Effect of Inorganic Compound on the Tensile Strength of Ordinary Portland Cement (OPC) Concrete

by

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Final Report submitted in partial fulfillment of
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Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

EFFECT OF INORGANIC COMPOUND ON THE TENSILE STRENGTH OF ORDINARY PORTLAND CEMENT (OPC) CONCRETE

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

Victor R. Macam Jr.
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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2008

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.

MOHAMAD ARIF BIN ABDILAH

ABSTRACT

This project which is entitled **Effect of Inorganic Compound on the Tensile Strength of Ordinary Portland Cement (OPC) Concrete** clearly comes with its main objective(s) that is to produce the OPC concrete that has higher tensile strength as it is generally known that concrete is strong in resisting compressive force and weak in resisting tensile stress. Dow Corning DC520 Silane (water based emulsion) is chosen to be the inorganic compound that is incorporated in the concrete mix and its implications towards the concrete tensile strength and other performances are going to be discussed in this report. The failure mechanism of concrete and theories to rectify the failure occurrences in the concrete is discussed and explained in this report. Every step taken in undertaking this respective project are explained in details and that includes the literature review, planning and scheduling, experimental programs and laboratory tests as in split tensile test and compression test. The conclusion section summarized all the findings from this project while the recommendation section will recommend the suitable measures in a way to improve this project and probably to make sure the objective is met.

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ABBREVIATIONS AND NOMENCLATURES

OPC	Ordinary Portland Cement
SCA	Silane Coupling Agent

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is well-renowned for its attribute that is "strong in resisting compressive force and weak in resisting tensile force". As a matter of fact, there were many studies been conducted in determining the reasons behind the weaknesses of concrete in resisting tensile force. As a result, researchers had come with their respective ideologies pertaining this respective phenomenon.

There is general agreement about the importance of the matrix-aggregate bond in the concrete. It is known that the transition zones (interfaces) are the weakest link of the composite material, playing a very important role in the process of concrete failure, as crack growth usually starts at the matrix-aggregate interfaces. Generally, the critical interfaces are those between coarse aggregate and mortar.

Crack propagation usually starts at the interfaces, and the cracks grow through the matrix. Coarse aggregates arrest crack growth, producing meandering and branching of cracks, and some particles are fractured. This mechanism depends greatly on the characteristics of the aggregate, especially surface texture and shape, and on the strength differences between aggregates and matrix. Thus, the type of coarse aggregate is one of the most important variables affecting the behavior of high strength concretes (HSC) [1].

In summary, as far as this project is concern there are two distinctive factors (failure mechanism) that are associated with the failure of concrete, namely:

- Transition zones (interfaces)
- Characteristics of the aggregates

It has been reported that there were many attempts on modifying the composition in concrete mix as in adding admixtures, and altering the attributions of coarse aggregates in a way to obtain as perfect adhesion as possible between the cement paste and aggregates in the concrete mixture .Thus, this project respectively comes with an initiative to produce a concrete mix that has a perfect adhesion between cement paste and aggregates which will lead to a concrete that possesses the attribution of 'high in resisting both compression and tensile force'.

1.2 Problem Statement

Concrete has a highly heterogeneous and complex structure. At the macroscopic level concrete may be considered to be a two-phase material, consisting of aggregate particles dispersed in a matrix of cement paste. At the microscopic level, a third phase – the transition zone – may be identified [2]. This transition zone exists as a thin shell, called the interfacial transition zone (ITZ), between aggregate particles and hydrated cement paste (HCP).

G.Giaccio and R.Zerbino had postulated that the transition zones (interfaces) are the weakest link of the composite material, playing a very important role in the process of concrete failure, as crack growth usually starts at the matrix-aggregate interfaces. Generally, the critical interfaces are those between coarse aggregate and mortar.

Therefore this project is carried out to modify the transition zones of the concrete by introducing Silane Coupling Agent (SCA) that is believed, capable of increasing the bond strength and durability of concrete by providing the chemical bridge to connect the inorganic materials in the concrete (such as cement paste and stone).

1.3 Objective of Research

The main objective(s) of this research are:

i) To experiment the effect of incorporating DC520 (Silane-water based emulsion) in the concrete mix, on the tensile strength of Ordinary Portland Cement (OPC) concrete.
ii) To determine the optimum mix design (coarse aggregate size and concentration of SCA that is used for coating the aggregate) of Ordinary Portland Cement (OPC) concrete treated with SCA, that produces the best strength performance.

The scope of study for this project includes the following:

i) Conducting research through journals and books published which are closely related to OPC concrete properties and DC520 (Silane-water based emulsion)

.

ii) Laboratory experimental assessment towards the properties of concrete incorporated with DC520 (Silane-water based emulsion) .Generally, the tests are split tensile test and compression test with static loads.

1.4 Scope of Research

The scope of work for this research is to investigate the tensile strength of Ordinary Portland Cement (OPC) concrete when its designed mix is incorporated with DC520 (Silane-water based emulsion). Concrete samples will be produced with certain parameters manipulated accordingly, and the control mix will be produced as it will be compared to the concrete samples.

Tests that are going to be conducted for this research are:

i) **Compression test** - a concrete cylinder is placed with its axis vertical between the platens of a testing machine, and the load is increase until failure by indirect tension in the form of cracking along the vertical height takes place.

ii) **Splitting tension test** – a concrete cylinder is placed with its axis horizontal between the platens of a testing machine, and the load is increase until failure by indirect tension in the form of splitting along the vertical diameter takes place.

CHAPTER 2

LITERATURE REVIEW

2.1 What is Concrete?

By definition, concrete is a structural masonry material made by mixing broken stone or gravel with sand, cement, and water and allowing the mixture to harden into a solid mass. Concrete solidifies and hardens after mixing and placement due to a chemical process whereby water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. The strength, durability and other characteristics of concrete depend upon the properties of its ingredients, the properties of the mix, the method of compaction and other controls during placing, compaction and curing. [3]

In the most general sense of the word, cement is a binder, a substance which sets and hardens independently, and can bind other materials together. The cement commonly used is Portland cement. Portland cement produced by intimately mixing together calcareous and argillaceous or other silica, alumina and iron oxide bearing materials, burning them at a clinkering temperature and grinding the resulting clinker.[3] Out of number of types of Portland cement, Ordinary Portland Cement (OPC) will be used throughout this project.

Ordinary Portland Cement has a medium rate of hardening and is suitable for most type of work. It is the one most commonly used for structural purposes when the special properties specified for other types of Portland cement are not required. [3]

2.2 Concrete Constituents

Concrete is made by mixing cement, water, and coarse and fine aggregates. The aim is to mix these materials in measured amounts to make concrete that is easy to transport, place, compact and place which will set, and harden to give strong and durable product. The amount of each material affects the properties of hardened concrete and as for this particular research's interests; it is more towards foreseeing the effect of each constituents to the tensile strength of concrete.

Cement is mixed with water and forms a paste. The paste acts like a glue and holds or bonds the aggregates together. As the cement content increases, so does strength and durability. Therefore to increase the concrete strength, increase the cement content of a mix [4].

Water is an important parameter for concrete. The principal reason for using water with cement is to cause hydration of cement. Water added in excess of hydration requirements will penetrates into the innumerable minute surface irregularities of sand and aggregate, bringing them into close adhesion. Besides functioning as a folding agent, water also enables the chemical reaction which cause setting and hardening and also to lubricate the mixture of fine and coarse aggregates and cement in order to facilitate placing [3].

Aggregate in concrete is a mass of particles which are suitable for resisting action of applied load, abrasion and percolation of moisture and the action of weather. It has been reported earlier in this report that aggregate surface texture is one of the most important factors affecting bond strength; rough surfaces usually have a higher bond than sawn surfaces. In addition, in the composite many characteristics of the aggregates affect properties in fresh concrete, which later will modify the behavior of hardened concrete [4].

2.3 Interfacial Transition Zone (ITZ)

In general, concrete is a material that comprise of three phases namely; the mortar, the aggregate and the Interfacial Transition Zone (ITZ) between the mortar and the aggregate. ITZ, which is structurally and mechanically different than the matrix, plays a critical role in determining the mechanical properties and failure behavior of concrete composites. The properties of the aggregates (type, shape, surface conditions, etc.), cement and admixtures and particularly the water-to-cement (w/c) ratio of the mixture are the main factors that form the structure of ITZ and thus its properties [6].

There is a general agreement about the importance of the ITZ region where it is notified as the weakest link of the composite material, playing a very important role in the process of concrete failure, as crack growth usually starts at the matrix-aggregate interfaces [1].

2.4 Strength of Concrete

Strength of concrete is commonly considered as its most valuable property, other than durability and impermeability. Nevertheless strength of concrete usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hardened cement paste. The strength of concrete is defined as the maximum stress it can resist or the maximum load it can carry (A. M. Neville, 2002).

The strength of concrete is further classified based on two (2) distinctive attribute:

a) Compressive strength signifies on the maximum load the concrete can carry. Cubes, cylinders and prisms are the three types of compression test specimens used to determine the compressive strength.
b) Tensile strength signifies on the maximum tensile stress the concrete may resists. Normally, tensile strength of concrete is only 5-10% of its compressive strength.

2.5 DC520 (Silane-water based emulsion).

DC520 (Silane-water based emulsion) is high purity, undiluted Isobutyltriethoxy-silane. When diluted with water, it can be used in the formulation of water repellent products. Upon proper application, the formulated product will penetrate and provide water repellence by chemically reacting with cementitious substrate. Treated substrates are hydrophobic and retain their original appearance. DC520 (Silane-water based emulsion) is a small molecule that allow for deep penetration into the cementitious surface. This material reacts with moisture in the air and in substrate in the presence of an alkaline or acidic environment to produce hydroxy groups. These hydroxy groups will bond with the substrate and itself to produce a hydrophobic treatment that inhibits water absorption into the substrates. An alkaline environment, such as new concrete, will catalyze the reaction and speed the formation of the hydrophobic surface.

Follows are the typical properties DC520 (Silane-water based emulsion).

Property	Result	Unit
Color	Milky white	
Non-Volatile Content	40	%
Volatile Organic Content (VOC)	<300	g/L
pH	4.5	
Density	8.216	lb/gal
Solvent (thinner)	Water	

Table 1: Properties of DC520 (Silane –water based emulsion)

2.5.1 Silane Coupling Agent (SCA)

Silane coupling agent (SCA) is a kind of auxiliary for modifying the interfacial layers of composites. SCA molecules have multifunctional groups with a general chemical formula of R-SiX_3 (*see figure 1.0)* where X stands for hydrolyzable groups bonded to Si, and R is a resin-compatible group.

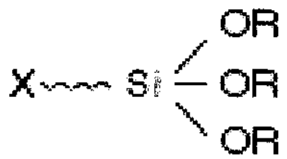

Figure 1.0 Chemical Structure of Silane

X represents the functional group that reacts with organic materials like synthetic resins and may be selected from the following types of functional groups namely; vinyl, epoxy, amino, methacryl, acryl, isocyanato, and mercapto.

OR represents the functional group that reacts with inorganic materials like glass, metals, and silica and may be selected from the following types of functional groups namely; methoxy group, ethoxy group, and acetoxy group.

SCA is commonly used to significantly increase the bond strength and durability by providing the chemical bridge to connect the inorganic material (especially silicon-containing materials) and resin. According to the experience of composite technology, concentration of SCA aqueous solutions has a significant influence on the bond strength of composites. On the one hand, an aqueous SCA solution with a very low concentration may be not enough to create a SCA network that fully covers the surface of an inorganic material, resulting in lower bond strength. On the other hand, an aqueous SCA solution with a very high concentration may induce a multiple molecular layer on the surface, creating a porous physically absorbent layer, leading to much lower bond strength [5].

In 1999, Ma has coated the surface of marble specimens with styrene-butadiene resin emulsion, or KH-550, KH-560, KH-570 SCA solutions separately, before applying cement mortar. Splitting tensile test was conducted and the result showed that the modified interfacial layers were 27%, 57%, 69% and 84% higher than that control specimens respectively. Xiong in 2004 stated that, SCA can noticeably improve the microstructures of cement hydrates in the ITZ. The modifying mechanism of the ITZ using SCA is worth further investigated.

It is assumed that, ITZ region is weak when there is pore that makes the adhesion between cement pastes and aggregates loose. The presence of pore is originated from the water attached at the aggregate's surface. During hydration process, the respective water is being absorbed by cement during hydration process and eventually the pore formed. Sustaining to this matter, SCA is introduced in the concrete mixture to be coated on the aggregate's surface in a hope to make the aggregate hydrophobic, which by the possibility of the pore exists can be reduced.

CHAPTER 3

METHODOLOGY

3.1 Introduction

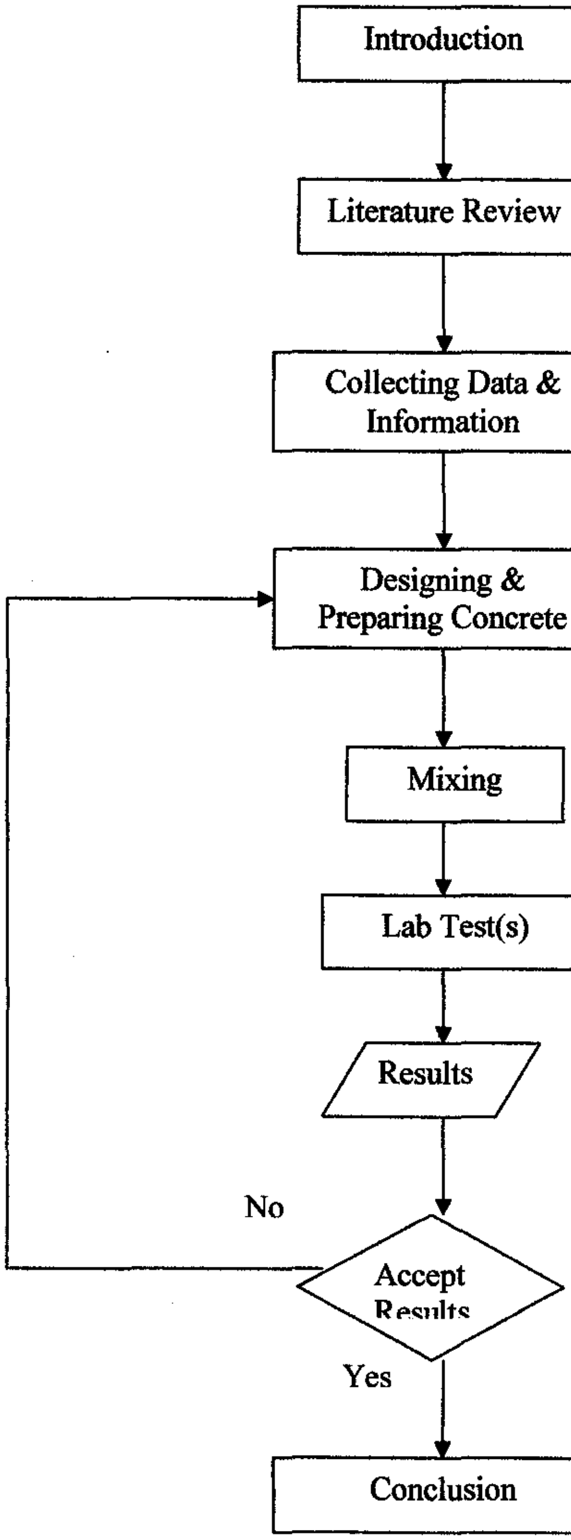

Figure 2.0 *Flow Chart of Research Methodology*

3.2 Concrete Mix using Silane Coupling Agent (SCA) Treated Aggregate with Size of 20mm, 14mm and 10mm.

This experiment is particularly to ascertain the early hypothesis of producing concrete with higher tensile strength by making the aggregate hydrophobic so that the presence of pore can be reduced. Design mix for every mixing was calculated based on BS1881 and the target strength is 30N/mm^2 at 28 days of strength. The procedures of the concrete manufacturing were the same as the normal practice. However, what differs this particular mix with the normal mix is the aggregate being coated with SCA before mixing took place.

3.2.1 Planning and details

Main tests	: Compression and tensile tests
Additional tests	: Slump test,
Sample	: Concrete grade 30
Size of sample	: Cylinder (100 mm x 200 mm)
Test days	: 2nd day, 7th day, 28th day
No of samples	: Control Mix (18 samples); SCA (54 samples)

Compression test

Coarse Aggregates : 10 mm			
	Test Days		
Concrete Samples	2nd	7th	28th
Control Mix	1	1	1
SCA	3	3	3
Coarse Aggregates : 14 mm			
	Test Days		
Concrete Samples	2nd	7th	28th
Control Mix	1	1	1
SCA	3	3	3
Coarse Aggregates : 20 mm			
	Test Days		
Concrete Samples	2nd	7th	28th
Control Mix	1	1	1
SCA	3	3	3

Tensile test

Coarse Aggregates : 10 mm			
Concrete Samples	Test Days		
	2^{nd}	7^{th}	28^{th}
Control Mix	1	1	1
SCA	3	3	3
Coarse Aggregates : 14 mm			
Concrete Samples	Test Days		
	2^{nd}	7^{th}	28^{th}
Control Mix	1	1	1
SCA	3	3	3
Coarse Aggregates : 20 mm			
Concrete Samples	Test Days		
	2^{nd}	7^{th}	28^{th}
Control Mix	1	1	1
SCA	3	3	3

3.2.2 Experimental programme

The sample preparation procedure is divided into several phases:

Sieving the aggregates

Preparing aggregates to achieve SSD (Saturated Surface Dry)

Coating aggregates with DC520 (Silane-water based emulsion)

Concrete Mix (18 samples for each coarse aggregates size)

Slump test

Casting & Curing

Compression & Tensile Test (2^{nd}, 7^{th}, 28^{th} days)

3.2.3 Variables

Three (3) sizes of coarse aggregates were used namely 10mm, 14mm and 20mm in a way to find the aggregate size in the concrete design mix that exhibit the highest tensile strength

3.2.4 Materials used

Ordinary Portland cement was used in this research. Crushed stone with size 10mm, 14mm and 20mm and medium river sand with a fineness modulus of 2.44 were used for making concrete and repair mortar, respectively. DC520 (Silane-water based emulsion) is mixed with water and the solution will was used to coat the aggregate. The mix ratios of this solution was 1:4 (Silane: Water) by volume.

3.2.5 Concrete Mix Design

The British Method of Normal Concrete Mix Design (Department of Environment, 1988) is being used throughout this project to produce the concrete samples. Applying the British Method, there are numbers of specified variables accordingly that are determined beforehand, namely:

- Characteristic Strength : __mm^2 at 28 days with proportion defective of __ %.
- Cement type : OPC (Ordinary Portland Cement)
- Maximum free water ratio : __:__
- Slump : __-__mm
- Maximum aggregate size : __mm
- Minimum cement content : __kg/m^3.

3.2.5.1 Stage 1

Then, according to these specified variables, the design is embarked with Stage 1 of the design. As for the standard deviation, the value is obtained from the table of relationship between standard deviation and characteristic strength.

As for the margin, for the value of k it corresponds to the value of proportion defective:

$$\textbf{margin} = k \, x \, s$$

Then , the target mean strength is calculated:

$$f_m = f_c + k*s$$

3.2.5.2 Stage 2

Moving to Stage 2 of the design the free water content is determined in accordance to the value of slump and maximum uncrushed aggregate size.

3.2.5.3 Stage 3

Next, to determine the cement content, the following formula is used:

Cement content = (free- water content) / (free- water/ cement ratio)

3.2.5.4 Stage 4.

At this stage, the value the value of the relative density of aggregate (SSD) is assumed. From the value of the relative density of aggregate (SSD) the value of the concrete density is determined.

Then using this formula, we can compute the total aggregate content:

$$\textit{Total aggregate content} = D - W_c - W_{fw}$$

Where: D , wet density of concrete (kg/m³)

W_c , cement content (kg/m³)

W_{fw} , free- water content (kg/m³)

3.2.5.4 Stage 5

The corresponding value of fine and coarse aggregate is determined.

Fine aggregate content = Total aggregate content x proportion of fines

Coarse aggregate content = Total aggregate content – fine aggregate content

3.2.5.6 Design mix for concrete mix using 10, 14, and 20 mm coarse aggregate.

Coarse aggregates : 10mm				
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Per m³ (to nearest 5 kg)	425	235	735	975
Per trial mix of 0.034 m³	14.45	7.79	25	33.15
Coarse aggregates : 14mm				
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Per m³ (to nearest 5 kg)	400	220	690	1030
Per trial mix of 0.034 m³	13.6	7.49	23.5	36.72
Coarse aggregates : 20mm				
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Per m³ (to nearest 5 kg)	375	205	625	1210
Per trial mix of 0.034 m³	12.15	6.97	21.25	41.14

Table 2: Design mix for concrete mix using 10, 14, and 20 mm coarse aggregate

3.2.6 Manufacture of test specimens

Coarse aggregates were sieved by using sieve machine to obtain 10mm, 14mm and 20 mm coarse aggregates. Those aggregates are then being washed and soaked into water for a day. Subsequently, the aggregates were allowed to dry on its own under constant temperature (±27 ^{0}C) for a day to achieve SSD condition. Then the designing, proportioning and quantifying works were done before the mixing. Just before the mixing took place, the coarse aggregate were coated with the solution of Dow Corning DC520 (Silane water-based emulsion) which was diluted with water beforehand. Next, the coated aggregates were dried under constant temperature (±27 ^{0}C) for 2 hours. The mixture of Silane and water is mixed by a ratio of 1:4 (Silane: Water) by volume. The concrete samples were casted into cylinder-shaped and 100 mm x 200 mm sized moulds. A vibrating table was used to compact the concrete. Full compaction was considered to have been achieved when air bubbles stopped appearing on the concrete surface. After vibrating, the concrete surface was finished smooth using a metal float and then covered with a polythene sheet to prevent evaporation of water from the concrete. The moulds were stripped next day and the hardened concrete samples were placed in the curing tank.

3.3 Mortar Mix using Silane Coupling Agent (SCA) Treated Aggregate with Different Mix Ratio between Silane and Water.

This experiment is particularly to determine the optimum concentration of Silane solution that is used to coat the aggregate which will produce concrete with highest tensile strength. Silane is diluted with water by three different mix ratios (Silane: Water) namely, (1:4), (1:8) and (1:12).

3.3.1 Planning and details

Main tests	: Compression (C) and tensile (T) tests
Additional tests	: Sieve Analysis, Silt Test
Sample	: Mortar
Size of sample	: Cylinder (60 mm x 120 mm)
Test days	: 2nd, 7th, 28th, 60th, 90th, 180th, 360th day.
No of samples	: Control Mix (42 samples); SCA (126 samples)

Days of Strength	Control		1:4		1:8		1:12	
	C	T	C	T	C	T	C	T
3	3	3	3	3	3	3	3	3
7	3	3	3	3	3	3	3	3
28	3	3	3	3	3	3	3	3
60	3	3	3	3	3	3	3	3
90	3	3	3	3	3	3	3	3
180	3	3	3	3	3	3	3	3
360	3	3	3	3	3	3	3	3
Total	21	21	21	21	21	21	21	21

3.3.2 Experimental programme

The sample preparation procedure is divided into several phases:

Sieving the aggregates

↓

Preparing aggregates to achieve SSD (Saturated Surface Dry)

↓

Coating aggregates with DC520 (Silane-water based emulsion)

↓

Mortar Mixing (42 samples for each Silane: Water ratio)

↓

Casting & Curing

↓

Compression & Tensile Test (2^{nd}, 7^{th}, 28^{th}, 60th, 90th, 180th, 360th days)

3.3.3 Variables

Aggregates were coated with the mixture of Silane and water and the mix ratio between both substances were varied (Silane: Water) 1:4, 1:8, and 1:12 to determine which mix ratio produce the best coating to the aggregates.

3.3.4 Materials used

Ordinary Portland cement was used in this experiment. Aggregates with size gaping from 10 mm -0.35mm were used for making mortar, respectively. The solution of DC520 (Silane-water based emulsion) which was mixed with water in three (3) different mix ratios was being used acting as coating material.

3.3.5 Mortar Mix Design

The design mix for this experiment is based on the ratio of 2:1 where two part of aggregate with one part of cement and water to cement ratio of 0.35.

3.3.6 Manufacture of test specimens

Coarse aggregates were sieved by using sieve machine to obtain aggregates with size gaping from 10mm – 0.35mm. Those aggregates are then being washed and soaked into water for a day. Subsequently, the aggregates were allowed to dry on its own under constant temperature (±27 ^{0}C) for a day to achieve SSD condition. Then the designing, proportioning and quantifying works were done before the mixing. Just before the mixing took place, the coarse aggregate were coated with the solution of Dow Corning DC520 (Silane water-based emulsion) which was diluted with water beforehand. Next, the coated aggregates were dried under constant temperature (±27 ^{0}C) for a day, **unlike the aggregates from the previous experiment** where the aggregates were left dried for only 2 hours. The mortar samples were casted into cylinder-shaped and 60 mm x 120 mm sized PVC moulds. A vibrating table was used to compact the concrete. Full compaction was considered to have been achieved when air bubbles stopped appearing on the mortar surface. After vibrating, the concrete surface was finished smooth using a metal float and then covered with a polythene sheet to prevent evaporation of water from the concrete. The moulds were stripped next day and the hardened concrete samples were placed in the curing tank

3.4 Test methods

3.4.1 Compression test

The cube, while still wet, was placed in the compression tester (Figure 3.0) with the cast faces in contact with the platens of the testing machine. The load on cube applied at a constant rate of stress equal to 0.2-0.4 MPa/second until it fails. The maximum load before the cube fails was taken and the compressive strength is calculated by dividing the maximum load to the cross-sectional area of the cube.

Figure 3.0: Compression tester

3.4.2 Splitting tension test

The cube, while still wet, is placed in specimen holder (Figure 4.0) with the cast faces in contact with the steel rod at both top and bottom of the specimen. The load on cube is applied at a constant rate of stress equal to 0.2-0.4 MPa/second until it fails. The maximum load before the cube fails is taken and the tensile strength is calculated by using the following equation:

$$\frac{2P}{\pi DL}$$

Where,

P = maximum load

D = Diameter of Specimen

L = Height of Specimen

Figure 4.0: Specimen Holder

3.5 Milestone for Final Year Project 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
	-Propose Topic														
	-Topic assigned to students														
2	Research Work														
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report														
4	Project Work														
	-Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report														
6	Project work continue														
	-Practical/Laboratory Work														
7	Submission of Interim Report Final Draft														
8	Oral Presentation														
9	Submission of Interim Report														

Milestone for Final Year Project 2

Detail/Week	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	E.M	W11	W12	W13	W14	SW
Preparation of Aggregates																
Mould Fabrication																
Mortar Mixing																
Test																
Progress Report Submission																
Poster Presentation																
Dissertation Report																
Oral Presentation																

3.6 HSE Requirement

3.6.1 Personal Protective Equipment (PPE) Provided in Concrete Technology Laboratories

The following figures are the safety equipments that provided in the concrete laboratory in Universiti Teknologi PETRONAS:

Goggles & earmuff

Face shield

Gloves

Dust masks

Aprons

Safety helmet

3.6.2 HSE Procedure for Laboratory Works in Concrete Laboratory

- Wear earmuff when sieving process takes place.
- Wear glove when dealing with cement and aggregates.
- Wear rubber shoes in concrete laboratory.
- During concrete mixing, the mixer should be closed as long as the machine turned on.
- During the compression and tensile test in progress, the test zone should be isolated by closing the gate.
- All concrete waste should be put into special tank provided.

3.6.3 Hazard Analysis for DC520(Silane-water based emulsion)

Problem	Hazard Produced	Safety Precautious
DC520 Silane (water-based emulsion) is harmful to human and environment	▪ Silane is flammable and evolves ethanol upon cure	▪ Silane may be applied to damp surfaces although dry surfaces are preferred to achieve maximum penetration into the substrate. ▪ Any plants or shrubs should be protected from exposure to the treatment. ▪ Any material that should not be exposed to solvents should also be protected. ▪ Do not store or use near sparks or open flames. ▪ Do not smoke in the vicinity of application ▪ Use in a well-ventilated area, or wear an air-supplied respirator. ▪ Always wear protective goggles and gloves. ▪ If inhaled, move immediately to fresh air. In case of skin or eye contact, flush immediately with water for 15 minutes. Remove contaminated clothing and shoes and call a physician.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Effect of Silane Coupling Agent (SCA) in concrete with three (3) different sizes of coated aggregate (10mm, 14mm and 20mm)

The following graphs are showing the results of compressive test and tensile test on the concrete samples. The sample comprises of control samples and the samples that were treated with SCA and of three sizes of coarse aggregate (10 mm, 14 mm, and 20 mm). Both compressive and tensile test have been conducted for 2^{nd}, 7^{th}, and 28^{th} days of strength for all concrete mixes; Control Mix, Mix 1 (10 mm), Mix 2 (14 mm), and Mix 3 (20 mm).

4.1.1 Mix 1(10 mm)

<u>Graph 1: Mix 1 (10 mm)</u>

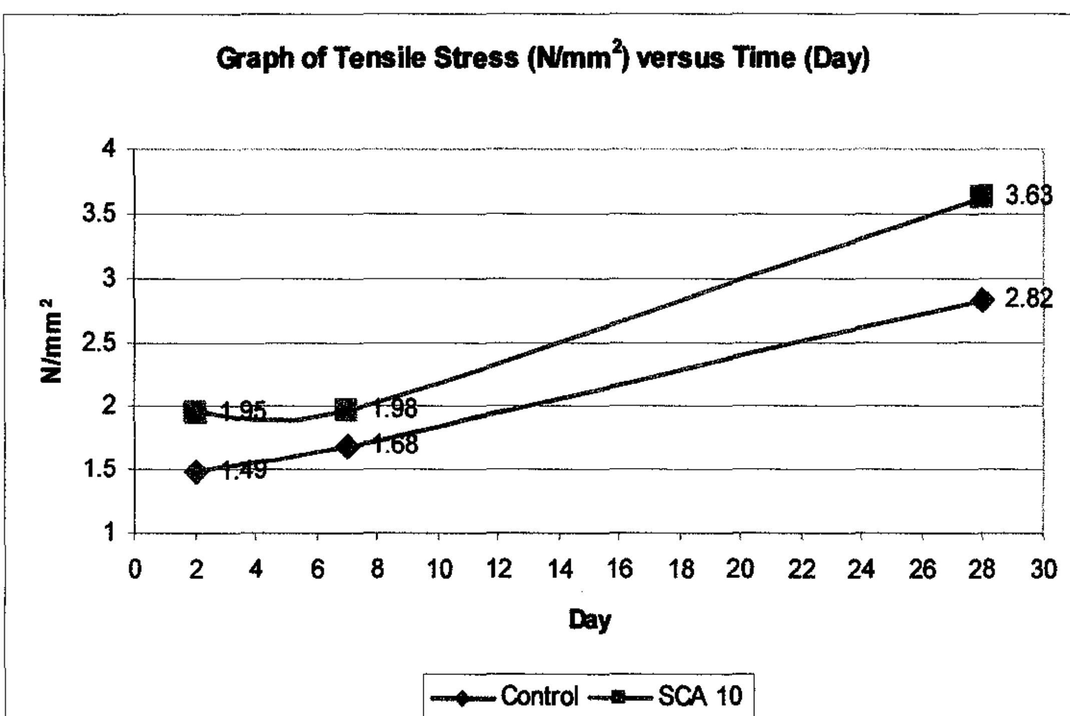

Figure 5.1 Graph of Tensile Stress (N/mm^2) versus Time (Day): Mix 1(10mm)

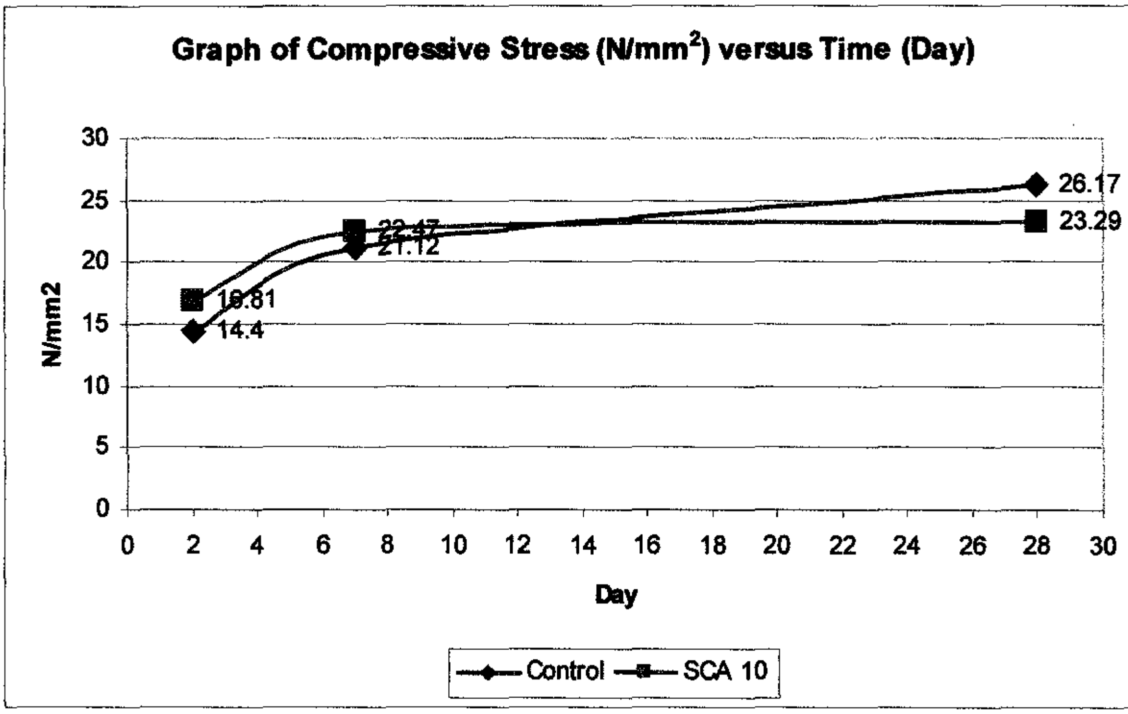

Figure 5.2 Graph of Compressive Stress (N/mm^2) versus Time (Day): Mix 1 (10 mm)

From Figure 5.1 and Figure 5.2, the concrete with 10 mm sized and SCA coated aggregates show tensile stress and compressive stress of 3.63 N/mm^2 and 23.29 N/mm^2 at 28th day of strength. In comparison to control mix, the SCA increased the tensile stress by 28.50% and decreased the compressive stress by 11.00%.

4.1.2 Mix 2 (14 mm)

Graph 2: Mix 2 (14 mm)

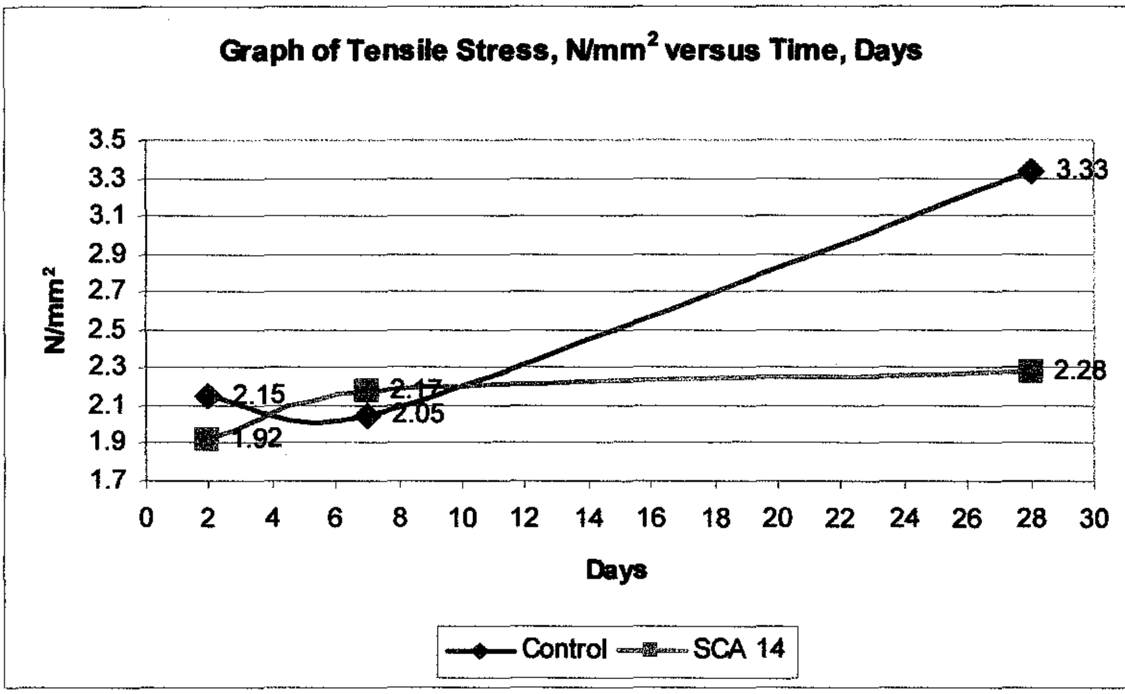

Figure 6.1 Graph of Tensile Stress (N/mm^2) versus Time (Day): Mix 2(14mm)

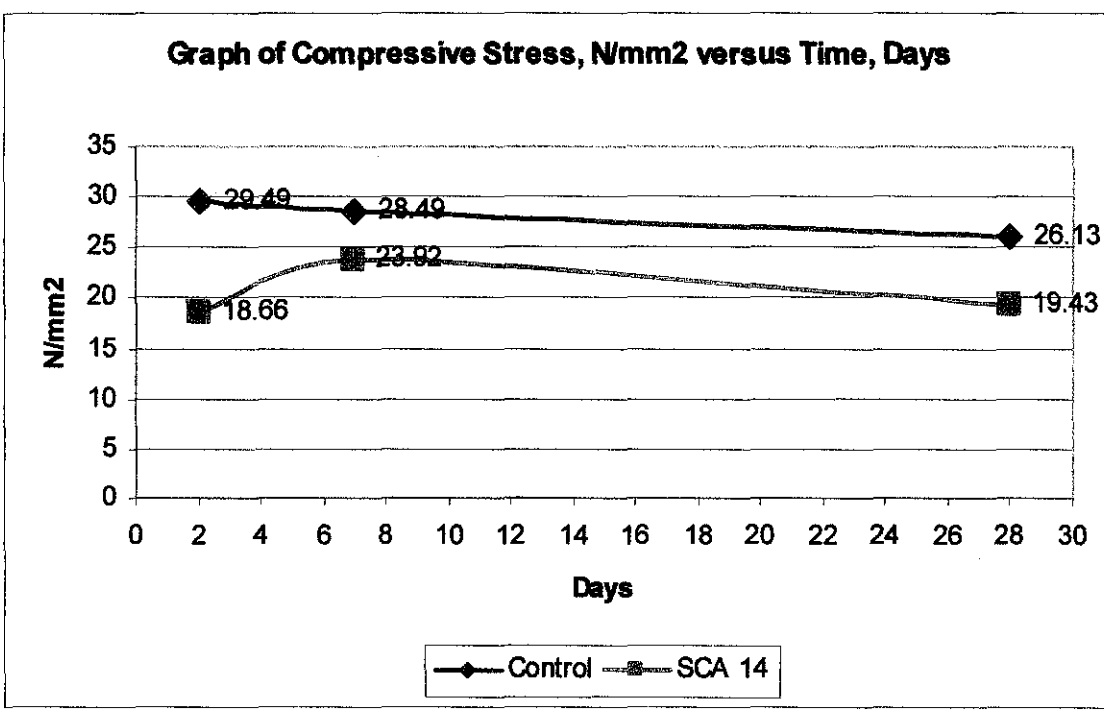

Figure 6.2 Graph of Compressive Stress (N/mm^2) versus Time (Day): Mix 2 (14 mm)

From Figure 6.1 and Figure 6.2, the concrete with 14 mm sized and SCA coated aggregates show tensile stress and compressive stress of 2.28 N/mm^2 and 19.43 N/mm^2 at 28th day of strength. In comparison to control mix, the SCA decreased both the tensile stress and compressive stress by 31.43% and 25.64% of decrement.

4.1.3 Mix 3 (20mm)

Graph 3: Mix 3 (20 mm)

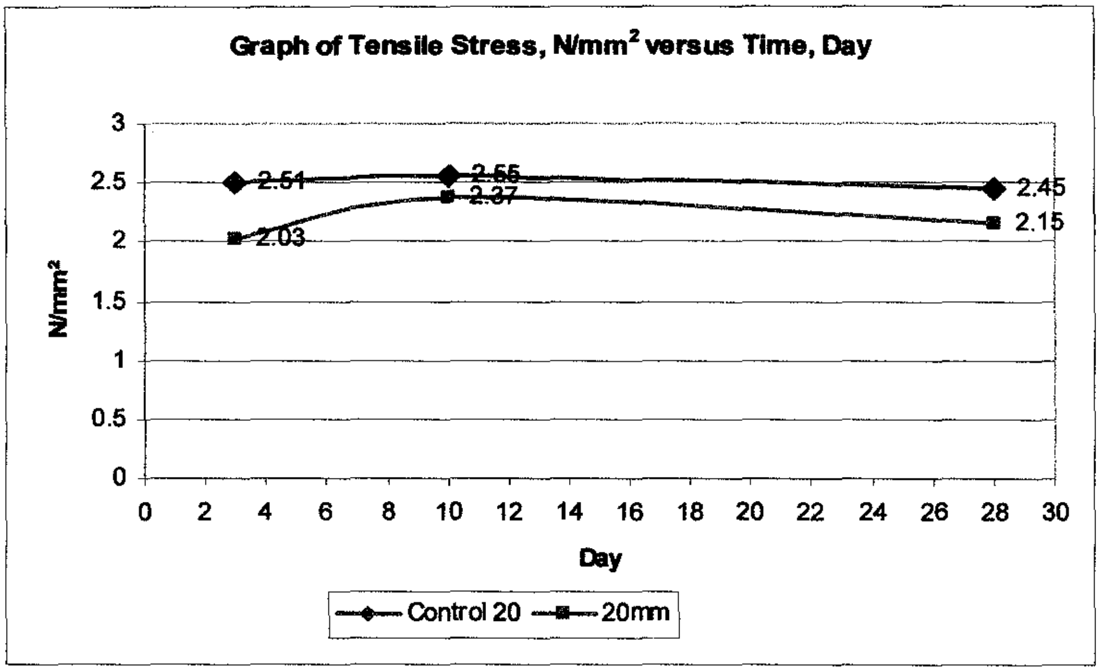

Figure 7.1 Graph of Tensile Stress (N/mm^2) versus Time (Day) :Mix 3(20mm)

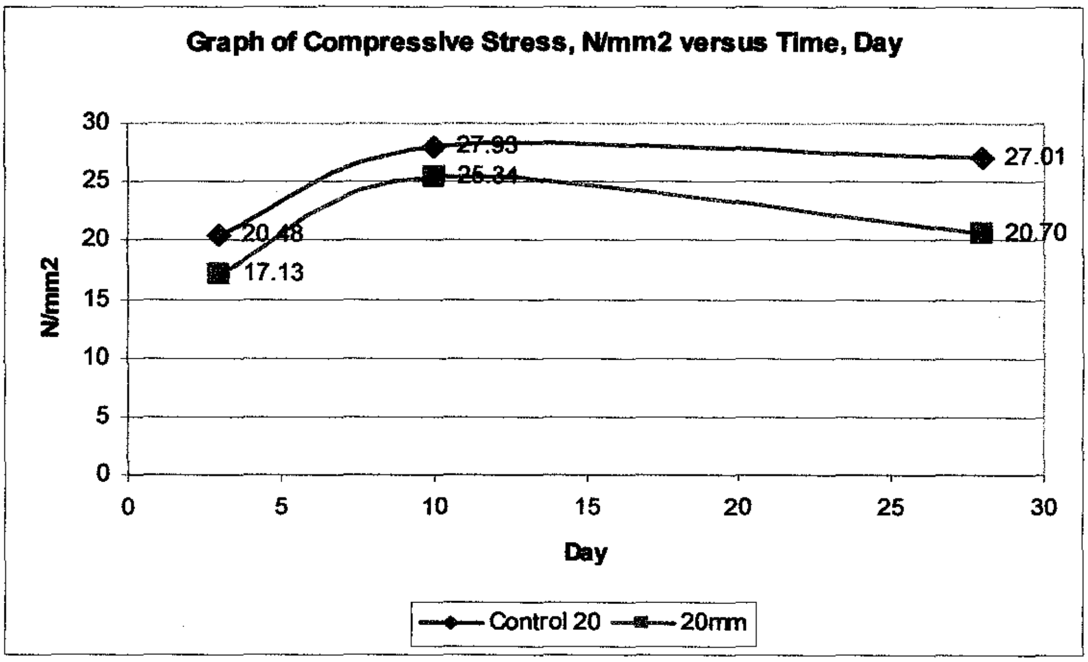

Figure 7.2 Graph of Compressive Stress (N/mm^2) versus Time (Day): Mix 3 (20 mm)

From Figure 7.1 and Figure 7.2, the concrete with 20 mm sized and SCA coated aggregates show tensile stress and compressive stress of 2.15 N/mm^2 and 20.70 N/mm^2 at 28^{th} day of strength. In comparison to control mix, the SCA decreased both the tensile stress and compressive stress by 12.00% and 23.61% of decrement.

4.2 Effect of Silane Coupling Agent (SCA) in mortar with three (3) different concentration of Silane that coat the aggregates.

The following graphs are showing the results of compressive test and tensile test on the mortar samples. The sample comprises of control samples and the samples with its aggregates that were treated with SCA of three different concentrations (Silane: Water) namely; 1:4, 1:8, and 1:12.Both compressive and tensile test have been conducted for 2^{nd}, 7^{th}, and 28^{th} days of strength for all mortar mixes; Control Mix, Mix 1 (1:4), Mix 2 (1:8), and Mix 3 (1:12).

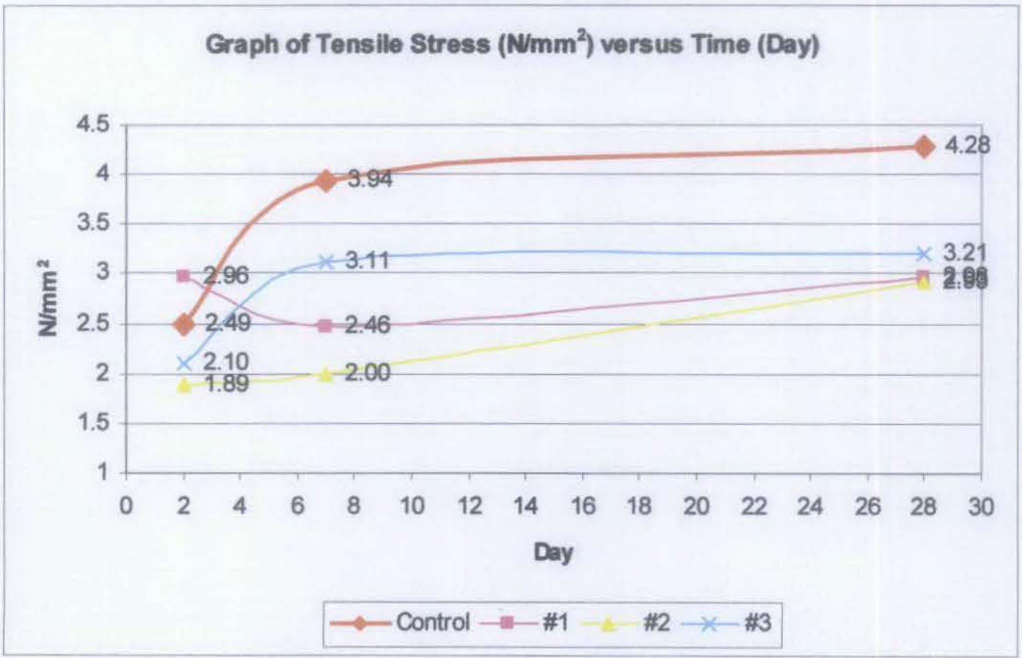

Figure 8.1 Graph of Tensile Stress (N/mm^2) versus Time (Day); Mortar

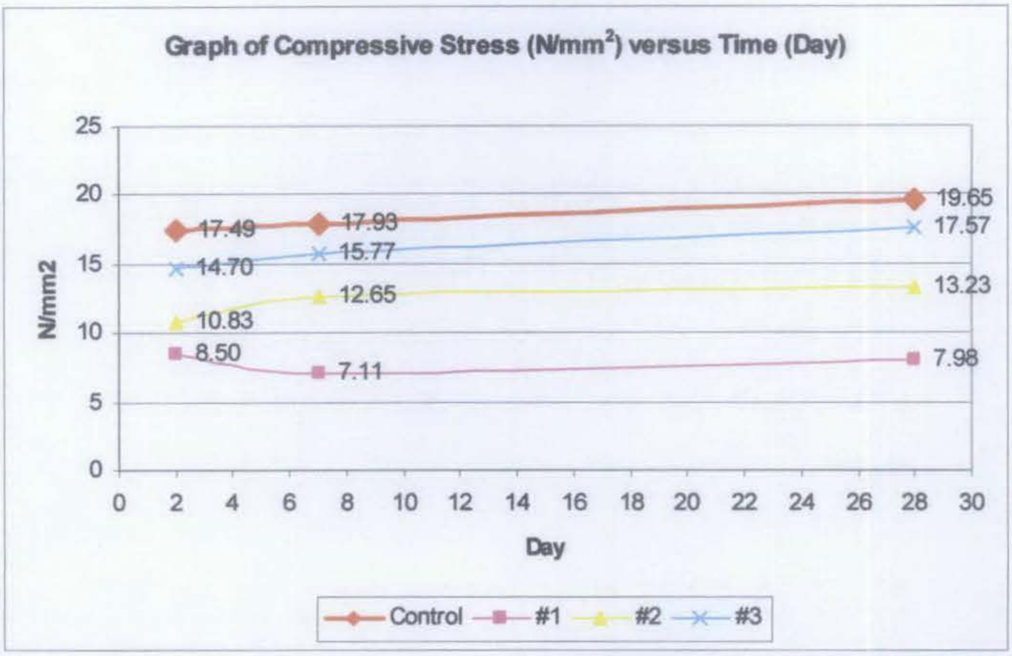

Figure 8.2 Graph of Compressive Stress (N/mm^2) versus Time (Day); Mortar

From Figure 8.1 and Figure 8.2, the mortar with its aggregates that were coated with concentration 1:4, 1:8, and 1:12 show tensile stress of 2.98 N/mm^2, 2.93N/mm^2, and 3.21N/mm^2 and the compressive stress of 7.98N/mm^2, 13.23N/mm^2 and 17.57 N/mm^2 at 28th day of strength. In comparison to control mix, the SCA decreased the tensile stress for all mixes; Mix 1, Mix 2, and Mix 3 by 30.37%, 31.54%, 25.00% of decrement, so as the compressive stress for all mixes; Mix 1, Mix 2, and Mix 3 that are decreased by 59.39%, 32.69%, 10.57% of decrement.

4.3 Overall Summary of Results

Two set of experimental programme were done to ascertain the early hypothesis which says that SCA is believed, capable of increasing the bond strength and durability of concrete by providing the chemical bridge to connect the inorganic materials especially silicon-containing materials and resin, in a hope it could manage to behave the exact way connecting inorganic materials in the concrete (such as cement paste and stone).

On the first experimental programme, two types of concrete mix were produced; control mix and concrete mix with its aggregates coated with SCA. In a way to have an adds-value, the concrete mix is further divided into 3 distinctive classes of samples by varying the coarse aggregates size (10mm, 14mm, and 20mm) to verify and observe the optimum aggregate size that will result in highest tensile strength.

According to the experience of composite technology, concentration of SCA aqueous solutions has a significant influence on the bond strength of composites. On the one hand, an aqueous SCA solution with a very low concentration may be not enough to create a SCA network that fully covers the surface of an inorganic material, resulting in lower bond strength. On the other hand, an aqueous SCA solution with a very high concentration may induce a multiple molecular layer on the surface, creating a porous physically absorbent layer, leading to much lower bond strength. Conclusively, the second experimental programme was conducted to determine the optimum Silane concentration that will result in highest tensile strength by varying the Silane concentration into three distinctive values in accordance to the ratio of Silane: Water (1:4, 1:8, and 1:12) and water is being used because DC520 is a Silane water-based and it only can be solved by water.

From the methodology perspective, during the first experiment, the aggregates coated with Silane were left dried for only 2 hours right after the coating took place. Unlike the first experiment, the aggregates coated with Silane were left dried for a day-long during the second experiment. The author deliberately altered this particular method to investigate how the drying period would effect the outcome.

Looking at the results for the first experiment, we may observe that at 28^{th} day's strength, all compressive stress of concrete specimens gave lower value in comparison to the compressive stress of control mix. Same thing happened to tensile stress, except for the concrete with 10mm aggregates that gave some increment in the tensile strength compare to the control mix. This indicates that SCA somehow have managed to improve the tensile strength of concrete; however the proper way of implementing Silane is still in ambiguous stage. Another reason why concrete with 10mm aggregates exhibited highest tensile strength out of other aggregates size might due to larger surface area of the aggregates that give more contact between hardened cement paste and aggregates.

For the second experiment, the mortar that was being incorporated with SCA continually to exhibit weaker tensile and compressive strength in comparison to the control mix. However, the author somehow obtained one finding, which by, the less the concentration of Silane, the stronger the strength performance of mortar.

Finally, pertaining to the drying period of coated aggregates, it can be observed that lengthening the drying period has no significant effect to the strength performance of concrete.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This Final Year Project is concern in producing High Tensile Strength Concrete as it is generally known that 'concrete is strong in resisting compressive stress and weak in resisting tensile stress'. In order to achieve this objective, study on the failure mechanism of concrete was carried out that lead to one simple conclusion saying that Interfacial Transition Zone (ITZ) is what that triggered the crack formation in concrete which subsequently lead to the failure for any particular concrete.

During the first semester, the focus was on doing literature review concerning the matter on concrete properties, concrete failure mechanism, and some remedial measures to improve the tensile strength of concrete. Secondly, the research on the inorganic compound that is to be implemented in the concrete mix to improve the tensile strength of concrete was carried out and as a result, Silane Coupling Agent (SCA) was chosen. The first experimental programme focused on experimenting the effect of SCA on the tensile strength of concrete and determining the optimum aggregate size that will result in highest tensile strength

For this second semester, the focus was also on experimenting the effect of SCA on the tensile strength of mortar and determining the optimum concentration of SCA that is used to coat the aggregates. Based on the results obtained, we may conclude that SCA most likely not an inorganic compound that is able to increase the tensile strength of concrete and mortar. However, there is a research which proved the success of increasing the strength of concrete by implementing SCA in the concrete mix. Sustaining to that matter, further research can be done especially on the method mixing and how to implement SCA in the mix correctly, as those are still in the ambiguous stage.

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MIX 1

ncrete mix design form

26/3/08

m	Reference or calculation	Values
Characteristic strength	Specified	30 N/mm² at 28 days; Proportion defective 5 per cent
Standard deviation	Fig 3	______ N/mm² or no data 8 N/mm²
Margin	C1	(k = 1.64) 1.64 × 8 = 13.12 N/mm²
Target mean strength	C2	30 + 13.12 = 43.12 N/mm²
Cement type	Specified	OPC/SRPC/RHPC
Aggregate type: coarse Aggregate type: fine		crushed uncrushed
Free-water/cement ratio	Table 2, Fig 4	0.55 — Use the lower value
Maximum free-water/cement ratio	*Specified*	______
Slump or V-B	Specified	Slump 10 mm or V-B ______ s
Maximum aggregate size	Specified	10 mm
Free-water content	Table 3	233 kg/m³
Cement content	C3	233 ÷ 0.55 = 423.6 kg/m³
Maximum cement content	*Specified*	______ kg/m³
Minimum cement content	*Specified*	______ kg/m³ — Use if greater than Item 3.1 and calculate Item 3.4
Modified free-water/cement ratio		______
Relative density of aggregate (SSD)		2.7 known/assumed
Concrete density	Fig 5	2365 kg/m³
Total aggregate content	C4	2365 − 423.6 − 233 = 1708.4 kg/m³
Grading of fine aggregate	BS 882	Zone 3
Proportion of fine aggregate	Fig 6	43 per cent
Fine aggregate content	C5	1708.4 × 0.43 = 734.6 kg/m³
Coarse aggregate content	C5	1708.4 − 734.6 = 973.8 kg/m³

ities	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg)
(to nearest 5 kg)	425	235	735	975
al mix of 0.034 m³	14.45	7.99	25	33.15

optional limiting values that may be specified (see Section 7).

Concrete mix design form

MIX 2

29/3/08

Item		Reference or calculation	Values
1.1	Characteristic strength	Specified	30 N/mm² at 28 days; Proportion defective 5 per cent
1.2	Standard deviation	Fig 3	N/mm² or no data 8 N/mm²
1.3	Margin	C1	(k = 1.64) 1.64 × 8 = 13.12 N/mm²
1.4	Target mean strength	C2	30 + 13.12 = 43.12 N/mm²
1.5	Cement type	Specified	OPC/~~SRPC/RHPC~~
1.6	Aggregate type: coarse Aggregate type: fine		crushed uncrushed
1.7	Free-water/cement ratio	Table 2, Fig 4	0.55 — Use the lower value
1.8	*Maximum free-water/cement ratio*	*Specified*	
	Slump or V-B	Specified	Slump 75 mm or V-B s
	Maximum aggregate size	Specified	14 mm
	Free-water content	Table 3	219 kg/m³
	Cement content	C3	219 ÷ 0.55 = 398.2 kg/m³
	Maximum cement content	*Specified*	kg/m³
	Minimum cement content	*Specified*	kg/m³ — Use if greater than Item 3.1 and calculate Item 3.4
	Modified free-water/cement ratio		
	Relative density of aggregate (SSD)		2.7 known/assumed
	Concrete density	Fig 5	2340 kg/m³
	Total aggregate content	C4	2340 − 348.2 − 219 = 1772.8 kg/m³
	Grading of fine aggregate	BS 882	Zone 2
	Proportion of fine aggregate	Fig 6	39 per cent
	Fine aggregate content	C5	1772.8 × 0.39 = 691.4 kg/m³
	Coarse aggregate content	C5	1772.8 − [illegible] = 1081.4 kg/m³

	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg)
[illegible] nearest 5 kg)	[illegible]	[illegible]	[illegible]	1080
[illegible]x of 0.034 m³	[illegible]	[illegible]	[illegible]	[illegible]

MIX 3

Concrete mix design form

Item		Reference or calculation	Values
1.1	Characteristic strength	Specified	30 N/mm² at 28 days; Proportion defective 5 per cent
1.2	Standard deviation	Fig 3	N/mm² or no data 8 N/mm²
1.3	Margin	C1	(k = 1.64) 1.64 × 8 = 13.12 N/mm²
1.4	Target mean strength	C2	30 + 13.12 = 43.12 N/mm²
1.5	Cement type	Specified	OPC/SRPC/RHPC
.6	Aggregate type: coarse Aggregate type: fine		crushed uncrushed
7	Free-water/cement ratio	Table 2, Fig 4	0.55 — Use the lower value
8	*Maximum free-water/cement ratio*	*Specified*	
1	Slump or V-B	Specified	Slump 75 mm or V-B s
2	Maximum aggregate size	Specified	20 mm
	Free-water content	Table 3	205 kg/m³
	Cement content	C3	205 ÷ 0.55 = 372.73 kg/m³
	Maximum cement content	*Specified*	kg/m³
	Minimum cement content	*Specified*	kg/m³ — Use if greater than Item 3.1 and calculate Item 3.4
	Modified free-water/cement ratio		
	Relative density of aggregate (SSD)		2.7 known/assumed
	Concrete density	Fig 5	2410 kg/m³
	Total aggregate content	C4	2410 − 372.73 − 205 = 1832.27 kg/m³
	Grading of fine aggregate	BS 882	Zone 2
	Proportion of fine aggregate	Fig 6	34 per cent
	Fine aggregate content	C5	1832.27 × [illegible] = 623 kg/m³
	Coarse aggregate content	C5	1832.27 − 623 = 1209.3 kg/m³

...ities	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg)
(to nearest 5 kg)	375	205	[illegible]	1210
...l mix of 0.034 m³	12.75	6.97	[illegible]	[illegible]

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Appendix B-1 Compression and Tensile Tests Results for Mix 1(10 mm)

MIX 1: SCA 10mm									
Control Mix									
Day	2			7			28		
	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)
Tensile	3.617	46.7	1.487	3.634	52.8	1.681	3.63	88.7	2.822
Compress	3.644	113.1	14.4	3.616	165.9	21.12	3.63	205.5	26.17
Split Tensile Test									
Day	2			7			28		
	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)
S1	3.631	61.2	1.949	3.571	58.5	1.863	3.66	114.8	3.654
S2	3.485	101.8	3.241	3.476	64.6	2.058	3.6	113	3.598
S3	3.374	61.2	1.948	3.268	62.9	2.003			
Average		**61.2**	**1.949**		**62**	**1.975**		**113.9**	**3.626**
Compression Test									
Day	2			7			28		
	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)	Weight (kg)	Max. Load (kN)	Stress (N/mm^2)
S1	3.473	133.2	16.96	3.677	169	21.51	3.64	175.6	22.36
S2	3.26	92.1	11.72	3.607	194.1	24.71	3.52	143.8	18.31
S3	3.459	130.9	16.66	3.608	166.5	21.19	3.45	190.2	24.21
Average		**132.05**	**16.81**		**176.53**	**22.47**		**182.9**	**23.29**

Summary

	Control		SCA	
Day	Tensile	Compression	Tensile	Compression
2	1.487	14.4	1.949	16.81
7	1.681	21.12	1.975	22.47
28	2.822	26.17	3.626	23.29

Appendix B-2 Compression and Tensile Tests Results for Mix 2(14 mm)

MIX 2: SCA 14mm									
Control Mix									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
Tensile	3.709	67.6	2.152	3.749	64.4	2.051	3.728	104.6	3.328
Compress	3.734	231.6	29.49	3.721	223.7	28.49	3.76	205.2	26.13
Split Tensile Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	3.659	65.2	2.076	3.626	62.8	1.998	3.638	96.6	3.074
S2	3.444	59.7	1.9	3.347	66.4	2.112	3.545	65.1	2.071
S3	3.386	55.6	1.771	3.539	70	2.227	3.64	90.8	2.89
Average		**60.17**	**1.916**		**68.2**	**2.170**		**93.7**	**2.982**
Compression Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	3.476	134.2	17.09	3.649	188.1	23.95	3.643	168.1	21.4
S2	3.409	116.6	14.85	3.662	187.6	23.89	3.901	147.7	18.8
S3	3.609	158.9	20.23	3.483	139.2	17.73	3.661	142.1	18.09
Average		**146.55**	**18.66**		**187.85**	**23.92**		**152.63**	**19.43**
Summary									

	Control		SCA	
Day	Tensile	Compression	Tensile	Compression
2	2.152	29.49	1.916	18.66
7	2.051	28.49	2.170	23.92
28	3.328	26.13	2.282	19.43

Appendix B-3 Compression and Tensile Tests Results for Mix 3(20 mm)

MIX 3: SCA 20mm									
Control Mix									
Day	**3**			**10**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
Tensile	3.816	78.9	2.511	3.8	80.1	2.551	3.791	76.9	2.448
Compress	3.799	160.9	20.48	3.79	219.4	27.93	3.73	212.1	27.01
Split Tensile Test									
Day	**3**			**10**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	3.709	82	2.611	3.76	72.7	2.316	3.747	65.9	2.098
S2	3.766	58.2	1.854	3.693	65	2.068	3.638	66.6	2.119
S3	3.635	69	2.196	3.547	76.1	2.423	3.631	70.5	2.244
Average		**63.6**	**2.025**		**74.40**	**2.370**		67.67	2.154
Compression Test									
Day	**3**			**10**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	3.513	153.4	19.53	3.814	194.2	24.72	3.743	162.4	20.68
S2	3.802	135.3	17.23	3.611	158.5	20.18	3.774	170.4	21.69
S3	3.77	133.7	17.02	3.68	203.8	25.95	3.59	155	19.74
Average		**134.5**	**17.125**		**199**	**25.335**		162.6	20.703
Summary									

	Control		SCA	
Day	Tensile	Compression	Tensile	Compression
3	2.511	20.48	2.025	17.125
10	2.551	27.93	2.370	25.335
28	2.448	27.01	2.154	20.703

Appendix C-1 Compression and Tensile Tests Results for Control Mix

CONTROL									
Split Tensile Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	705.5	30.6	2.946	702.29	51.1	4.929	712.81	48.3	4.659
S2	691.54	24.7	2.378	693.72	31.5	3.035	697.02	38.6	3.719
S3	693.76	22.2	2.137	714.16	39.9	3.853	692.38	46.2	4.461
Average		**25.833**	**2.487**		**40.833**	**3.939**		**44.367**	**4.280**
Compression Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	700.3	42.5	17.88	705.13	42	17.69	712.69	46.1	19.39
S2	712.27	43.2	18.19	682.43	44.2	18.6	704.42	48.9	20.57
S3	742.61	39	16.4	727.89	41.6	17.51	706.29	45.1	18.99
Average		**41.567**	**17.490**		**42.600**	**17.933**		**46.700**	**19.650**
Summary									

	Control	
Day	Tensile	Compression
2	2.487	17.49
7	3.939	17.933
28	4.280	19.65

Appendix C-2 Compression and Tensile Tests Results for Mix 1

MIX 1									
Split Tensile Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	673.06	23.5	2.265	676.24	22.642	2.068	652.16	38.1	3.672
S2	652.11	33.5	3.228	654.85	33.715	2.638	692.18	21.1	2.036
S3	667.9	35.1	3.386	668.9	30.239	2.768	690.81	33.4	3.22
Average		**30.700**	**2.960**		**28.865**	**2.491**		**30.867**	**2.976**
Compression Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	672.57	23.6	9.936	659.56	13.664	5.751	681.29	25.1	10.57
S2	666.7	19	8.003	678.61	22.074	9.291	651.05	11.8	4.973
S3	678.97	17.9	7.549	640.89	14.969	6.301	679.92	19.9	8.384
Average		**20.167**	**8.496**		**16.902**	**7.114**		**18.933**	**7.976**
Summary									

	MIX 1	
Day	Tensile	Compression
2	2.96	8.496
7	2.491	7.114
28	2.976	7.976

Appendix C-3 Compression and Tensile Tests Results for Mix 2

MIX 2									
Split Tensile Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	683.22	22.5	2.166	664.48	22.4	2.156	681.91	21.5	2.073
S2	672.49	11.1	1.069	675.56	19.1	1.739	684.68	39.6	3.821
S3	682.54	25.2	2.428	661.94	22.3	2.098	679.47	29.9	2.886
Average		**19.600**	**1.888**		**21.267**	**1.998**		**30.333**	**2.927**
Compression Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	662.09	26	10.93	664.05	23.7	9.957	684.12	31.6	13.29
S2	673.19	26	10.92	672.2	32.9	13.83	682.27	29.1	12.25
S3	684.06	25.3	10.64	667.37	33.7	14.17	680.67	33.6	14.14
Average		**25.767**	**10.830**		**30.100**	**12.652**		**31.433**	**13.227**
Summary									

	MIX 2	
Day	Tensile	Compression
2	1.888	10.83
7	1.998	12.652
28	2.927	13.227

Appendix C-4 Compression and Tensile Tests Results for Mix 3

MIX 3									
Split Tensile Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	698.44	25	2.31	676.89	30.7	2.851	691.16	39.1	3.769
S2	697.18	15.6	1.445	698.77	34.7	3.125	696.57	34.2	3.297
S3	698.19	27.8	2.533	703.26	36.9	3.345	699.48	36.6	2.565
Average		**22.800**	**2.096**		**34.100**	**3.107**		**36.633**	**3.210**
Compression Test									
Day	**2**			**7**			**28**		
	Weight (kg)	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**	**Weight (kg)**	**Max. Load (kN)**	**Stress (N/mm^2)**
S1	690.37	32.1	13.52	683.85	37.9	15.81	703.78	37.3	15.88
S2	682.88	35.4	14.9	684.81	35.9	14.89	702.59	39.5	16.64
S3	709.47	37.3	15.68	697.34	39.4	16.60	682.6	48	20.2
Average		**34.933**	**14.700**		**37.733**	**15.767**		**41.600**	**17.573**
Summary									

	Control	
Day	Tensile	Compression
2	2.096	14.7
7	3.107	15.767
28	3.21	17.573