EFFECTS OF POLYVINYL ALCOHOL (PVA) FIBER ON TENSILE STRENGTH OF CONCRETE

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by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
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Approved by,

____

(Puan Nabilah binti Abu Bakar)

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TRONOH, PERAK
JANUARY 2009

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

(SHAREENA AZLIANI ABDUL AZIZ)

ABSTRACT

Polyvinyl alcohol (PVA) fiber is considered as one of the most suitable polymeric fibers used as reinforcements in concrete. Concrete is good in compression but weak in tension. The characteristics of PVA fiber can be used to substitute steel and increase the tensile strength of concrete. The objective of this project is to investigate the effects of PVA fiber on the tensile strength of concrete. In this study, the use of PVA fiber in concrete is to be perfected. It includes the research of the effects of PVA fiber to concrete strength and the tensile strength characteristics of concrete of 435 days old. The methodology includes research through journals and reading materials; and laboratory experiments related to concrete strength, PVA fibers and fiber reinforced concrete. The concretes with PVA fibers have been mixed by a senior student. An experiment was conducted to see the effects of PVA on concrete's strength after 435 days. The tests were carried through with the age of concrete of 435 days of curing. The results were compared with a set of 67 days old PVA fiber reinforced concrete.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Concrete is a composite material mix consisting of cement, water and aggregates. The cement acts as the binding medium in the mix. The commonly used cement is the Portland cement. Concrete is well-known for its ability to resist compression force and its weakness to withstand tensile force. Many studies were done by researchers and experts to identify the main reason to concrete's weakness in withstanding tensile force. A lot of ideas merge from these researches to improve concrete's resistance to tensile force.

The compressive strength of a concrete is typically in the range of 3000 to 5000 psi, whereas the tensile strength is one-tenth of its compressive strength (Amril, 2008). Reinforcement steel bars are commonly used to improve concrete's tensile strength and ductility. Steel bars have high strength in tension and is placed in concrete to resist compression as well as tensile force.

However, there have been many other alternatives to replace steel as reinforcement of concrete such as using glass or plastic fibers. The fibers are not only to improve tensile strength but also to enhance ductility, resistance to cracking etc. A variety of fibers are taken into research to improve the characteristics mentioned. Fibers are used to control plastic shrinkage cracking and drying shrinkage cracking. They also lower the permeability thus reducing concrete bleeding (, 10th August 2008, 9:15 pm). The fibers' main purpose is to increase the energy absorption capacity and toughness of the material as well as increasing the tensile and flexural strength (Zuliezamri, 2007).

Many new methodologies have been applied to analyze crack formation and propagation in concrete. The properties of concrete depend on the properties of the component phase and their interaction among themselves. Many studies have been done on different variables that alter cement paste-aggregate bond mostly on the interfaces of composite specimens specially used for that purpose. Mechanical tests, analysis of the microstructures and compounds; and many other tests methods have been used (Soh, 2008). In this study, the polyvinyl alcohol fiber will be tested in its ability to provide tensile strength for concrete.

Polyvinyl Alcohol (PVA) is one of the most suitable polymeric fibers to be used as reinforcements of concrete. The hydrophilic nature of PVA fiber imposed challenge in the composite design, as the fibers are applicable to rupture instead of being pulled out because of its strong bond to cementitious mixture (Wang et al). PVA has good durability, impose less damage during mixing and is less hazardous. PVA fiber displays higher tenacity and modulus of elasticity than other general organic fibers. It also has good weather resistance, alkali resistance and is reasonably cost effective (Zuliezamri, 2007).

This study will test on the concrete's tensile strength when PVA fiber is added. Tensile strength gives concrete the ability to resist bending. Compressive strength, which is easier to measure than tensile strength, can be used as an index of tensile strength, once the empirical relationship between them has been established for the materials used in the mix. The mix ratio is improved to better the tensile strength of the PVA fiber concrete mix.

The tests that will be conducted are compressive and tensile splitting test to measure the tensile strength of the PVA fiber reinforced concrete.

1.2 Problem Statement

Concrete has good compression strength and is weak in tensile strength. Measures were taken to improve its tensile strength such as fiber reinforcements. In construction, reinforcing bars are normally used in concrete to withstand imposed tensile and shear stress. Nowadays, PVA fiber is used as reinforcements of concrete. PVA fiber is considered as the most suitable polymer fibers used as reinforcements as it will never rust, has high durability and economical.

1.3 Objectives and Scope of Study

The main objectives of this project are:-

a) to investigate the tensile behaviour of PVA fiber reinforced concrete;
b) to study about the advantages of adding PVA fiber reinforcements in concrete;
c) To determine the effectiveness of PVA fibers in amplifying the properties of concrete in its tensile or flexural strength after 435 days.
d) To study the effects of fiber aspect ratio and average diameter of PVA fiber to tensile strength.

Scope of study :

Laboratory experiments will be conducted on hardened concrete testing of PVA fiber reinforced concrete of grade 30 to analyze the effects of using PVA fiber in concrete after 435 days. Concrete cubes size 100x100 mm are used. Scanned Electron Microscopic (SEM) test will also be conducted to further study the reaction between PVA fiber surface, cement and super plasticizer in concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Polyvinyl Alcohol (PVA) Fiber

Polyvinyl Alcohol (PVA) is a water soluble synthetic polymer. It has an excellent film forming, emulsifying and adhesive properties. It is also resistant to oil, grease and solvent. However, PVA's properties depend on humidity; the higher the humidity, the more water is absorbed. The water acts as a plasticizer then can reduce its tensile strength, but increase its elongation and tear strength (, 10th August 2008, 9:15 pm). Due to its high strength in tension and flexibility, PVA is an organic material that can be used as reinforcement fibers. It consists of carbon, hydrogen and oxygen (hydrocarbon) (Figure 2.1).

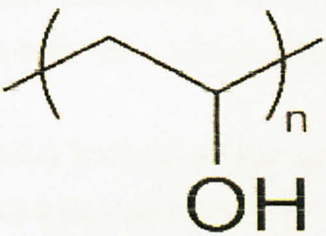


Figure 2.1: Chemical structure of polyvinyl alcohol (PVA)

From the studies of Shuxin Wang and Victor C. Li, PVA fiber emerged during a search of low cost high performance fibers for Engineered Cementitious Concrete (ECC). The hydrophilic nature of PVA fiber imposed great challenge in the composite design, as the fibers are apt to rupture instead of being pulled out because of the tendency for the fiber to bond strongly to cementitious matrix. Proper engineering in fiber geometry, fiber/matrix interface and matrix properties is of vital importance to achieve high ductility in PVA-ECC (Wang et al, 2006).

The PVA nature of strong bond to the surrounding cementitious matrix tends to limit the multiple cracking effect and leads to lower strain hardening profiles for the composite (Redon et al, 2001).

As the PVA properties incorporate high tensile strength and tear resistance, the PVA fibers are less likely to be damaged during concrete mixing process compared to other fibers such as glass and steel. PVA fibers are also proven to be safe under burning fire. It does not emit any dangerous chemical substances when it burns. It only emits water and carbon dioxide (Amril, 2008).

The suitability of Polyvinyl Alcohol (PVA) in engineered cementitious composites as its reinforcements despite the unique microstructure characteristics of PVA fiber adds challenge to the material design. According to the composite guideline, the tensile strain capacity 2 % is considered sufficient in most applications. It is also desirable if the ECC compressive strength is comparable with regular high strength concrete. Previous studies done by the writer suggested that permeability would be in the same order of sound concrete when the crack width is below 80 – 100 μm (Wang et al).

From the study (Bezerra et al, 2004), the formulations with PVA fibers content of 3.23 % by volume presented better mechanical behaviour at 28 days. After initial cracking, the fibers offer stiffness and strength to the matrix. The adhesion between the PVA fibers and cementitious matrix is one of the major factors responsible for the efficiency of load transfer. Tensile strength of the composite is represented by the pullout. The pullout work represents the energy consumed in the failure process, which is the toughness of the composite. An increase in the wet ability of the fiber in the polar matrix mix is caused by the hydroxyl groups on the PVA fiber surface. The increased wet ability enhanced the dispersion of the fibers when coupled with mechanical agitation on mixing. The physical properties of formulations with PVA fiber is shown in Table 2.1.

Formulation	WA (% by mass)		AP (% by volume)		BD (g/cm³)	
	28 days	50 cycles	28 days	50 cycles	28 days	50 cycles
PVA2.16	19.6 ± 1.3	16.8 ± 1.4	32.3 ± 1.2	27.8 ± 1.7	1.65 ± 0.05	1.65 ± 0.04
PVA2.70	21.6 ± 0.8	19.5 ± 1.5	34.1 ± 0.6	31.2 ± 1.9	1.58 ± 0.03	1.60 ± 0.03
PVA3.23	19.4 ± 1.0	18.2 ± 1.6	32.2 ± 1.0	30.4 ± 1.8	1.66 ± 0.04	1.67 ± 0.05
PVA3.76	19.1 ± 0.6	15.9 ± 1.0	31.3 ± 0.7	23.4 ± 1.5	1.65 ± 0.02	1.66 ± 0.02
PVA4.28	19.1 ± 0.6	17.8 ± 0.9	31.3 ± 0.6	29.4 ± 1.3	1.64 ± 0.02	1.66 ± 0.02

Table 2.1: Physical properties of formulations with PVA Fiber at 28 days or accelerated aging test for all formulations.

2.2 Concrete strength

Compressive strength of concrete can be defined as the measured maximum resistance of a concrete specimen to axial loading. Compressive strength of concrete is a primary physical property and is frequently used in design calculations for bridges, buildings and other structures. The flexural strength or modulus of rupture of concrete is used to design pavements and other slabs on ground. There are many factors that affects concrete strength, namely, concrete porousity, water/cement ratio, aggregate paste bond and cement related parameters. Voids in concrete can be filled with air or water. The less porous the concrete, the higher the compressive strength (Zuliezamri, 2007).

Compressive strength and tensile strength are closely related. The tensile strength will increase as the compressive strength increases, but with a decreasing rate compared to the compressive strength throughout the 28 days. Fatigue behaviour of concrete due to cyclic loadings must be taken into considerations too. The mechanism of fatigue failure in concrete can be divided into three stages. One, it involves the weak regions within the concrete or is termed as flaw initiation. Two, it is characterized by slow and progressive growth of the inherent flaws to a critical size known as micro cracking. Lastly, when enough number of unstable cracks has formed, a continuous and macro cracking will occur, eventually leading to failure (Amril, 2008).

From Figure 2.2a based on Shuxin Wang and Victor C. Li research, rapid gain strength was seen in the first 14 days with the strength of 65 Mpa. The strength gain then decreased and reached 75 Mpa after 8 months. Like high strength concrete, PVA-ECC M45 shows almost linear behaviour under compression prior to failure.

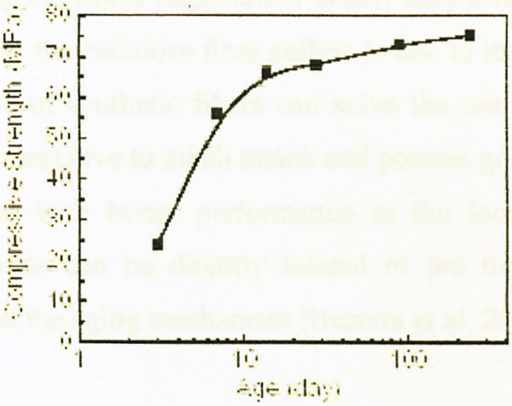


Figure 2.2: Compressive Strength Development

According to the study from Bengi Arisoy and Hwai-Chung Wu, in which its efforts concentrated on lightweight aggregate and air entraining agents due to the nature of concrete that has its strength (compressive, tensile, flexural and fracture strengths) reduced by incorporating lightweight aggregate and air entraining agents. These weight-reduction components have a significant effect on the matrix fracture toughness. The water content was observed to be adjusted with the amount of lightweight aggregate to ensure consistent workability. The water contents would be increased with increasing lightweight aggregate contents due to its absorbent structure. The addition of silica fume to the mix increased workability. The silica fume also decrease concrete density compared to cement and fly ash. The addition of fibers decreased the workability however. It is essential to add just enough water and not excessively (Arisoy et al, 2006).

The term pozzolan has always cover all siliceous/aluminous materials that in fine form with the presence of water will react chemically with calcium hydroxide (CH) to form compounds with cementitious properties. The CH created from the mixing of OPC and water does not make a contribution to the mechanical strength and can be harmful to concrete durability. If CH is eliminated or reduced, the reaction with the pozzolans results in enhanced durability and strength to the cement matrix. Due to the retention of cement particles in industrial processes and some reinforcement effect in the early ages, the use of cellulose fibers in cement composites is important. However, some natural fibers containing higher amounts of other constituents are sensitive to the alkaline environment. It leads to the fibers degradation which causes reduction in the composite durability. The weakness the cellulose fiber suffers is due to its mineralization inside the cement matrix. The use of synthetic fibers can solve the reinforcement problems. The synthetic fibers are less sensitive to alkali attack and possess good mechanical properties, resulting in composites with better performance in the long term. The degradation process of the composite can be directly related to the matrix and fiber type, the composite porousity and the aging mechanism (Bezerra et al, 2006).

2.3 Fiber Reinforced Concrete (FRC)

Fiber reinforced concrete (FRC) is used mainly in relatively thick-section applications historically serviced by non-reinforced or conventionally reinforced concrete. An ACI report (ACI Committee 544, 1993) offers guidance for specifying FRC in which compressive strength is normally specified for structural applications and flexural strength specified for paving applications. However, neither compressive strength nor flexural strength are substantially improved by less than 1.5 % by volume of fibers typical of most FRC's as they depend mostly on the strength of the parent matrix (Johnston, 2001).

ECC is a special type of high-performance fiber reinforced cementitious composite (HPFRCC) featuring significant tensile ductility and moderate fiber volume fraction; typically 2 %. The design of ECC is guided by micromechanics models, in which the desired high tensile ductility is based on. The high tensile ductility is achieved by strain-hardening and multiple-cracking. For PVA fiber, the fiber/matrix interaction is characterized by interfacial frictional stress τ_0, chemical bond and slip-hardening coefficient accounting for the slip-hardening behaviour during fiber pullout (Wang et al, 2006).

In some research results have shown that, the immediate benefit of prestressing FRP composites are that the cracking and yielding moment capacity and serviceability of the beams can be improved and the beam failure mode can change from concrete crushing to FRP rupture (Yu et al, 2008).

Concerning the water/cement ratio, low w/c ratio is also beneficial to maintain mixture consistency and facilitate fiber distribution. In the exemplary mix from this journal, w/c ratio 0.24 is used. Tensile ductility may be gauged by the strain-hardening index Ec/ε with Ec is the complementary energy of the fiber bridging stress vs. opening σ(∂) relation and ε as the matrix toughness (Wang et al).

From the study of Shuxin Wang and Victor C. Li, regarding the fiber pull-out test, PVA-fiber may be pulled out from both sides across the crack due to significant slip-hardening response during pullout. This contradicts the one-way pullout typically observed in steel and polymeric fibers. Matrix spalling at the fiber exits has to be taken into consideration for accurate estimation of crack opening. A very strong interface bond leads to fiber rupture at small crack opening and vice versa.

It is said in the paper that the toughening effect comes from the sliding and debonding between the surface of fibers and matrix that uses energy dissipation to increase fracture resistance. It is known that the results of different reinforcements have different static and dynamic behaviours (Bin Mu et al, 2000).

This study (Bin Mu et al, 2000) presents a few batches of different mixing proportions. Two tests were carried out; tensile test and impact test. The results showed that the tensile strength increases as the amount of slag is added. The tensile strength of the batch with slag to cement ratio of 2.33 is about 50 % higher than that of the control batch. For the impact test, both impact strength and stiffness increase with the increasing of the slag proportion, just like the tensile strength.

It can be concluded from this study that cementitious sheets with a large amount of slag to cement ratio shows better mechanical properties. However, the glass fiber reinforced composite is more brittle than the one reinforced by the PVA fiber. So, the mixing of both fibers can improve the composite performances in both strength and toughness Bin Mu et al, 2000).

It is a known fact that a typical lightweight concrete is weaker than normal concrete. It is desirable to obtain a strong lightweight concrete. In the study of Bengi Arisoy and Hwai-Chung Wu, it is emphasized that an engineered composite, such as fiber reinforced lightweight concrete must show pseudo strain hardening or multiple cracking more than regular concrete. As the micro crack forms, the load originally carried by the matrix is transferred to the bridging fibers. The fibers act as a bridge and transfer the load back to the matrix through the interface. The load then builds up again in the matrix forming another crack. Repetition of this process will lead to multiple cracking. If there is continuously increasing loads, the fiber will pull out or rupture leading to the composite final failure (Arisoy et al, 2006).

For multiple cracking to occur, it must be on some conditions. A critical fiber volume fraction has been defined as the minimum fiber quantity required for achieving multiple cracking. The bridging fibers must be ensured to have high enough frictional bond strength and friction surface to take over the sustained load by the cracked matrix. A relationship between fiber volume fraction and composites energy absorption is given below.

$$V_f^{crit} = \frac{12 G_{tip}}{g \tau^2 L_f} E_f (d_f / L_f)^2 (1 + \eta)$$

G_{tip} : composite energy absorption at crack tip

g : snubbing factor

f : snubbing coefficient

τ : frictional bond strength

L_f : fiber length

d_f : fiber diameter

In terms of tension and flexural strength relationship, the bond strength can be estimated from the multiple cracking theories using the ultimate tensile strength, σ_{tu}.

$$\sigma_{tu} = 0.5g\,\tau\,V_f\,[(L_f/\,d_f)$$

The ultimate strength may be estimated from relationship between flexural strength and tensile strength. Malej and Li according to this study (Arisoy et al, 2006) plotted a curve showing the variation of the ratio of flexural strength to tensile first cracking strength as a function of the ratio of ultimate tensile strength to tensile first cracking strength.

The materials used to improve the brittle texture of lightweight concrete are many kinds of fibers. Fibers are split into a few categories namely metallic or steel fibers, polymer fibers and natural fibers.

The results obtained showed that all fiber reinforced lightweight aggregate concretes has high ductility. The ultimate loads decrease with the increment of lightweight aggregate in the mix. This can be observed from Figure 2.3.1.

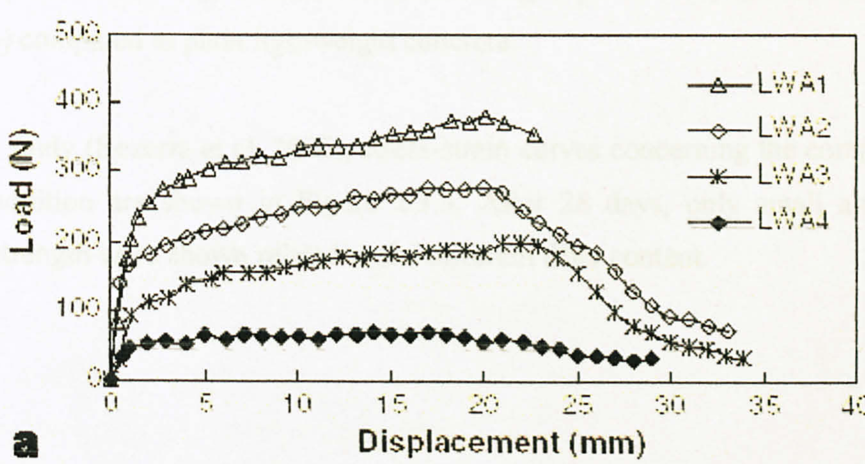


Figure 2.3.1: Load-displacement curves of Fiber Reinforced Concrete

The ductility is reduced while the flexural strength is high for the composition containing lightweight aggregate less than 40 %. This is due to the increased in strength of the matrix that the ones with lightweight aggregate content of 40 % to 60 % so that fiber rupture may be severe. However, if the aggregate content is too high, the matrix becomes weak and the uniformed fiber distribution would be disturbed that can cause pre-matured failure of the concrete composites. This can be seen in Figure 2.3.2 below.

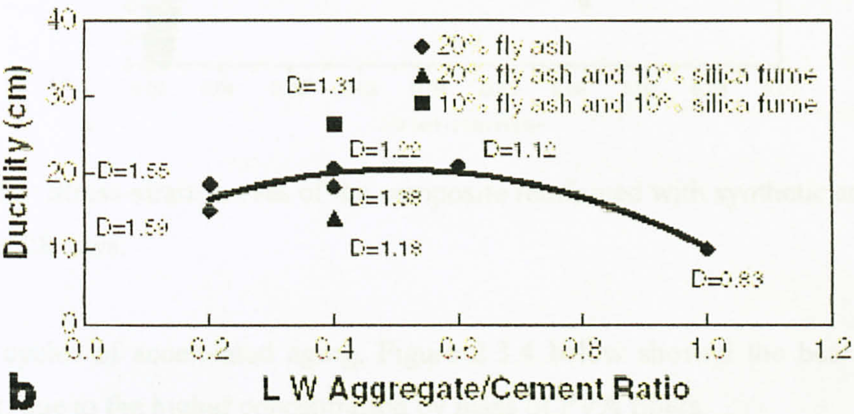


Figure 2.3.2: Effect of lightweight aggregate content on ductility

From the study (Arisoy et al, 2006), it was concluded that fiber reinforcements improves ductility (5000-15000 %), ultimate flexural strength (50-250 %) and decreases weight (30-65 %) compared to plain lightweight concrete.

From the study (Bezerra et al, 2006), stress-strain curves concerning the composites with fly ash addition are shown in Figure 2.3.3. After 28 days, only small alterations of flexural strength were shown related to the different fiber content.

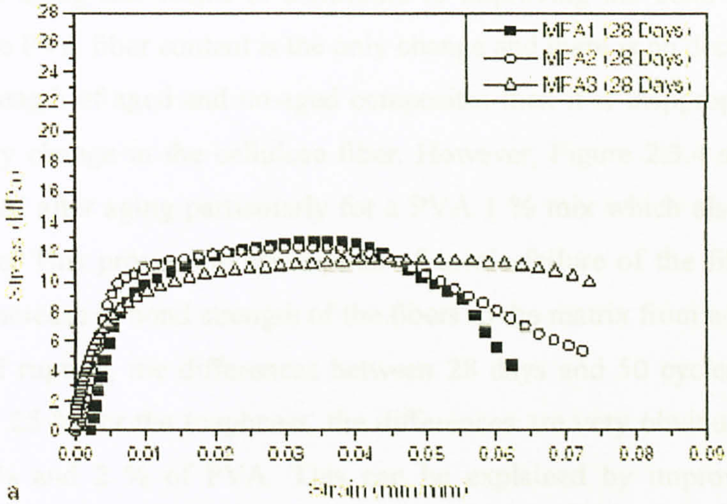


Figure 2.3.3: Stress-strain curves of the composite reinforced with synthetic and cellulose fibers after 28 days.

After 50 cycles of accelerated aging, Figure 2.3.4 below showed the best mechanical behaviour, due to the higher concentration by mass of PVA fibers.

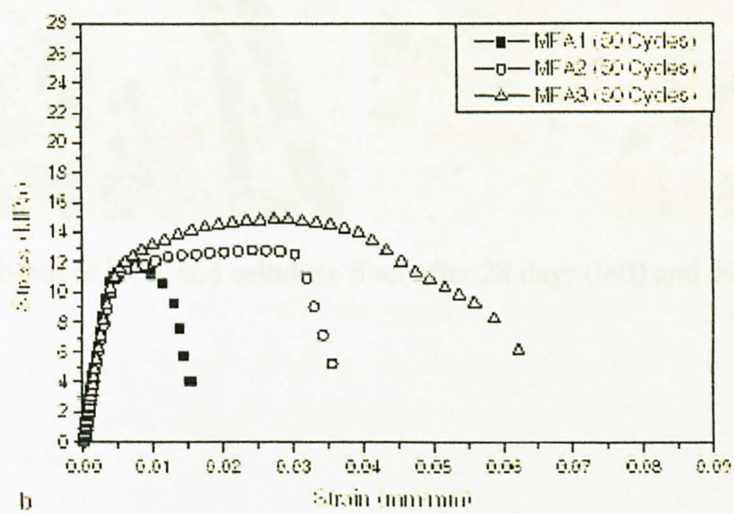


Figure 2.3.4: Stress-strain curves of the composite reinforced with synthetic and cellulose fibers after 50 cycles of accelerated aging test.

The accelerated aging test seems to contribute to improving the bond of the fibers as whole. Since the PVA fiber content is the only change and there is no decrement between the ultimate strength of aged and un-aged composites then it is inappropriate to assume that there is any change in the cellulose fiber. However, Figure 2.3.4 shows the strain failure is reduced after aging particularly for a PVA 1 % mix which also reflects in the toughness value. This proves the assumption of brittle failure of the fibers after aging because of an increase in bond strength of the fibers to the matrix from additional curing. For modulus of rupture, the differences between 28 days and 50 cycles of accelerated aging are up to 25 % for the toughness, the differences are very obvious, especially for composites 1 % and 2 % of PVA. This can be explained by improvement of fiber adhesion. This can be seen in micrographs of fracture surface in Figure 2.3.5.

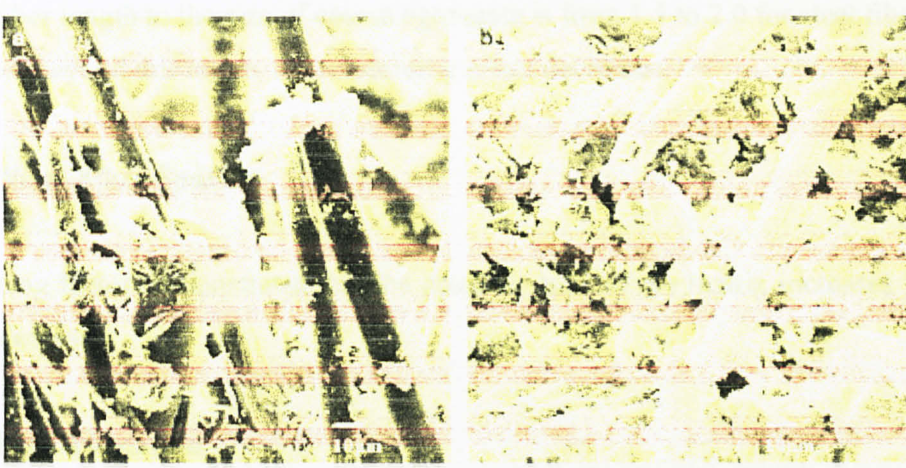


Figure 2.3.5: Pull-out of PVA and cellulose fiber after 28 days (left) and 50 cycles (right).

2.4 Mechanics of Fiber Reinforcement

The usage of fibers in the plain concrete matrix has proven to improve the mechanical properties of the concrete at the early stage of research. The fibers act as a discontinuous reinforcement in the concrete matrix throughout compressive and tensional zone which resist the development of micro and macro cracking especially in the early stage of the concrete. The cracking is the main cause of fatigue failure of concrete. (Amril, 2008)

2.4.1 Critical Fiber Length

The length factor demonstrates that the relationship between the composite strength and the fiber length is continuously linear. As written by Chengkui et al (1995), the typical ratio of fiber length to the size of coarse aggregate is from 1.5 to 2.0 for steel fibers. If the value goes beyond this range, the reinforcing effect decreases.

2.4.2 Critical Fiber Spacing

The spacing factor demonstrates that the cracking load of the matrix increases when the spacing decreases.

2.4.3 Fiber Orientation

Fiber efficiency factor determines the efficiency of the fibers to resist the tensile forces at its direction; similar to the concept of using vertical shear stirrups in reinforced concrete beams to resist the inclined diagonal tension stress.

2.4.4 Fiber Aspect Ratio

(Bezerra et al, 2004), the fiber aspect ratio is a measure of the slenderness of individual fibers. It is computed as the fiber length divided by the equivalent fiber diameter for an individual fiber. PVA fibers represent a diameter of 10 to 20 μm and a tensile strength of

2000 to 2500 MPa. Fibers with small average diameter have low flexural stiffness, thus having a certain ability to conform to the shape of the space they occupy in the paste shape of concrete mixture between aggregate particles. Fibers with large average diameters have larger flexural stiffness and will have a greater effect on consolidation of aggregates during the mixing and placement process. The use of hybrid fibers of different types and sizes can reduce of the size and amount of cracking at different scales.

2.5 Curing

The paper (Yazdani, 2005) studies about the accelerated curing of silica fume concrete (SFC). From the findings, the steam cured SFC achieved target minimum compressive strengths at 28 days of 41.7 MPa, while at 365 days showed a significant increment of compressive strength compared to 28 days old SFC. The surface resistivity also increased with time. Moist cured concrete gained more resistivity than steam cured. At 365 days, moist cured SFC showed highest resistivity. The SFC's permeability decreased with time too from 28 days to 365 days; with low to very low permeability respectively. After 364 days of monitoring, there is no distress of prestressed piles observed due to shrinkage cracking. There are also no visual signs of shrinkage crack.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

3.1 Project Planning

3.1.1 Research and Literature Review

Literature review provides background information on the on going study and also the studies done before. It includes all relevant theories, hypotheses, facts and data which are useful for this research. These sources of information namely journals and books are obtained from the library, websites and information or data from the supervisor.

Research is done through reading and understanding the reading materials. This is to gain as much knowledge related to the project. The gathered information is summarized for future references and analysis purpose.

3.1.2 Discussion

Discussions are done on weekly basis with the supervisor to ensure the smoothness of the progress of the project. This is mainly to keep the supervisor in the know of the project's progress and give advices on project matters. Since this project is pioneered by previous 2005/2006 Final Year Project (FYP) students, most of the basic knowledge would be available, but they are only limited to the static tests of the fiber in reinforced concrete using PVA. The latest research of 2007/2008 FYP is to study the effects of PVA fiber on the tensile strength of concrete. The discussions will also include the senior students to pass down the knowledge to the new FYP students.

3.2 Mix Design and Laboratory Experiments

3.2.1 Hazards Assessment

All laboratory works will be done based on the laboratory rules and regulations. This is to make sure the proper Health, Safety and Environment (HSE) policy is followed. The main objective of the policy and rules is to prevent unwanted accidents in the laboratory involving students or any personnel.

Hazard can be defined as a potentially harmful situation, although not usually the event itself. There are three causes of hazard, namely:-

a) Natural – which is caused by a natural process
b) Man made – hazards created by human
c) Activity related – some hazards are created by the undertaking of certain activity and the cessation of the activity will negate the risk.

An assessment known as Hazards Assessment will be done before entering the laboratory.

3.2.2 Mix Design

Mix design must be ensured that it contains the right amount of PVA fiber, admixtures and super plasticizer so that it can increase the tensile, flexural and fatigue strength of concrete. (BS 1881) Appendix..

3.2.3 Concrete Testing

The following test is to be carried out with concrete with 435 days of curing.

3.2.3.1 Hardened concrete testing

a) Tensile Test (Split Tensile Test)

1. The dry sample is placed in specimen holder.
2. 2 pieces of hardboards are placed between the holder and the sample.
   NOTE: The size of the hardboard is 4mm thick and 15mm wide as specified by BS 1881:117:1983.
3. The load on cube is applied at a constant rate of stress equal to 0.47 MPa/second until it fails.
4. The maximum load before the cube fails is taken and the tensile strength is calculated by using the following equation:

$$T = \frac{2P}{\pi l d}$$

where,

T = Tensile splitting strength in kPa

P = Applied load at the time of failure of the specimen in kN

l = Length of the cylindrical specimen in m

d = Diameter of the specimen in m

Figure 3.2.3.1: Compression and Flexural Machine

CHAPTER 4

RESULTS AND DISCUSSION

This research concentrates on the tensile behaviour of concrete with the addition of PVA fiber. Tensile strength is the stress at which concrete breaks or permanently deforms. It is the ability of concrete to resist bending. Concrete is assumed to be about 10 % as strong in tension as it is in compression. The low tensile strength and tensile strain capacity of concrete can be improved by adding PVA fiber.

Fiber reinforced concrete has higher cement content, higher fine aggregate content and smaller size of coarse aggregate (Zuliezamri, 2007) compared to normal concrete mixes. Mix proportions are best determined by trial mixes. The final mix is reached by adjusting as necessary to meet the requirements of workability, strength and durability.

The studies of the fiber size have also been conducted throughout this project. The specifications of the PVA fiber used are as the following:-

Specifications	
Fiber length	30 mm
Fiber diameter	660 μm
Tensile strength	0.8 GPa

Table 4.1: Specifications of PVA fiber

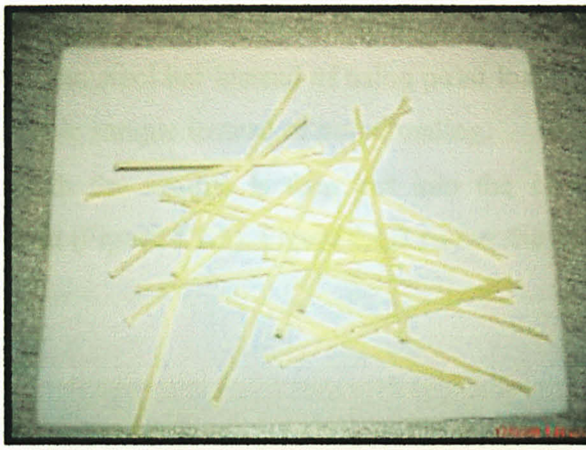


Figure 4.1: PVA fiber

4.1 Split Tensile Test

For split tensile test of cubic concrete sample, a sample holder is used and 2 pieces of hardboards are placed between the holder and the sample (where the load is applied). The size of the hardboard is 4mm thick and 15mm wide as specified by BS 1881: 117: 1983.

Figure 4.1.1: Cylindrical sample holder for tensile test.

Split tensile test equipment is not available in Universiti Teknologi PETRONAS, so, the test was done using a prism steel bar instead of using point loading. The platen produces a uniform load on the cubic sample instead of point loading.

The holder together with the sample is then put into the compression and flexural machine to apply the load (Figure 4.1.3). Figure 4.1.2 shows the failure line at the surface of the sample.

Figure 4.1.2: Line of failure of sample

From the figure, the test is a success since the line of failure is along the middle section of the sample.

Figure 4.1.3: 2000 kN Compression and Flexural Machine

4.2 Split Tensile Test Results

Trial concrete mixes have been done by previous students to determine the best mix for PVA fibers and concrete. All mixes for concrete tests are done using different proportions of PVA fibers which are 0%, 1%, 2% and 3% for each mix. The concrete cubes tested have been mixed by previous student (2007/2008) and they are kept for tensile test after 435 days.

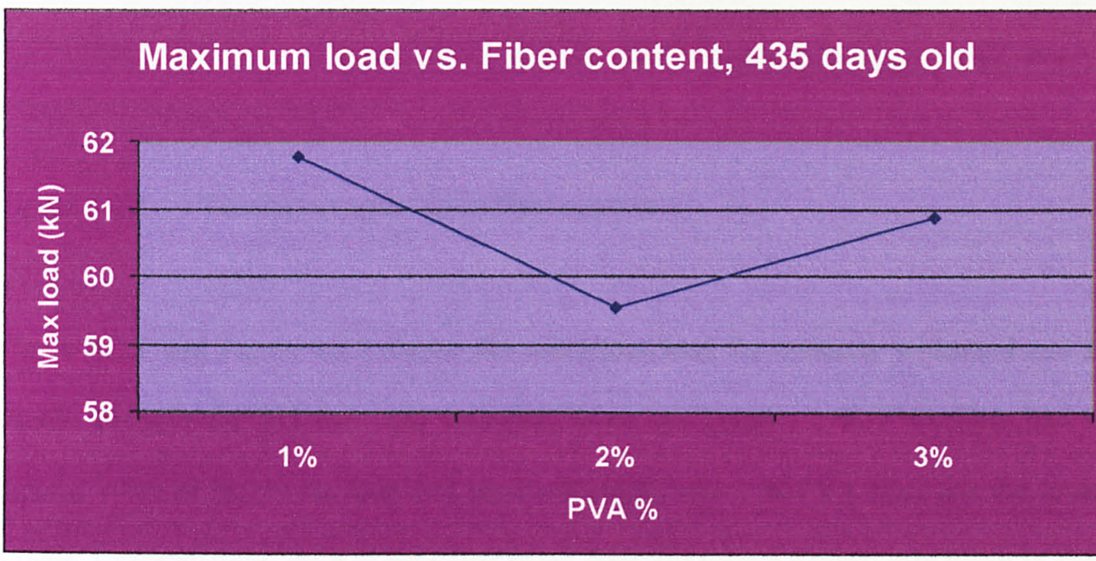


Figure 4.2.1 : Maximum load versus fiber content

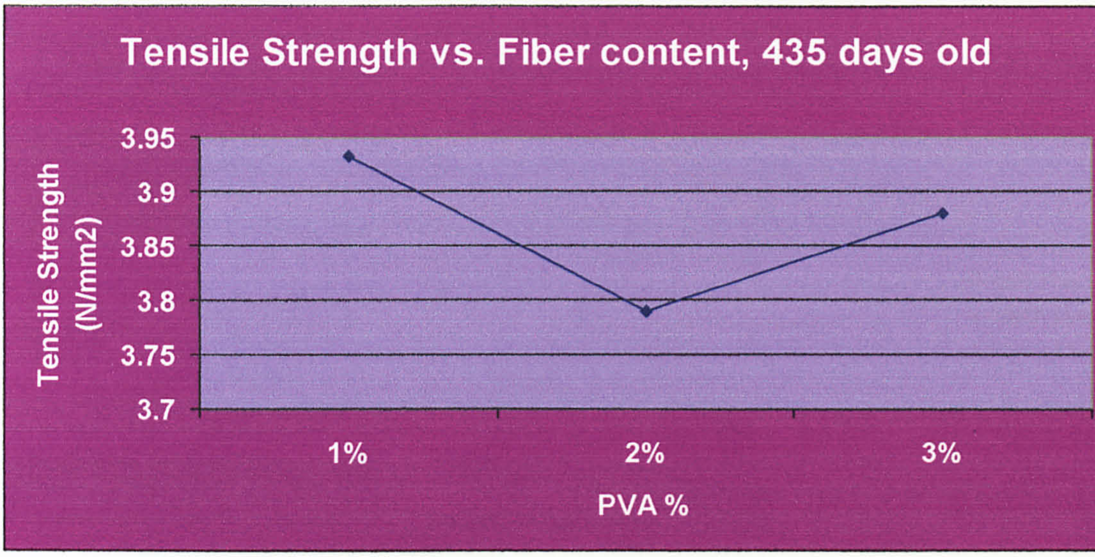


Figure 4.2.2 : Tensile strength versus fiber content

Figure 4.2.1 and Figure 4.2.2 shows the maximum load the concrete withstand and the tensile strength for 435 days old concrete. From the graphs, 1 % PVA fiber has the highest value of maximum load and tensile strength; and 2 % PVA fiber has the lowest values. Unfortunately, the 435 days mix batch does not have a control mix batch to show the increment of tensile strength of 435 days old of PVA fiber reinforced concrete. Figure 4.2.3 is the previous student's (2008) result that shows the increment of tensile strength with the optimum amount of 1 %. From the studies by Bengi Arisoy and Hwai-Chung Wu (2006), the optimum PVA fiber content obtained is 1 %, which supports the results obtained in this study.

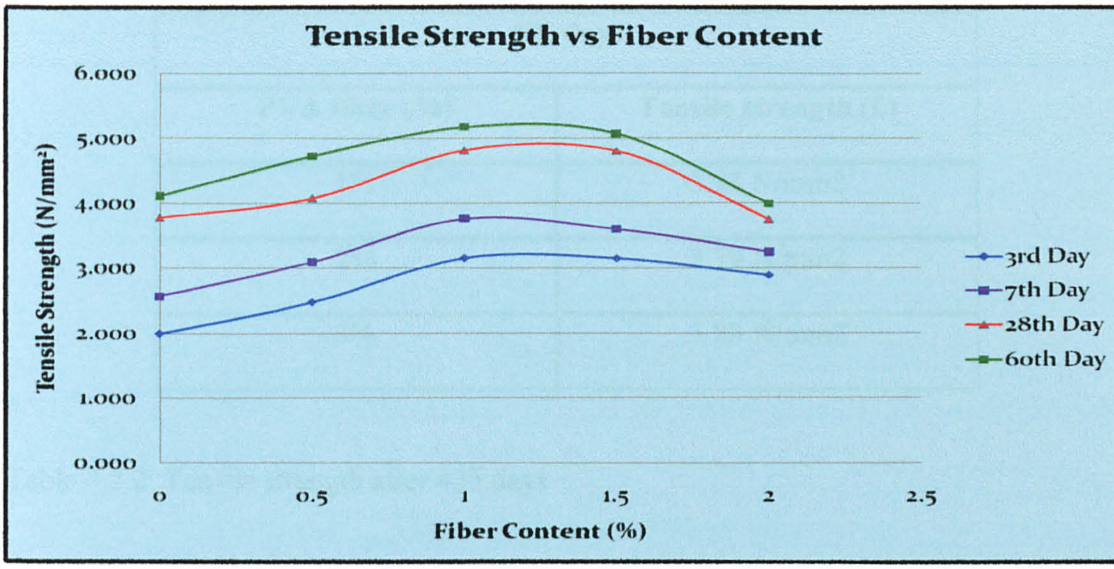


Figure 4.2.3: Tensile strength versus fiber content (2008)

67 days		
PVA fiber (%)	**Compression strength (f_c)**	**Tensile strength (ft) $f_t = 0.2(f_c)^{0.7}$**
1%	48.03 N/mm2	3.01 N/mm2
2%	41.47 N/mm2	2.71 N/mm2
3%	40.77 N/mm2	2.68 N/mm2

Table 4.2.1: Tensile strength after 67 days

435 days	
PVA fiber (%)	**Tensile strength (f_t)**
1%	3.93 N/mm2
2%	3.79 N/mm2
3%	3.88 N/mm2

Table 4.2.2: Tensile strength after 435 days

Table 4.2.1 and Table 4.2.2 show the comparison between the previous student's (2007/2008) results for concrete cubes of 67 days old. The percentage of tensile strength increment for 435 days old concrete as compared with 67 days old concrete is shown in Table 4.2.3.

PVA fiber percentage	Tensile strength increment percentage
1%	30.8%
2%	39.7%
3%	44.7%

Table 4.2.3: Percentage of tensile strength increment between 67 days old and 435 days old of PVA fiber reinforced concrete.

The one with the highest increment is 3% PVA fiber with 44.7% of increment.

4.3 Size of PVA Fiber

The fiber size used is the same for all samples. From the specifications, the fiber aspect ratio can be calculated;

Fiber aspect ratio = Fiber length/Equivalent diameter

Fiber aspect ratio = $30 \times 10^{-3}/660 \times 10^{-6}$ = *45.45*

Average diameter = *660 μm*

From E.M. Bezerra et al (2004), they discovered that fibers with small diameter have lower flexural stiffness and have the ability to conform to shape of space in the paste phase. However, fibers with large average diameter have higher flexural stiffness and have higher effect on consolidation of aggregate during mixing and placement. Fibers for FRC can have a typical fiber aspect ratio value ranging from 40 to 1000, but more commonly less than 300. The fiber aspect ratio of the PVA fiber used ranges from 40 to 300 which is 45.45. For this study, unfortunately, comparison between different sizes of PVA fiber's tensile strength could not be done since all samples available have used the same type of PVA fiber.

The PVA fiber's average diameter of 660 μm is quite high. From Carl Redon et al (2001) studies of different fiber's average diameter, the results have showed the comparison between Fiber A (average diameter of 44 μm) and Fiber B (average diameter of 700 μm). From the pull out test, it showed that Fiber B was almost pulled out completely without rupture whereas most of Fiber A ruptured during the slip hardening phase.

4.4 Scanning Electron Microscope (SEM) Test

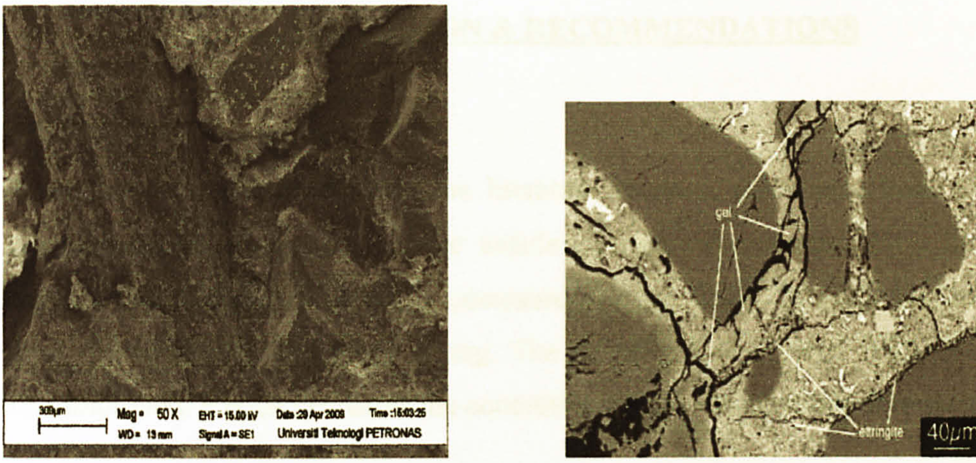
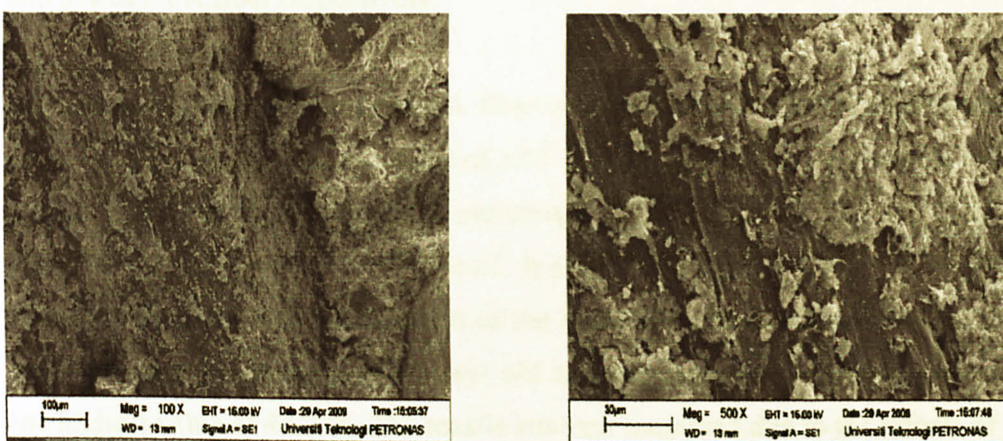


Figure 4.4.1:

Bonding between PVA fiber and cement after 435 days → Comparison between PVA reinforced concrete and plain concrete.



Bonding between PVA fiber and cement after 435 days → 100 X and 500 X zoom

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

According to the findings from the literature reviews, there have been proofs of the effectiveness of PVA fiber on the tensile strength of concrete. PVA fiber has high tenacity and modulus of elasticity compared to other fibers. The bonding between PVA fiber and cement is also fairly strong. The ductility and ultimate flexural strength was also improved. It even decreases the concrete's weight which means it is easier to handle.

Some studies have shown that PVA fiber proportion of 1 % and 2 % achieves the best results (Bezerra et al, 2004; 2006). The hardened concrete testing has been done on 3 sets of 8 concrete cubes of 435 days old; with each set of 1% of PVA fiber, 2% of PVA fiber and 3% of PVA fiber respectively.

From the results obtained, the PVA fiber content that gives the highest tensile strength after 435 days is 1% with the value of 3.93 N/mm2. Comparing the results with previous studies and research, the optimum percentage of PVA fiber in concrete aged 67 days is also 1% with the value of 3.01 N/mm2. It shows that there has been an increment in the tensile strength of 30.8 %. In terms of the highest increment of tensile strength between the PVA fiber percentages of 67 days old and 435 days old, 3 % PVA fiber content has the highest value of 44.7 %. The tensile strength increased due to the effects of curing.

The PVA fiber's fiber aspect ratio of 45.45 falls under the typical range of 40 to 300. The average diameter of 660 μm as compared with journals' results showed its competency to enhance concrete's tensile strength.

From the results obtained, it can be said that the objective of this project is met.

There are a few recommendations that can be made to improve the reliability of the results through research. The concrete samples of 435 days old of age are lacking a batch of control samples. This has made it harder to proof the optimum PVA fiber content. A set of control samples should be mixed for each testing batch. It is also rare to find other research or findings that cure concrete up to 435 days.

Testing equipments in the laboratory should be added as the split tensile test that was conducted was done using a prism steel bar to transmit the load on the test rig instead of using point loading. This has caused the platen to transmit uniform load on the sample instead of point loading as it should be in a typical split tensile testing.

Further studies on PVA fiber sizes that affect concrete's tensile strength should be conducted. There should be more variety of PVA fibers used to obtain more data in determining the best PVA fiber size to be incorporated in concrete. Pull out test between different PVA fiber sizes can also be conducted to see which size when mixed with concrete gives the highest pull out strength.

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APPENDICES

Appendix 1 – Properties of PVA fibers

A. Specifications and properties

Item Property	High strength & modulus I.	High strength & modulus II.	Super-short staple fiber I. for building materials	Super-short staple fiber II. for building materials
Density (g/cm^2)	1.26	1.26	1.26	1.26
Titre (dtex)	2.0 _0.3	2.0_0.3	1.7 - 3.0	1.7 - 3.0
Length (mm)	2 - 65	2 - 65	2 - 65	2 - 65
Tenacity (CN/dtex)	> 10.5	> 10.5	≥8	≥6
Modulus (CN/dtex)	> 240	> 240	>200	>150
Breaking elongation (%)	< 7_1.5	<7_1.5		
Reduction in hot water	< 2	< 3		
Acid proof	Good	good	good	good
Alkali resistance	Good	good	good	good
Ultraviolet resistance	Good	good	good	good
Electric conductivity	Low	low	low	low
Thermal conductivity	Low	low	low	low

B. Fiber breaking elongation comparisons

Fiber	Vinylon (high strength)	Vinylon (usual)	Nylon	PP fiber	Polyester (usual)	Polyester (high strength)
Breaking elongation %	7	15	20 - 40	15 - 35	14 - 25	10 - 14

C. Alkali resistance comparisons

Test condition			Fiber strength loss ratio (%)			
Density %	Temperature°C	Duration time (hr)	Vinylon-high strength	Viscose fiber yarn	Nylon 6	Polyester
1	20	10	0	12	0	1
1	100	100	7	29	25	71
40	20	10	0	100	18	4

D. Sunshine resistance comparisons

Exposed in the sunshine(hour)	Fiber strength loss ratio (%)			
	High strength vinylon	Nylon 6	Viscose fiber	Cotton
100	3.05	19.6	4.26	3.67
300	7.93	41.2	7.45	30.73
500	10.98	65.09	25.00	38.53
700	11.16	74.51	63.30	49.54

Appendix 1b – Typical properties of Glass reinforced concrete

PROPERTIES				Process	
				Spray	*Premix*
Fibre Content			[wt. %]	5	3
Density	(dry state)		[g/cm³]	1.8 ÷ 2.2	1.7 ÷ 2.1
Strength	Bending Strength	MOR	[N/mm²]	22 ÷ 32	9 ÷ 13
		LOP	[N/mm²]	7 ÷ 13	6 ÷ 9
		Young Modulus	[kN/mm²]	15 ÷ 25	14 ÷ 24
	Tensile Strength	UTS	[N/mm²]	8 ÷ 12	3 ÷ 6
		BOP	[N/mm²]	4 ÷ 6	3 ÷ 5
		Ultimate strain	[%]	0.6 ÷ 1.2	0.1 ÷ 0.2
	Compressive Strength	Out-of-plane	[N/mm²]	50 ÷ 80	40 ÷ 60
		In-plane	[N/mm²]	40 ÷ 70	40 ÷ 60
	Shear Strength	Out-of-plane	[N/mm²]	25 ÷ 35	4 ÷ 6
		In-plane	[N/mm²]	7 ÷ 12	4 ÷ 6
		Interlaminar	[N/mm²]	2 ÷ 4	4 ÷ 6
	Charpy impact		[N mm/mm²]	15 ÷ 25	7 ÷ 12
	Poisson's ratio			0.24 ÷ 0.3	0.24 ÷ 0.3
Water	Water absorbing ratio		[%]	10 ÷ 15	10 ÷ 15
	Drying shrinkage		[%]	0.1 ÷ 0.2	0.1 ÷ 0.2
Heat	Thermal conductivity		[W/m °C]	0.9 ÷ 1.5	0.9 ÷ 1.5
	Thermal expansion coefficient		[x 10⁻⁶/°C]	7 ÷ 12	7 ÷ 12

Legenda: MOR: Modulus of Rupture; LOP: Limit of Proportionality
UTS: Ultimate Tensile Strength BOP: Bend-Over Point

**Details were extracted from [16]

Appendix 1c – Typical properties of natural fibers

Fibre type	Coconut	Sisal	Sugar cane bagasse	Bamboo	Jute	Flax	Elephant grass	Water reed	Plantain	Musamba	Wood fibre (Kraft pulp)
Fibre length, mm	50 - 100	N/A	N/A	N/A	175 - 300	500	N/A	N/A	N/A	N/A	2,5 - 5,0
Fibre diameter, mm	0,1 - 0,4	N/A	0,2 - 0,4	0,05 - 0,4	0,1 - 0,2	N/A	N/A	N/A	N/A	N/A	0,025 - 0,075
Relative density	1,12 - 1,15	N/A	1,2 - 1,3	1,5	1,02 - 1,04	N/A	N/A	N/A	N/A	N/A	1,5
Modulus of elasticity, GPa	19 - 26	13 - 26	15 - 19	33 - 40	26 - 32	100	5	5	1,5	1,0	N/A
Ultimate tensile strength, MPa	120 - 200	275 - 570	180 - 290	350 - 500	250 - 350	1 000	180	70	90	80	700
Elongation at break, %	10 - 25	3 - 5	N/A	N/A	1,5 - 1,9	1,8 - 2,2	3,6	1,2	5,9	9,7	N/A
Water absorption, %	130 - 180	60 - 70	70 - 75	40 - 45	N/A	N/A	N/A	N/A	N/A	N/A	50 - 75

Notes

N/A Properties not readily available or not applicable.

**Details were extracted from [16]

Appendix 1d – Selected synthetic fiber types and properties

Fibre type	Equivalent diameter µm	Relative density	Tensile strength MPa	Elastic modulus GPa	Ultimate elongation %	Ignition tem-perature °C	Melt, oxidation, or decomposition temperature °C	Water absorption per ASTM D 570, % by mass
Acrylic	13 - 104	1,16 - 1,18	270 - 1 000	14 - 19	7,5 - 50,0	-	220 - 235	1.0 - 2.5
Aramid I	12	1,44	2 900	60	4,4	high	480	4.3
Aramid II†	10	1,44	2 350	115	2,5	high	480	1.2
Carbon, PAN HM▲	8	1,6 - 1,7	2 500 - 3 000	380	0,5 - 0,7	high	400	nil
Carbon, PAN HT§	9	1,6 - 1,7	3 450 - 4 000	230	1,0 - 1,5	high	400	nil
Carbon, pitch GP**	10 - 13	1,6 - 1,7	480 - 790	27 - 35	2,0 - 2,4	high	400	3 - 7
Carbon, pitch HP††	9 - 18	1,8 - 2,15	1 500 - 3 100	150 - 480	0,5 - 1,1	high	500	nil
Nylon▲▲	23	1,14	970	5	20	-	200 - 220	2.8 - 5.0
Polyester	20	1,34 - 1,39	230 - 1 100	17	12 - 150	600	260	0.4
Polyethylene▲▲	25 - 1 000	0,92 - 0,96	75 - 590	5	3 - 80	-	130	nil
Polypropylene▲▲	-	0,90 - 0,91	140 - 700	3,5 - 4,8	15	600	165	nil

Notes

* Not all fibre types are currently used for commercial production of FRC

† High modulus

▲ Polyacrylonitrile based, high modulus

§ Polyacrylonitrile based, high tensile strength

** Isotropic pitch based, general purpose

†† Mesophase pitch based, high performance

▲▲ Data listed is only for fibres commercially available for FRC

**Details were extracted from [16]

Appendix 2 – Tables and Figures for Mix Proportioning

*Based on Concrete Technology Book by A. M. Neville (1999) at [13]

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 14.9 (pg. 763): Approximate Compressive Strengths of Concretes Made with a Free Water/Cement Ratio of 0.5.

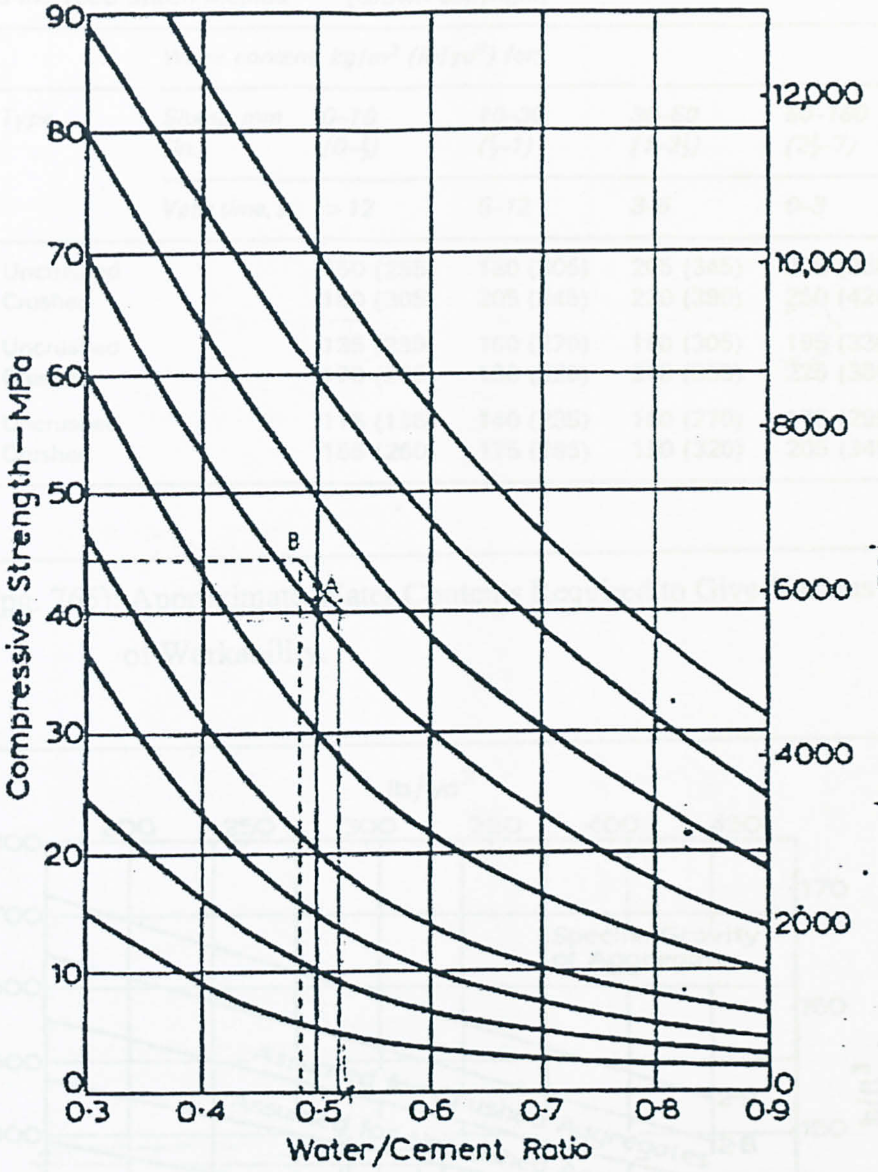

Fig. 14.12 Relation between compressive strength and free water/cement ratio for use British mix selection method[14.11] (see Table 14.9) (Crown copyright)

Figure 14.12 (pg. 764): Relation between compressive strength and free water/ratio for use British mix selection method.

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: Max size, mm (in.)	Aggregate: Type	Water content, kg/m³ (lb/yd³) for: Slump, mm (in.)	0–10 (0–$\frac{1}{2}$)	10–30 ($\frac{1}{2}$–1)	30–60 (1–2$\frac{1}{2}$)	60–180 (2$\frac{1}{2}$–7)
		Vebe time, s	>12	6–12	3–6	0–3
10 ($\frac{3}{8}$)	Uncrushed		150 (255)	180 (305)	205 (345)	225 (380)
	Crushed		180 (305)	205 (345)	230 (390)	250 (420)
20 ($\frac{3}{4}$)	Uncrushed		135 (230)	160 (270)	180 (305)	195 (330)
	Crushed		170 (285)	190 (320)	210 (355)	225 (380)
40 (1$\frac{1}{2}$)	Uncrushed		115 (195)	140 (235)	160 (270)	175 (295)
	Crushed		155 (260)	175 (295)	190 (320)	205 (345)

Table 14.10 (pg. 765): Approximate Water Contents Required to Give Various Levels of Workability.

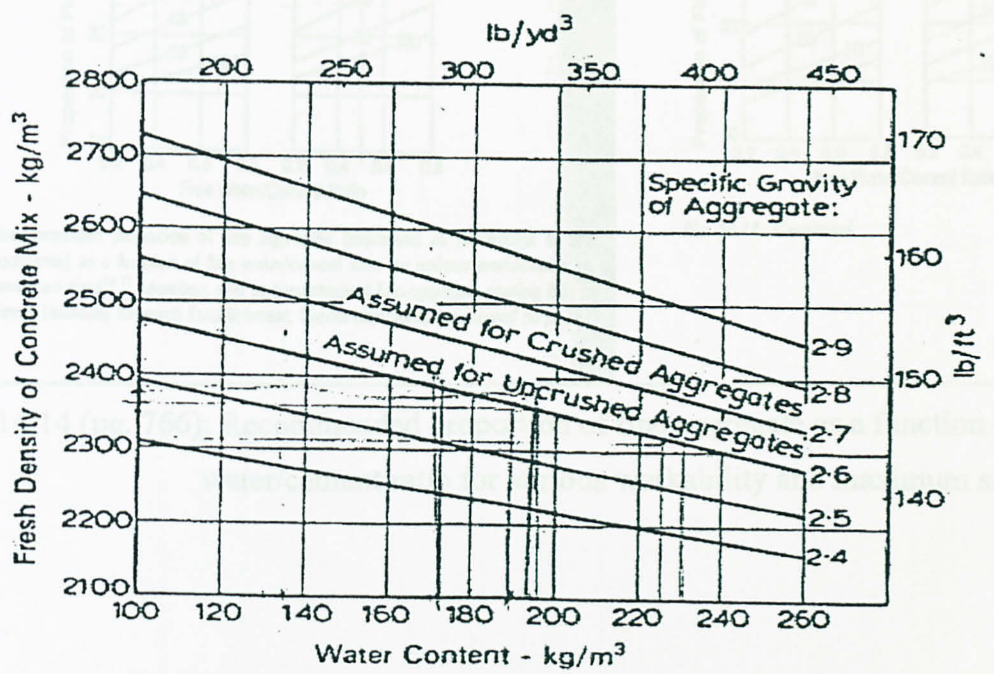

Fig. 14.13 Estimated wet density for fully compacted concrete[14.11] (specific gravity is given for saturated and surface-dry aggregate) (Crown copyright)

Figure 14.13 (pg. 765): Estimated wet density for fully compacted concrete.

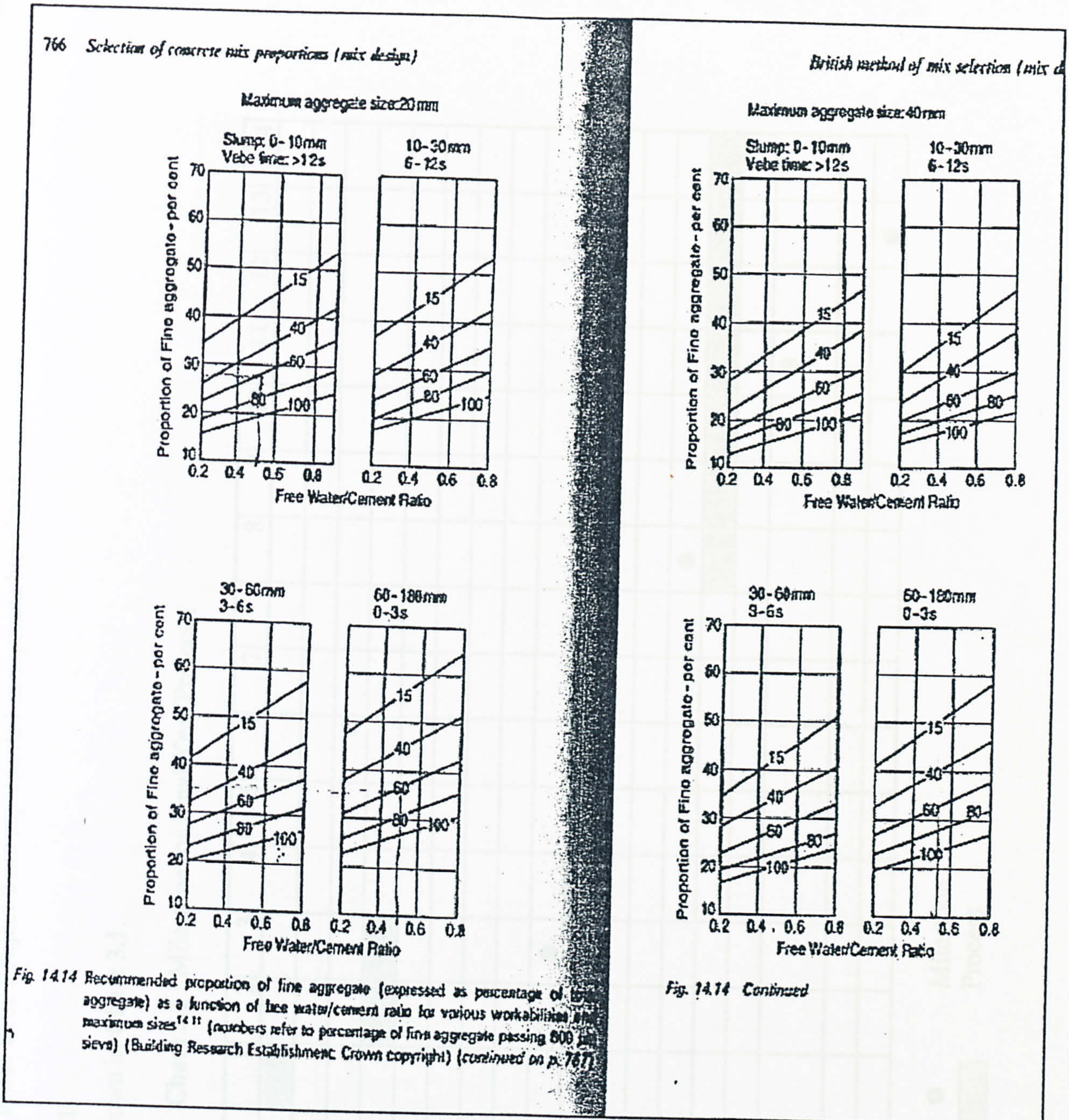

Figure 14.14 (pg. 766): Recommended proportion of fine aggregate as a function of free water/cement ratio for various workability and maximum sizes.

3.10 Key Milestone

The progress of **Final Year Project 1** and **Final Year Project 2** are represented in separate bar charts.

3.10.1 Milestone for Final Year Project 1

The progress of **Final Year Project 1** is shown in **Chart 3.1**.

Chart 3.1 : 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

■ Process

3.10.2 Milestone for Final Year Project 2

The progress of **Final Year Project 2** is shown in **Chart 3.2.**

Chart 3.2 : Milestone for Final Year Project 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Project Work Continue	■	■	■	■	■										
2	Submission of Progress Report 1						●									
3	Project Work Continue						■	■	■	■						
4	Submission of Progress Report 2										●					
5	Seminar (compulsory)									■	■		■			
5	Project work continue										■					
6	Poster Exhibition										●					
7	Submission of Dissertation (soft bound)												●			
8	Oral Presentation															
9	Submission of Project Dissertation (Hard Bound)														●	