38**
			1	80.78	
			2	82.29	
		12	3	81.1	**81.70**
			1	96.63	
			2	102.28	
	1	16	3	79.12	**99.46**
			1	43.89	
			2	?	
		10	3	50.49	**47.19**
			1	78.85	
			2	61.13	
		12	3	81.71	**80.28**
			1	104.13	
			2	121.96	
control-1	2	16	3	121.97	**121.97**
			1	49.98	
			2	50.01	
		10	3	50.62	**50.00**
			1	77.48	
			2	77.6	
		12	3	77	**77.54**
			1	75.72	
			2	72.7	
	1	16	3	121.33	**74.21**
			1	50.29	
			2	50.68	
		10	3	33.1	**50.49**
			1	58.99	
			2	76.93	
		12	3	76.77	**76.85**
			1	119.47	
			2	120.09	
control-1 (CT)	2	16	3	122.32	**119.78**
			1	50.1	
			2	49.32	
		10	3	49.41	**49.37**
			1	80.66	
			2	80.18	
M1	1	12	3	80.54	**80.60**

			1	86.1	
			2	84.45	
		16	3	94.21	**85.28**
			1	19.21	
			2	49.04	
		10	3	49.24	**49.14**
			1	80.87	
			2	78.14	
		12	3	78.33	**78.24**
			1	75.42	
			2	82.61	
	2	16	3	80.44	**81.53**
			1	50.09	
			2	49.75	
		10	3		**49.92**
			1	57.41	
			2	81.48	
		12	3		**69.45**
			1	80.62	
			2	65.9	
	1	16	3		**73.26**
			1	49.82	
			2	48.76	
		10	3		**49.29**
			1	79.59	
			2	77.98	
		12	3		**78.79**
			1	94.82	
			2	98.03	
M2	2	16	3		**96.43**
			1	48.6	
			2	50.41	
		10	3		**49.51**
			1	57.17	
			2	77.44	
		12	3		**67.31**
			1	85.25	
			2	101.88	
	1	16	3		**93.57**
			1	49.06	
			2	49.99	
		10	3		**49.53**
			1	70.79	
			2	78.00	
		12	3		**74.40**
			1	122.39	
			2	112.96	
M3	2	16	3		**117.68**

			1	86.1	
			2	84.45	
		16	3	94.21	**85.28**
			1	19.21	
			2	49.04	
		10	3	49.24	**49.14**
			1	80.87	
			2	78.14	
		12	3	78.33	**78.24**
			1	75.42	
			2	82.61	
	2	16	3	80.44	**81.53**
			1	50.09	
			2	49.75	
		10	3		**49.92**
			1	57.41	
			2	81.48	
		12	3		**69.45**
			1	80.62	
			2	65.9	
	1	16	3		**73.26**
			1	49.82	
			2	48.76	
		10	3		**49.29**
			1	79.59	
			2	77.98	
		12	3		**78.79**
			1	94.82	
			2	98.03	
M2	2	16	3		**96.43**
			1	48.6	
			2	50.41	
		10	3		**49.51**
			1	57.17	
			2	77.44	
		12	3		**67.31**
			1	85.25	
			2	101.88	
	1	16	3		**93.57**
			1	49.06	
			2	49.99	
		10	3		**49.53**
			1	70.79	
			2	78.00	
		12	3		**74.40**
			1	122.39	
			2	112.96	
M3	2	16	3		**117.68**

not included

APPENDIX 2: COMPRESSIVE STRENGTH RESULTS

mix	set	sample weight, kg 1	2	3	average weight, kg	sample compressive stress, Mpa 1	2	3	averege compressive stress, Mpa	average compressive stress for each mix, Mpa
control-1	1	8.15	8.43	8.24	8.27	80.59	71.02	80.73	77.45	
	2	8.26	8.2	8.25	8.24	58.13	82.27	75.23	71.88	75
CT	1	8.25	8.12	8.05	8.14	51.67	64.09	65.11	60.29	
	2	7.97	7.95	7.92	7.95	55.65	57.95	62.43	58.68	59
M1	1	8.18	8.12	8.1	8.13	65.65	70.55	69.83	68.68	
	2	8.08	8.02	8.09	8.06	49.21	50.66	54.47	51.45	60
M2	1	7.78	7.61	7.95	7.78	56.48	47.35	59.24	54.36	
	2	7.93	8.04	7.92	7.96	64.63	64.63	64.63	64.63	59
M3	1	7.96	7.87	7.99	7.94	53.83	53.83	53.83	53.83	
	2	8.1	8.02	7.87	8.00	54.69	54.69	54.69	54.69	54

APPENDIX 3: THEORETICAL BOND STRENGTH VALUE

from BS 8110 :part 1

$$fb=0.5(fcu)^{0.5}$$

mix	average compressive strength, fcu (Mpa)	fb
control 1	75	4.33
CT	59	3.84
M1	60	3.87
M2	59	3.84
M3	54	3.67

APPENDIX 4: SAMPLE RESULT FOR 16 MM STEEL BAR (M3-SET 1)

WORKSHOP 3 EXPORTED DATA: [C:\Workshop 96 lama\agus-dominic\mix3 - set1_16mm-1.W01 - 1]

****

Source of data:

WS3 File Version: 1.05

Number of bytes in subfile: 1209

Total number of data points: 69

Test date: 28/04/2009

Test time: 09:03:33

Player Step: 1

Step Capture No: 1

Actuator: 1

****

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:2
A1 Load : Current (kN)	A1 Stroke : Current (mm)	Time (s)
-0.07	0.00	0.266
-0.06	0.01	0.532
-0.04	0.01	0.813
-0.01	0.01	1.094
0.02	0.01	1.360
0.06	0.01	1.641
0.12	0.01	1.938
0.17	0.02	2.219
0.23	0.02	2.500
0.29	0.02	2.766
0.38	0.02	3.063

0.47	**0.03**	**3.344**
0.57	**0.03**	**3.625**
0.68	**0.03**	**3.891**
0.81	**0.03**	**4.188**
0.96	**0.04**	**4.469**
1.18	**0.04**	**4.735**
3.80	**0.08**	**5.000**
15.61	**0.25**	**5.297**
25.32	**0.40**	**5.579**
33.15	**0.53**	**5.860**
39.38	**0.64**	**6.141**
44.18	**0.73**	**6.422**
47.63	**0.81**	**6.688**
51.19	**0.89**	**6.969**
54.46	**0.95**	**7.235**
57.03	**1.01**	**7.500**
60.24	**1.08**	**7.797**
62.88	**1.14**	**8.094**
65.41	**1.19**	**8.360**
67.53	**1.25**	**8.625**
69.89	**1.30**	**8.891**
72.16	**1.36**	**9.172**
74.33	**1.42**	**9.438**
76.42	**1.48**	**9.704**
78.43	**1.53**	**9.985**
80.00	**1.58**	**10.250**
81.67	**1.64**	**10.516**
83.16	**1.70**	**10.782**
84.26	**1.75**	**11.047**
85.25	**1.80**	**11.313**
84.37	**1.86**	**11.594**

43.28	1.93	11.875
40.29	2.00	12.141
37.03	2.05	12.407
33.70	2.11	12.688
31.32	2.18	12.969
29.92	2.23	13.235
28.64	2.29	13.500
26.86	2.35	13.766
23.63	2.39	14.032
20.82	2.45	14.313
18.69	2.52	14.594
16.01	2.58	14.860
13.70	2.63	15.125
12.29	2.68	15.391
10.00	2.74	15.672
8.64	2.79	15.938
7.88	2.85	16.219
7.33	2.91	16.485
6.90	2.96	16.750
6.40	3.02	17.016
6.06	3.08	17.282
5.58	3.13	17.563
5.34	3.18	17.829
5.07	3.24	18.110
4.71	3.30	18.391
4.29	3.34	18.657
3.77	3.38	18.922

APPENDIX 5: GRAPH FOR SAMPLE IN APPENDIX 4