Effects of Polyvinyl Alcohol (PVA) in the Compressive Fatigue Strength of Concrete

by

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Dissertation submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

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Supervisor

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TRONOH, PERAK

January 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.

AMRIL HADRI BIN JAMALUDIN

ABSTRACT

An experimental program is carried out to evaluate the performance of plain concrete and fiber-reinforced concrete on size 100mm x 100mm x 100mm under compressive static loading after 67 days of curing and compressive fatigue loading after 97 days of curing. Polyvinyl alcohol (PVA) fibers (30 mm length) are used for test with different fiber volume fraction and their performance compared. The results of the fatigue test are presented as two types of *S-N* diagrams. The first one is expressed as the percentage of maximum stress level to the number of loading cycles to failure. The fatigue equation can be determined using regression equation from the graph obtained and the percentage fatigue strength for the N^{th} cycles can be determined. The second one is expressed as the actual fatigue stress applied to the number of loading cycles to failure. Both graphs are compared and analyzed to find the optimal fiber volume and the effectiveness for incorporating the PVA fibers in improving the compressive fatigue strength of the concrete.

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TABLE OF CONTENTS

CERTIFICATION OF APPROVAL			i
CERTIFICATION OF ORIGINALITY			ii
ABSTRACT			iii
ACKNOWLEDGEMENT			iv
TABLE OF CONTENTS			v
LIST OF FIGURES			vii
LIST OF TABLES			viii
CHAPTER 1:	**INTRODUCTION**		1
	1.1	Background of Study	1
	1.2	Problem Statement	3
	1.3	Objectives and Scope of Study	4
CHAPTER 2:	**LITERATURE REVIEW**		5
	2.1	Relationship Between Compression and Tensile Strength	5
	2.2	Fatigue Behaviour of Concrete	5
	2.3	Polyvinyl Alcohol Properties	7
	2.4	Mechanics of Fiber Reinforcement	8
		2.4.1 First Cracking Load	9
		2.4.2 Critical Fiber Length	10
		2.4.3 Critical Fiber Spacing	11
		2.4.4 Fiber Orientation	11
	2.5	The Fiber Bridging Effects	11
	2.6	Static Behavior of FRC in Compression	12
	2.7	Slump Behavior for Fresh FRC	12
	2.8	Fatigue Behavior of FRC in Compression	13
CHAPTER 3:	**PROJECT WORK AND METHODOLOGY**		14
	3.1	Project Planning	14
	3.2	Laboratory Works	15
		3.2.1 Hazards Assessment	16
		3.2.2 Mix Proportioning	19
		3.2.3 Concrete Mixing	21
		3.2.4 Concrete Testing	22
		3.2.4.1 Fresh Concrete Test	22
		3.2.4.2 Hardened Concrete Test	23

CHAPTER 4:	**RESULTS AND DISCUSSION** . .		26
	4.1 Fresh Concrete Test . . .		26
	4.1.1 Slump Test . . .		26
	4.2 Hardened Concrete Test . .		27
	4.2.1 Static Compression Test .		27
	4.2.2 Split Tensile Test . .		29
	4.2.3 Dynamic Compression Test .		30
	4.2.4 Scanning Electron Microscope		31
CHAPTER 5:	**CONCLUSION AND RECOMMENDATION**		33
REFERENCES	. . . .		35
APPENDICES	. . . .		37

LIST OF FIGURES

Figure 2.1	Polyvinyl alcohol (PVA) fibers	7
Figure 2.2	The composition of PVA polymers	8
Figure 2.3	Load-deflection diagram of fiber reinforced concrete	9
Figure 2.4	The bridging effects by the fibers incorporated into the concrete matrix	10
Figure 3.1	Process of concrete mixing	21
Figure 3.2	Slump test done for 2% PVA volume	23
Figure 3.3	Compression test using compression machine	24
Figure 3.4	Dynamic compression test using UTM	25
Figure 4.1	Compression strength development from day 0 to day 60 for 0%, 1%, 2%, and 3% PVA fiber reinforced concrete cube samples for Session 2006/2007	27
Figure 4.2	Static compression test after 60 days of curing period for session 2006/2007 (grade 40)	27
Figure 4.3	Static compression test after 67 days of curing period for session 2007/2008 (grade 30)	28
Figure 4.4	Tensile strength development from day 0 to day 60 for 0%, 1%, 2%, and 3% PVA fiber reinforced concrete cube samples for session 2006/2007 (grade 40)	29
Figure 4.5	The adhesion of PVA fiber with the concrete matrix under 50x zoom using SEM (sample A)	31
Figure 4.6	The adhesion of PVA fiber with the concrete matrix under 500x zoom using SEM (sample B)	31
Figure 4.7	The adhesion of PVA fiber with the concrete matrix under 5000x zoom using SEM (sample A)	32

LIST OF TABLES

Table 3.1 Hazard assessment in the concrete laboratory		18
Table 4.1 Results for the slump test in 2006/2007 session (grade 40)		26
Table 4.2 Results for the slump test in 2007/2008 session (grade 30)		26

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Concrete is defined as a composite material that consists from hydraulic cement that acts as a binding medium, water and aggregates. The Portland cement is the most important hydraulic cement for concrete mixture. Concrete is widely used as a construction materials in ordinary construction practice, because of it easiness to be moulded and shaped into desired structural members besides economically available compared to steel structures. Typical concrete have volume fractions of aggregates from 0.7 to 0.8 approximately. Remaining volume is occupied with water, cement, admixtures (if any) and also air voids [1].

Concrete mixture is good in compression strength which refers to what concrete is capable to resist loads when they are being pushed. However, it is weak in tensile strength and this makes it more brittle and low in ductility. The compressive strengths for concrete are usually in the range of 3000 to 5000psi, while the tensile strength is only about one tenths of its compressive strength. To overcome this, steel reinforcement bars are usually used to improve the ductility of the concrete. Steel bars are responsible in sustaining the tensile loadings on the structural member, while concrete will sustain the compressive load and providing the concrete covers to the steel bars from any damage to the steel bars.

In addition, there is other alternative to improve the performance of concrete not only in tensile strength but also other properties such as compressive strength, ductility, resistance to cracks due to plastic and drying shrinkage and etc. This can be achieved by using small, randomly distributed fibers to reinforce the concrete. Since 1900's, asbestos fiber were being used. By 1960 steel, glass and synthetic fiber such as polypropylene fibers were used to reinforce the concrete. The usage of fibers will allow the reducing in pavement thickness [2] for concrete highway and improve the performance of airport runway or other concrete-based structures.

A wide variety of different types of fibers have been proposed for use in concrete. For each application, it needs to be determined which type of fiber is optimal in satisfying the product specifications. This selection process has to consider whether the fibers are chemically and mechanically compatible with the cement matrix. The general types of fiber reinforcement materials are:

- Steel - including high-tensile strength and stainless steel.
- Glass - either 'E' or alkali-resistant.
- Synthetic - including polypropylene, polyethylene, polyester, acrylic, and Kevlar.
- Carbon - either high-modulus or high-strength.
- Natural - including wood, sisal, coconut, bamboo, jute, and elephant grass.

Polyvinyl alcohol (PVA) is considered as one of the most suitable polymeric fibers to be used as reinforcement of concrete not only due to its resistant to corrosion, PVA also has good durability, less damaged during the mixing process using the conventional mixture machine and less hazardous. It has been reported that the durability of the aged products using this fibers after 3 to 7 years in natural weather in Switzerland is good and showed slight increment in the flexural strength with time [3]. Even though the toughness of the material has been reported to decrease about 50 percent in the first year and stable in the next years, there is increment occurred to the material strength in the natural aging test up to 4 years [3].

This study would be looking into the fatigue behavior of concrete when being added with PVA fiber. Fatigue is one of the major causes for the rupture of materials and catastrophic damage in structural components. Fatigue is the tendency of a material to break under repeated cyclic loading at a stress considerably less than the tensile strength in a static load. The process of fatigue occurs by the initiation and propagation of cracks. Fatigue behavior is strongly affected by loading conditions, material, and environment.

1.2 PROBLEM STATEMENT

Concrete possessed characteristics whereby it has high strength in compression but weak in tension. In order to mend this disadvantage of concrete, PVA fibers is to be use to reinforce the normal mix of concrete. PVA fibers is considered as one of the most suitable polymeric fibers to be used as the reinforcement of concrete due to its advantages such as it will never rust, having high durability through out years, not hazardous and less cost to obtain compared to other type of fibers.

However, even though the fiber reinforced concrete by using PVA fibers is good in durability and compressive strength, the repeated application of loads on the material using the same PVA composition might well results in fatigue behavior; when subjected to cyclic loadings of a given level but below it ultimate capacity, it would eventually fail as in normal concrete composition [4]

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objectives of this project are:

- To study about PVA, its characteristics and the advantages it would bring to concrete.
- To determine the behavior of concrete when added with PVA through the dynamic compression test.
- To determine the effectiveness of PVA fibers in enhancing the properties of concrete in the compressive fatigue strength criteria and the optimal volume for the fiber to be incorporated into the concrete mix.

The scope of study would include:

- Research through journals and reading materials in relation to PVA fibers and concrete.
- Lab experiments to determine behavior of concrete with PVA, including static compression test after 67 day of samples curing and dynamic compression test after 100 day of samples curing.
- Analyzing the data obtained from each experiment to produce *S-N* diagrams or Wöhler diagrams through certain computer software.
- Determining the increment in percentage of fatigue strength and their effectiveness through the *S-N* diagrams or Wöhler diagrams and by using the fatigue equation as follows:

$$S = a - b \log(N) \qquad (1)$$

Where a and b are experimental coefficients, S representing stress level, and N is the number of cycles to failure.

CHAPTER 2

LITERATURE REVIEW

2.1 RELATIONSHIP BETWEEN COMPRESSION AND TENSILE STRENGTH

The compressive strength of the concrete will indicates the property of the casted concrete and normally the standard 28 days compressive strength is taken as the standard reading of design strength. The other type of strength that the concrete has is the tensile strength which is usually lesser than that compressive strength of the particular concrete. This indicates that the concrete is actually good in compressive but weak against tensile force acting on it, as discussed before. The two types of the strength mentioned are actually close related. As mentioned by A. M. Neville [5], the tensile strength will also increases as the compressive strength increases, but with a decreasing rate compared to the compressive strength through out the 28 days.
According to Oluokun as recited by Neville [6], the relationship between compressive strength and tensile strength can be related to the below equation:

$$f_t = 0.2(f_c)^{0.7} \qquad (2)$$

Where f_t and f_c is tensile strength and compressive strength respectively, and the strengths are in megapascals; the coefficient becomes 1.4 in pounds per square inch.

2.2 FATIGUE BEHAVIOUR OF CONCRETE

Fatigue may be defined as a process of progressive, permanent internal structural changes in a material subjected to repeated loading. In concrete, these changes are mainly associated with the progressive growth of internal micro-cracks, which results in a significant increase of irrecoverable strain. At the macro level, this will manifest itself as changes in the material's mechanical properties.

Fatigue loading is usually divided into two categories i.e. low-cycle and high-cycle loading. Low-cycle loading involves the application of a few load cycles at high stress levels. On the other hand, high cyclic loading is characterized by a large number of cycles but at lower stress levels.

It has been expected that different loading cycle categories produce different failure mechanisms within concrete. For low-cycle fatigue, the dominant mechanism is the formation of mortar cracks leading to continuous cracked networks. On the other hand, high-cycle fatigue produces bond cracks in a slow and gradual process

Fatigue crack growth can be divided into two stages; the first stage is a deceleration stage, where the rate of crack growth decreases as the crack grows, and the second stage is an acceleration stage, where there is a steady increase in the crack growth rate right up to failure of material.

Concrete is a heterogeneous material which is inherently full of flaws such as pores, air voids, and shrinkage cracks. The mechanism of fatigue failure in concrete can be divided into three stages. The first stage involves the weak regions within the concrete and is termed flaw initiation (crack initiation). The second stage is characterized by slow and progressive growth (crack propagation) of the inherent flaws to a critical size and is known as microcracking. In the final stage, when a sufficient number of unstable cracks have formed, a continuous or macrocrack will develop, eventually leading to failure.

2.3 POLYVINYL ALCOHOL PROPERTIES

Polyvinyl alcohol (PVA) is white and granular, soluble in hot water but insoluble in cold water and organic solvents. It will form transparent films when prepared in water solutions which are then the water will be evaporated. The transparent films will have high tensile strength and tear resistance, which offer excellent adhesion to porous and hydrophilic surfaces. With these properties, PVA might be proven useful in enhancing the mechanical properties and fatigue strength of plain concrete since both the coarse and fine aggregates both have porous and hydrophilic surfaces. Additional advantage that might be obtained from the use of PVA fibers as reinforcement in the concrete is that less care could be taken during the mixing of the concrete using the conventional concrete mixer. Here, as the PVA properties incorporate high tensile strength and tear resistance, the PVA fibers are less to be damaged during the concrete mixing processes, unlike other type of fibers such as steel fibers and glass fibers. Therefore, the normal mixing procedure could be executed instead of using Hatschek-based Process; which is the process used to manufactured and incorporate the fragile fibers into cementitious matrices [7].

Figure 2.1: Polyvinyl alcohol (PVA) fibers

PVA fibers also have been proved to be safe if burned under fire. Yokoi et al. [8] has demonstrated this fact by exposing five rats under the smoke emitted by burned materials. All the rats have been recorded to stay alive under exposure of smoke by burned PVA since the PVA is not emitting any dangerous chemical or substances if burned. When burned, PVA that is only composed of carbon, hydrogen, and oxygen only emit water and carbon dioxide.

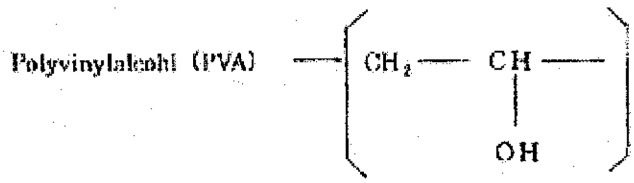


Figure 2.2: The composition of PVA polymers

2.4 MECHANICS OF FIBER REINFORCEMENT

For the early stage of research, it is found that the usage of fibers in the plain concrete matrix has proven to improve the mechanical properties of the concrete. The fibers will act as discontinuous reinforcement in the concrete matrix throughout compressive and tensional zone. This will resists the development of micro and macrocrackings especially in the earlier stage of the concrete. These crackings are the main cause of fatigue failure of the concrete structure under repeated applications of loadings such as wind loads across the buildings or the bridge deck structures.

Below are the mechanics of fiber reinforcement which affects the performance of fiber reinforced concrete.

2.4.1 First Cracking Load

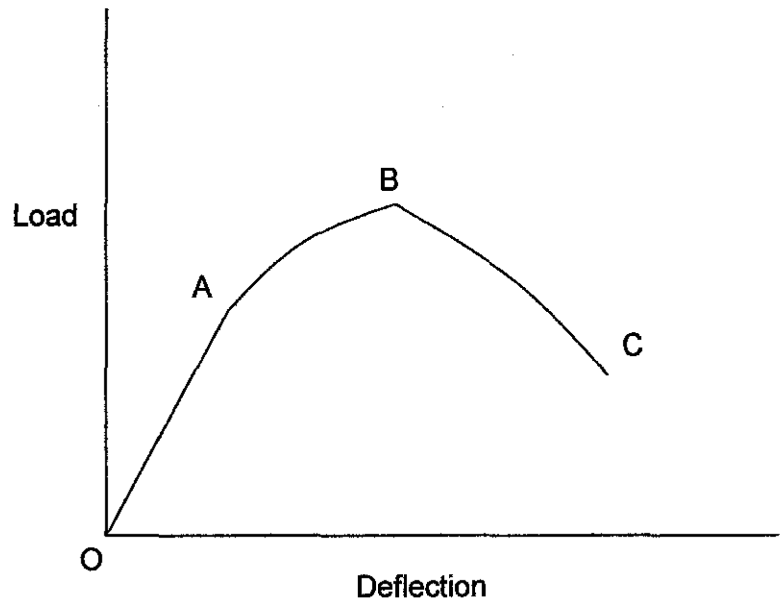


Figure 2.3: Load-deflection diagram of fiber reinforced concrete.

The trilinear deformation diagram above is obtained from fiber reinforced concrete in flexure. For point OA in the load-deflection diagram represents the first cracking load that can be termed the first-crack strength [9]

Point AB shows that when the matrix is cracked, the applied loads are transferred to the fibers. This indicates the failure of the aggregates to resist the shear forces through the interlocking between the aggregates mechanism. Here, the fibers will endure the loads as it bridges and tie the crack from opening further and delay the growth of the cracks. This mechanism is causing the strength of FRC to increase.

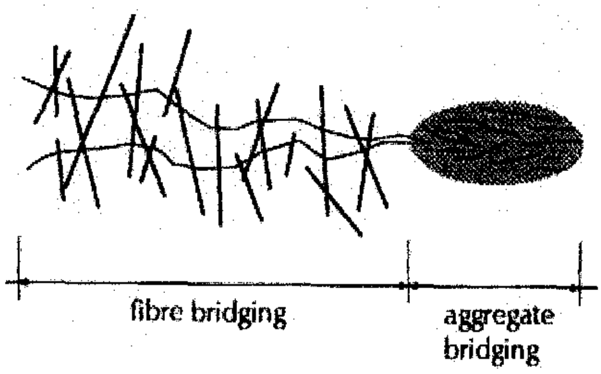


Figure 2.4: The bridging effects by the fibers incorporated into the concrete mix (source: Jan G.M. van Mier "*Fracture Process of Concrete*", pg 105)

As the load increases, the fibers will continue to deform and reaches point B of the load-deflection diagram where the debonding and pullout of some fibers will occur without reaching the yield strength in most of the fibers. Further deflection continues in the BC region, where debonding and pullout of fibers continue. The fibers may fail by yielding or by fracture of the fiber element depending of their spacing and size.

2.4.2 Critical Fiber Length: Length Factor

This factor demonstrates that the strength of a composite increases continuously with the fiber length. However, as reported by Chengkui et al. [2], the typical ratio of fiber length to the size of coarse aggregate is ranging from 1.5 to 2.0 for steel fibers and claimed that beyond this range the reinforcing effect of the said fibers may be lower.

2.4.3 Critical Fiber Spacing: Spacing Factor

This factor demonstrates that the cracking load of the matrix is higher when the spacing used is closer.

2.4.4 Fiber Orientation: Fiber Efficiency Factor

This will determines the efficiency of the fibers to resist the tensile forces in their direction as similar to the usage of vertical shear stirrups in reinforced concrete beams to resist the inclined diagonal tension stress.

2.5 THE FIBER BRIDGING EFFECTS

The ability to bridge the opening cracks due to the failure of the interlocking mechanism between the aggregates to resist the applied load on the concrete is called as the bridging effects. This effect is an important advantage that the fiber reinforced concrete posses to enhance the properties of plain concrete. The inclined fiber at an angle to the plane of the matrix crack will lead to the increment of the bridging force, as the inclined fiber will provide additional normal force acting on the surface of the fiber [10]

However, as demonstrated by the previous experimental study by Zhang et al. [11] in researching the bridging behavior of fiber reinforced concretes, it was found that the bridging effects will degrades with the increment of the number of load cycles. The degradation of the interfacial bond between the concrete matrix and the fibers is said to be the primary factor of this behavior.

2.6 STATIC BEHAVIOR OF FRC IN COMPRESSION

By using hooked-end steel fibers with 30 mm (0.8 mm in diameter) and 60 mm (0.5 mm in diameter) in length for each, and coarse aggregate size of within 5 mm to 15 mm, Cachim et al. [12] has recorded that there is an increment of about 17% higher than the corresponding plain concrete strength by using the 30 mm fiber length. However, by using the 60 mm fibers in length incorporated into the concrete, it was recorded that the compression strength under monotonic test was identical to that plain of concrete. These test results are in agreement with the statement by Chenkui et al. [2] where the strengthening effects of steel fiber is only within range of 0.5 to 2.0 in ratio of fiber length to the size of coarse aggregate. Therefore, the typical ratio that beyond of this range might have a lower strengthening effects in the concrete.

2.7 SLUMP BEHAVIOR FOR FRESH FRC

Chang et al. [13] has investigated the relationship between the surface area of the fibers per unit volume and the slump value of the fresh FRC by using the steel fibers with different length measurement. There are three equations that have been used in this investigation as follows:

$$A_f = [(2\pi d^2)/4] + \pi dL = \tfrac{1}{2}\pi d(d+2L) \qquad (3)$$

$$N = (p/100) / [(\pi d^2/4)L] = p/(25\,\pi d^2 L) \qquad (4)$$

$$A_{sur} = A_f N\,(p/50d)\,[(d/L) + 2] \qquad (5)$$

where from equation (3), (4), and (5) above, A_f is the surface area of a fiber, *d* and *L* are the diameter and length respectively of the fiber, *N* is the number of fibers per unit volume of concrete, *p* is the fiber content and A_{sur} is the surface area of fibers per unit volume. The authors propose that when the surface area of fibers per unit volume is more than 0.6 cm^2 cm^{-3}, the water content has to increased or water reducing agent are to be used.

2.8 FATIGUE BEHAVIOR OF FRC IN COMPRESSION

The addition of steel fibers and polypropylene fibers can significantly improve the fatigue performance of concrete members [14]. Most researchers agree that fiber reinforced concrete (FRC) has better fatigue behavior compared to plain concrete. The extent of improvement on the fatigue capacity of fiber reinforced concrete can be expected to depend upon the fiber volume content, fiber type and geometry. Various combinations of these parameters will give rise to different fatigue characteristics.

By using the same fiber type as mentioned in section 2.6 in this report, Cachim et al. [12] has also recorded that there is an increment in the fatigue life of fiber concrete when series I of the samples (30 mm in length, 0.8 mm in diameter) are tested. However, in contrast, the samples in series II (60 mm in length, 0.5 mm in diameter) was found to show smaller fatigue life than that of plain concrete. The authors have concluded that the behavior recorded in the fatigue life could be related to the initial imperfections that exist in concrete, such as micro-cracks or voids. The presence of the bigger fibers would be an additional cause to these imperfections, which also affects the initial residual stresses.

CHAPTER 3

PROJECT WORK AND METHODOLOGY

3.1 PROJECT PLANNING

For the first month of the project in part 1, there will be more on the literature researches via relevant journals and reference books. Since this project was pioneered by the previous 2005/2006 Final Year Project (FYP) students, most of the basic knowledge would be available, but only limited to the static test of the fiber reinforced concrete using PVA. The current research of 2007/2008 FYP is to study the effects of the PVA fiber on the compressive fatigue strength of the concrete and finding the optimum fiber volume in the optimum compression fatigue strength.

The concrete casting works and most tests will be done in the Concrete Technology Laboratory in Building 13, UTP. Previous casting session on 2006/2007 for grade 40 have been done with 18 samples for each 0%, 1%, 2%, and 3% of PVA volume using 150mm x 150mm x 150mm steel moulds. The samples are subjected to static compression loading for the test session on 1^{st}, 3^{rd}, 7^{th}, 19^{th}, 28^{th}, and 60^{th} of the sample curing ages. The results will then be compared with each other according to the fiber volume and optimum PVA fiber volume will be acquired.

For the part 2 of the project (2007/2008 session), 12 samples of 100mm x 100mm x 100mm grade 30 concrete are casted. Each 12 samples are divided into three groups according to the fiber volume used i.e. 1%, 2%, and 3%. Three samples from each group will be used for the static compressive strength test on the 67^{th} curing day and the results will then be used for the dynamic compressive test on the 100^{th} curing day to determine the fatigue compressive strength of the PVA FRC. The *S-N* diagrams will be produced and analyzed to determine the percentage of fatigue strength using equation (1).

3.2 LABORATORY WORKS

The laboratory works for the research mainly consists of concrete casting works and tests such as static compression test and dynamic compression test to study the effects of the PVA in the FRC in enhancing the compressive fatigue strength of the concrete.

The first laboratory works in 2006/2007 session consist of static compressive test only with the total of 72 samples of grade 40 concrete, sized 150mm x 150mm x 150mm, with each group of 18 samples according to the fiber volume used, that is 0%, 1%, 2%, and 3% of PVA. All the casting works and tests are done according to the laboratory standards and safety. The 2006/2007 session works are more focused on studying the effects and performance of the FRC when PVA fibers are incorporated and mostly are done by the current researcher in the said session.

The 2007/2008 session laboratory works will focus in the dynamic compression tests to achieve the objectives of this report. The concrete grade of the samples has been reduced from 40 to 30 and the sizes of the mould used also have been reduced to 100mm x 100mm x 100mm. This is to ensure that the sample compressive fatigue strength did not goes near to the max load of Universal Testing Machine (UTM) 2000kN in the laboratory, so that the time taken for the fatigue test would be shorter for the sample to be fails since there exists the time limit for this study to be done.

Two machines will be used to determine the compression static strength and the compression fatigue strength of the samples. The machines are ELE ADR 2000 and ZWICK ROELL HA2000 for respective tests.

3.2.1 Hazards Assessment

All the laboratory works will be done according to the laboratory standards and regulations. This is to ensure that the proper Health and Safety Environment (HSE) policy in UTP would be fully adopted and followed. The primary objective in following the correct procedures during the laboratory works is to prevent any unwanted accidents in the laboratory involving the student or any personnel in the laboratory. The rightful acts by abiding the HSE policy in UTP would give a good image and performance to the university itself.

By definition, hazard could be anything that can cause any danger to the personnel inside or outside any facility. The sources or hazard could be anywhere when working inside the concrete laboratory and therefore, an assessment known as Hazard Assessment will be done before entering the concrete laboratory and proceed with the research. Some assessment that has been done and classified by the laboratory instrumentals and materials can be viewed on the next page.

Instrument/material	Sequence of Basic Job Steps	Potential Accidents or Hazards	Recommended Safe Job Procedure
Vibrating table	Switching on the machine Waiting near the machine	Electric shock Damage to hearing	Avoid switching on the machine using wet hands Avoid continuous usage without any short breaks and use earplugs if possible
Sieving machine	Loosening the lock Waiting near the machine	Could injure user hands Damage to hearing	Wear proper hand gloves Avoid continuous usage and use earplugs if possible
Overhead crane	Moving a heavy object	Falling of object from high level	Avoid walking below the crane while the machine is operating and wear proper safety helmets
Compression machine	Loading of sample in place Running the test	Heavy concrete drop Loading steel drop Could injure user hands Chips of flying hitting body parts	Wear proper safety shoe Wear proper safety shoe Wear proper hand gloves Close the and lock the protection gate
Universal Testing Machine 2000kN	Loading of sample in place Running the test	Heavy steel drop Steel chips Heavy concrete drop Chips of steel and concrete flying hitting body parts	Wear proper safety shoe Wear proper hand gloves Wear proper safety shoe Wear proper safety jackets and goggles

Concrete mixer	Switching on the machine Mixing the concrete	Possible of electric shock Injuries to part of the body	Avoid switching the mixer with wet hands Close the mixer cover before
Cements	Scoping and transporting the cement	Harmful to lung when inhaled	Wear proper face mask

Table 3.1: Hazard assessment in the concrete laboratory

3.2.2 Mix Proportioning (Mix Design)

The mixing proportions were done according to the British method. Similarly to the American Concrete Institute (ACI) approach, the British method explicitly recognizes the durability requirements in the mix selection. Below are the steps and calculations taken for the mix proportioning works.

a. Target design strength (28 days) = 30 MPa

b. Referring to the Table I appendix, the compressive strength for Type 1 OPC cement at the age 28 days is 42 MPa

c. From the Figure I appendix, the water/cement ratio is 0.63

d. As in Table II appendix, slump 60-180 mm and maximum aggregates of 20 mm uncrushed were chosen. Therefore, the water content for the mix is 195 kg/m^3

e. The cement content for the mix is given by:

Water content / wc ratio = 195/0.63

= 309.52 kg/m^3

f. According to Figure II appendix, fresh density of concrete mix is 2361.11 kg/m^3

g. Thus, total aggregates content is given by:

= 2361.11 kg/m^3 – 309.52 kg/m^3

= 2051.59 kg/m^3

h. From Figure III appendix, fine aggregates proportion is 38.5%. Thus, fine aggregates is given by:

$= (38.5/100) \times 2051.59$

$= 789.84 \text{ kg/m}^3$

i. Therefore, coarse aggregates value is given by:

$= 2051.59 \text{ kg/m}^3 - 789.84 \text{ kg/m}^3$

$= 1261.75 \text{ kg/m}^3$

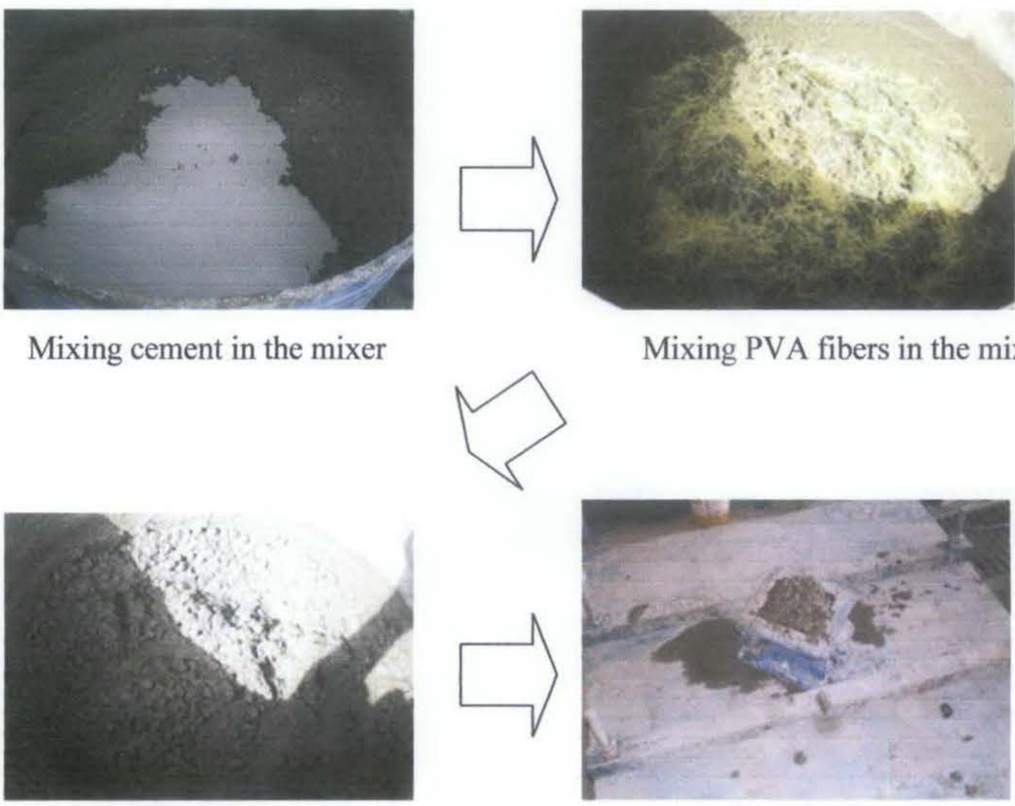
Hence, the summary is as below (for each 1 m^3 concrete volume):

W/C	= 0.63
Cement	= 309.52 kg/m^3
Fine aggregate	= 789.84 kg/m^3
Coarse aggregate	= 1261.75 kg/m^3
Water	= 195 kg/m^3

3.2.3 Concrete Mixing

Concrete mixing adopted in this experiment is of the normal concrete. The procedure of mixing is as the following:

1. Pour all coarse aggregate and fine aggregate into mixer and mix for 25 seconds.
2. Pour half of the water (mixed with super plasticizer) and mix for 1 minute
3. Leave the mix for 8 minutes
4. Pour cement and mix for 1 minute
5. Pour another half of water (mixed with super plasticizer) and add for 3 minutes
6. Add PVA fibers in the mix and mix for another 2 minutes
7. Perform hand mixing until it reach uniform stage



Mixing cement in the mixer

Mixing PVA fibers in the mix

Fresh mixed concrete

Placing concrete in moulds

Figure 3.1: Process of concrete mixing

3.2.4 Concrete Testing

Concrete testing to investigate the static properties of the PVA fiber reinforced concrete are done in two main types which is testing for the fresh mix – which is done immediately after the mixing works – and hardened concrete test – which are done after the curing process. All the test methods are described further in the Interim Report part.

3.2.4.1 Fresh Concrete Test

3.2.4.1.1 Slump Test (BS 1881 : Part 102 : 1983)

Objective

To measure the shear resistance of concrete to flowing under its own weight.

Procedure

1. The mould for the slump test which is the frustum of a cone, 300 mm in high is placed on a smooth surface with smaller opening at the top.
2. The cone is moistened before the test commence.
3. Concrete is filled in three layers, with each layers is tamped 25 times using a standard 16 mm diameter steel rod, rounded at the end. The mould is firmly held against the base facilitated by handles to the mould.
4. Struck off the top surface of the mould by using rolling motion of the tamping rod after finish filling the mould.
5. The cone is slowly lifted.
6. The measurement is made by measuring to the highest point of the decrement.

Figure 3.2: Slump test done for 2% PVA volume

3.2.4.2 Hardened concrete test

3.2.4.2.1 Static Compression Test (BS 1881 : Part 116 : 1983)

Objective

To measure the compression strength of the casted concretes.

Procedure

1. The cube samples are being brought from the curing tank to the testing machine.
2. While still wet, the hardened cube sample is placed in the testing machine, with the cast faces in contact with the platens.
3. Maximum limit of 40mm from the top platen to the sample is to be sure.
4. The setting of machine is changed to test 100mm by 100mm by 100mm test sample and the constant rate of load of 3.00kN/second is to make sure to be applied.

5. The compressive strength reading after the sample is failed is recorded to the nearest 0.5MPa.

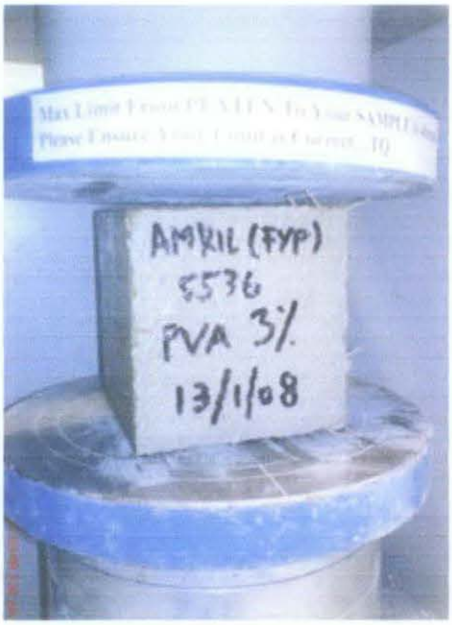


Figure 3.3: Compression test using compression machine

3.2.4.2.2 Dynamic Compression Test

Objective

To measure the compression strength of the casted concretes.

Procedure

6. The cube samples are being brought from the curing tank to the testing machine platform.
7. The actuator is adjusted to suitable height.
8. While still wet, the hardened cube sample is placed in the testing machine, with the cast faces in contact with the platform.
9. Dynamic testing mode is selected in the computer program followed by inserting the relevant inputs.

10. The rest of the processes are computer controlled until the sample fails.
11. Collected readings are saved in the computer and printed out to be analyzed.

Figure 3.4: Dynamic compression test using UTM

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 FRESH CONCRETE TEST

4.1.1 Slump Test

Mix	Slump (mm)
PVA 0%	150.0
PVA 1%	62.00
PVA 2%	25.00
PVA 3%	0.000

Table 4.1: Results for the slump test in 2006/2007 session (grade 40)

Mix	Slump (mm)
PVA 1%	97.50
PVA 2%	41.00
PVA 3%	30.00

Table 4.2: Results for the slump test in 2007/2008 session (grade 30)

From the slump test results shown in the table above, the high slump up to 150 mm can be achieved on the 0% of PVA fibers, that is the control mix of the experiment. The height of slump decrease with the increment of the PVA percentage by the cement weight of each sample. From here, it could be conclude that the higher the volume of PVA fibers, the lesser the height of the slump would be, due to the porosity of the PVA fibers to absorbs water content and bond together within the sample matrix. As stated by Spadea et al. [15] the slump test could be a good field guide of workability properties for practical applications. In the next session, the usage of superplastisizer of 0.15% of the cement weight is used and this improves the slump height of the fresh concrete.

4.2 HARDENED CONCRETE TEST

4.2.1 Static Compression test

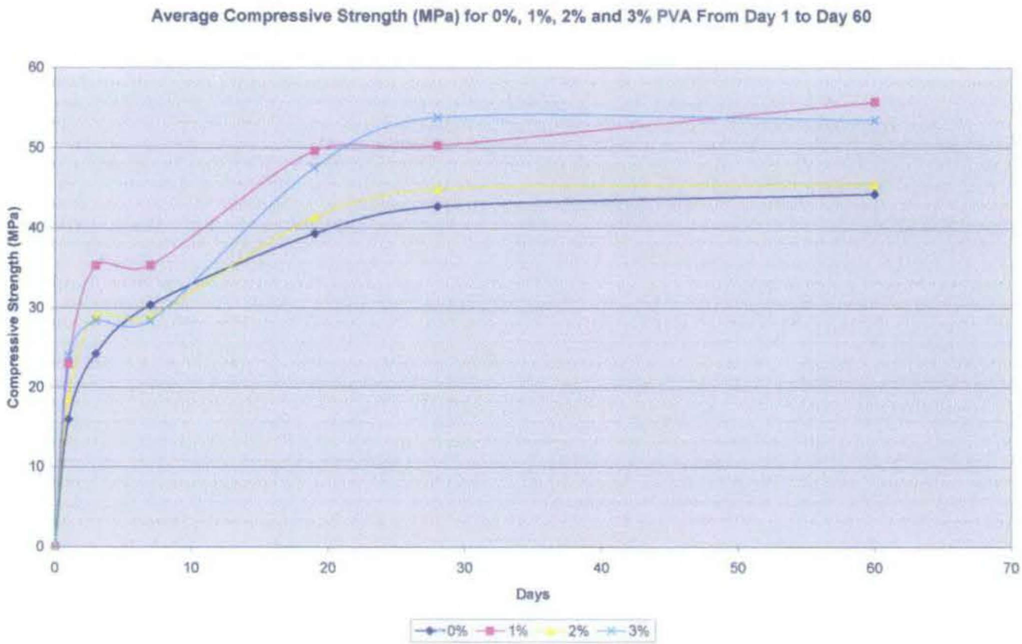


Figure 4.1: Compression strength development from day 0 to day 60 for 0%, 1%, 2%, and 3% PVA fiber reinforced concrete cube samples for session 2006/2007 (grade 40)

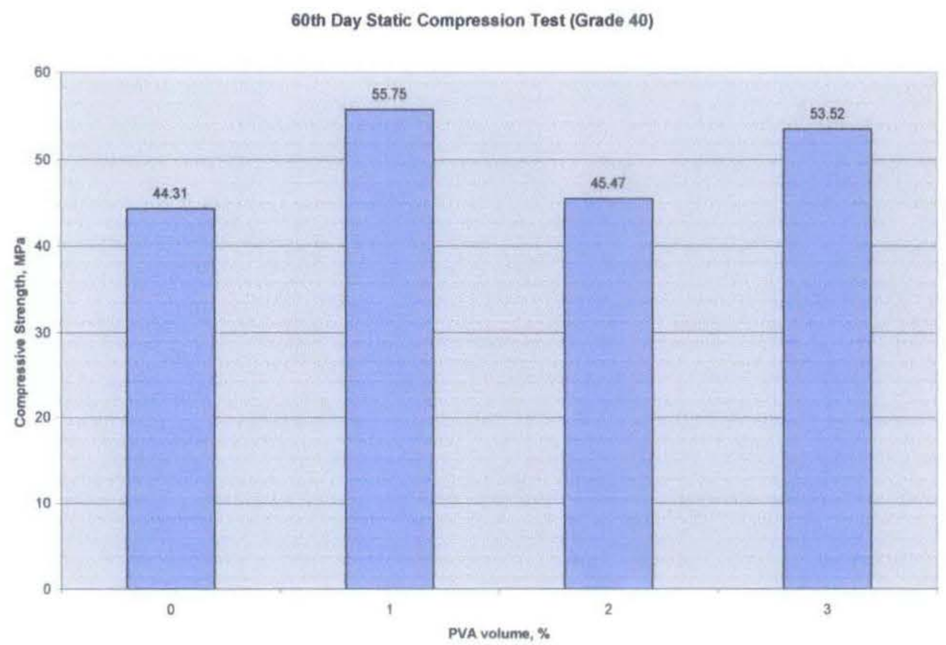


Figure 4.2: Static compression test after 60 days of curing period for session 2006/2007 (grade 40)

Figure 7 shows the development of the compression strength for all the PVA fiber reinforced cube samples which have been tested in the 2006/2007 session. From the graph above, it could be seen that there exists some unconformities on the values of stress recorded for concrete samples incorporated with the PVA compared with the control samples which have a uniform values through the 60 days observations. On the 60^{th} day compression test result from Figure 8, the 1% PVA volume gives the higher reading with 26% increment from the target design strength. Apparently, when 28^{th} day is concerned, it could be seen that 3% of PVA fiber achieve higher compressive strength value compared to the expected 1% value.

These occurrence might proves the balling effect, which occurred because the consolidation of the fibers will becomes more difficult with increasing fiber content and aspect ratio [16] Furthermore, the absence of superplastisizer in the concrete mix will worsen the fresh concrete condition especially when mixing with the higher volume of PVA fibers and this will result in low workability and have been proved from the slump test done.

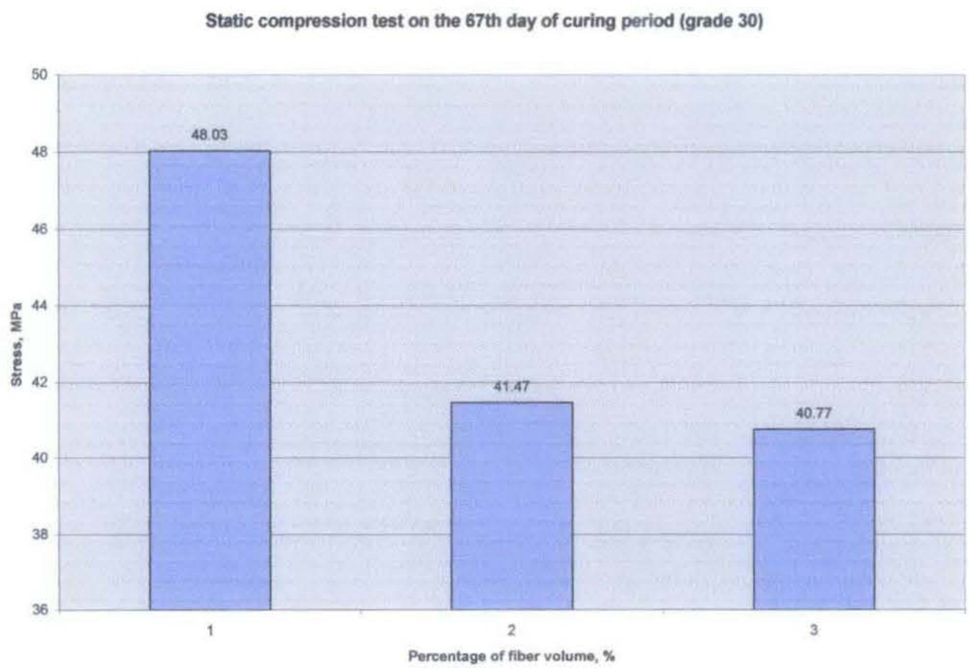


Figure 4.3: Static compression test after 67 days of curing period for session 2007/2008 (grade 30)

For 2007/2008 session, the static compression results on the 67th day can be seen as in Figure 9. The highest value is given by the 1% PVA volume with the increment of 60% from the target design strength of 30MPa, followed by 2% and 3% with increment of 38% and 36% respectively. These results agree with the static compression test done by Chenkui et al. [2] using the steel fibers, where there are increments in concrete strength when increasing the steel fiber content but decrease in concrete strength containing 2% fiber volume, due to the poorer workability of the mixture. Furthermore, to minimize the occurrence of air bubbles inside the fresh mix during compacting, the usage of poker vibrator is replaced with the vibrating table. This replacement would ensure that the concrete mix is compacted uniformly to gives more acceptable results.

4.2.2 Split tensile test

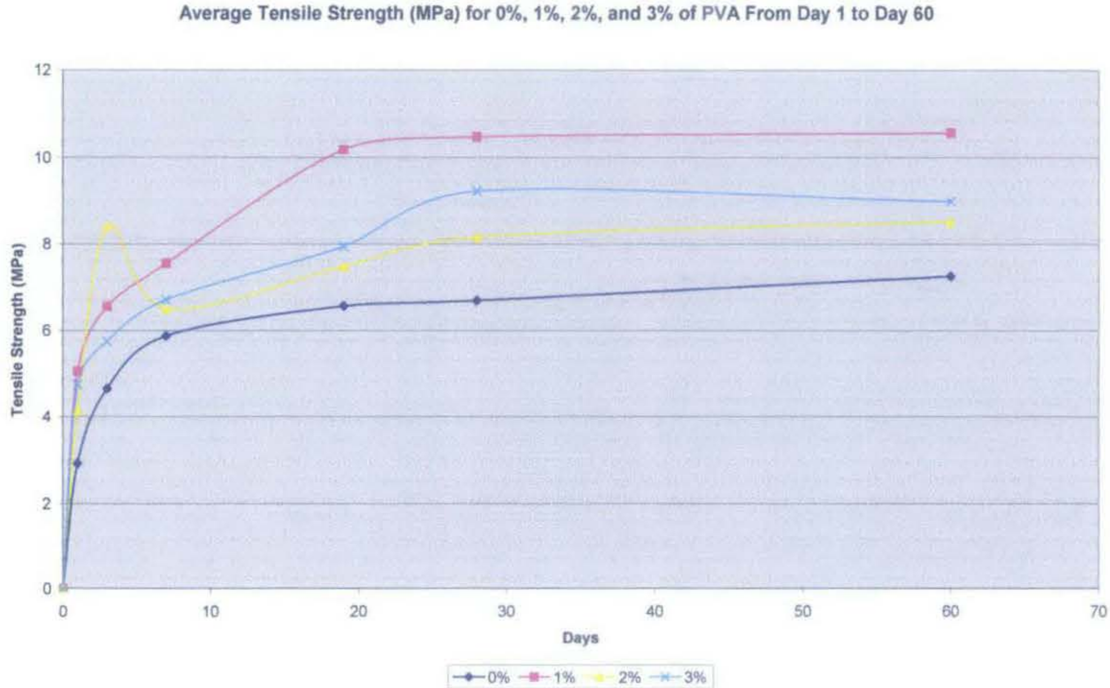


Figure 4.4: Tensile strength development from day 0 to day 60 for 0%, 1%, 2%, and 3% PVA fiber reinforced concrete cube samples for session 2006/2007 (grade 40)

From the graph obtained above from the split tensile test on the cube samples, there is strong evidence that by incorporating the PVA fibers in the concrete matrix, the higher tensile strength can be achieved compared to normal concrete mixes. Still, there is some doubt left from the result obtained from the split tensile tests that have been done. This can be seen for the 0% PVA fiber content, where the value of the tensile strength obtained is much higher compared that what it should be, that is according to equation (2), the relationship he proposed, $f_t = 0.2(f_c)^{0.7}$ is not met. This is because there are not enough instruments to be used to run the said test on the cube samples. Due to this, instead of using point loading, the prism steel bar has been used. Apparently, the usage of prism steel bar to transmit the load on the test rig will cause platen to transmit uniform load on the sample, instead of point load that should be used in the split tensile test.

The trend of the results are not in agreement with Singh et al. [17] with optimal increment of tensile strength in higher to lower order is 1%, 3%, and followed by 2%, where the said authors claimed that 1% to 2% of fiber volume give the highest increment compared to 3% fiber volume. These results also are not in agreement with workability theory as discussed before. Nevertheless, the overall result in the split tensile test for 2006/2007 session is only for reference and will not be used to achieve the main objective of this research.

4.2.3 Dynamic compression test

Due to the UTM machine failure in Block J in UTP and time constraint for the research to be continue, the dynamic compression test could not be done and therefore, there is no result obtained in this section.

4.2.4 Scanning Electron Microscope (SEM)

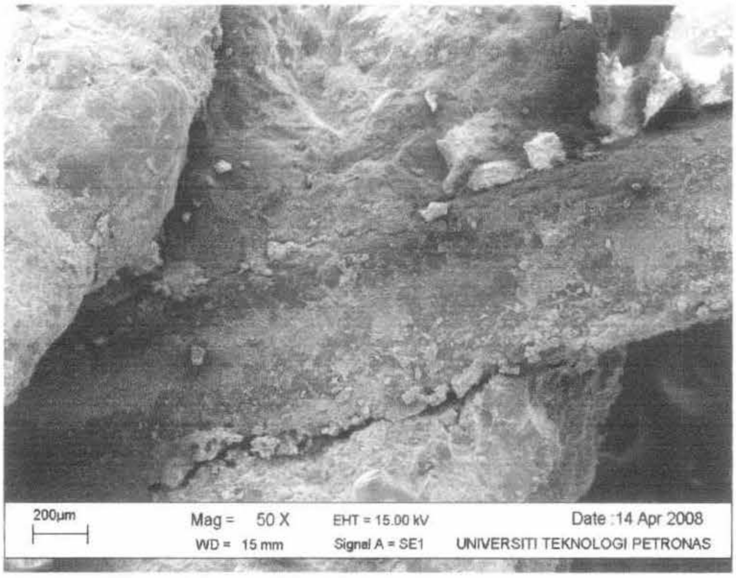


Figure 4.5: The adhesion of PVA fiber with the concrete matrix under 50x zoom using SEM (sample A)

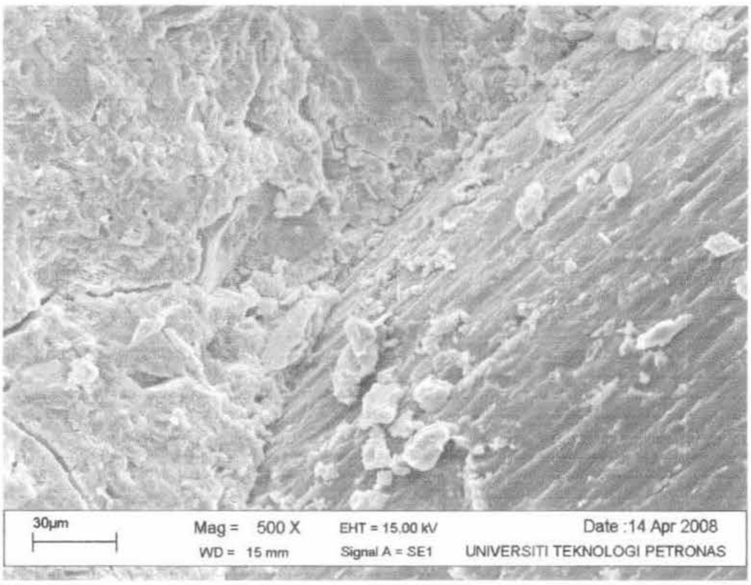


Figure 4.6: The adhesion of PVA fiber with the concrete matrix under 500x zoom using SEM (sample B)

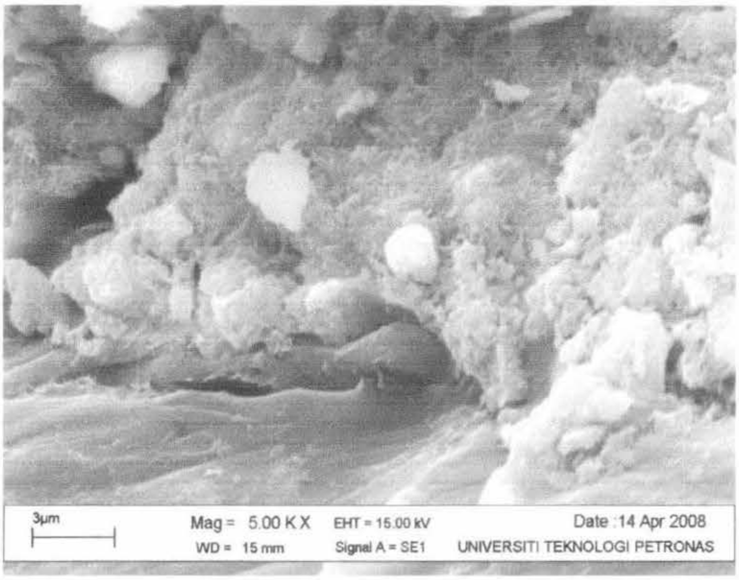


Figure 4.7: The adhesion of PVA fiber with the concrete matrix under 5000x zoom using SEM (sample A)

The residue of the concrete samples have been taken after the failure in the static compression test to the Mechanical Engineering Department for viewing the adhesion between the PVA fiber with the concrete matrix using Scanning Electron Microscope (SEM). The rough surface of PVA fiber offers excellent friction with the concrete matrix and this will provide an excellent fiber bridging effects between the fibers and concrete matrix to bridge the micro-cracks and thus slowing the crack growth which will results in improvement of the concrete properties.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The project is based on researching the effectiveness of PVA fiber to enhance the concrete's properties as well as to achieve the said objectives set by the author especially in finding the optimal value of the fiber volume to be incorporated in the concrete mix to give the optimum compressive fatigue strength of the concrete when loaded under dynamic compressive stress. Based on the literature reviews, PVA fiber has high tenacity and modulus of elasticity compared with other type of fibers. Furthermore, the PVA fibers also offer excellent adhesion with the concrete matrix as shown in the SEM images. In addition to these, PVA fiber would be excellent in the FRC due to it good durability, will not corrode, and are not hazardous if burned.

From the static compression test result on the 60^{th} day of curing period, the increment of 26% in compressive strength is achieved by incorporating the 1% PVA volume in the 2006/2007 session. Unfortunately, when 28^{th} day is concerned, the optimal value is given by 3% fiber volume, and thus exists some uncertainties in the reliability of the data. In the 2007/2008 session, some improvement have been made to give more reliable data and the result on the 67^{th} day of curing period gives the optimal volume of 1% of fiber volume by increment of almost 60% in compressive strength of the concrete. The results seem to be in agreement with other researchers where 2% and 3% fiber volume gives lower percentage of increment in the compressive strength of the FRC.

However, the main objectives of this research could not be obtain by the author, since the UTM machine is down in Block J in UTP at the time when the machine is to be used to test the samples at 110^{th} day of curing, and there is a time constraint for the research to be finish within time.

There are three recommendations that could be made here to improve the reliability of the results throughout the research. The usage of superplastisizer is an important element when mixing the concrete with any fibers. As proved by the author and other researchers, incorporating the fibers in the fresh concrete will result in poor workability as the percentage of the fiber volume is increased. This will affect the strength of the hardened concrete later on as proved by the author in the 2006/2007 session. Therefore, suitable percentage of superplastisizer should be used when mixing the FRC.

The determination of when to incorporate the fibers during the mixing phase also plays an important role in minimizing the said balling effects. The author has determined that the best way to put the fibers is during the early stage of the mixing process, and that is to put the fibers uniformly together with the coarse aggregates and mix. The fine aggregates are then poured together in the conventional mixer and mix altogether with the coarse aggregates and fibers mix. The rest of the mixing steps remain as the same.

While compacting the fresh concrete mix in casting phase, it is best to avoid the usage of poker vibrator as it could lead to less uniform compaction in the concrete samples. This might lead to the formation of pores in the concrete due to the air bubbles formed from the movement of in and out of the poker vibrator while compacting the mix in the mould. The usage of vibrating table can be more effective in providing a uniform compaction to the concrete mix and get rid of the air bubbles at the same time. However, the vibrating time must be observed carefully as to avoid the segregation of the mix.

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APPENDICES

Mix Proportioning

Table 14.9 Approximate Compressive Strengths of Concretes Made with a Free *Water/Cement Ratio of 0.5 According to the 1988 British Method*[14.11]

Type of cement	*Type of coarse aggregate*	*Compressive strength* (MPa (psi)) at the age of (days):* 3	7	28	91
Ordinary Portland (Type I) / Sulfate resisting Portland (Type V)	Uncrushed	22 (3200)	30 (4400)	42 (6100)	49 (7100)
	Crushed	27 (3900)	36 (5200)	49 (7100)	56 (8100)
Rapid hardening Portland (Type III)	Uncrushed	29 (4200)	37 (5400)	48 (7000)	54 (7800)
	Crushed	34 (4900)	43 (6200)	55 (8000)	61 (8900)

*Measured on cubes

Table I: Approximate compressive strength of concrete

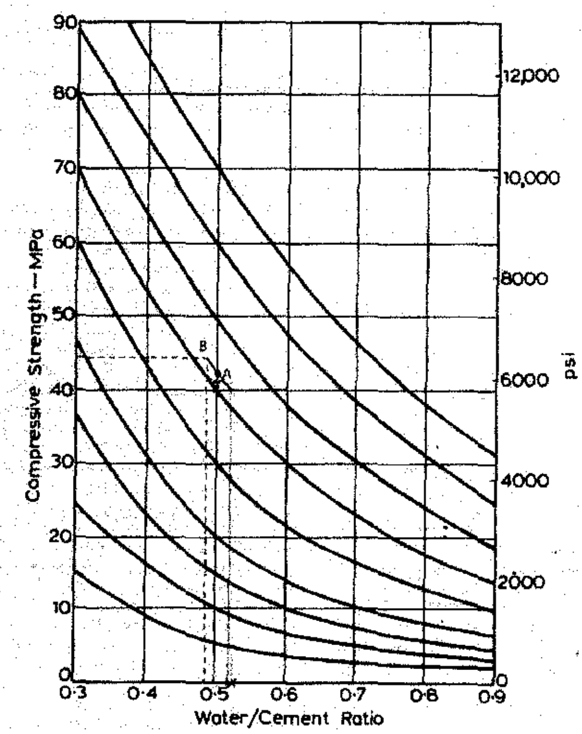

Figure I: Relation between compressive strength and free water/cement ratio

Table 14.10 Approximate Free Water Contents Required to Give Various Levels of Workability According to the 1988 British Method[14.11] (Crown copyright)

Aggregate		*Water content, kg/m³ (lb/yd³) for:*				
Max size, mm (in.)	*Type*	*Slump, mm (in.)*	*0–10 (0–½)*	*10–30 (½–1)*	*30–60 (1–2½)*	*60–180 (2½–7)*
		Vebe time, s	*>12*	*6–12*	*3–6*	*0–3*
10 (⅜)	Uncrushed		150 (255)	180 (305)	205 (345)	225 (380)
	Crushed		180 (305)	205 (345)	230 (390)	250 (420)
20 (¾)	Uncrushed		135 (230)	160 (270)	180 (305)	195 (330)
	Crushed		170 (285)	190 (320)	210 (355)	225 (380)
40 (1½)	Uncrushed		115 (195)	140 (235)	160 (270)	175 (295)
	Crushed		155 (260)	175 (295)	190 (320)	205 (345)

Table II: Approximate free water contents required for various levels of workability

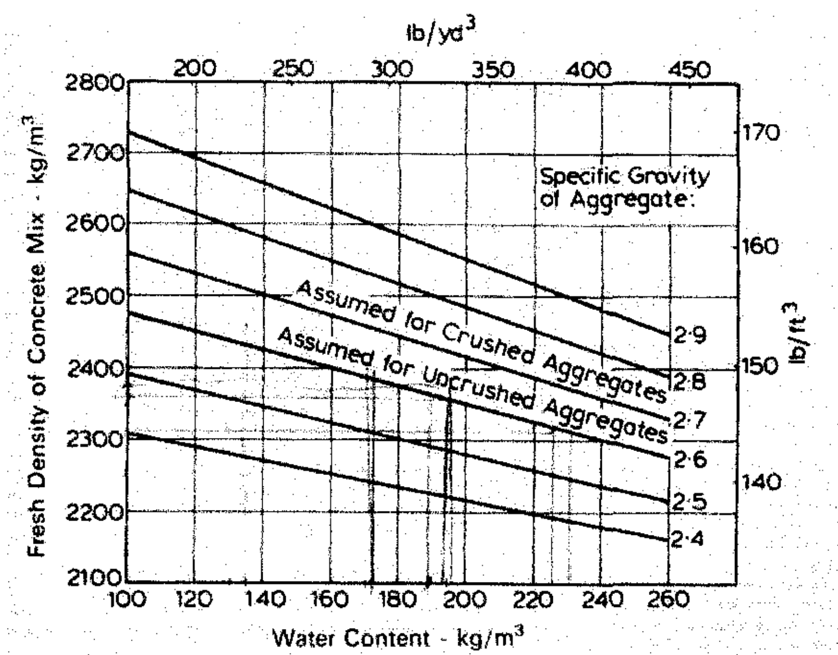

Figure II: Estimate wet density for fully compacted concrete

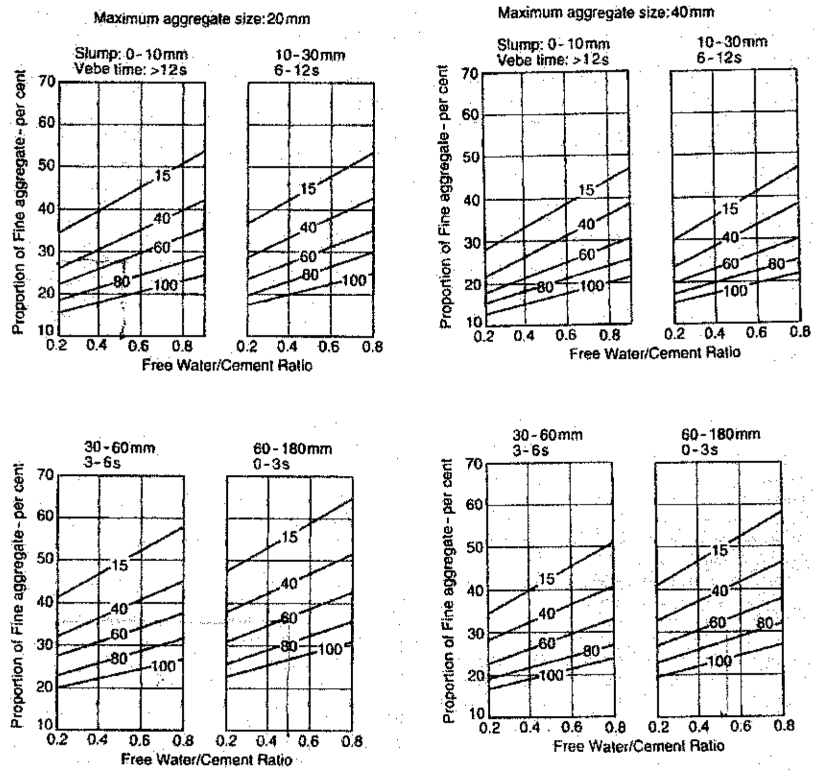

Figure III: Recommended proportion of fine aggregate as a function of free water/cement ratio for various workabilities and maximum sizes

Recorded Data for Compression and Split Tensile Tests (grade 40)

% PVA	COMP			TENSION			
	WGH (kg)	MX LD (kN)	STRS (N/mm2)	WGH (kg)	MX LD (Kn)	STRS (N/mm2)	
0	8.33	359.8	15.99	8.14	103.5	2.9281	
	8.15			8.25	99.72	2.8211	2.9273
	8.18			8.22	107.2	3.0327	
1	8.47	486.6	21.63	8.38	186.1	5.2649	
	8.32			8.24	178.4	5.0470	5.0517
	8.18	549.7	24.43	8.31	171.2	4.8433	
2	8.26	418.1	18.58	8.23	134.0	3.7909	
	8.23			8.23	158.0	4.4699	4.1436
	8.34			8.25	147.4	4.1700	
3	8.35	541.7	24.07	8.37	167.5	4.7387	
	8.26			8.29	152.8	4.3228	4.7387
	8.33			8.19	182.2	5.1545	
0	8.13	546.3	24.28	8.11	158.0	4.4699	
	8.14			8.093	164.5	4.6538	4.6463
	8.21			8.2	170.2	4.8151	
1	8.38	795	35.33	8.52	267.7	7.5734	
	8.26			8.46	204.3	5.7798	6.5559
	8.31			8.4	223.2	6.3144	
2	8.2	652.7	29.01	8.3	191.7	2.9281	
	8.25			8.25	189.0	5.3469	8.3980
	8.31			8.41	186.1	5.2649	
3	8.27	639.3	28.41	8.35	180.7	5.1121	
	8.2			8.32	211.8	5.9919	5.7486
	8.38			8.19	217.1	6.1419	
0	8.22	683.3	30.37	8.08	214.0	6.0542	
	8.18			8.23	201.4	5.6977	5.8759
	8.25			8.07	207.7	5.8759	
1	8.42	918.1	40.81	8.57	270.2	7.6441	
	8.39			8.42	252.7	7.1490	7.5498
	8.24			8.26	277.7	7.8563	
2	8.12	752.5	33.44	8.33	207.5	5.8703	
	8.17			8.42	252.7	7.1490	6.5059
	8.21			8.21	229.7	6.4983	
3	8.3	737.4	32.77	8.32	259.9	7.3527	
	8.38			8.21	222.1	6.2833	6.7162
	8.28			8.13	230.2	6.5125	
0	8.12	885	39.33	8.39	262.8	7.4348	
	8.2			8.22	227.7	6.4418	6.5691
	8.14			8.43	206.1	5.8307	
1	8.32	1117	49.66	8.45	360.2	10.1903	
	8.3			8.41	349.2	9.8791	10.1846

	8.22			8.23	370.6	10.4845	
2	8.26	930.6	41.36	8.3	320.6	9.0699	
	8.21			8.12	225.9	6.3908	7.4791
	8.4			8.34	246.6	6.9764	
3	8.36	1071	47.59	8.25	292.7	8.2806	
	8.3			8.42	259.2	7.3329	7.9440
	8.28			8.33	290.5	8.2184	
0	8.31	961.9	42.75	8.17	214.3	6.0627	
	8.28			8.11	232.2	6.5691	6.6964
	8.19			8.25	263.6	7.4574	
1	8.39	1173	52.15	8.44	359.8	10.1789	
	8.34			8.34	378.7	10.7136	10.4779
	8.37	1091	48.47	8.85	372.6	10.5411	
2	8.23	1009	44.86	8.22	290.7	8.2241	
	8.24	1012	44.98	8.39	280.1	7.9242	8.1599
	8.22			8.51	294.5	8.3316	
3	8.34	1198	53.27	8.4	345.3	9.7687	
	8.44	1222	54.33	8.4	354.4	10.0262	9.2208
	8.38			8.35	278.1	7.8676	
0	8.18	997.1	44.31	8.29	282.2	7.9836	
	8.09			8.31	252.7	7.1490	7.2575
	8.22			8.16	234.7	6.6398	
1	8.33	1228	54.6	8.31	378.0	10.6938	
	8.41	1280	56.9	8.41	345.2	9.7659	10.5675
	8.32			8.39	397.4	11.2427	
2	8.26	1073	47.68	8.29	263.5	7.4546	
	8.28	973	43.25	8.34	336.5	9.5198	8.5164
	8.42			8.44	303.1	8.5749	
3	8.31	1141	50.71	8.45	351.2	9.9356	
	8.38	1268	56.34	8.24	338.4	9.5735	8.9860
	8.22			8.33	263.3	7.4489	

Recorded Data for Compression and Split Tensile Tests (grade 30)

Date	Percnt	Number	Weight (kg)	Max. load (kN)	Stress (MPa)	Ave (MPa)
18/3/08	2%	1	2.409	438.2	43.82	
		2	2.415	391.2	39.12	41.47
		3	2.423	242.2	24.22	
21/3/08	3%	1	2.414	410.2	41.02	
		2	2.439	407.7	40.77	40.77
		3	2.404	405.3	40.53	
24/3/08	1%	1	2.444	485.6	48.56	
		2	2.423	477.7	47.77	48.03
		3	2.462	477.6	47.76	