Compression Behaviour of Concrete with Polyvinyl Alcohol (PVA) Fiber

by

Mohd Aizat B. Kamarudin

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JULY 2007

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

(Dr. Victor R Macam Jr)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JULY 2007

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.

MOHD AIZAT B. KAMARUDIN

ABSTRACT

Fiber reinforced concrete is reinforced by a small amount of short randomly dispersed into cement concrete and this composite material is superior to normal plain concrete with respect to flexural strength, impact resistance and ductility. But the consistency of fiber reinforced concrete is extremely decreased by adding fiber so that in some cases it becomes difficult to place and mold by the ordinary method. These phenomena are observed irrespective of kinds of fibers used.

This paper studied on the effects on compression strength by using polyvinyl alcohol (PVA) as fiber reinforced concrete. Literature review on the characteristics of PVA fiber and the advantages it would bring to concrete is studied. The method and the amount of fiber used were investigated. Experimental lab also has been conducted to test the compressive strength of concrete with PVA fiber.

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1.0 INTRODUCTION

1.1 Background Studies

Concrete is derived from "concretors" which signifies 'growing together' means binding of loose particles into a single mass. The properties of concrete have been altered since Roman and Egyptian times, when it was discovered that adding volcanic ash to the mix allowed it to set under water. Similarly, the Romans knew that adding horse hair made concrete less liable to shrink while it hardened, and adding blood made it more frost resistant. In modern times, researchers have added other materials to create concrete that is extremely strong, and even concrete that can conduct electricity.

Concrete is a mixture of cement, water and aggregates. Some material is added to increase the strength behavior. The strength increase with time; the longer the time, the higher will be the concrete strength.

Although fresh concrete is only of transient interest, we should note that the strength of concrete of given mix proportions is very seriously affected by the degree of its compaction. It is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed, compacted, and finished sufficiently easily and without segregation.

Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariable a vital element of structural design and is specified for compliance purposes.

1.2 Problem statement

Fiber reinforced concrete is reinforced by a small amount of short randomly dispersed into cement concrete and this composite material is superior to normal plain concrete with respect to flexural strength, impact resistance and ductility. But the consistency of fiber reinforced concrete is extremely decreased by adding fiber so that in some cases it becomes difficult to place and mold by the ordinary method. These phenomena are observed irrespective of kinds of fibers used.

1.3 Objective & Scope of Study

The main objectives of this project are to;

- study on the compressive behavior of concrete with PVA fiber,
- study on the characteristics of PVA fiber and the advantages it would bring to concrete,
- study about the effects of fiber contents in concrete,

The scope of study would include research through journals and reading materials in relation to fatigue, PVA fiber and concrete. Besides, lab experiment will be carried out to investigate the effects of infusing PVA fiber in concrete mix.

2.0 LITERATURE REVIEW

Normal Portland cement concrete can be reinforced with various fibers and this material is called 'fiber reinforced concrete'. Fiber reinforced concrete is defined as cement mortar of concrete containing a dispersion of randomly discontinuous, discrete fibers(1). It is a superior construction material for structural applications because the characteristics such as ductility, toughness, tensile strength, flexural strength and dynamic resistance, are improved by adding fibers into cement mortar or concrete. There are various fibers for reinforcement including steel, glass, carbon, polymer and asbestos.

Cement concrete is required to have suitable consistency or flowability so as to be filled easily in a mold. However, it should be noted that the applications of fiber into cement concrete would always encounter difficult problems about the consistency or workability of the mixture(2). The workability is seriously influenced by the amount of fibers added into concrete mixture. Generally, two main methods are used for placing concrete(3). The first is a casting method in which the prepared pre-mixing concrete is casted into the mold. And the second is a shotcreting method. These methods can be also applied to fibers reinforced concrete.

Fiber reinforced concrete may be used for slope stabilization, tunnel lining and dome structures by using shotcrete method, as described in State-of-the-Art by ACI Committee 506(4). Though the reinforcing effect of fibers obtained by pre-mixing method are smaller than that by the shotcreting method, the pre-mixing method is evidently advantageous in applying to the structures, such as mass concrete, from the viewpoints of quickness and easiness of construction.

2.1 Historical Development

Fibers have been used to reinforce brittle materials from time immemorial, dating back to the Egyptian and Babylonian eras if not earlier. Straws were used to reinforce sun-baked bricks and mud-hut wall, horse hair was used to reinforce plaster, and asbestos fibers have been used to reinforce Portland cement mortars. Research by Romualdi and Batson (1963) and Romualdi and Mandel (1964) on closely spaced random fibers in the late 1950s and early 1960s, primarily on steel fibers, heralded the era of using the fiber composite concretes we know today. In addition, Shah and Rangan (1971), Swamy (1975), and several other researchers in the United States, United Kingdom, and Russia embarked on extensive investigations in the area, exploring other fibers in addition to steel. By the 1960s, steel fiber concrete started to be used in pavements in particular. Other developments using bundled fiber glass as the main composite reinforcement in concrete beams and slabs were introduced by Nawy et al. (1971) and Nawy and Neuweth (1977). From the 1970s to the present, the use of steel fibers has been well established as a complimentary reinforcement to increase cracking resistance, flexural and shear strength, and impact resistance of reinforced concrete element both situ cast and precast.

2.2 General Characteristics

Concrete is weak in tension. Microcracks start to generate in the matrix of a structural element at about 10-15% of the ultimate load, propagating into microcracks at 25-30% of the ultimate load. Consequently, plain concrete members cannot be expected to sustain large transverse loading without the addition on continuous- bars reinforcing elements in the tensile zone of supported members such as beams and slabs. But the developing microcracking and macrocracking still cannot be arrested or slowed by the sole use of continuous reinforcement. The function of such reinforcement is to replace the function of the tensile zone of a section and assume the tension equilibrium force in the section.

Consequently, the addition of randomly spaced discontinuous fibers elements should aid in arresting the development or propagation of the microcracks that are known to generate at the early stages of loading history. While fibers have been used to reinforce brittle materials such as concrete since time immemorial, newly developed fibers have been extensively used worldwide in the past three decades. Different type of commercially available such as those made from steel, glass, polypropylene, or graphite. They have proven that they can improve the mechanical properties of the concrete, both as a structure and a material, not as a replacement for continuous-bar reinforcement when it is needed, but in addition to it.

Concrete fibers composites are concrete elements made from a mixture comprising hydraulics cements, fine and coarse aggregates, pozzolanic cementitious materials, admixture commonly used with conventional concrete, and a dispersion of discontinuous, small fibers made from steel, glass, organic polymers, or graphites. The fibers could also be vegetable fibers such as sisal or jute.

The introduction of fiber addition to concrete as of the early 1900s was aimed principally at enhancing the tensile strength of concrete. As is well known, the tensile strength is 8-14% of the compressive strength of normal concretes with resulting cracking at low stress levels. Such a weakness is partially overcome by the addition of reinforcing bars, which can be either steel or fiberglass, as main continuous reinforcement in beams and one-way and two-way structural slabs or slabs on grade [Nawy and Neuwerth, 1977; Nawy et al., 1971]. As indicated earlier, the continuous reinforcing elements cannot stop the development of microcracks. Fibers, on the hands, are discontinuous and randomly distributed in the matrix, both in the tensile and compressive zones of a structural element. They are able to add to the stiffness and crack control performance by preventing the microcracks from propagating and widening and also by increasing ductility owing to their energy absorption capacity. Common application of fiber-reinforced concrete include overlays in bridge decks, industrial floors, shotcrete applications, highway and airport pavements, thin shell structure, seismic and explosion-resisting structures, super flat surface slabs on grade in warehouse and for reduction of expansion joints.

2.3 Mixture Proportioning

Mixing the fibers with the other mix constituents can be done by several methods. The method selected depends on the facilities available and the job requirements, namely, plant batching, ready-mixed concrete, or hand mixing in the laboratory. The most important factor is to ensure uniform dispersion of the fibers and to prevent segregation or balling of the fibers during mixing. Segregation or balling during mixing is affected by many factors that can be summarized as follows:

1. aspect ratio l/d_f – most important,
2. volume percentage of the fiber,
3. coarse aggregate size, gradation, and quantity, and
4. water/cementitious ratio and method of mixing

2.4 Mechanics of Fiber Reinforcement

2.4.1 First Cracking Load

Fiber-reinforced concrete in flexure essentially undergoes a trilinear deformation behavior as shown in Figure 1. Point A on the load-deflection diagram represents the first cracking load, which can be termed the first-crack strength [Mindess and Young, 1981]. Normally, this is the same load level at which a nonreinforced elements cracks. Hence, segment OA in the diagram would be the same and essentially have the same slope for both plain and fiber-reinforced concrete.

Once the matrix is cracked, the applied load is transferred to the fiber that bridge and tie the crack to keep it from opening farther. As the fibers deform, additional narrow cracks develop and continued cracking of the matrix takes place until the maximum load reaches point B of the load-deflection diagram. During this stage, debonding and pullout of some of the fibers occurs. But the yield strength in most of the fibers is not reached.

In the falling branch BC of the load-deflection diagram, matrix cracking and fiber pullout continue. If the fibers are long enough to maintain their bond with the surrounding gel, they may fail by yielding or by fracture of the fiber element depending on their size and spacing.

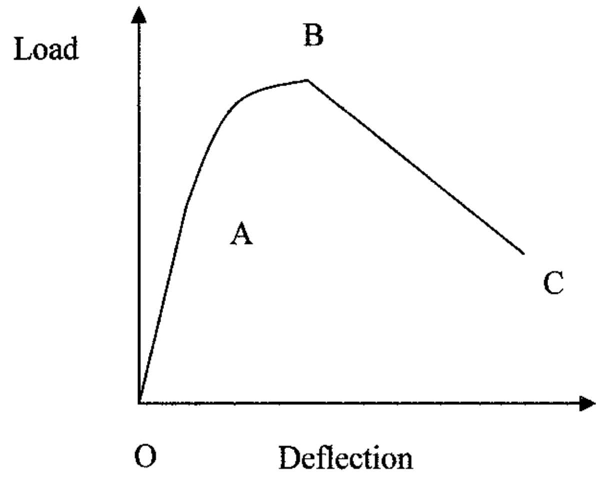

FIGURE 1: Schematic load-deflection relationship of fiber-reinforced concrete

2.4.2 Critical Fiber Length: Length Factor

If l_c is the critical length of a fiber above which the fiber fractures instead of pulling out when the crack intersects the fiber at its midpoint, it can be approximate by Mindess and Young (1981).

$$l_c = (d_f/2v_b)\sigma_f$$

Where

d_f = fiber diameter

v_b = interfacial bond strength

σ_f = fiber strength

Bentur and Mindess (1990) developed an expression to relate the average pullout work and the fiber matrix interfacial bond strength in terms of the critical fiber length, demonstrating that the strength of a composite increases continuously with the fiber length. This is of significance as it indicates that pullout work may go through a maximum and then decreases as bond strength increases over a critical value. This loss of pull-out work would be reduced to a typical range of l = 10 mm in the cement-based composites. If a critical v_b value of 1.0 MPa is chosen and a small diameter fiber d_f = 20 μm, namely, a cementitious system which such a small diameter fiber, an increase in bond may result in reduced toughness.

2.4.3 Fiber Orientation: Fiber Efficiency Factor

The orientation of the fibers with respects to load determines the efficiency with which the randomly oriented fibers can resist the tensile forces in their directions. This is synonymous with the contribution of bent bars and vertical shear stirrups provided in beams to resist the inclined diagonal tension stress. If one assumes perfect randomness, the efficiency factor is $0.41l$, but it can vary between $0.33l$ and $0.65l$ close to the surface of the specimen as trowling or leveling can modify the orientation of the fibers [Mindess and Young, 1981].

2.5 Mechanical Properties of Fibrous Concrete Structural Elements

2.5.1 Control Factors

The mechanical properties of fiber-reinforced concretes are influenced by several factors. The major properties are

1. the type of fiber, namely, the fiber material and shape
2. the aspect ratio l/d_f, namely, the ratio of the fiber length to its nominal diameter
3. the amount of fiber in percentage by volume, ρ
4. the spacing of the fiber, s
5. the strength of the concrete or mortar matrix, and
6. the size, shape, and preparation of the specimen.

Hence it is important to conduct laboratory tests to failure on the mixtures using specimen models similar in form to the elements being designed. As the fiber affects the performance of the end product in all material-resistance capacities such as in flexure, shear, direct tension, and impact, it is important to evaluate the test specimen performance with regard to those parameters.

2.5.2 Strength in Compression

The effect of the contribution of the fibers to the compressive strength of the concrete seems to be minor for test using steel fiber. However, the ductility and toughness are considerably enhanced as a function of the increase in the volume fractions and aspect ratios of the fibers used. Figure show the effect of the increase in volume fraction on the stress-strain relationship of the fibrous concrete through increasing the fiber volume from zero to 1.5% for concrete having a compressive strength of 13,100 psi (90.3MPa). Figures 2 depict a similar trend with respect to both a volume fraction ratio up to 3% and an aspect ratio in the range 47-100. Figure also demonstrates the influence of the increase in fiber content on the relative toughness of reinforced concrete members.

Toughness is a measure of the ability to absorb energy during information. It can be estimated from the area under stress-strain or load-deformation diagram

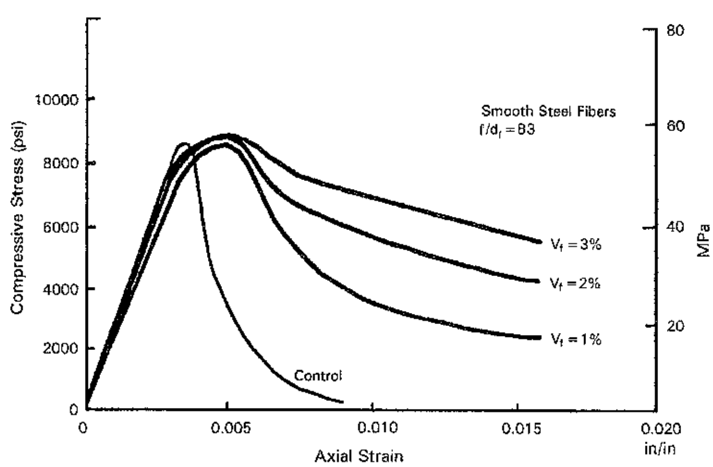

FIGURE 2: Influence of volume fraction of steel fibers on stress-strain behavior for 9000psi concrete

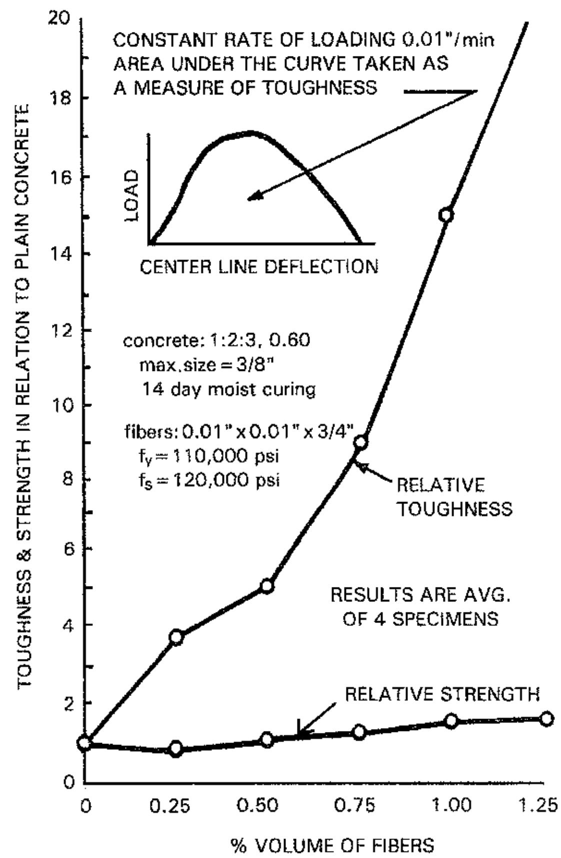

FIGURE 3: Relative toughness and strength versus fiber volume ratio

2.5.3 Strength in Direct Tension

The effect of different shapes of the fibers elements on the tensile stress behavior of steel fiber reinforced mortars in direct tension in demonstrated in Figure. The descending portion of the plots shows that the fibers-reinforced with better anchorage quality increase the tensile resistance of the fiber-reinforced concrete beyond the first cracking load.

2.5.4 Flexural Strength

Fibers seem to affect the magnitude of flexural strength in concrete and mortar elements to a much greater extent than they affect the strength of comparable elements subjected to direct tension or compression [ACI Committee 544, 1993]. Two stages of loading portray the behavior. The first controlling stage is the first cracking load stage in the load-deflection diagram, and the second controlling stage is the ultimate load stage. Both the first cracking load and the ultimate flexural capacity are affected as a function of the product of the fiber volume concentration, ρ, and the aspect ratio, l/d_f. Fiber concentration less than ½% of volume of the matrix and with an aspect ratio less 50 seem to have a small effect on the flexural strength, although they can still have a pronounced effect on the toughness of the concrete elements.

2.5.5 Shear Strength

A combination of vertical stirrups and randomly distributed fibers in the matrix enhances the diagonal tension capacity of concrete beam. The degree of increase in the diagonal tension capacity is a function of the shear span/depth ratio of a beam. This ratio determines the mode of failure in normal beams that do not fall in the category of deep beams and brackets as details by Nawy (1996a). Williamson (1978) found that when 1.66% by volume of straight steel fibers are used instead of stirrups, the shear capacity increased by 45% over beams without stirrups. When steel fibers with deformed ends were used at a volume ratio of 1.1%, the shear capacity increased by 45-67% and the beams failed by flexure. Using crimped-end fibers increased the shear capacity by almost 100%.

In general, as the shear span/depth ratio, a/d, decreased and the fiber volume increased, the shear strength increased proportionally. Test by Sharma (1986) resulted in the following expression in the ACI Committee 544 report (1993) for the average shear stress, v_c, for beams in which steel fibers were added:

$$v_{cf} = 2/3 f'_t (d/a)^{1/4}$$

where

f'_t = tensile splitting strength

d = effective depth of a beam

a = shear span; equal to distance from the point of application of the load to the face of the support when concentrated loads are acting or equal to the equal to the clear beam span when distributed load are acting.

2.6 Environmental Effects

2.6.1 Freezing and Thawing

The addition of fibers to a matrix does not seem to result in an appreciable improvement in the freezing and thawing performance of concrete since its resistance to such an environmental effect is controlled by permeability, void ratio, and freeze-thaw cycles. Fibers tend, however, to hole the scaling, concrete pieces together, thereby reducing the extent of apparent scaling.

2.6.2 Shrinkage and Creep

No appreciable improvement in the shrinkage and creep performance of concrete results from the addition of fibers but perhaps a slight decrease in shrinkage owing to the need for more paste mortar in the mixture when fibers are also used. Cracking due to drying shrinkage in restrained elements can be slightly improved as the cracks are kept from generating because of the bridging effects of the randomly distributed fibers.

2.6.3 Dynamic Loading Performance

The cracking behavior of concrete elements under dynamic loading seems to be three to ten times better that of plain concrete. Also the total energy absorbed by the steel fibrous concrete beams can be 40 to 100 times that for plain concrete beams depending on the type, deformed shape, and percent volume of the fibers [ACI Committee 544, 1993].

2.7 Polyvinyl Alcohol (PVA) Fiber

Polyvinyl alcohol (PVA) is an organic material that we use to make concrete reinforcement fibers, among many other uses. It is made from carbon, hydrogen, and oxygen. Polyvinyl alcohol has excellent film forming, emulsifying, and adhesive properties. It is also resistant to oil, grease and solvent. It has high tensile strength, flexibility, as well as high oxygen and aroma barrier. However, these properties are dependent on humidity; in other words, with higher humidity more water is absorbed. The water which acts as a plasticiser will then reduce its tensile strength, but increase its elongation and tear strength.

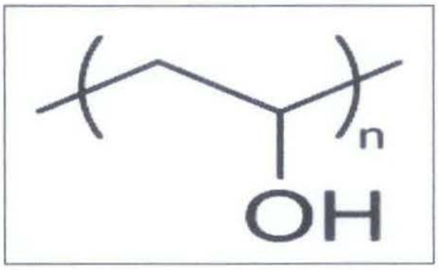

FIGURE 4: Chemical structure of polyvinyl alcohol (PVA).

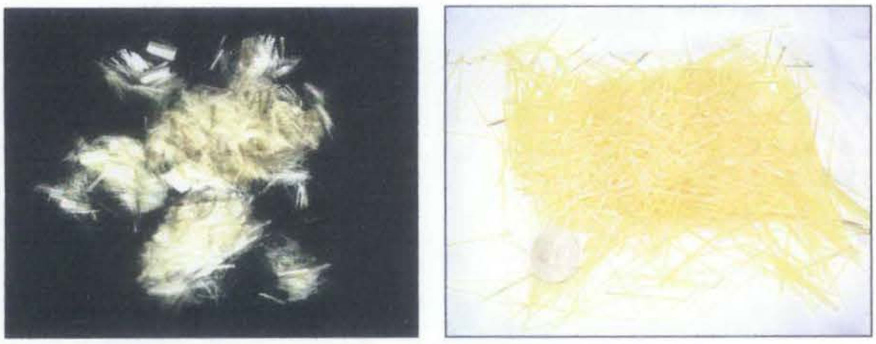

FIGURE 5: Polyvinyl alcohol (PVA) fiber.

PVA fibers are true structural concrete reinforcement fibers, like steel and glass. Common plastic fibers perform one task in concrete which is they restrain plastic shrinkage. But after the first 24 hours, they are largely ineffective in restraining drying shrinkage or other cracking because their modulus of elasticity is less than that of concrete. That's another way of saying they are more stretcher than concrete. To be a true structural fiber, the fiber should be stiffer than the concrete it is reinforcing.

PVA (polyvinyl alcohol) fibers are very high-performance reinforcement fibers for concrete and mortar. In *Figure 6*, the plot shows that PVA-ECC is stronger in tension than any fiber-reinforced mortar. PVA fibers have excellent characteristics for a concrete or mortar repair product. PVA fibers are also unique in their ability to create a molecular bond with mortar and concrete that is 300% greater than other fibers.

PVA fibers are superior in several ways:

1. High bond strength with concrete help to keep the patch together even it is damaged
2. PVA Fibers will not cut the user or equipment
3. PVA fibers will never rust
4. High modulus of elasticity and tensile strength help keep the concrete intact
5. PVA fibers have a very high abrasion resistance
6. PVA fibers produce concrete and mortar with very high fatigue resistance
7. PVA fibers have superior crack fighting properties
8. PVA fibers are resistant to UV rays, alkali, abrasion and most chemicals

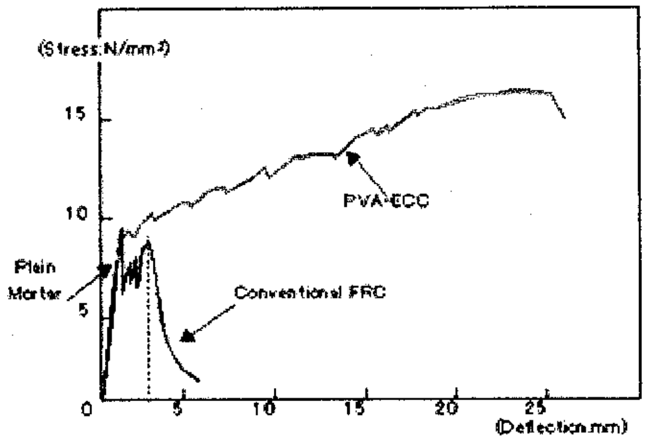

FIGURE 6: Strain-hardening curve for PVA-ECC.

PVA fibers are also used to reduce many types of concrete cracks. To restrain shrinkage cracking, the fiber should be stiffer than the concrete it is reinforcing. PVA fibers reduce normal cracks to micro-cracks that restrict water penetration and protect steel reinforcement. Because they are less "stretchy" with a higher modulus of elasticity, PVA fibers are more effective than other fibers in reducing long-term drying cracking. Relatively low dosages of PVA fibers can effectively reduce many types of cracking, including drying shrinkage, settlement and fatigue-related cracks.

TABLE 1: Standard properties of PVA fiber.

Fiber type	Diameter (mm)	Thickness (dtex)	Cut length (mm)*	Tensile Strength (N/mm^2)	Elongation (%)	Young's Modulus (kN/mm^2)	Specific Gravity	Primary Applications
RECS7	0.027	7	6	1600 (1.6GPa)	-	39	1.3	Crack control and reinforcement of mortar applications
RECS15	0.04	15	8	1600 (1.6GPa)	7	40	1.3	PVA-ECC and other mortar reinforcement
RSC15	0.04	15	8	1300 (1.3GPa)	7	30	1.3	Crack control at very low dosages
RFS400	0.2	400	18	1000 (1.0GPa)	8	29	1.3	Mortar, concrete
RF4000	0.66	4444	30	900 (0.9GPa)	7	23	1.3	Aggregate above 3/4" (20mm) and shotcrete

2.8 Comparison of PVA fiber with other fibers

Steel fibers have greater tensile strength than PVA fibers, but this strength is rarely used. Steel fibers, like rebar, are passive reinforcement, meaning they have no reinforcing effect until the concrete cracks. The problem then is that steel fibers tend to pull out rather than hold the concrete together. Many techniques have been used to increase the mechanical bond of steel fibers--hooks and waffles are among the most popular--but even so the steel fibers pull out easily. Contrast this with PVA fibers which create a molecular bond with the cement during hydration. When you try to pull a PVA fiber out, it holds on firmly, taking full advantage of PVA's tensile strength.

PVA fiber is about the same price as glass, but you use 1/3 as much, so it ends up being much less expensive. It is a little more expensive than polypropylene and nylon, but it offers far greater performance. PVA does not break down in concrete.

Even the best AR glass degrades in strength dramatically over time, up to 80%. Field studies have shown that PVA degrades about 1% over 20 years. PVA is extremely tough and durable. You can bend PVA fibers over a hundred times before they break. No other concrete reinforcement fiber is so tough.

They differ in many ways, but as reinforcement for concrete, these differences are especially notable. Polypropylene, nylon and the other synthetic fibers used in concrete serve only one purpose: to restrain plastic shrinkage during the first 24 hours after concrete is poured. Because of their high elongation, or "stretchiness", these fibers are essentially useless for the drying shrinkage and other sorts of cracking that all concrete suffers from. These cracks, in addition to plastic cracking, is what PVA is designed to handle. In that regard it is a structural fiber like steel and AR glass.

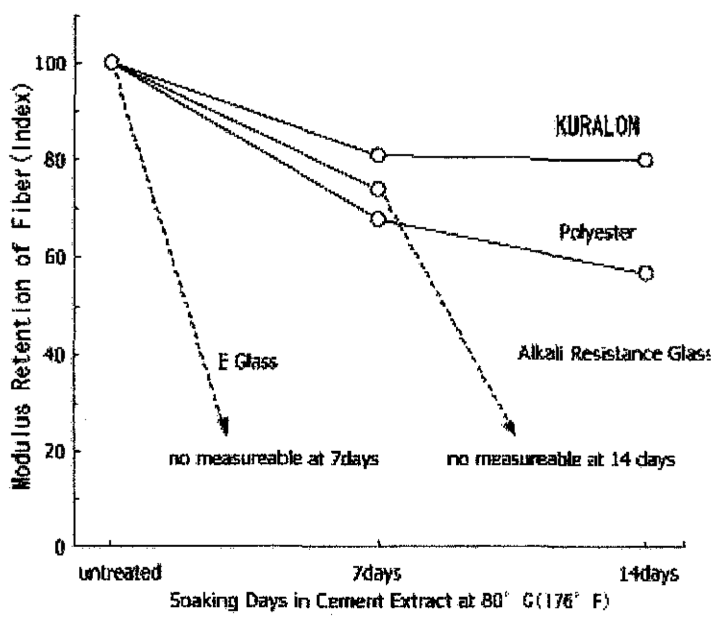

FIGURE 7: Comparison of Modulus Retention between KURALON and other fibers

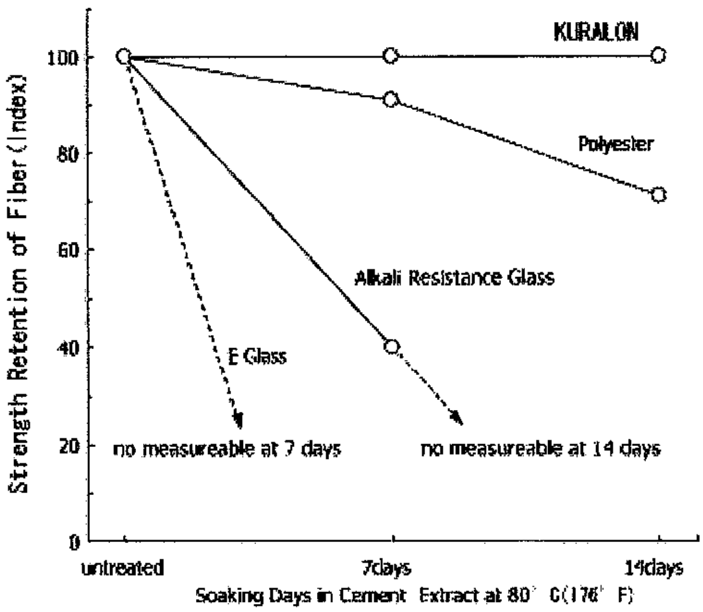

FIGURE 8: Comparison of Strength Retention between KURALON and other fibers

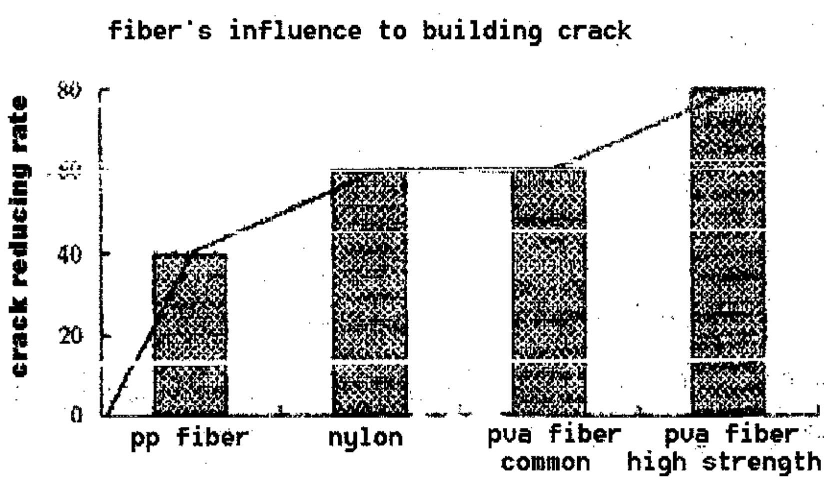

FIGURE 9: Comparison of crack reducing rate of PVA fibers and other fibers

PVA resin, which is the raw material of PVA-fiber, is designated by the FDA (U. S. Food and Drug Administration) as a safe material. PVA's chemical structure is based solely on carbon, hydrogen and oxygen. When burned, harmful substances such as dioxin and ammonia are not created. (This structure is quite different from polyvinyl chloride.) As PVA fiber is composed of carbon , hydrogen and oxygen, only water and carbon dioxide is generated during burning.

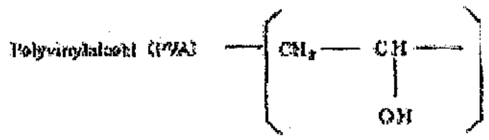

TABLE 2: Gases released during burning of fibers

Gas	CO		CO_2		NH_3		HCN		H_2S	
Fiber	600	400	600	400	600	400	600	400	600	400
PVA-fiber	0.45	0.13	0.59	0.13	-	-	-	-	-	-
Polyacrylonitrile-fiber	1.33	0.16	0.15	0	0.06	0.05	0.09	0.02	-	-
Polyamide-fiber	0.88	0.1	0.4	0.01	0.05	traces	0.03	0	-	-
Cotton	4.33	0.46	0.75	0.34	-	-	-	-	-	-
Wool	2	0.1	0.59	0.15	0.1	0.06	0.05	0.01	0.04	0.05

Reference: Magazine "Fiber" No.29 (3) 1977 Suwada

TABLE 3: Result of toxicity test of PVA fiber and other fibers

Fiber	The number of living rats					
	5min.	10min.	15min.	20min.	30min.	24hrs.
PVA-fiber	5	5	5	5	5	5
Polyacrylonitrile-fiber	0	-	-	-	-	-
Polyamide-fiber	5	5	5	5	5	4
Metha-alamide-fiber	5	5	5	5	5	0
Wool	5	2	2	1	1	-

*measurement by Kuraray Co., Ltd.

3.0 METHODOLOGY

3.1 PROJECT PLANNING

For the first month of the project, there will be more on the literature researches via relevant journals and reference books. Since this project was pioneered by the previous Final Year Project 1 (FYP 1) 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 is to prove that the test subject was also improved in the fatigue strength under repeated cyclic compression loadings.

There will be a concrete casting works together with the FYP 1 students in the concrete lab using the engineered PVA provided as the fiber and certain mix proportions to be experimented using trial and error method. The concrete casting works need to be done in part 1 of the project because it will take up to 3 months curing period before the concrete samples are ready to be used in the fatigue strength test, which will be held in the part 2 of the project.

3.2 LABORATORY WORKS

On the middle of the semester, several laboratory works have been done to investigate the effects of PVA fibers incorporated together in the normal concrete mixes. The works focus mainly on the static properties of the PVA reinforced concrete that is to investigate the compressive and tensile strength of the said concrete mixes and comparing with the normal mixes (control mixes) which does not have PVA fibers incorporated in the mixes.

3.2.1 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) = 40 MPa

b. Referring to the Table 1 (14.9 pg 763) below, the compressive strength for Type 1 OPC cement at the age 28 days is 42 MPa

c. From the Table 2 (14.12 pg 764) below, the water/cement ratio is 0.52

d. As in Table 3 (14.10 pg 765) below, slump 60-180 mm and maximum aggregates of 40 mm uncrushed were chosen. Therefore, the water content for the mix is 175 kg/mm^3

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

Water content / wc ratio = 175/0.52

= 336.54 kg/mm^3

f. According to Diagram 2 (14.13 pg 765), fresh density of concrete mix is 2415 kg/mm^3

g. Thus, total aggregates content is given by:

= 2415 kg/mm^3 – 336.51 kg/mm^3 – 175 kg/mm^3

= 1903.46 kg/mm^3

h. From Diagram 3 (14.14 pg 766-767), fine aggregates proportion is 34%. Thus, fine aggregates is given by:

= (34/100) x 1903.46

= 647.17 kg/mm^3

i. Therefore, coarse aggregates value is given by:

$= 1903.46 \text{ kg/mm}^3 - 647.17 \text{ kg/mm}^3$

$= 1256.28 \text{ kg/mm}^3$

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

W/C	= 0.52
Cement	= 336.54 kg/mm^3
Fine aggregate	= 647.17 kg/mm^3
Coarse aggregate	= 1256.28 kg/mm^3
Water	= 175 kg/mm^3

For concrete mix of 0.101 m^2, the calculated mix proportions are as the following:-

Table 4: Summary of Mix proportioning

Mix	Coarse aggregate (kg)	Fine aggregate (kg)	Cement (kg)	Water (kg)	PVA fibers (kg)
PVA 0%	128.14	66.02	34.32	17.86	0
PVA 1%	128.14	66.02	34.32	17.86	0.343
PVA 2%	128.14	66.02	34.32	17.86	0.686
PVA 3%	128.14	66.02	34.32	17.86	1.030

3.2.2Concrete 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 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 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 10: Process of concrete mixing

3.2.2 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.

Slump test

Objective

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

Procedure

1) Start the test within 5 min. after obtaining the final portion of the mixed sample.
2) Dampen the mold (inside) and place on the dampened base plate.
3) Hold the mold firmly in place during the filling and rodding operation.
4) Fill the mold in 3 layers, each approximately one-third the volume of the mold.
5) Rod each layer with 25 strokes of the tamping rod. During filling and rodding the top layer, heap the concrete above the mold before rodding is started.
6) Strike off the surface by a screeding and a rolling motion of the tamping rod.
7) Remove the mold immediately by raising it in a vertical direction.
8) Place the empty mold (inverted) adjacent to the concrete sample and measure the vertical difference between the top of the mold and the displaced original center of the sample. The slump is measured.

FIGURE 11: Slump test done on 0% PVA FRC (left) and 3% PVA FRC (right)

Hardened concrete test

Compression test

Objective

To measure the compression strength of concrete.

Procedure

1) Maintain the specimen in a moist condition up to the time of compression testing. Compression tests are made as soon as practicable after removal from moist storage. The specimens are tested in this cured moist condition.
2) Wipe clean the bearing surfaces of the upper and lower platens of the compression testing machine. Also, wipe clean both end caps of the test specimen.
3) Center the specimen on the lower platen of the testing machine.
4) Carefully align the axis of the specimen with the center of thrust of the spherically seated upper platen.
5) Bring the upper platen to bear on the specimen, adjusting the load to obtain uniform seating of the specimen.
6) Apply the load at a loading rate based on the size of concrete specimen. The time to failure for 3000 psi concrete is 1 to 2.5 minutes.
7) Apply the load at the prescribed loading rate until the specimen fails. Record the maximum load (lb). Note the type of failure and the appearance of the concrete.

FIGURE 12: Compression test using compression machine

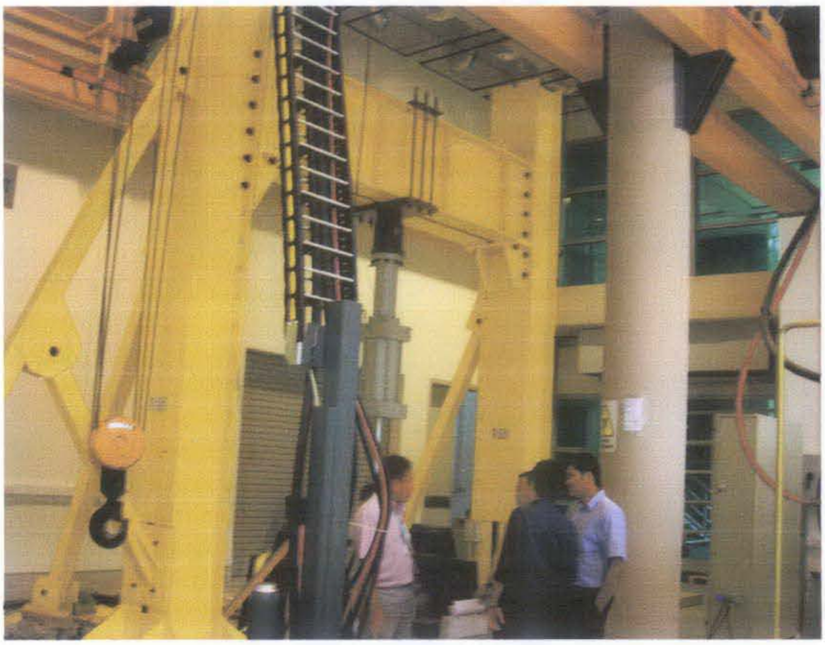

FIGURE 13: Compression test using UTM machine

FIGURE 14: Compression test using UTM machine

4.0 RESULTS AND DISCUSSION

4.1 FRESH CONCRETE TEST

4.1.1 Slump Test

TABLE 5: Result of slump test

Mix	Slump (mm)
PVA 0%	150
PVA 1%	62
PVA 2%	30
PVA 3%	0

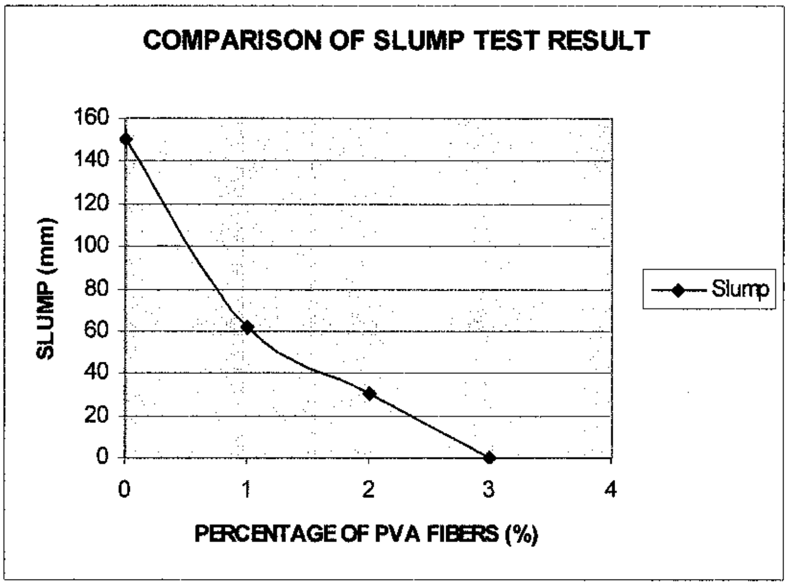

FIGURE 15: Comparison of slump test result

It is noted that standard slump test has been found to be an appropriate measure of the workability of fiber reinforced concrete since its mixtures with apparently low slump values can be quite workable in the field. From Table 5, it shows that mix with no fiber give high value of slump compare to mix with fiber which means reduction in workability the more PVA fibers added in the mix. For proper compaction, fiber reinforced concrete mixtures must be placed using vibration and so workability tests that involved vibration are more appropriate. It is therefore recommended that either Vebe test or the inverted slump cone test be used. The latter test involves the time required for the fiber reinforced concrete to flow through an inverted standard slump cone under internal vibration.

4.1.2 Hardened concrete test

Test result using the compression machine

Figure 16 shows the strength development diagram in compression. From the figure, it shows the strength of concrete increases with time. All specimens have almost the same projection of line, but the different is the plain concrete has the less strength compared to the others. From this we can say that the concrete with fiber may increase the concrete strength.

For concrete with fibers, it shows that the concrete with 3% PVA fiber has the highest strength at 28 days followed by 1% and 2%. This is because that the interaction between fiber and matrix becomes to grow more intense and, consequently, the cracks are distributed more widely over the specimens. But in between, it gives different result. For example in day 19, the highest strength concrete is the concrete with 1% PVA fiber followed by 2% and 3% accordingly. This may happen because of the fibers affect in the concrete. The concrete may not mix properly with the fiber. Theoretically, the fibers must be mix equally with the aggregates during mixing. There might be some errors which is the fibers may not mix equally that cause the fibers segregate or balling.

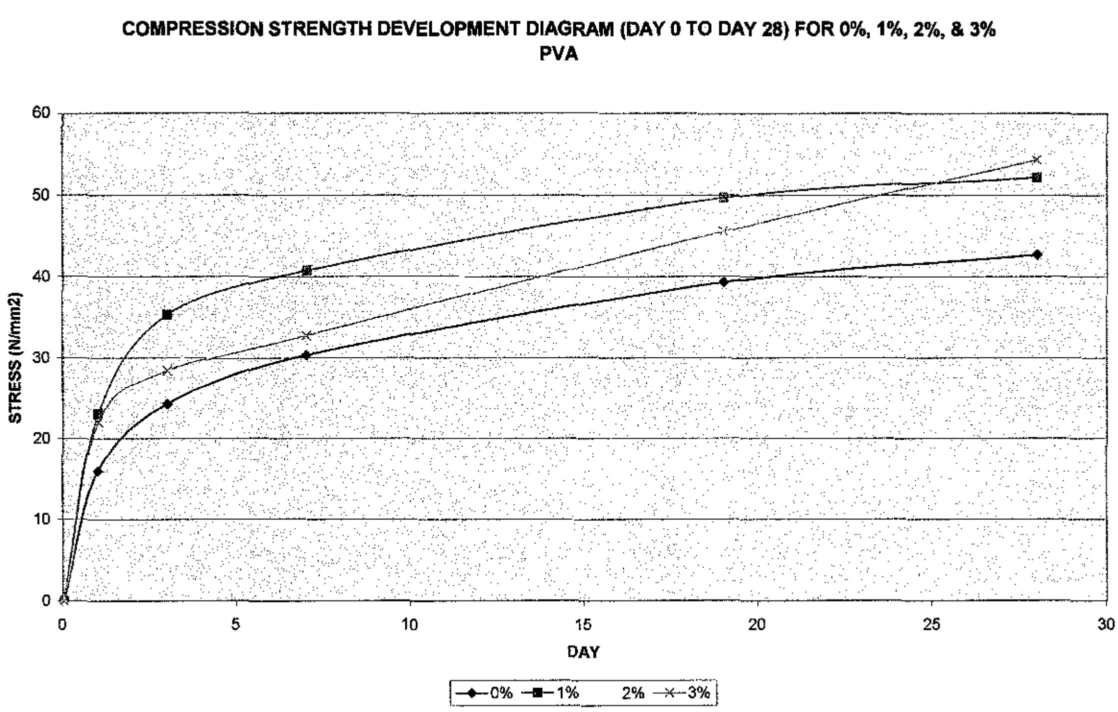

FIGURE 16: Compression strength development diagram

From the test using the UTM machine, graphs load vs deflection were plotted. The tests were done for only 1 day. There are four samples; 0% to 3% of PVA fibers accordingly. From the graph, sample with 2% PVA fibers gives high maximum load that is 514.73 kN compared to the others. Theoretically, the concrete with 3% should gives high maximum load. As we can see from Figure 20, the maximum load gives the value of 360.99 kN. But after that particular point, the line went down to the left, which is far different from the theory. This is because, went the test is conducted, the load keep increasing without any crack at the sample. The technicians who run the test decided to stop the machine because worry it could damage the equipment test. The equipment cannot support the load more than 400 to 450 kN. For the sample with 2% PVA fibers, the test was run till the end even though the load was more than desire one. During this time, we decided to continue running the test because crack has occurred during 400 kN. Assumption was made that even the result gives high value for sample with 2%, but the sample with 3% could reach more than that. The data for the test is attached in the appendices. After plotting the graph, the author comes out with the stress-strain diagram as shown below for each sample using the formula:

Stress = load (N) / area (mm^2)

Strain = deflection (mm) /depth of sample (mm)

Test result using the UTM machine

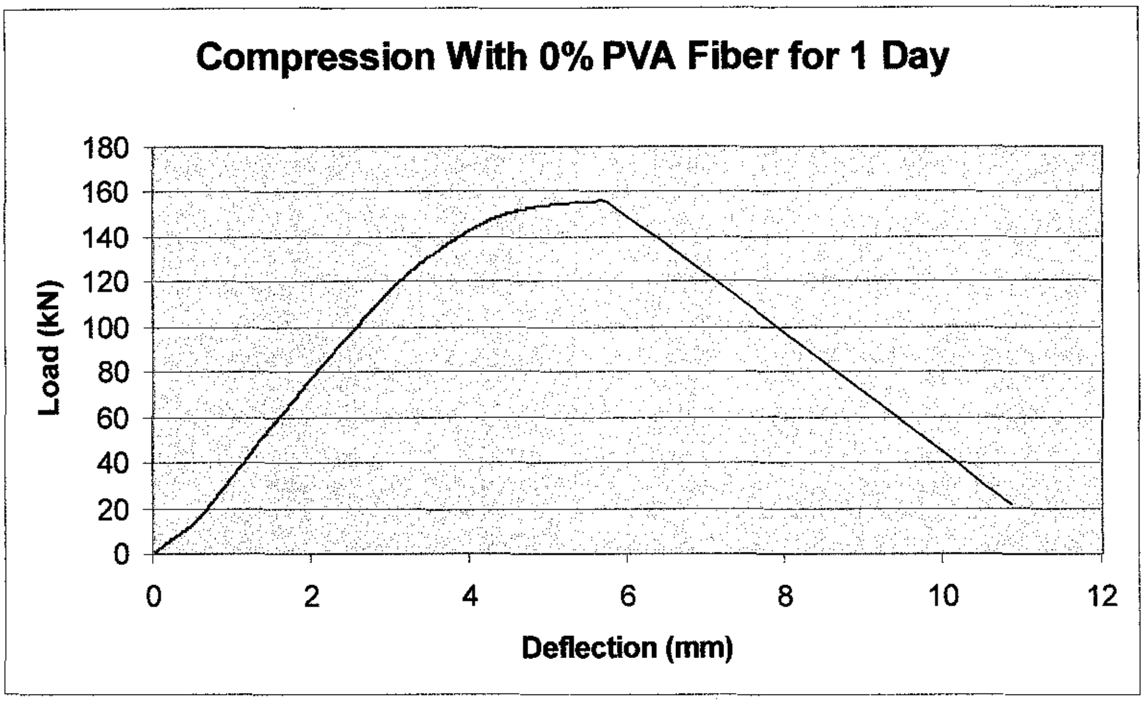

FIGURE 17: Compression strength development diagram with 0% PVA fiber

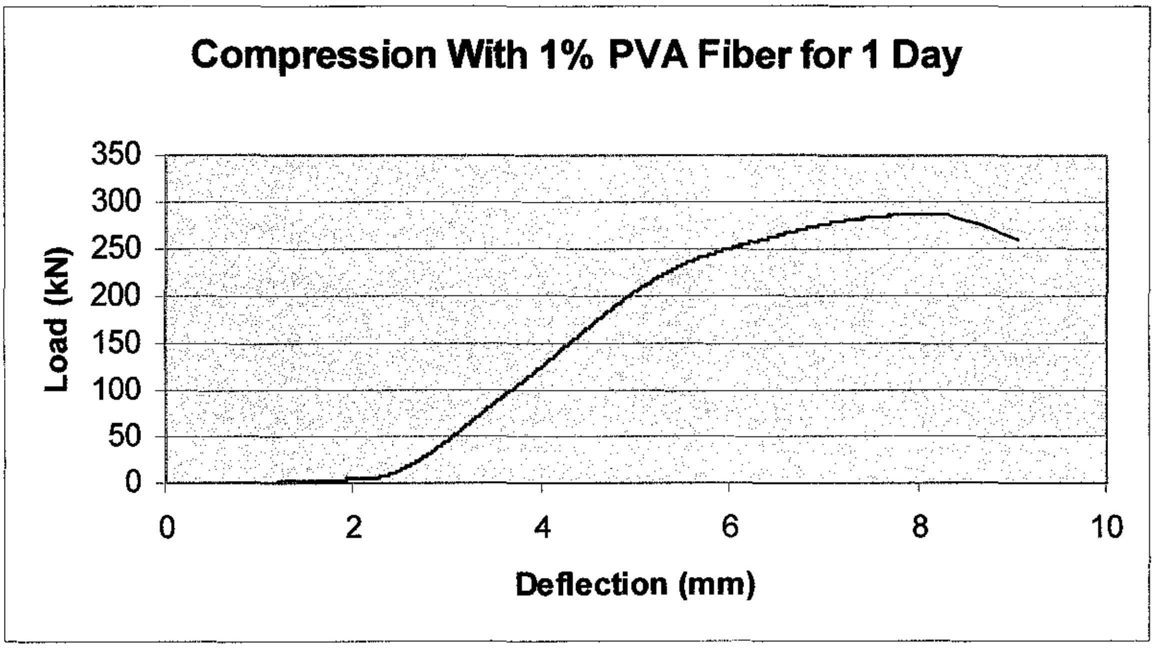

FIGURE 18: Compression strength development diagram with 1% PVA fiber

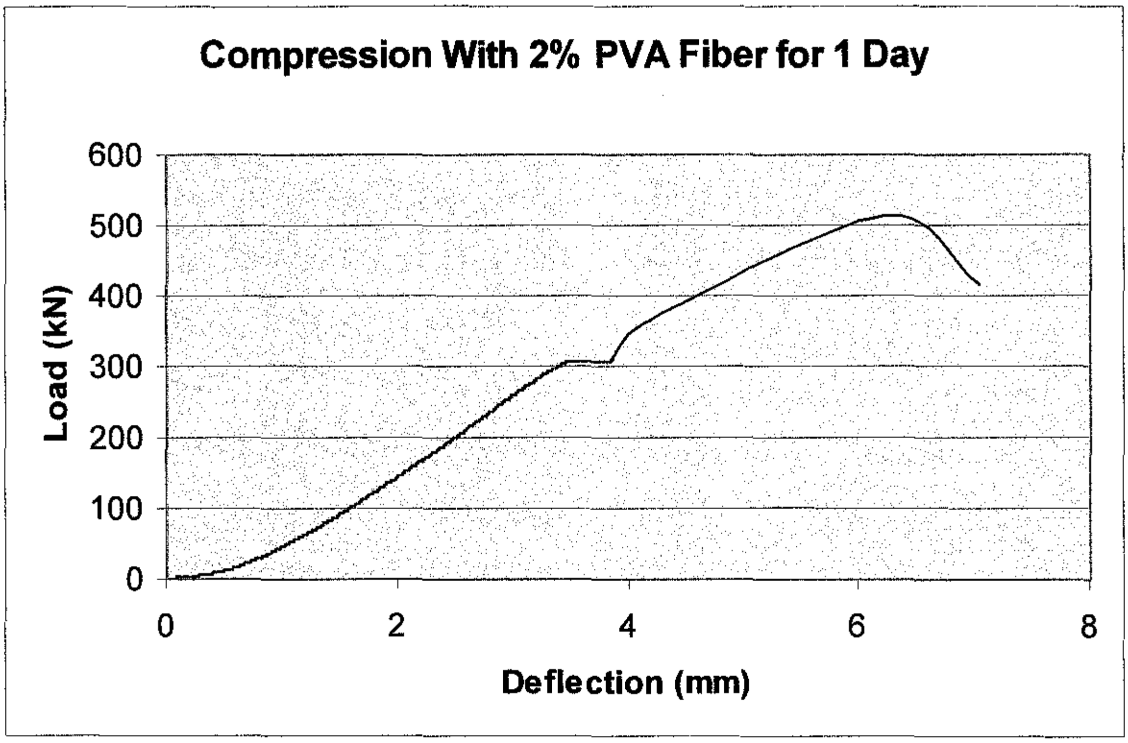

FIGURE 19: Compression strength development diagram with 2% PVA fiber

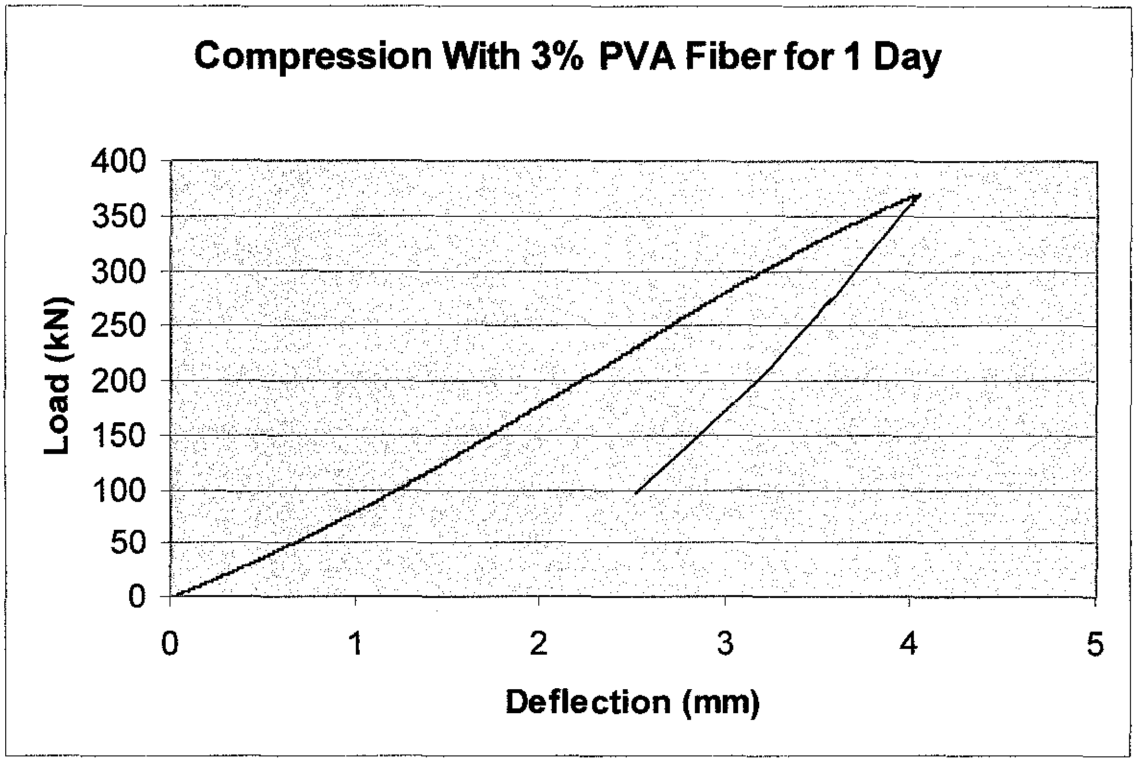

FIGURE 20: Compression strength development diagram with 3% PVA fiber

Summarize of the graph is shown on the table below.

TABLE 6: Maximum load and deflection for different percentage of PVA fibers

PVA (%)	MAX LOAD (kN)	DEFLECTION (mm)
0	155.13	5.756
1	287.11	8.328
2	514.73	6.217
3	360.99	4.001

The stress strain diagram below was interpolated from the data got from the UTM machine. Sample with 2 % PVA fibers gives high stress-strain compared to the others. It is same with the result got for graph load-deflection. For overall result, it can be conclude that the content of PVA influence the strength of concrete. From the literature review, it is important during mixing the concrete with the PVA. This is to ensure the PVA fibers are spread out equally in the mixing. The non-equally mixing of the fibers may affect the result because the author mixes the fibers manually.

It is also proven that by using the PVA fibers in the concrete can increase the strength of concrete compare with normal concrete. This can be seen from the results, which are the samples with fibers give high value of load compare to the control mix.

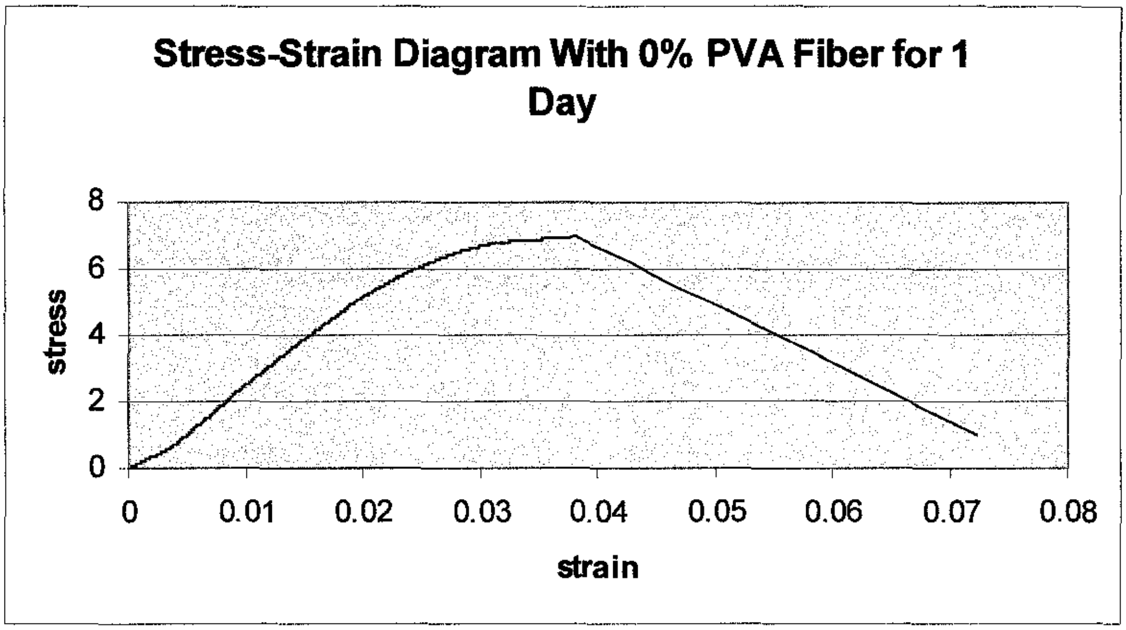

FIGURE 21: Stress-Strain Diagram With 0% PVA Fiber

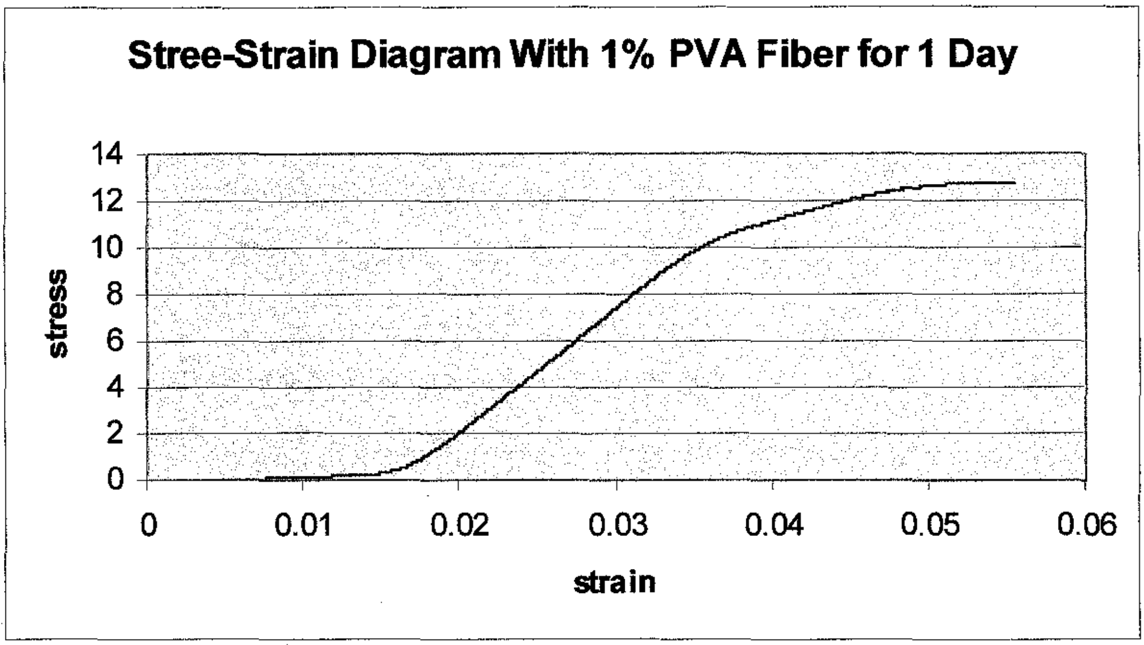

FIGURE 22: Stress-Strain Diagram With 1% PVA Fiber

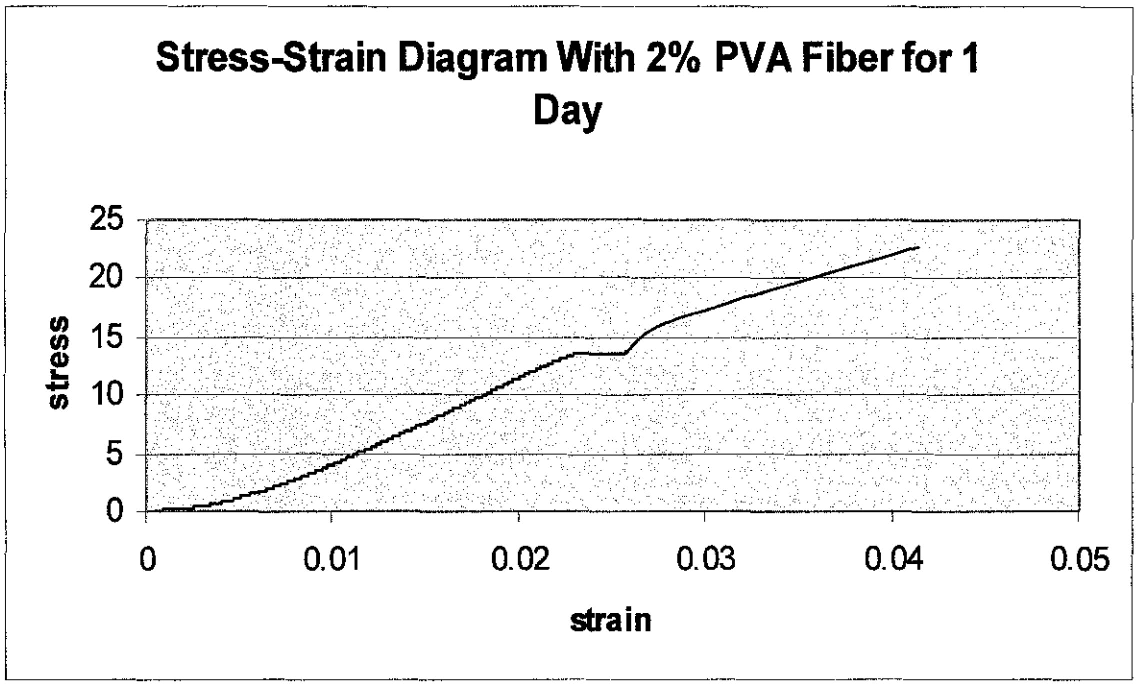

FIGURE 23: Stress-Strain Diagram With 2% PVA Fiber

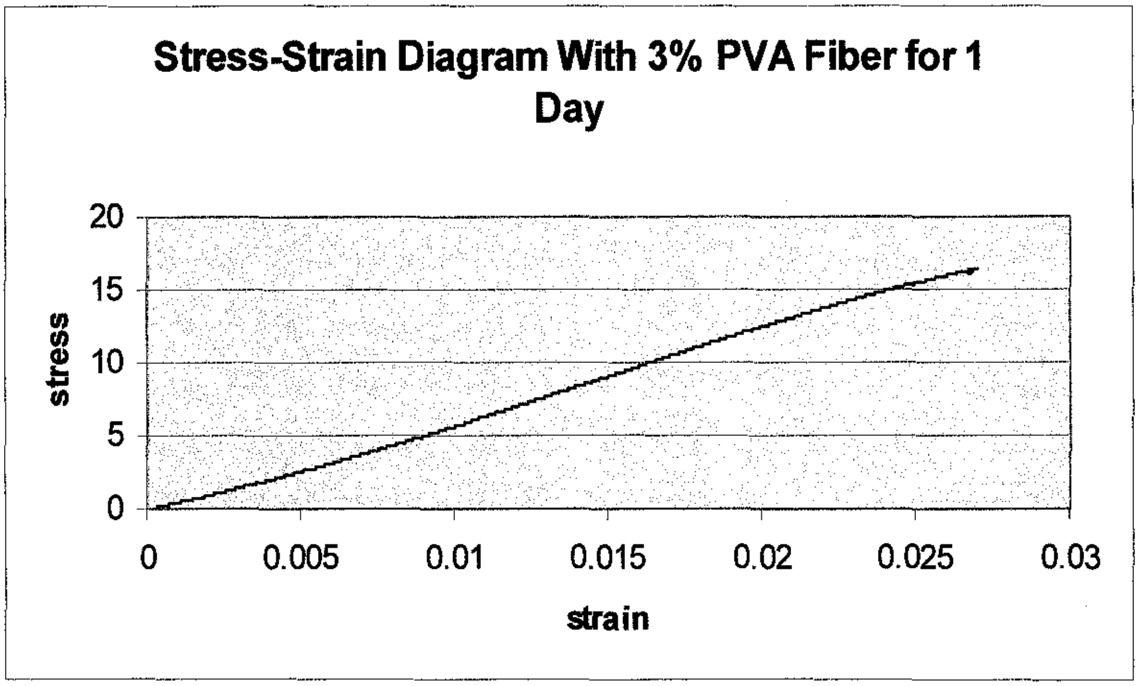

FIGURE 24: Stress-Strain Diagram With 3% PVA Fiber

5. CONCLUSION AND RECOMMENDATION

In the first half of the semester, the project focused more on the literature review of PVA fibers and fiber reinforced concrete. At this time preparation of aggregates has been done including sieving and saturated surface dry (SSD). Literature also focused on getting the best proportion of mixing using the PVA fibers. In order to get that, a few self concrete sample mixes were done to determine the appropriate mix to be used for the mix using PVA fibers and in order to come up with the proposed mix proportion.

In the second half of the semester, concrete mix was done using the PVA fibers. Plain concrete also was mixed as a control mix to be compares with concrete with PVA fibers. Eventually, concrete mixes with PVA fibers were conducted using normal concrete procedures. 4 PVA concrete mixes were conducted; consist of 0% (control mix), 1%, 2% and 3% PVA fibers. The main focus was to determine the hardened properties of the PVA fiber reinforced concrete, especially on the compressive and flexural strength.

Some recommendations to improve on this project would be to make more mixes with varying content of PVA fibers. The purpose is to observe in a bigger scope on how PVA fibers would act with concrete. In addition to that, variation of tests could also be conducted to determine other properties of PVA fiber reinforced concrete. Some other admixtures might also be infused in the concrete mix to alter or improve the properties of PVA reinforced concrete. Some of the constraints in this project came from the conditions and environment of the concrete lab. Tests were not able to be executed on specified time because testing machine was having some problem and could not function properly. It is critical to ensure all the equipments and machines in the lab are ready before any mix or test is going to be performed. It is also essential to follow all the procedures throughout the whole project to ensure it would flow smoothly. Time management plays an important role in ensuring the project success. A timeline should be constructed so that all the activities are going to run correspondingly.

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4. Steven H. Gebler, "Consolidation of Concrete", ACI SP-96 (1987)
5. Edward G. Nawy, "Concrete Construction Engineering Handbook", CRC Press, Boca Raton , New York (1997)
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APPENDICES

Properties of PVA fibers

A. Specifications and properties

Item / Property	High strength & modulus □.	High strength & modulus □.	Super-short staple fiber □. for building materials	Super-short staple fiber □. 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	Good	good	good	good

resistance				
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□	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

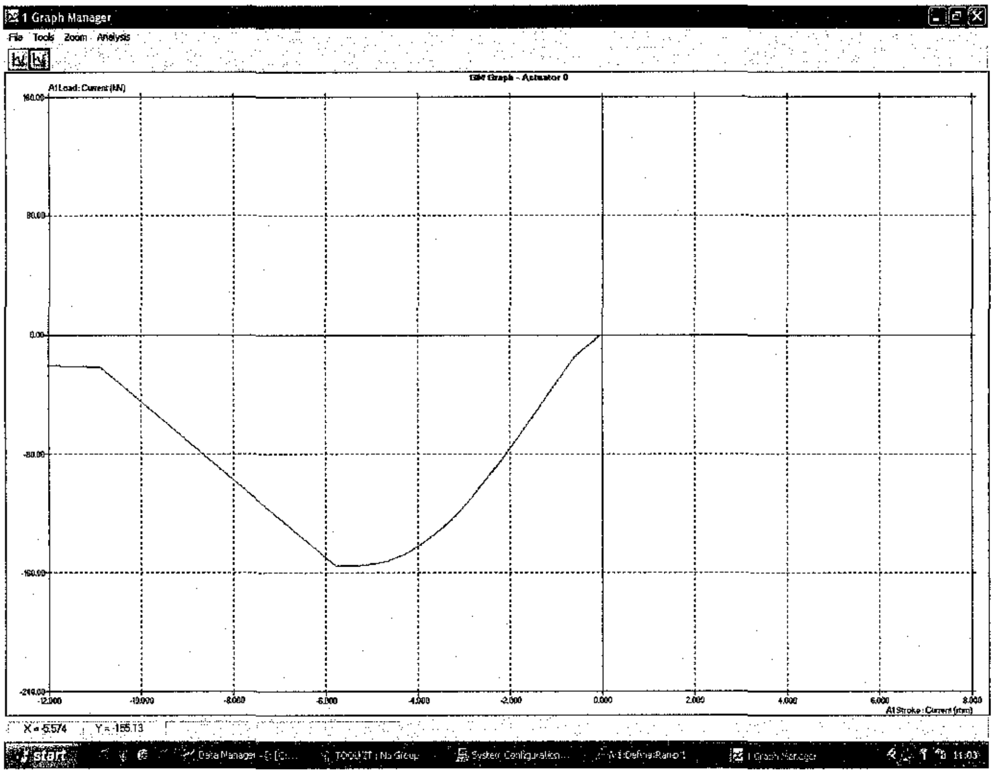
D. Sunshine resistance comparisons

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

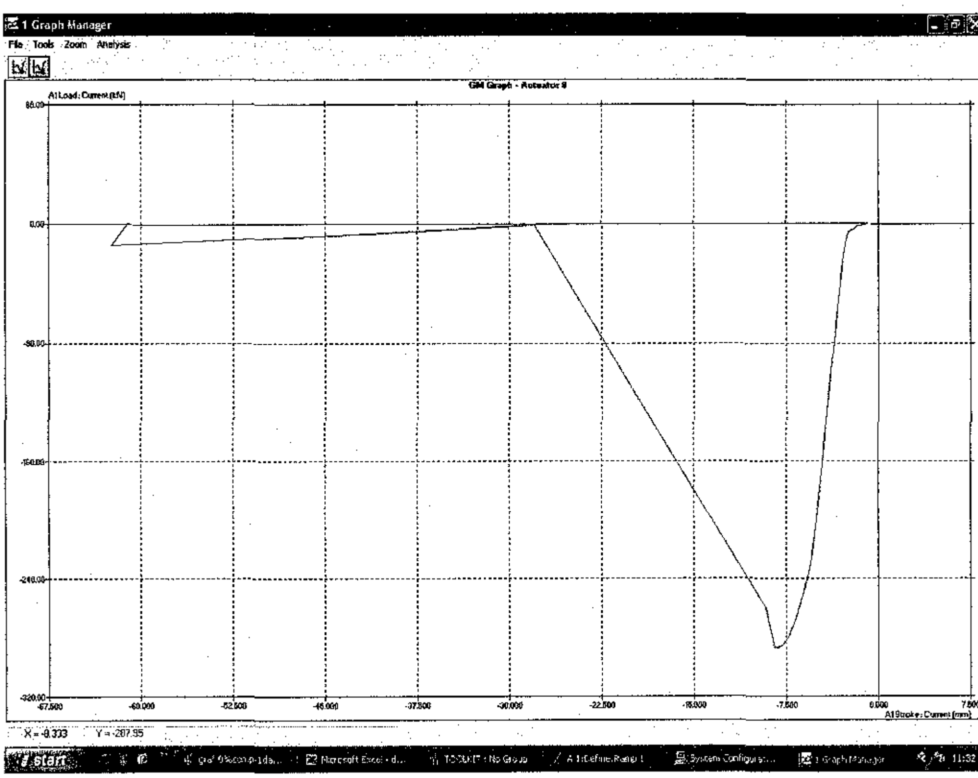
Concrete tested (days)

DAY	% PVA	COMP			
		WGH (kg)	MX LD (kN)	STRS (N/mm2)	AVRGE
1	0	8.33	357.5	15.89	
		8.15	378.7	16.83	15.99
		8.18	343.1	15.25	
	1	8.47	509.2	22.63	
		8.32	524.9	23.33	23.03
		8.18	520.4	23.13	
	2	8.26	410	18.22	
		8.23	449.6	19.98	18.58
		8.34	394.7	17.54	
	3	8.35	521.3	23.17	
		8.26	583	25.91	24.07
		8.33	520.4	23.13	
3	0	8.13	543.6	24.16	
		8.14	536.9	23.86	24.28
		8.21	558.5	24.82	
	1	8.38	785.7	34.92	
		8.26	776.9	34.53	35.33
		8.31	822.2	36.54	
	2	8.2	657.2	29.21	
		8.25	645.1	28.67	29.01
		8.31	655.9	29.15	
	3	8.27	641.5	28.51	
		8.2	619	27.51	28.41
		8.38	657.2	29.21	
7	0	8.22	684.5	30.42	
		8.18	709.2	31.52	30.37
		8.25	656.3	29.17	
	1	8.42	936.5	41.62	
		8.39	933.8	41.5	40.81
		8.24	884.5	39.31	
	2	8.12	725.9	32.26	
		8.17	723.8	32.17	33.44
		8.21	807.5	35.89	
	3	8.3	755.1	33.56	
		8.38	684	30.4	32.77
		8.28	772.9	34.35	
19	0	8.12	854.6	37.98	
		8.2	893.9	39.73	39.33

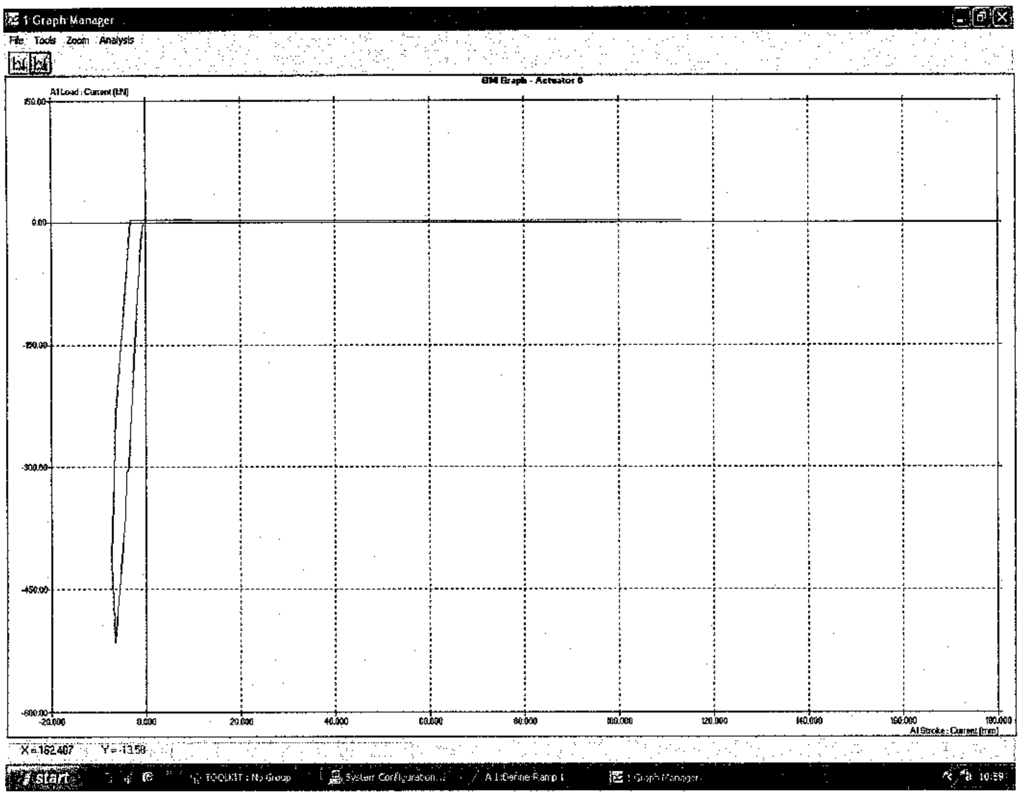
		8.14	906.3	40.28	
	1	8.32	1136.7	50.52	
		8.3	1078	47.91	49.66
		8.22	1137.4	50.55	
	2	8.26	930.6	41.36	
		8.21	973.1	43.25	41.36
		8.4	888.1	39.47	
	3	8.36	1109.9	49.33	
		8.3	1049	46.62	47.59
		8.28	1053.5	46.82	
28	0	8.31	989.8	43.99	
		8.28	922.3	40.99	42.75
		8.19	973.6	43.27	
	1	8.39	1152	51.2	
	1	8.34	1090.6	48.47	50.31
		8.37	1153.4	51.26	
	2	8.23	1009.4	44.86	
	2	8.24	1037.7	46.12	44.92
		8.22	985.1	43.78	
	3	8.34	1198.6	53.27	
	3	8.44	1142.8	50.79	53.8
		8.38	1290.2	57.34	
60	0	8.18	997	44.31	
		8.09	1023.5	45.49	44.31
		8.22	970.4	43.13	
	1	8.33	1228.5	54.6	
		8.41	1280.3	56.9	55.75
		8.32	1254.4	55.75	
	2	8.26	1063.8	47.28	
		8.28	973.1	43.25	45.34
		8.42	1023.5	45.49	
	3	8.31	1141	50.71	
		8.38	1267.7	56.34	53.42
		8.22	1197.2	53.21	



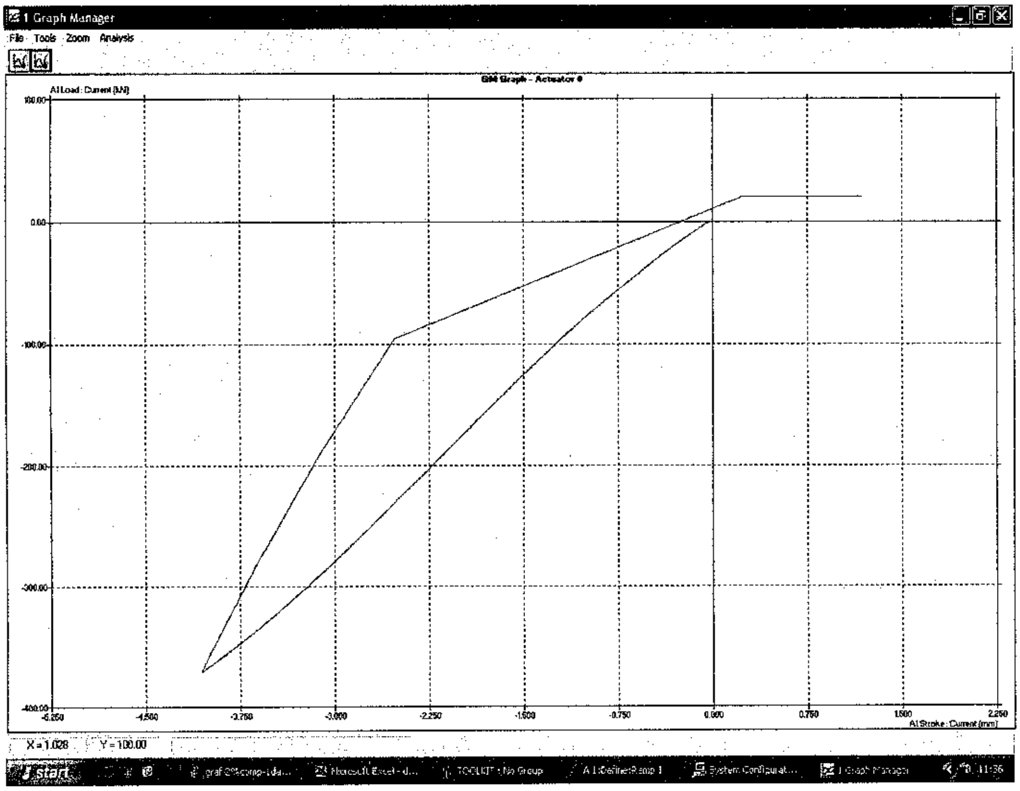
A. Compressive test with 0% PVA



B. Compressive test with 1% PVA



C. Compressive test with 2% PVA



D. Compressive test with 3% PVA

3% compression failure

PVA in concrete

Compression test