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Mechanical Properties of Engineered Cementitious Composite Mixture

By

Nadhir Abdulwahab Murshed Alyousefi

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

SEPTEMBER 2013

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CERTIFICATION OF APPROVAL

Mechanical Properties of Engineered Cementitious Composite Mixture

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NADHIR ABDULWAHAB

ABSTRACT

The concrete is the man-made material which is well-known and enormously utilized by the whole world. This matter leads to crucial problems related to its design and expectation to finally gain an economic cost of the product for both short and long duration. The concrete need to be also environmental friendly during its fabrication process. Engineered Cementitious Composite (ECC) has different abilities compare to the normal concrete. It has the passing and filling ability plus give higher strength with the addition of Polyvinyl Alcohol (PVA). The aim of the research work reported in this thesis is to develop engineered cementitious composite mixtures satisfying the self-compacting requirements and to evaluate the hardened properties of self-compacted ECC mixtures. To enhance the concrete performance, PVA is used. The PVA improved some characteristics and properties of the concrete. Ten mixes with different Polyvinyl Alcohol (PVA) fiber contents (0.0%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0%, 3.5%, 4.0%, 4.5% and 5.0%) have been prepared. Three cubes (100mm x 100mm x 100mm), three beams (100mm x 100mm x 500mm) and three cylinders (150mm diameter and 300mm height) have been cast for each mix and tested at the age of 7 and 28 days for compressive strength and at age of 28 days for splitting and flexural strength. The V-funnel, L-box and slump test also have been conducted to access the fresh properties like workability and flowability of the concrete. The results indicated the increase in the strength of the concrete and the formulas for predicting the compressive, splitting and flexural strength from PVA (%) has been developed.

ACKNOWLEDGEMENT

First and foremost, pray to Allah the Al-Mighty for His bless and love, giving me all the strength to complete the final year project. After everything had been planned, efforts were made, the project managed to be finished within the time frame. Without the help and guidance from other people, this study would not be able to complete successfully. Hence, on this page I would like to express my gratitude to those parties who had directly or indirectly involved in helping me for this project.

I would like to dedicate this project as a token of gift to my beloved parents for their support and pray.

My truly deepest appreciation goes to my supervisor, Dr. Bashar. Without his guidance and patience, I would not succeed to complete the project. His advices were of valuable and priceless.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

The most popular engineering material is concrete. It is used for buildings, industrial structures, bridges and dams. Every day the quality of concrete is improving, to achieve better characteristics, lower prices and to be environmentally acceptable. The project is about creating "Engineered Cementitious Composites" (ECC) or it is possible to call it "Self-Compacting Concrete" (SCC), and showing its qualification and worthiness to be used in the construction and manufacturing industries. ECC content defers from the content of the high performance concrete (HPC). The components for the ECC mixture are cement, fine aggregate, PVA, fly ash and super-plasticizer. They are carefully selected to achieve the optimal mixture. The significant components of the ordinary concrete which are reinforcement re-bars, and coarse aggregates, are not utilized in the project mixture. That differs the ECC from the ordinary high performance concrete Engineered Cementitious Composites (ECC) is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits, and build structures that are strong, durable, and sensitive to environment. A comparison of the physical, mechanical, and durability properties of ECC and HPC (High Performance Concrete) shows that ECC possesses better strength (both compressive and flexural) and lower permeability compared to HPC. High-Performance Concrete (HPC) is not just a simple mixture of cement, water, and aggregates. HPC has achieved the maximum compressive strength in its existing form of microstructure. However, at such a level of strength, the coarse aggregate becomes the weakest link in concrete. In order to increase the compressive strength of concrete even further, the only way is to remove the coarse aggregate. This view point has been employed in Engineered Cementitious Composites (ECC). Engineered Cementitious Composites unlike common fiber reinforced concrete, is a family of micromechanically designed material [6]. As long as a cementitious material is designed/developed based on micromechanics and fracture mechanics theory to feature large tensile ductility, it can be called an ECC. Therefore, ECC is not a fixed material design, but a broad range of topics under different stages of research, development, and implementations. The ECC material family is expanding. The development of an individual mix design of ECC requires special efforts by systematically engineering of the material at nano-, micro-, macro- and composite scales. Engineered Cementitious Composites (ECC) is an ultra-high-strength and high ductility cementitious composite with advanced mechanical and physical properties.

1.2 PROBLEM STATEMENT AND PROBLEM IDENTIFICATION

Large amount of reinforced steel re-bars usage and waste in the high performance concrete forming process. As it is well known that the pure concrete possesses a low ductility characteristic. Thus in order to obtain such kind of characteristic the reinforcement steel bars (re-bars) are mostly used in the concrete manufacturing process. Re-bars have the ductile characteristic in themselves. However the steel is considered a quite expensive material and it is well known as a heavy material, it can give an extra weight to the concrete blocks. The need to create tensile stress withstanding concrete in the concrete technology sphere in order to replace the use of the steel re-bars in the tensile areas of concrete beams and slabs.

1.3 SIGNIFICANCE OF THE PROJECT

This project work is based on the proofing that ECC can satisfy all the requirements of concrete technology industry, and ECC can reduce the percentage of using steel materials (re-bars) in concreting process. ECC is also an ultra-ductile fiber reinforced cement based composite that has metal like features when loaded is tension. The uniaxial stress-strain curve shows a yield point followed by strain-hardening up to several percent of strain, resulting in a material ductility of at least two orders of magnitude higher in comparison to normal concrete or standard fiber reinforced concrete. ECC has an unique cracking behavior. When loaded to beyond the elastic range, ECC provides crack width to below 100 μm, even when deformed to several percent tensile strain [5]. As such few investigations into the comparative static performance of ECC and HSC (High Strength Concrete) in reinforced beam and slabs elements have been undertaken.

1.4 OBJECTIVES AND SCOPE OF STUDY

1.4.1 Objectives

1- To develop ECC mixtures satisfying the self-compacting requirements.

2- To evaluate the hardened properties of self-compacted ECC mixtures.

1.4.2 Scope of Study

This project essentially focuses on the performance of PVA with the concrete. The concrete basically will be added with some cement replacement material (CRM) like fly ash. The performance of PVA into concrete is evaluated under some fresh test and hardened test of the concrete. For fresh concrete, the performance of PVA can be examined for the test for slump flow, T50, L-box and V - funnel while for the hardened concrete, the PVA performance is assessed in terms of compressive strength, splitting test as well as the flexural test. The outcome to be achieved is by finding out the optimum percentage of PVA need to be added into concrete. This correlation may help in understanding the best percentage of fibers added in concrete which is suitable to be used in construction industry.

1.5 THE RELEVANCY OF THE PROJECT

Definitely the chosen project topic is relevant to my area of study which is civil engineering area, it takes many disciplines of the industrial works, the concrete technology and manufacturing is considered as main subject in the civil engineering. Because mostly used construction material is considered cement and its product concrete. The improvement or innovations in the concrete technology and manufacturing will definitely benefit the civil engineering sphere. Since a lot of concrete is used in the construction work, it is important to find out the better improvement for the quality of the concrete for cost saving and future use. Nowadays, numerous types of high rises and mix buildings have been constructed because the land cost is expensive. In fact, high rise building is more risky and need better concrete for the durability of the building. The SCC has special characteristic which is high in ductility, thus the durability of the concrete is also high. Another important aspect is that this material will help to save the construction cost as SCC doesn't need any labor workers for compaction. Besides, it reduces noise levels at construction site, thus, environmental pollution can be prevented.

1.6 FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

The project will be done in two semesters that includes three area of study which are research, development of application and also beta-testing and improvement of the full prototype. The project will involve some experimental works in order to check the good mixture of fiber. Further testing will be carried out for the better outcome. Based on the description above, it is very clear that this project will be feasible to be carried out within the time frame.

CHAPTER 2
LITERATURE REVIEW

ECC is a self-compacting concrete from the report Self-Consolidating Concrete by Frances Yang, SCC itself is standing for Self-Consolidating Concrete, or Self-Compacting Concrete and sometimes is called as High-Workability Concrete, Self-Leveling Concrete, or Flowing Concrete. Those terms above are used to specify this highly workable concrete only requires little to no vibration for compaction. It is an innovative concrete that can be compacted into every corner of the formwork by means of its self-weight only does not requires vibration for placing and compaction. It is in want of a standard definition, but may be nominally considered a concrete mix of exceptional deformability during casting, which still meets resistance to segregation and bleeding. The normal consolidated concrete which experience inadequate vibration in heavily congested areas basically will lead to surface shrinkage and inadequate bond with the rebar. SCC has low and can be used to make "super-flat" floors without post-pour leveling [1].

It had becoming a major issue regarding to the problem of the durability of concrete structures in Japan early 1983 as the skilled worker started to decrease gradually in the industry. In order to create the durable concrete structure, sufficient amount of labor were required for compaction activity. The only solution to achieve high durable concrete structures was not rely to the quality of construction but to have self-compacting concrete, which can be compacted into every side of a formwork, merely by means of its own weight and vibrating compaction automatically by itself. The SCC idea was proposed into scientific world in Japan in 1986 by Professor Hajime Okamura from Tokyo University. K. Ozawa developed the first prototype in 1988 as a response to the growing problems associated with concrete durability and the high demand for skilled workers. SCC becomes well known throughout the world and it has been the subject of multitudinous investigations so that it can be adapted into the production of modern concrete [2]. Meanwhile, the numerous productions of additives have been developed as well as sophisticated plasticizers and stabilizers tailor-made for the precast. In comparison with other high-performance concretes, these concretes have their own special characteristics and differ from other normal concretes and can be only by systematic optimization both of the individual constituents and of the composition.

In terms of material constituents, ECC utilizes similar materials as fiber reinforced concrete (FRC). It made from water, cement, fine aggregate, fiber, and some common chemical additives. Coarse aggregates are not used because they tend to negatively affect the unique ductile behavior of the composite. A typical composition use w/c ratio and fine aggregate/cement ratio of 0.5 or less. Unlike some high performance FRC, ECC does not utilize large amounts of fiber. In general 2% or lower by volume of discontinuous fiber is suitable, even though the composite is designed for structural applications. Due to the relatively small amount of fibers, and its chopped (divided) nature, the mixing process of ECC is similar to those used in mixing normal concrete. Also by deliberately limiting the amount of fibers, a number of proprietary studies have concluded economic feasibility of ECC in specific structural applications. Various type of fiber can be used in ECC, but the detail composition must follow certain rules imposed by micromechanics considerations [4]. This means that the fiber, cementitious matrix, and the interface (mechanical and geometric) properties must be correctly combination in order to attain the unique behavior of ECCs. Thus ECC designs are guided by micromechanical principles. Most data so far has been recorded on PVA-ECC (reinforced with Polyvinyl Alcohol fibers) and PE-ECC (reinforced with high modulus polyethylene fibers). The most fundamental mechanical property difference between ECC and FRC is that ECC strain-hardens rather than tension-softens after first cracking. Fiber reinforced high strength concrete (FRC), the first crack keep to open up as fibers are pulled out or ruptured and the stress-carrying capacity decreases. This post-peak tension softening deformation is typically represented by a softening stress-crack opening relationship. In ECC, first cracking is followed by a rising stress accompanied by increasing strain. This strain-hardening response gives way to the common FRC tension softening response only after several percent of straining has been attained, thus achieving a stress-strain curve with shape similar to that of a ductile metal. Closely associated with the strain-hardening behavior are the high fracture toughness of ECC, reaching around 30 kJ/m_2, similar to those of aluminum alloys [3].In addition, the material is extremely damage tolerant [7], and remains ductile even in severe shear loading conditions [9]. To show the ductility of ECC, Figure 2.1 shows the deformed shape of an ECC plate subjected to flexural load.

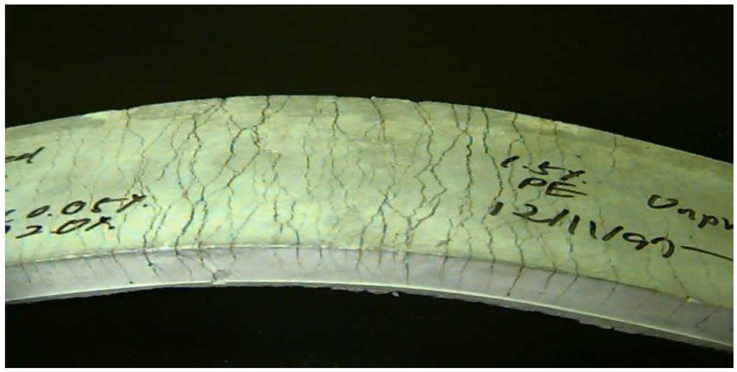

Figure 2.1: Flexural Behaviour of a PVA-ECC [7]

2.1 DUCTILITY OF CONCRETE

Ductility is the strain ability of the materials can take before rupturing. It is the ability of a section to deform beyond its yield point without a significant strength loss. A material with high ductility will be able to be drawn into long, thin wires without breaking. A material with low ductility is instead brittle, and though it may be strong, once it deforms enough, it will simply rupture. Ductility can be expressed in terms of displacement, rotation, or curvature ratios [11].

2.1.1 Factor Affecting Ductility

1. The higher tension steel area causes a less ductile behaviour for the section [12].
2. Increase in the steel yield strength also causes a less ductile behaviour for the section [12].
3. The compression reinforcement carries part of the compression force that would be carried by the concrete in a singly reinforced beam, the required depth of the neutral axis is decreased and the section reaches a much higher curvature (higher ductility) before the concrete reaches its maximum useable strain [20]. The ductility of

comparison between the ductile concrete and ordinary concrete shown in the Table 2.1.

Table 2.1: Ductile Concrete Comparison [4]

Properties/ Material present	**Ductile Concrete**	**Ordinary Concrete**
Cement	Yes	Yes
Fine aggregate	Yes	Yes
Coarse aggregate	May/May not be	Yes
Water/cement ratio	Low	Relatively high
Fibers	Yes	No
Superplastocizer	Yes	May/May not be
Mineral Admixture	Yes	May/May not be
Compressive Strength	High	Normal
Tensile Strength	High	Low

2.2 DEVELOPMENT OF ECC

It had becoming a major issue regarding to the problem of the durability of concrete structures in Japan early 1983 as the skilled worker started to decrease gradually in the industry. In order to create the durable concrete structure, sufficient amount of labour were required for compaction activity. The only solution to achieve high durable concrete structures was not rely to the quality of construction but to have self-compacting concrete, which can be compacted into every side of a formwork, merely by means of its own weight and vibrating compaction automatically by itself [1]

The ECC idea was proposed into scientific world in Japan in 1986 by Professor Hajime Okamura from Tokyo University [2]. K. Ozawa developed the first prototype in 1988 as a response to the growing problems associated with concrete durability and the high demand for skilled workers [1] [2]. ECC become well known throughout the world and it has been the subject of multitudinous investigations so that it can be adapted into the production of modern concrete. Meanwhile, the numerous production of additives have been developed as well as sophisticated plasticizers and stabilizers tailor-made for the precast. In comparison with other high-performance concretes, these concretes have their own special characteristics and differ from other normal concretes and can be only by systematic optimization both of the individual constituents and of the composition [2].

2.3 MECHANISM FOR ACHIEVING ECC

In the making of ECC, it involves considering with a lot of factors that affect deformability and segregation. These factors include water to cement ratio and the several properties of the aggregate: volume, size, distribution, and spacing, void content, ratio between fine aggregate, surface properties, and density. The chemical admixtures like HRWRA, VMA and SCM are other factor need to be highlighted [21], [24]. For overall, Okamura and Ozawa have proposed those formula to achieve ECC [2]:

a) Limited aggregate content
b) Low water-powder ration
c) Use of super plasticizer

In order to make sure the satisfactory achievement of ECC during its wet phase and for its successful categorization, there are three key aspects of workability which need to be carefully controlled [26]:

1. Filling ability which mean the ability of the concrete to flow, maintaining homogeneity while undergoing the deformation necessary to fill the formwork completely, encasing the reinforcement and achieving consolidation through its own weight without vibration.
2. Resistance to segregation which mean the ability of the particle suspension to maintain a cohesive state throughout the mixing, transportation and casting processes.

Passing facility which mean the ability to pass through closely spaced reinforcement or enter narrow sections in formwork, and to flow around other obstacles without blocking.

2.4 ADVANTAGE OF ECC

ECC has many advantages such as the followings:

1. From the contractors point of view, ECC has the ability to fill complex forms with limited accessibility, rapid pumping of concrete and improve aesthetics of flatwork for less effort, thus improving the efficiency of the building site as well as shorten the construction period. Besides, the labor operations' cost can be saved [1],[2],[5]
2. There are no poker vibration which gives huge advantages for them to have good quality working environment [2]
3. As there is no vibration omitted from casting operations, the workers experience a less strenuous work because noise and vibration exposure are eliminated especially at concrete products plan [1][2]
4. ECC is believed to increase the durability relatively to vibrated concrete (this is due to the lack of damage to the internal structure, which is normally associated with vibration)

2.5 FIBERS

Low tensile strength of concrete is due to the propagation of single internal crack. If the crack restrained locally by extending into other matrix adjacent to it, the initiation of crack is retarded and higher tensile strength of concrete is achieved [32]. This restrained can be achieved by adding small length fibres to concrete. In addition to increase the tensile strength, addition of fibres enhance fatigue resistance [33], energy absorption, toughness, ductility and durability [34].

Behaviour under flexural and direct tension depends upon the fibre type and fibre contents in concrete. The fibre classification is shown in the Figure 2.2.

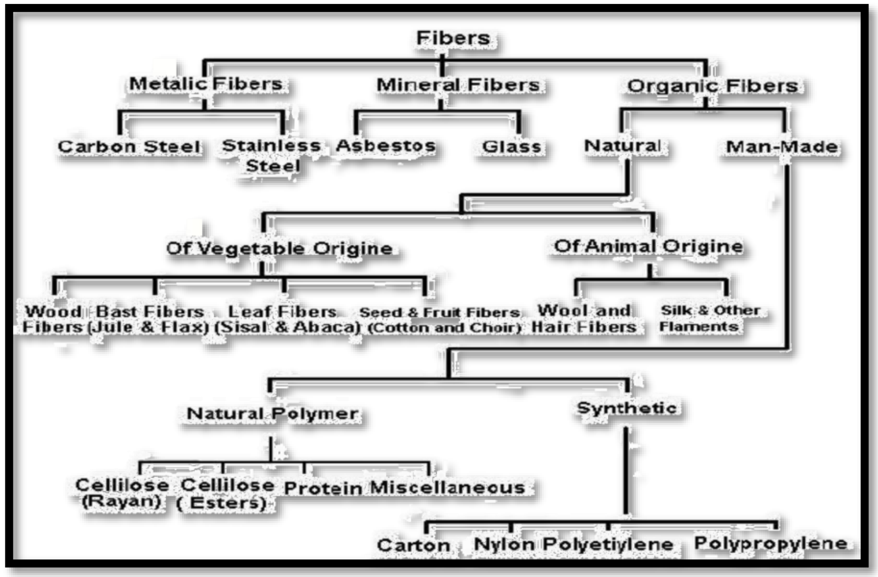

Figure 2.2: Fibre Classifications [25].

2.5.1 Properties of Fiber

1. Fibres are primarily used for their ability to provide post-cracking resistance to the concrete [26].
2. The addition of fibres to concrete in low-to-moderate dosages (1.5% by volume) does not greatly affect compression strength and elastic modulus. Improvements in post-peak behavior, however, have been observed, characterized by an increased compression strain capacity and toughness [26].
3. In tension, the ability of fibres to enhance concrete post-cracking behavior primarily depends on fiber strength, fiber stiffness, and bond with the surrounding concrete matrix [26].
4. Fibres are designed to pullout through the concrete matrix. Thus, the behavior of ductile concrete is highly dependent on the ability of the fibres to maintain good bond with the concrete as they are pulled out [26].
5. PVA fibres of about 5% in volume, increase the cracking resistance, splitting tensile strength and direct tensile strength up to 2.5 times the strength of unreinforced concrete and 10 to 15 times increase the ductility of the member [27].

2.6 FIBRE REINFORCEMENT ECC

For some researches done, fibers are mixed together with concrete to enhance its tension and compression performance, as well as perseverance and durability of the concrete. Furthermore, fiber reinforced concrete (FRC) has also been proclaimed to give contribution in increased shear and bending resistance in structural members, and to lead to improvement in the bond of reinforcing bars under monotonic and cyclic loading. These advantages enticed researchers to consider and evaluate fiber reinforced concrete for seismic applications as early as in the 1970's. High-performance fiber reinforced cement composites are a class of fiber reinforced concrete characterized by a tensile stress-strain response that exhibits strain-hardening behavior in tension accompanied by multiple cracking up to relatively high composite strains.

One the other hand, when conventional FRC is subjected to direct tension, it essentially exhibits a linear behavior until the first cracking stress, u_{cc}, is reached.

2.7 PREVIOUS RESEARCH

Though adding fibers will extend the range of applications of ECC, a reduction in workability due to fiber addition may become a handicap in practice. Besides the fibers, there are also many parameters which affect the flowability of fresh ECC [31]. Indeed, the type, diameter, aspect ratio, and volume fraction of fibers come in addition to the maximum aggregate size, coarse aggregate content, fine aggregate content to play an important role in flowability of ECC with fibers.[26],[31].The mix proportions of the exemplary PVA-ECC (referred as M45) are given in Table 2.2 the volume fraction of fiber is 2%. ASTM Type I Portland cement and low calcium ASTM class F fly ash were used. Large aggregates were excluded in ECC mix design, and only fine sand was incorporated. The silica sand used here had a maximum grain size of 250 µm and an average size of 110 µm. The PVA fiber had a diameter of 39 µm, a length of 12 mm, and overall Young's modulus of 25.8 MPa. The apparent fiber strength when embedded in cementitious matrix was 900MPa. The fiber surface was treated with oil coating to reduce interface bond and the oiling content is 1.2%.

Table 2.2: Mix proportions of PVA-ECC (kg/m3) [8]

Cement	Sand	Class F Fly ash	Water	Superplasticizer	PVA Fiber
583	467	700	298	19	26

2.7 CHEMICAL ADMIXTURES

2.7.1 Superplasticizer

Superplasticizer causes a significant increase in flowability with little effect on viscosity as it is showing in the Figure2.3 below. This can be explained through the experiment where the addition of 0.3 to 1.5 percent (by weight of cement) conventional superplasticizer to a concrete mix with 50-70 mm slump increases slump to 200-250 mm [21]. This means, it exhibited enormous increases in slumps at the recommended dosage [22].

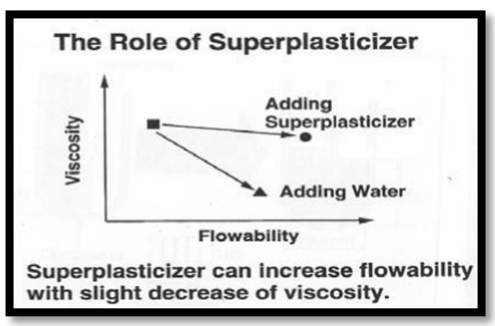

Figure 2.3: Effects of superplasticizer (Okamura) [21]

The new generation of superplasticizers is based on polycarboxylated ethers, which act as powerful cement dispersants that require less mix water to provide dramatic increase in flow [21]. At the recommended dosage rates the compressive strengths of test cylinders cast from superplasticized concretes were equal to or greater than the strengths of cylinders cast from the control mix even though no at-tempt was made in these tests to reduce the water-cement ratio. This was true for cylinders compacted by vibration as well as those not compacted by vibration [22].

The requirements for superplasticizer in ECC are summarized below:

3. High dispersing effect for low water/powder (cement) ratio: less than approx. 100% by volume
4. Maintenance of the dispersing effect for at least two hours after mixing
5. Less sensitivity to temperature changes.

2.8 CEMENT REPLACEMENT MATERIALS

Since the discovery of concrete, it keeps evolving from a simple mixture to an advanced concrete technology. Originally, the concrete mixing comprise cement, sand, aggregates and water but nowadays the concrete integrates with chemical admixtures, cement replacement materials and others.

Cement replacement materials also called as supplementary cementitious materials. They are special types of naturally occurring materials or industrial waste products that can be used in concrete mixes to partially replace some of the portland cement. The cement replacement materials can be added in percentage which the amount is depending on the type of CRM used as they have their own desired properties and effect on concrete. It is a material that, when used in conjunction with Portland cement, contributes to the properties of the concrete through hydraulic or pozzolanic activity, or both. Surprisingly, concrete with cement replacement materials can actually give higher in term of strength and also high in durability compare to the concrete which ordinary Portland cement [18].

2.8.1 Fly Ash

Fly ash is a finely divided residue (powder resembling cement) that results from the combustion of pulverized coal in electric power generating plants. During combustion, the coal's mineral impurities (such as clay, feldspar, quartz, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. In the process, the fused material cools and solidifies into spherical glassy particles called fly ash. It is a waste by-product material that must be disposed of or recycled. The physical and chemical properties of fly ash given below in the Table 2.3 and Table 2.4 respectively.

Table 2.3: Physical properties of Fly Ash

Selected Properties of Typical Fly Ash		
	Class F fly ash	Class C fly ash
Loss on ignition, %	2.8	0.5
Blaine fineness, m^2/kg	420	420
Relative density	2.38	2.65

Table 2.4: Chemical Properties of Fly Ahs

Chemical Analysis of Typical Fly Ash,		
	Class F fly ash	Class C fly ash
SiO_2, %	52	35
Al_2O_3, %	23	18
Fe_2O_3, %	11	6
CaO, %	5	21
SO_3, %	0.8	4.1

CHAPTER 3
METHODOLOGY

3.1 RESEARCH METHODOLOGY

This project will be conducted according to this methodology to meet the objectives. In order to find the performance of PVA self-compacting concrete, detailed review as well as brief research about the topic is focused on the selected papers which concentrate on the design mixture itself. The issues relevancy between the selected papers and our project's objective need to be taken into account to ensure the credibility of this project.

For the other sub objective which is to outline the study of mixture and strength of concrete, literature reviews as well as brief research about the topic are carried out on several resources such as books, journals and also internet. The Figure 3.1 show the project flow for this research which will be starting from selection the materials and ending with the final report.

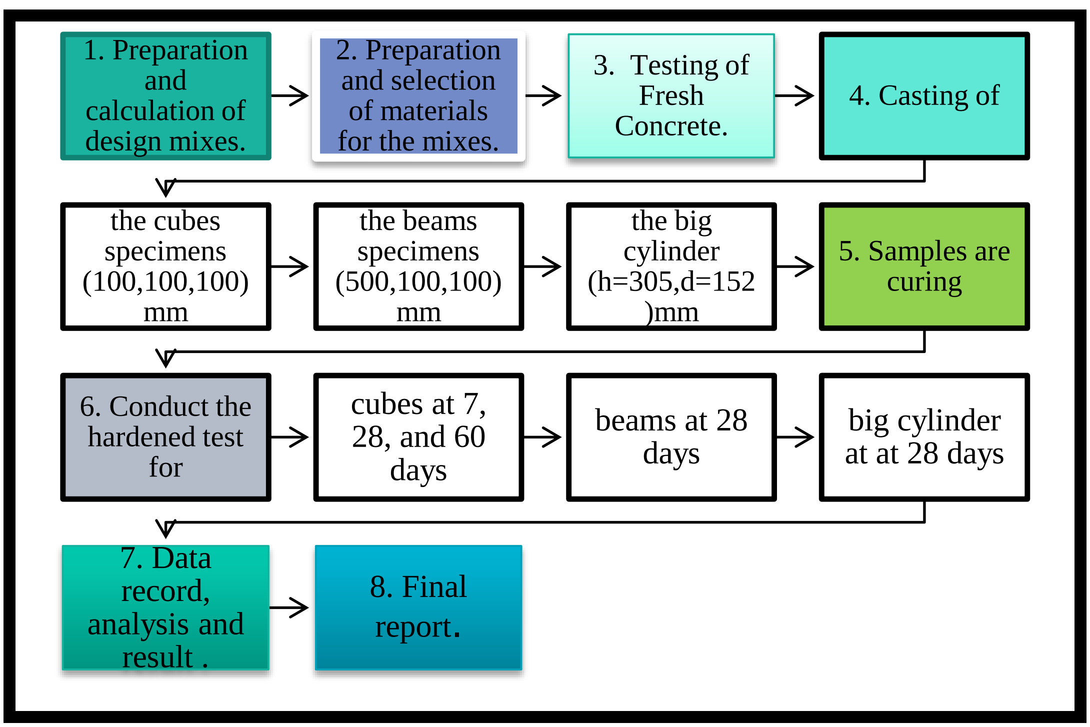

Figure 3.1: Project flow

3.3 FLOW CHART FOR THE EXPERIMENT

Mix design often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles. The mix composition is chosen to satisfy all performance criteria for the concrete in both the fresh and hardened states. Curing is important for all concrete but especially so for the top-surface of elements made with ECC. These can dry quickly because of the increased quantity of paste, the low water/fines ratio and the lack of bleed water at the surface. Initial curing should therefore commence as soon as practicable after placing and finishing in order to minimize the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation. The flow chart for this research is shown in the Figure 3.2 below.

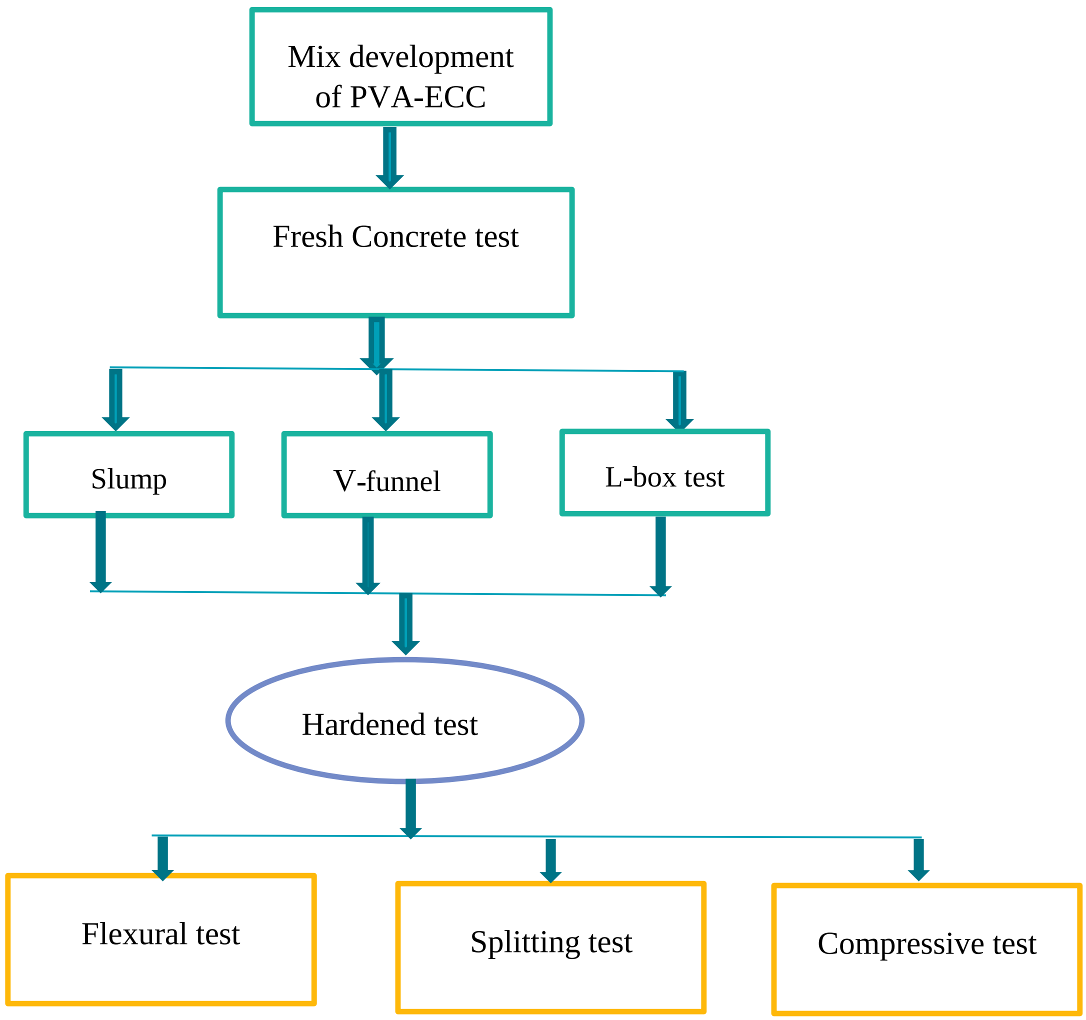

Figure 3.2: Flow Chart

3.4 MIX DESIGN

The objective was to find the optimum percentage of PVA fibers added into the concrete that shall produce very workable and at the same time very durable concrete. Accordingly, there are ten mixes using different of PVA fibers plus cement replacement materials (CRM) fly ash used were performed. The proportions of concrete mixtures are summarized in Table 3.1 below. The mix content for this project are water, cement, super-plasticizer, fly ash, sand and PVA.

Table 3.1: Mix Design

MIX.NO.	Sand (Kg/m3)	Cement (Kg/m3)	W/C	Water (Kg/m3)	Fly Ash (Kg/m3)	SP(Kg/m3)	PVA (%)	PVA (Kg/m3)
M1	467	583	0.32	187	700	4.5	0	0
M2	467	583	0.32	187	700	4.5	1	13
M3	467	583	0.32	187	700	4.5	1.5	19
M4	467	583	0.32	187	700	9.5	2	26
M5	467	583	0.32	187	700	9.5	2.5	32
M6	467	583	0.32	187	700	9.5	3	38
M7	467	583	0.32	187	700	9.5	3.5	45
M8	467	583	0.32	187	700	9.5	4	51
M9	467	583	0.32	187	700	9.5	4.5	58
M10	467	583	0.32	187	700	9.5	5	64

3.4.1 Mix Group 1 (6 cubes 3 beams and 3 cylinder)

A total of three samples of 150 mm diameter and 300 mm height cylinders, three samples of 100mm x 100mm x 500mm beams and six samples of 100mm x 100mm x 100mm cubes were cast for each mix. Removal of each cast sample from the moulds was done after 24 hours and the samples were then placed in curing tank at 20^0C. Curing was continued until the testing date which was at the age of 28 days. On the test date, the samples were removed from the curing tank, their surfaces are dried before testing. By calculating the volume for each moulds and also the number of moulds to be used in the experiment the amount of materials have been calculated in (kg) shown in the Table 3.2.

Table 3.2: Mix group 1

MIX.NO.	Sand (Kg)	Cement (Kg)	W/C	Water (Kg)	Fly Ash (Kg)	SP(Kg)	PVA (%)	PVA (Kg)
M1	18.91	23.61	0.32	7.57	28.35	0.385	0	0.00
M2	18.91	23.61	0.32	7.57	28.35	0.385	1	0.53
M3	18.91	23.61	0.32	7.57	28.35	0.385	1.5	0.77
M4	18.91	23.61	0.32	7.57	28.35	0.385	2	1.05
M5	18.91	23.61	0.32	7.57	28.35	0.385	2.5	1.30
M6	18.91	23.61	0.32	7.57	28.35	0.385	3	1.54
M7	18.91	23.61	0.32	7.57	28.35	0.385	3.5	1.82
M8	18.91	23.61	0.32	7.57	28.35	0.385	4	2.07
M9	18.91	23.61	0.32	7.57	28.35	0.385	4.5	2.35
M10	18.91	23.61	0.32	7.57	28.35	0.385	5	2.59

ECC mix design varies from the conventional concrete in many ways. The first is that it has high volume of paste, which means that the cement and water in the ECC mix design is higher than conventional concrete. However, the paste ratio should not be too excessive to avoid heat of hydration. This is where the cement replacement materials are recommended to lower the heat of hydration.

Next, ECC mix design needs high volume of fine particles (< 80 micrometer) to ensure good workability and reduce risk of segregation or bleeding. Optimum dosage of superplastiser which in this experiment is about two percent from the weight of total mix is essential to obtain good fluidity. However, a dosage near saturation amount can lead to concrete segregation. To enhance the flowability, ECC requires no volume of coarse aggregate as this there will not be problem with coarse aggregate being stuck at reinforcement bars. The mix proportions of water cement ratio (W/C) are same for all of the mixes since there is no change in cement replacement material which will not affect the workability. The superplasticzer was incorporated in all mixes.

3.5 MATERIALS

3.5.1 Polyvinyl Alcohol Fiber (PVA)

Polyvinyl alcohol fiber is considered as one of the most suitable polymeric fibers. PVA fiber has suitable characteristics as reinforcing materials for cementitious composites. The PVA Fibre also available in UTP Concrete Laboratory. The portion of PVA fibre varies in each sample. It starts with 2% and lastly 3%. The percentage of PVA fibre is calculated by cement weight. There are three sizes available in the UTP Concrete Laboratory which is 8mm, 12mm and 20mm. In this project, the 12mm sizes will be used the Figure 3.3 show the type of PVA used in this research.

Figure 3.3: Polyvinyl Alcohol Fiber

3.5.2 Fly Ash

Fly ash is a finely divided residue (a powder resembling cement) that results from the combustion of pulverized coal in electric power generating plants. During combustion, the coal's mineral impurities (such as clay, feldspar, quartz, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. In the process, the fused material cools and solidifies into spherical glassy particles called fly ash. It is a waste by-product material that must be disposed of or recycled. The fly ash can be obtained from the UTP Concrete Laboratory. The properties of fly ash obtained from UTP lab as shown below. The comparison properties between OPC and Fly ash is shown in the Table 3.3 below.

Table 3.3: Chemical properties of OPC and fly ash

Chemical composition	Portland cement	Fly ash
Silica	21.95%	2.30
Alumina	5.1%	3.7
Lime	63.8%	0.5%
Iron	2.4%	0.2%
Sulphur	2.4%	0.7%
Magnesia	2.7%	9.2%
Alkalines	0.5%	trace
LOI	.2	22.3%
Specific Gravity	3.15	52.8%

3.5.3 Fine Aggregate

Local river sand was used as the fine aggregate in the concrete mixture. The preparation of sand one day before mixing needed to be done to make sure the aggregate is dry. The sands are sieved to obtain the specified size of 3.0. The sieve analysis was carried out in the accordance with requirement of ASTM C136 [18].the result shown in Figure 3.4 below.

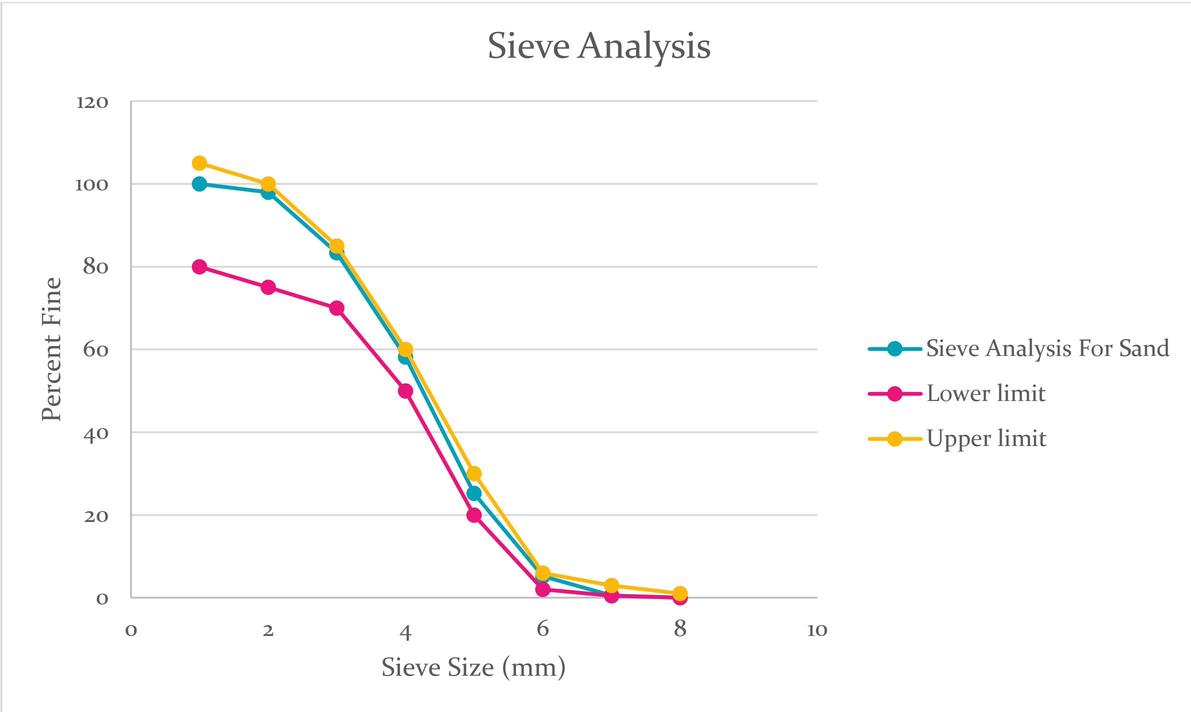

Figure 3.4: Sieve Analysis

3.5.4 Water

The water ratio for this project is 0.32. The purpose of having the low water/cement ratio is to prevent decreasing in concrete strength. The amount of water is measure in liter for all the mixes the water is provided by UTP lab including the equipment to measure the water.

3.5.5 Superplasticizer

In this study, the type of super plasticizer used is Sica VicoConcrete - 25MP provided by Sica Kimia. Sica VicaConcrete - 25MP is a third generation super plasticizer for concrete and mortar. It meets the requirement for high range water reducing super plasticizer according to EN 934 - 2.

3.5.6 Cement

ASTM, Type I, ordinary Portland cement (OPC) was used in this project. It was supplied by Tasek Corporation Berhad.

3.6 MIXING AND CASTING

The concrete mixes were prepared using a pan mixer shown in Figure 3.5 below. The interior of the drum was initially washed with water to prevent absorption. The mixing time is referred from the previous researcher named Modhere, 2009.

Procedure for concrete mixing:

1. The fine aggregate were mixed first and wait for one minute.
2. The mix followed by the cement and the cement replacement materials and wait for one minute and half.
3. Then, half the water will be added on the mix for one minute and a half. The rest of the water will be added together with the super plasticizer.
4. The mix was left for six minutes to let the water to be absorbed by the fly ash and aggregates.
5. In the middle of the six minutes, the PVA are added.

Note that, PVA must be uniformly distributed and randomly oriented throughout concrete to improve its structural and microstructure properties. Proper mixing method is vital to ensure the homogeneity of the fiber distribution.

Figure 3.5: Pan Mixer

After the mixing was completed, tests were conducted on fresh concrete to determine the rheological properties. The tests conducted were slump flow test, slump T50, L-box and V-funnel test. Segregation and bleeding was visually inspected during the slump flow test. Three mould of 100-mm cubic specimens, three mould of 100mm x 100mm x 500mm beams and three 152mm diameter x 305mm height of columns were prepared for each mix proportion. No compaction was applied in any of the mixtures. After 1-day, the specimens were demoulded, and stored in curing tank shown in Figure 3.6 below.

Figure 3.6: Curing tank

3.7 FRESH CONCRETE TEST

For determining the self-compatibility properties slump flow, slump T50, L-box and V-funnel tests were performed and measured. Slump flow test is tested by the flow diameter of the concrete, while slump T50 is tested by testing the flow of concrete by 500mm in second (time) and last but not least is the V - Funnel test which is tested by testing the flow of the concrete in second (time). All fresh test measurements were duplicated and average of measurement was given. In order to reduce the effect of workability loss on variability of test results, the fresh-state properties of mixtures were determined right after mixing.

All the tests for fresh concrete tests are in accordance with The European Guidelines for Self Compacting Concrete (2005), which reference standards is European Standard.

3.7.1 Slump Flow Test

Slump flow test is proposed for testing filing ability (flowability) and deformability. Slump flow test judges the capability of concrete to deform under its own weight against the friction of the surface with no external restraint present. No compaction energy must be applied during the test so that the SCC flows only under the influence of gravity. It is based on the slump test described in EN 12350-2. The result is an indication of the filling ability of self-compacting concrete.

Apparatus:

1. Abram's cone - standard Abram's con as defined in ASTM C143/C143M shown in Figure 3.7.
2. Slump flow board - a non-absorbent rigid plate. A circle 500mm in diameter should be marked at the center in order to measure the T_{50} value as shown in the Figure 3.8.

The procedure for slump flow test:

In general, the slump flow test for self-compacting concrete is about the same as the conventional concrete.

1. Prepare the slump flow board and the Abram's cone

2. The Abram's cone is placed at the center of the board either at normal orientation or inverted.
3. Pour the fresh concrete into a Abram's cone.
4. Then withdraw the cone vertically upwards in one movement, without interfering with the flow of concrete.
5. Without disturbing the base plate or the concrete, the largest diameter of the flow spread of the concrete to the nearest 10mm.
6. Then the diameter of the flow spread at right angles to it is measured, and the mean of the reading is the slump flow.

The concrete spread is also checked for segregation. If segregation is observed, then the test is considered unsatisfactory.

Figure 3.7: Abram's cone

Figure 3.8: Slump flow T500mm in diameter

3.7.2 V-Funnel

V-funnel test is proposed for testing viscosity and deformability of concrete. The viscosity of a suspension is dependent mainly on the water/solids ratio and the overall grading curve. This means that a SCC with higher water content flows faster out of the funnel and has a lower viscosity than SCC with lower water content. It is based on the V-funnel test described in EN 12350-2.

Apparatus:

1. V shaped funnel shown in Figure 3.9. The dimension of V-Funnel shown in Figure 3.10.
2. Stopwatch to measure the time for the concrete to pass through small opening.

Procedure:

1. The test is carried out by filling a V shaped funnel with fresh concrete
2. The time taken for the concrete to flow out of the funnel is measured
3. The time is recorded as the V-funnel flow time.

Figure 3.9: V-shaped funnel

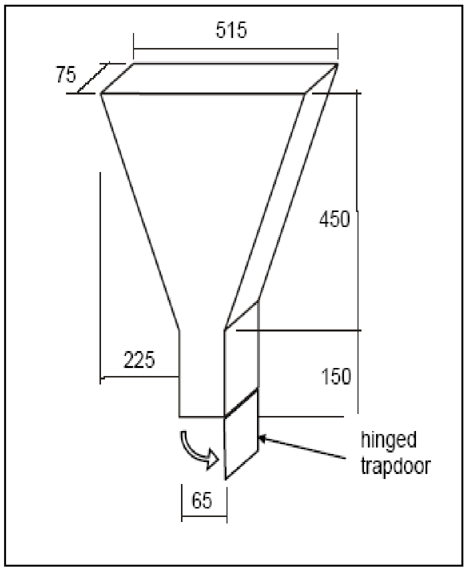

Figure 3.10: V-funnel dimension

3.7.3 L-Box

L-box test is proposed for testing passing ability of the ECC as shown in the Figure 3.11 .L-box test judges the capability of concrete to pass through congested reinforcement in the construction of beams or slabs. It is based on the L-box described in EN 12350-2.

Procedure

1. About 14 litre of concrete is needed to perform the test, sampled normally.

2. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.

3. Moisten the inside surfaces of the apparatus, remove any surplus water

4. Fill the vertical section of the apparatus with the concrete sample.

5. Leave it to stand for 1 minute.

6. Lift the sliding gate and allow the concrete to flow out into the horizontal section.

7. Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks.

8. When the concrete stops flowing, the distances “H1” and “H2” are measured.

9. Calculate H2/H1, **the blocking ratio.**

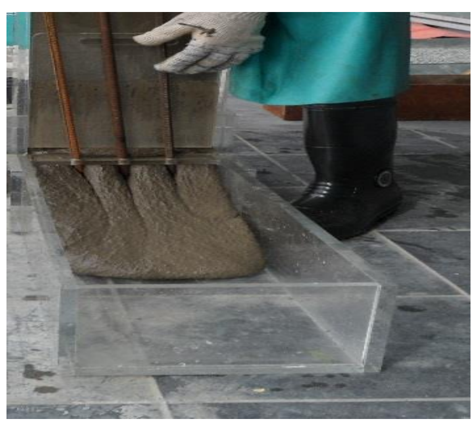

Figure 3.11: L-box shape

3.8 HARDENED CONCRETE TEST

3.8.1 Compressive Strength Test:

To determine the compressing strength of the concrete based on the BS 1881: Part 116: 1983. In BS 5328, the compressive strength is expressed as ‘grade’, which is the minimum characteristic cube strength. The industry still uses the old standard when dealing with concrete types. In the new BS EN 206-1 and BS8500, the characteristic compressive strength is expressed as a strength class.

Apparatus: Compression Testing Machine shown in Figure 3.12 (it complies with the requirement of BS 1610)

Procedure for compressive strength test:

1. Remove the specimen from the curing tank and wipe the surface water and grit off the specimen.
2. Put the specimen under the sunlight to let them dry (the moisture on the specimen can affect the result of the test)
3. Weight each of the specimen to the nearest kg.
4. Clean the top and lower platens of the testing machine. Carefully center the cube on the lower platen and ensure that the load will be applied to two opposite cast faces of the concrete.
5. Check the reading at the monitor. Change it to suitable type of test (for this test is compressive test) and suitable specimen (cube 100mm x 100mm x 100mm)
6. The load is applied and increased continuously at nominal rate within the range 0.2 N/mm^2 to 0.4 N/mm^2 until no greater load can be sustained. The maximum load applied to the cube is recorded.
7. The type of failure and appearance of cracks is noted.
8. The compressive strength of each cube is calculated by dividing the maximum load by the cross sectional area.

Figure 3.12: Compression machine (ADR 1500)

3.8.2 Splitting and Flexural Strength Test:

The tensile strength is the test on the column with size of 152 diameter x 305mm height while flexural test is the test on the beam with the size of 100mm x 100mm x 500mm. Both procedure is about the same as compressive strength. The different is, we need to change the mode at the monitor of the type of test and the size of sample. Apparatus: Splitting and Flexural testing Machine shown in Figure 3.13 and Figure 3.14 respectively (it complies with the requirement of BS 1610).

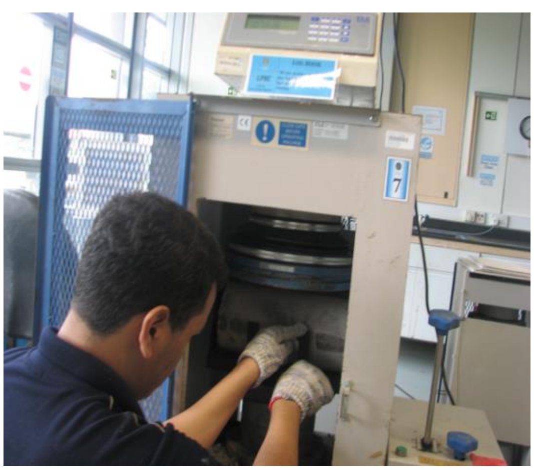

Figure 3.13: Splitting test

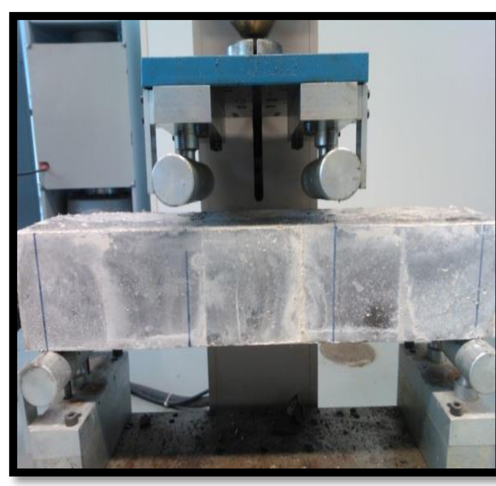

Figure 3.14: Flexural test

CHAPTER 4

RESULT & DISCUSSION

In this study, there are ten mixes all together. Fly ash represent the type of cement replacement materials added into the concrete in all mixes. Each mix represent a different percentage of the PVA added in the mixture as shown in the Table 4.1. The Figure 4.1 show that the ECC can consider as self-compacting.

Table 4.1: Total number of mixes

Mix NO	PVA (%)	Mix NO	PVA (%)
M1	0.0	M6	3.0
M2	1.0	M7	3.5
M3	1.5	M8	4.0
M4	2.0	M9	4.5
M5	2.5	M10	5.0

Figure 4.1: Self-compacting ECC

4.1 FRESH CONCRETE RESULT TEST

The fresh properties of PVA fiber-reinforced ECC are shown in Table 4.2. All the mixes satisfied the requirements for SCC established by EFNARC [6]. Slump flow fall within 650 mm and 800 mm except for mixes M_1 (830 mm) which exceeds the maximum requirement for SCC. The values of T_{50} obtained are all in the range of 2 – 5 seconds required for SCC. V-funnel flow times obtained were between 6 and 12 seconds and (h_2/h_1) for L-box were within the established range of 0.8 – 1.0. Visual Stability Index of zero (VSI = 0) has been assigned for all mixes based on ASTM C 1611 Ratings.

Table 4.2: Fresh concrete result

Mix NO	MIXING	Slump flow (mm)	SlumpT50 (sec)	V-funnel (sec)	L-box H2/H1(mm)
1	M_1-00	830	2	6	0.98
2	M_2-1% PVA	829	2	6	0.97
3	M_3-1.5% PVA	828	3	7	0.95
4	M_4-2% PVA	825	3	7	0.93
5	M_5-2.5% PVA	789	3	8	0.92
6	M_1-3%	785	4	11	0.92
7	M_2-3.5% PVA	812	5	12	0.92
8	M_3-4% PVA	740	5	12	0.91
9	M_4-4.5% PVA	673	5	11	0.87
10	M_5-5% PVA	670	6	12	0.82

For the slump flow test, the highest result showing the good sample which mean that particular sample has high flowability which in term of fresh concrete it is good. For the mix M1, it showed that the sample with no additional PVA give the highest results which is 830mm in diameter. From the Figure 4.2 below we observed that the diameter for the slump start to decrease with increase in PVA percentage except for the mix M_7 at the percentage of 3.5% showed sudden increase in the results, the result is increasing from 785mm to 812mm and then decrease back to 740mm at the percentage of 4.0%PVA. This might be happened due to the inaccurate measurement of water content or might be a result of the increase in the amount of SP. The results then started to decrease eventually from the percentage of 4.5% to 5.0%, therefore this means that the addition of PVA in the concrete will affect the behaviour of the fresh concrete by decrease with increase the PVA percentage.

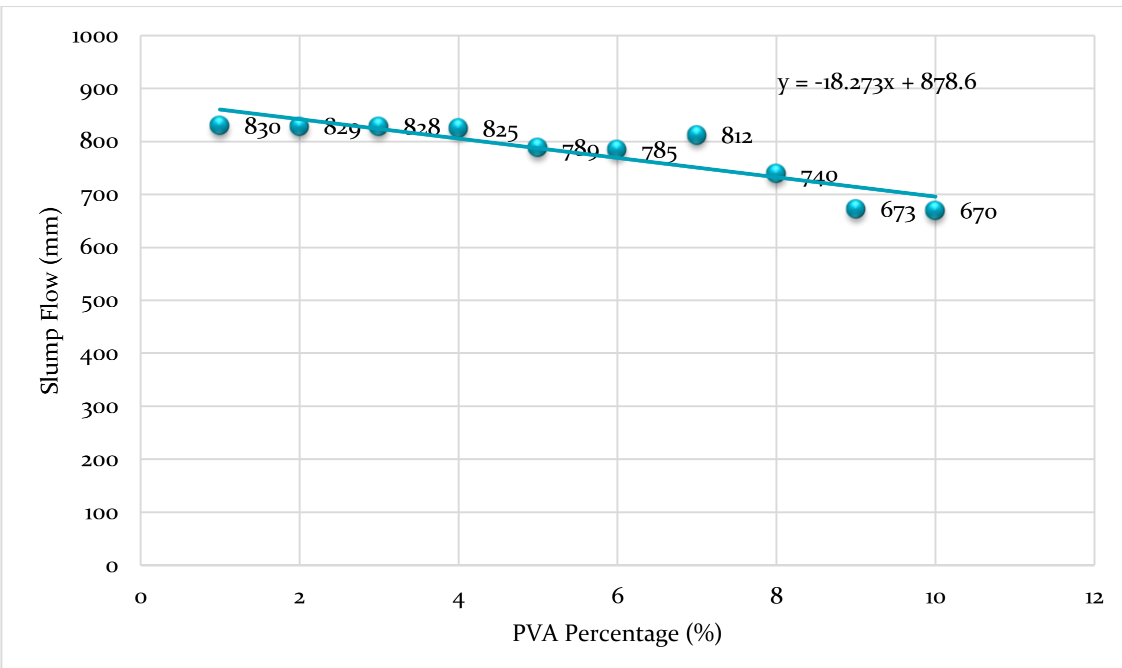

Figure 4.2: Slump flow test comparison among all the ten mixes

Slump T_{50} time is a test to assess the flowablity and the flow rate of SS in the absence of obstruction as per stated on the slump test described in EN 1235-2. It is a time to measure the fresh concrete speed flow and hence the viscosity. In order for the fresh concrete to be characterized as SCC, the slump T_{50} should passing the time range of 2 – 6 second. From the Figure 4.3 below we observed that all the mixes show a good results which is within the allowable range, on the other hand as the percentage of PVA addition increase, the value T50 start to decrease as it showed in the last mix M_{10} which give the result above 5 sec which it means that the addition of PVA in the concrete will affect the behavior of the fresh concrete. The overall results showed the majority is between the 2-6 second that conclude all mixes are satisfied the SCC requirement.

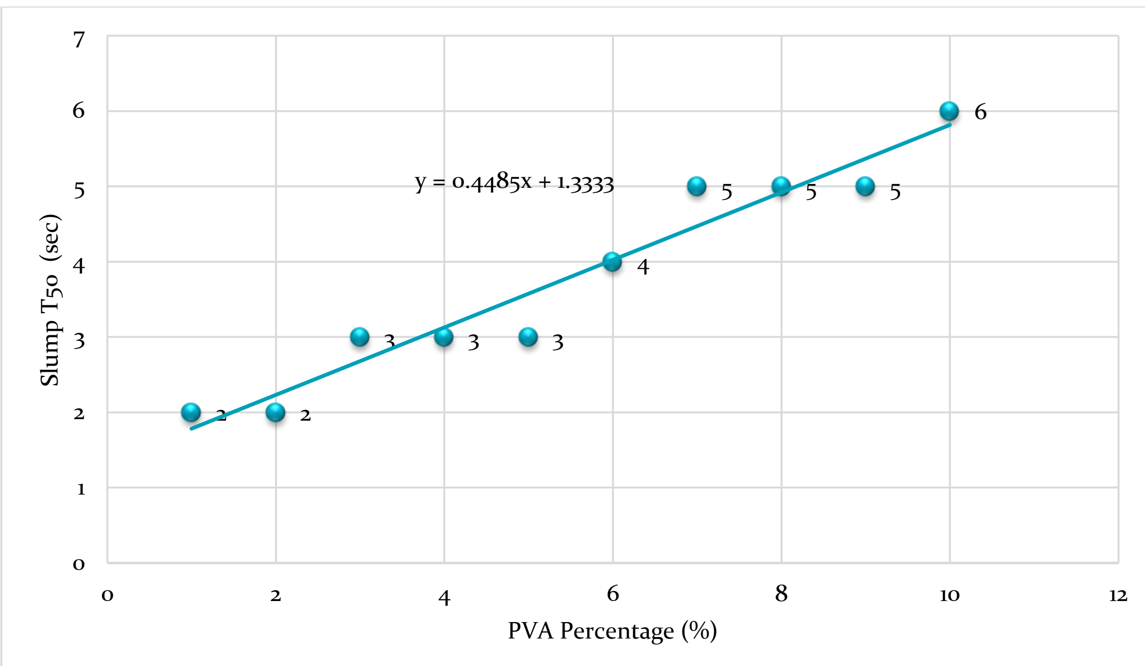

Figure 4.3: slump T_{50} test comparison among all the ten mixes

The recommended value for V-funnel test for mix to be characterized as self-compacting concrete should be on the range of 6-12 second. From the Figure 4.4 below the result showed that all the mixes satisfied the SCC requirements and all the results values are between 6-12 second. On the other hand the results also showed that as the PVA percentage increase the ECC start to loss the self-compacting behaviour, in additional the M_1 and M_2 gave the best result which is 6s.

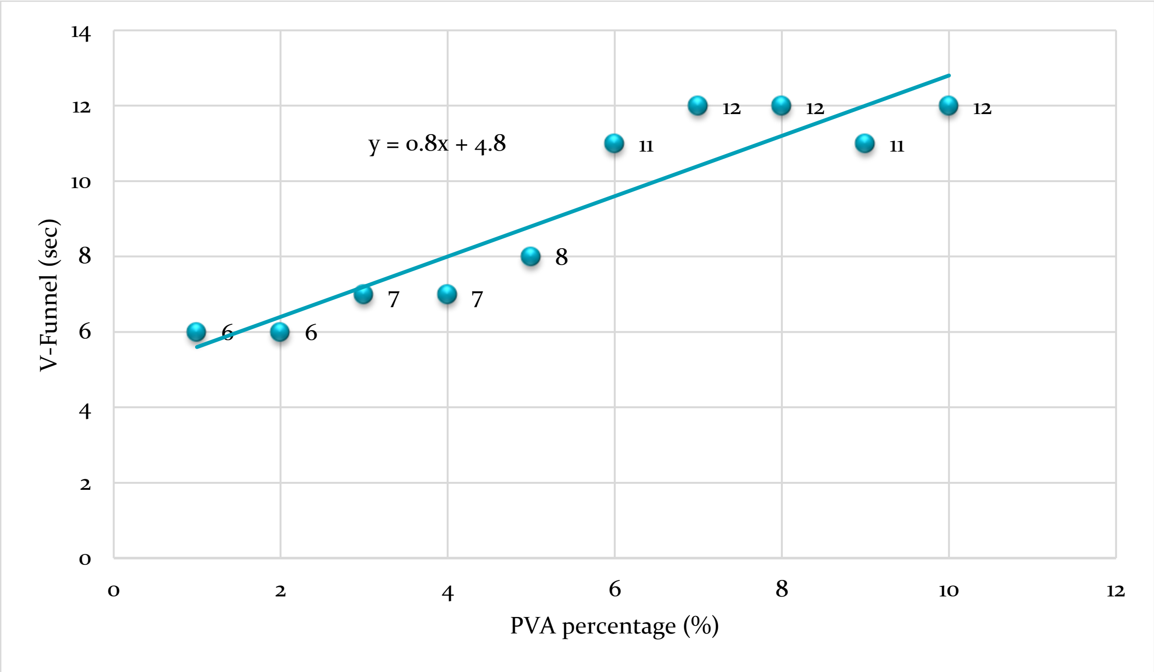

Figure 4.4: V-funnel test comparison among all the ten mixes

The Figure 4.5 below showed the real process for measuring the V-funnel test where the procedures are explained in chapter three under the fresh concrete test section.

Figure 4.5: V-funnel Test

The recommended value for L-Box test for mix to be characterized as self-compacting concrete should be on the range of (H2/H1) 0.8-1. From the Figure 4.6 below the result showed that all the mixes satisfied the SCC requirements and all the results are above 0.80, furthermore the results also showed that the mixes M_1 to M_3 gave the best result which is 0.95 and 0.98 respectively.

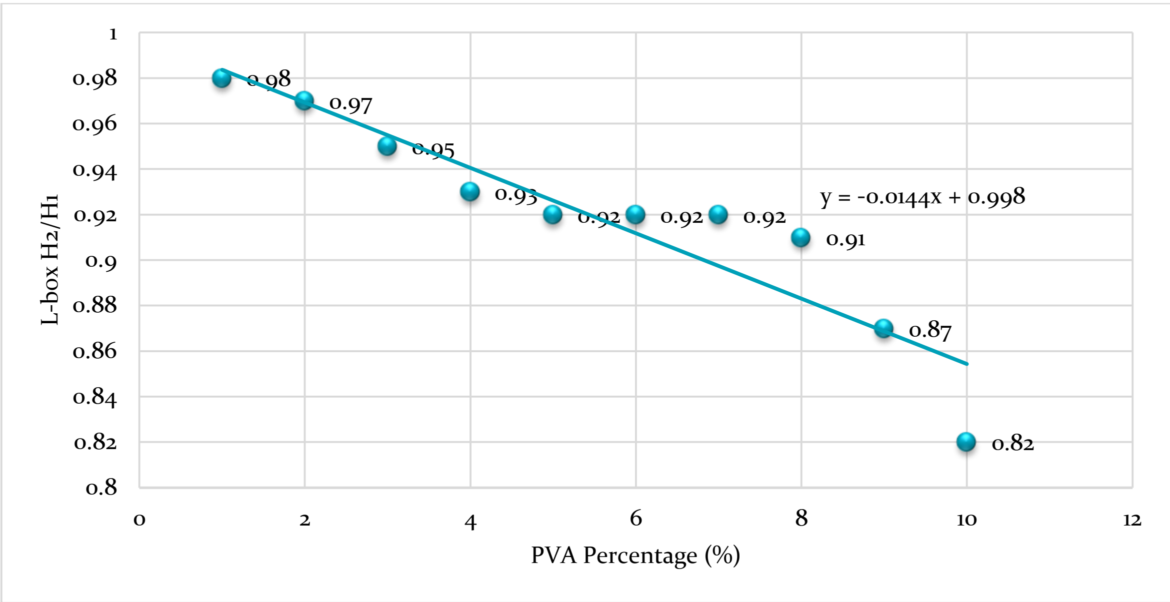

Figure 4.6: L-box test comparison among all the ten mixes

The Figure 4.7 below showed the real process for measuring the L-box test where the procedures are explained in chapter three under the fresh concrete test section.

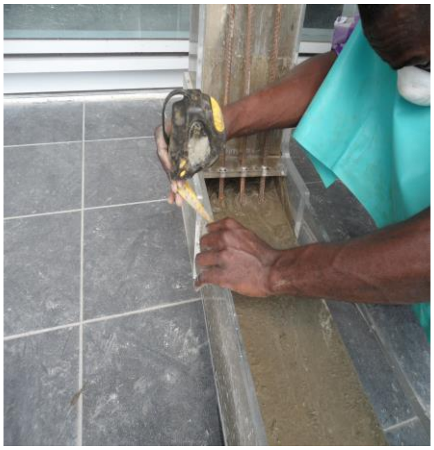

Figure 4.7: L-box Test

4.2 HARDENED CONCRETE TEST RESULTS

The three hardened tests for this research are compressive, flexural, and splitting strength are successfully obtained and achieved with an acceptable results. The results will be discussed further in this chapter.

4.2.1 Compressive Strength

By taking the average of three mixes the compressive strength results for the ten mixes have been obtained and showed in the Table 4.3. The test has conducted for 7 and 28 days.

Table 4.3: Compressive strength test for 7 and 28 days

No	Mix	7 days	28 days
1	M_1-00%	81.23	103.50
2	M_2-1% PVA	91.71	103.42
3	M_3-1.5% PVA	86.07	109.00
4	M_4-2% PVA	85.2	95.53
5	M_5-2.5% PVA	76.63	91.88
6	M_1-3%	74.37	97.47
7	M_2-3.5% PVA	71.57	96.47
8	M_3-4% PVA	71.13	90.59
9	M_4-4.5% PVA	76.88	89.93
10	M_5-5% PVA	65.95	84.89

For the normal concrete the density is 2240 - 2400 kg/m^3 (140 - 150 lb/ft^3) and the Compressive strength is 20 - 40 MPa (3000 - 6000 psi). The density results showed that all the samples for all the ten mixtures have a good result as all of them are in the range of 2240 - 2400 kg/m^3 and some of them exceed 2400 kg/m^3.The illustrated Figure 4.8 showed the compressive strength for 0.0% PVA is 81.23 N/mm^2 after adding 1.0% PVA the concrete strength increase then start to decrease even though the result started to decrease as the PVA percentage increase the results still much more higher than the normal concrete. Therefore concluded that the increase in the percentage of PVA decrease the compressive strength of concrete specifically after 2.5% PVA but still higher than the normal concrete.

Equations 1 for predicting the compressive strength of ECC with different percentages of PVA at 7 days. The Figures 4.8 were obtained with coefficient of determination (R^2) 0.7964.

[1] F_c= -2.4297 PVA (%) + 90.841

Where, F_c= compressive strength, MPa.

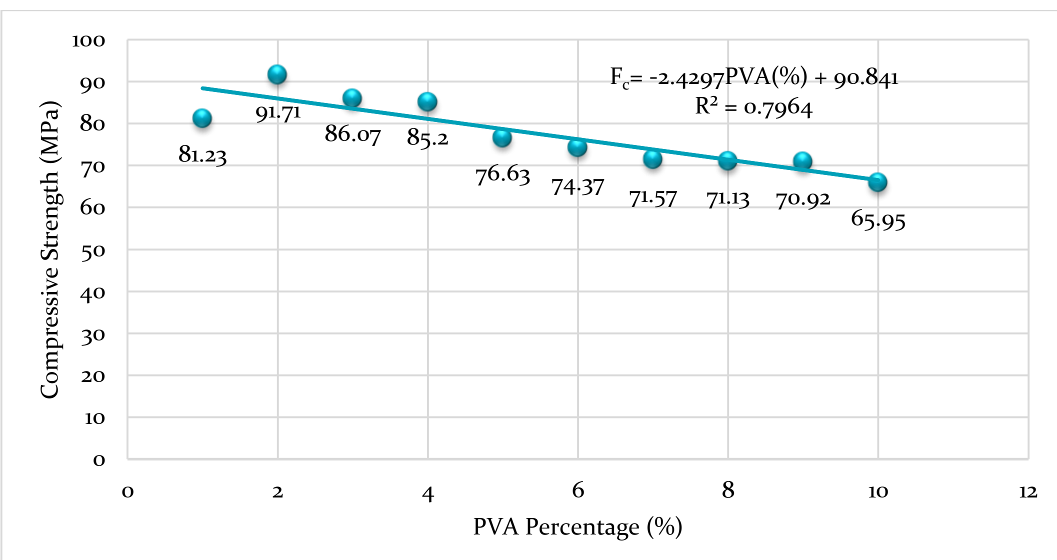

Figure 4.8: Compressive strength test for 7 days result

The illustrated Figure 4.9 showed the compressive strength for 28 days. the compressive strength for 0.0% PVA is 103.50 N/mm^2 after adding 1.0% PVA the concrete strength increase, furthermore by adding 1.5% PVA the strength become 109.0 N/mm^2 which is the highest among all the mixes then the results start to decrease even though the results started to drop still the concrete has high compressive strength than the normal concrete therefore we conclude that the increase the percentage of PVA decrease the compressive strength of concrete specifically after 2.5% PVA in the same time the results still much more higher than the normal concrete.

Equations 2 for predicting the compressive strength of ECC with different percentages of PVA at 28 days. The Figures 4.9 were obtained with coefficient of determination (R^2) 0.7404.

[2] $F_c = -2.0943 \text{ PVA } (\%) + 107.79$

Where, F_c= compressive strength, MPa.

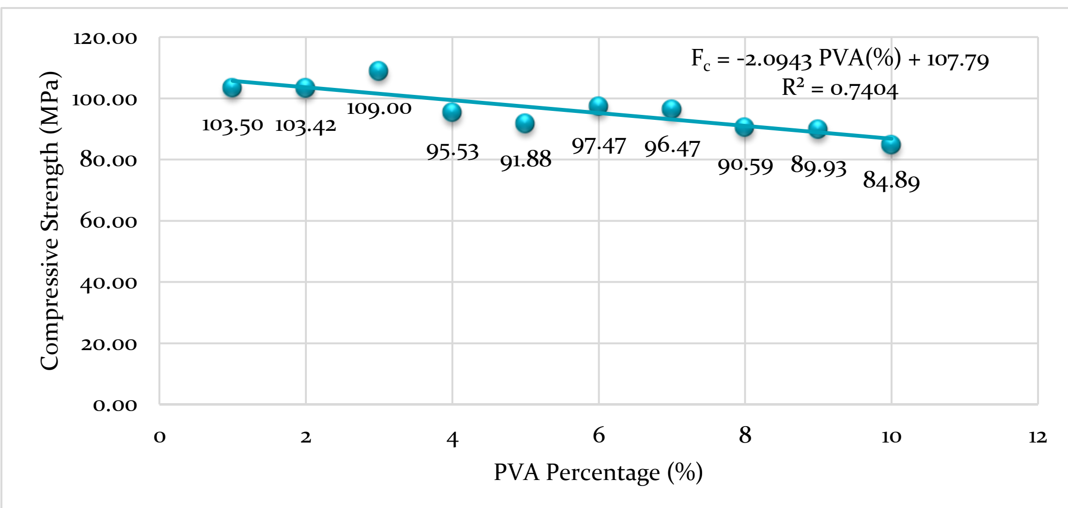

Figure 4.9: Compression strength test for 28 days result

On the other hand the increase in PVA percentage keep the concrete cube undamaged just small crack will appear in the surface of concrete as show below in Figure 4.10. It can also be noted that the cube can stand more compression, thus high ductility.

0.0% PVA 1.0% PVA 4.5% PVA

Figure 4.10: Compressive strength test result for different percentage of PVA.

Compare with compressive strength at 7 days, compressive strength at 28 days give higher result this because the concrete strength increase with aging. The M_3 1.5% PVA give the highest compressive strength result compare to others mixes, furthermore from the Figure 4.11 illustrated that increase in PVA percentage reduce the compressive strength of the concrete in the same time still higher than the normal concrete.

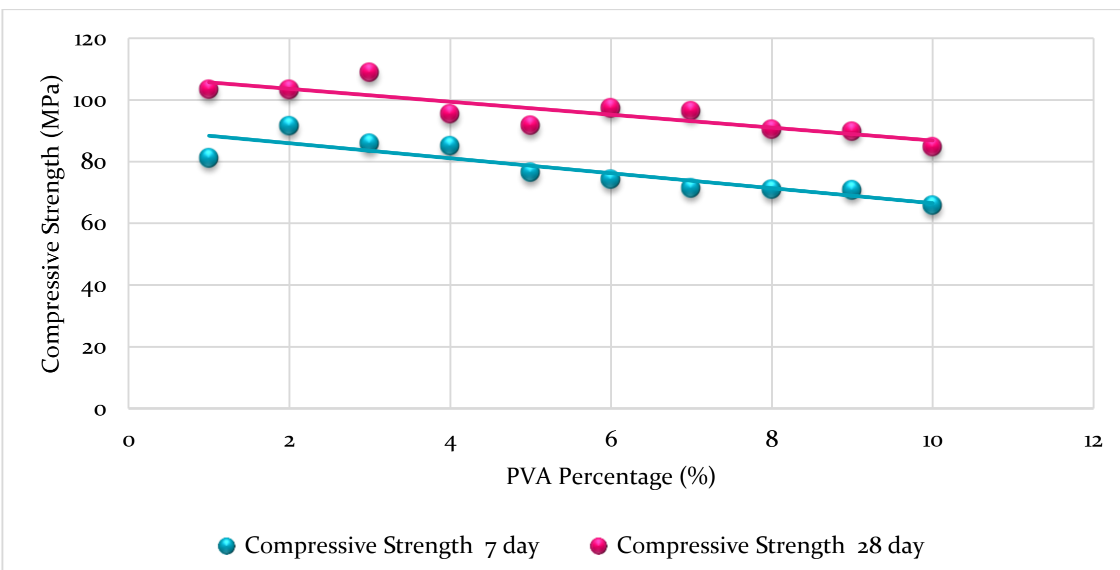

Figure 4.11: Comparison the compression strength test for 7 and 28 days result

4.2.2 Splitting Strength

The splitting test has been conducted at 28 days and the results are obtained for all the mixes and showed in the Table 4.4.

Table 4.4: Splitting strength test result for 28 days

NO	Mix	Splitting
1	M_1-00%	5.73
2	M_2-1% PVA	6.33
3	M_3-1.5% PVA	5.68
4	M_4-2% PVA	5.89
5	M_5-2.5% PVA	6.39
6	M6-3%	8.02
7	M7-3.5% PVA	7.34
8	M8-4% PVA	6.39
9	M9-4.5% PVA	8.42
10	M10-5% PVA	6.27

For the normal concrete, the standard splitting strength is about 2 - 5 MPa (300 - 700 psi). Compare with the results obtained above, it showed that ECC with PVA addition increase the splitting strength with increase the PVA percentages. All of the results are in the range of 5.73 – 8.42 Mpa which are above the splitting strength for the normal concrete. For this test, M_9 PVA gave the highest results which is 8.42Mpa, furthermore The result in Figure 4.12 showed that, it might be noted that the maximum value attained was 8.42Mpa which the splitting strength increase 66.24% by addition of 4.5% PVA. Thus ductility of concrete increase as PVA is added.

Equations 3 for predicting the splitting strength of ECC with different percentages of PVA at 28 days. The Figures 4.12 were obtained with coefficient of determination (R^2) 0.31.

[3] $F_s = 0.1759 \text{ PVA } (\%) + 5.6787$

Where, F_s= Splitting strength, MPa.

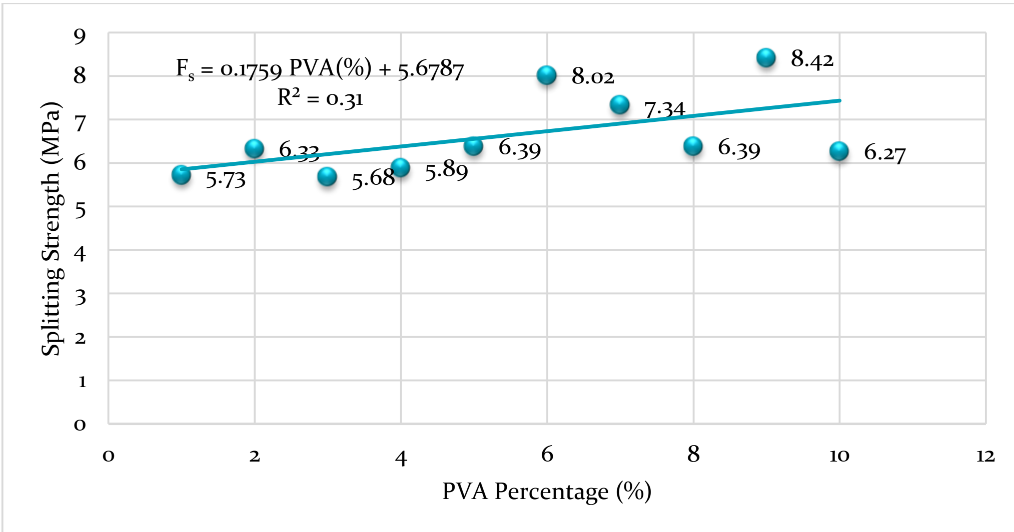

Figure 4.12: Splitting strength test result 28 days

The pictures Figure 4.13below showed the results of engineered cementitious concrete with fiber addition and no fiber addition. With no fiber addition, the result of the concrete is totally crash while with fiber addition only cracks appears on the column this can be noted that the column can stand more tension, thus high ductility.

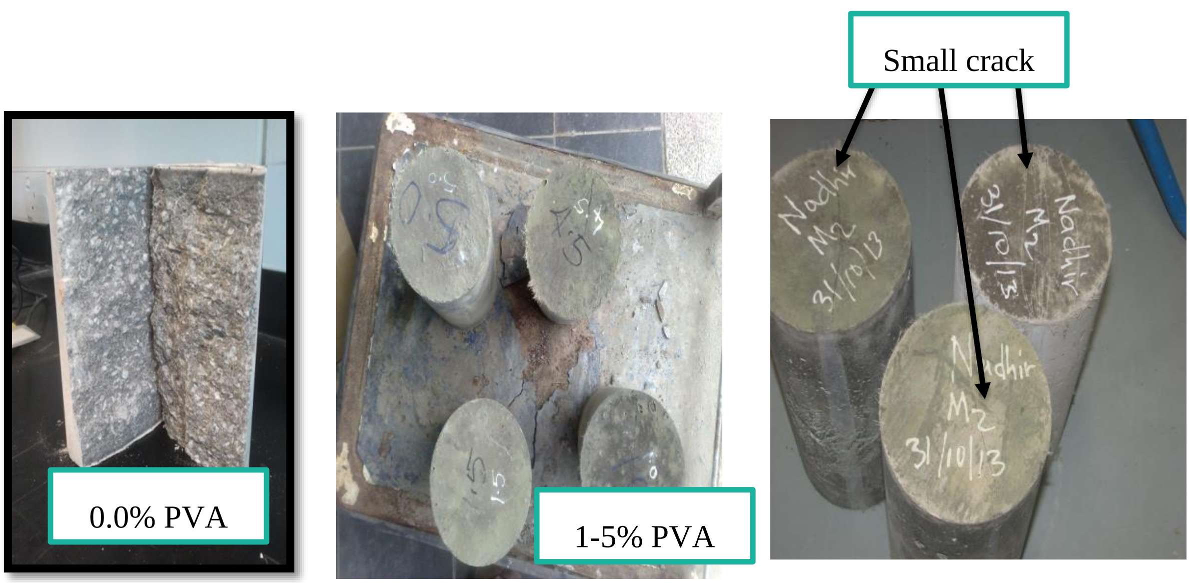

Figure 4.13: Splitting strength test for different percentage of PVA.

4.2.3 Flexural Strength

The flexural strength results has been conducted at 28 days and the results are obtained for all the mixes and showed in the Table 4.5 below.

Table 4.5: Flexural strength test result for 28 days

No	**Mix**	**Flexural**
1	M_1-00	5.45
2	M_2-1% PVA	5.65
3	M_3-1.5% PVA	6.86
4	M_4-2% PVA	8.45
5	M_5-2.5% PVA	8.09
6	M6-3%	10.85
7	M7-3.5% PVA	11.46
8	M8-4% PVA	11.31
9	M9-4.5% PVA	11.42
10	M10-5% PVA	11.7

For flexural test, normal concrete is about 3 - 5 MPa (400 - 700 psi) which about the same as tensile strength. Compare with the Figure 4.14, it showed that ECC with PVA addition increase the flexural strength. All of the results are in the range of 5.45 – 11.70 Mpa which are above the flexural strength for the normal concrete. For this test, M_{10} PVA gave highest result which is 11.7Mpa. It showed that the optimum fiber addition is about 5.0% with Flexural strength is 11.42Mpa which increasing by 62.65% from normal concrete flexural strength. Therefore it's showed that adding of PVA will increase the ductility of concrete.

Equations 4 for predicting the flexural strength of ECC with different percentages of PVA at 28 days. The Figures 4.14 were obtained with coefficient of determination (R^2) 0.9025.

[4] $F_f = 0.792\ PVA\ (\%) + 4.768$, Where, F_f= Flexural strength, MPa

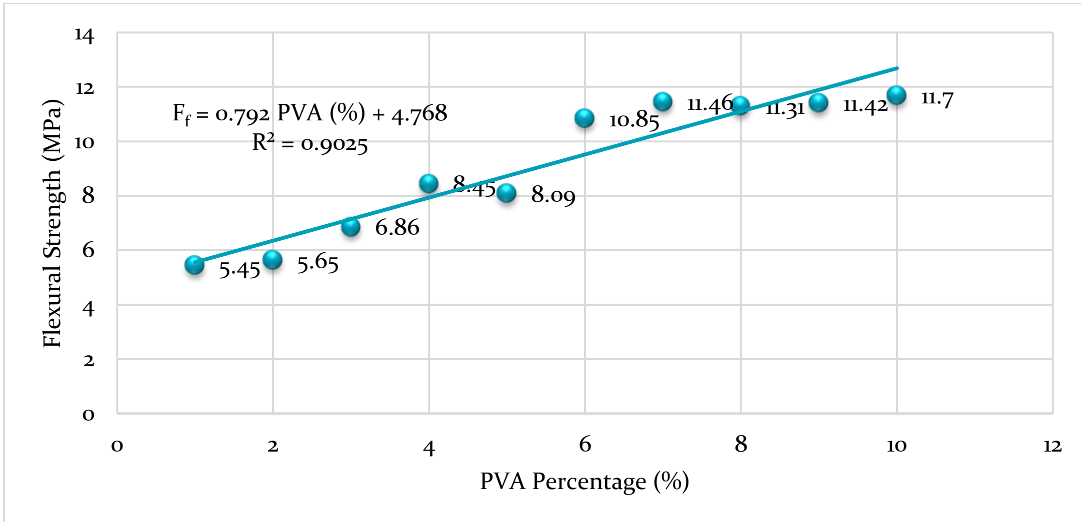

Figure 4.14: Flexural strength test result 28 days

The Figure 4.15 below showing the results of beams with fiber addition and no fiber addition. With no fiber addition, the results of the concrete is totally crash while with fiber addition, the beam bend without breaking into two pieces and only cracks appears on the beam. It can be noted that the beam has high in flexural strength, thus high ductility.

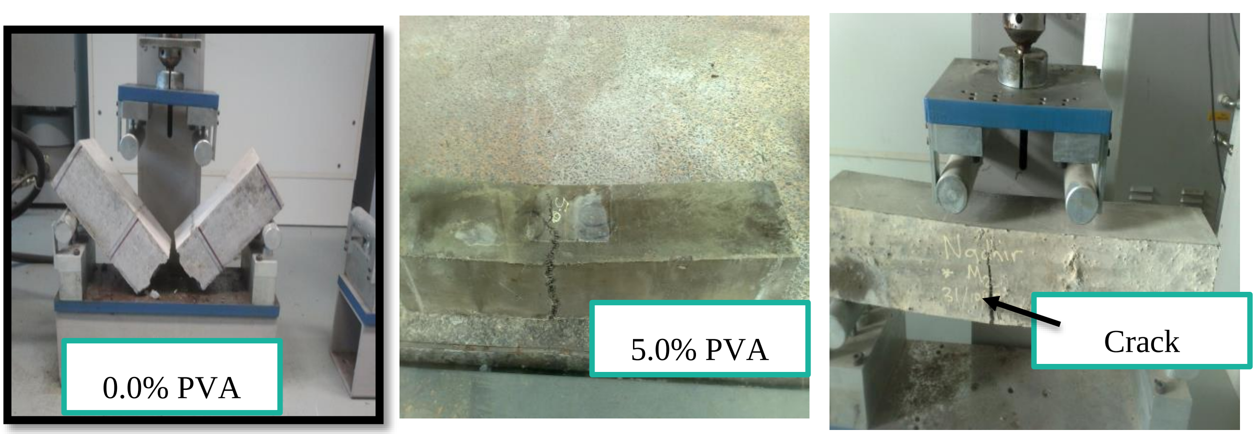

Figure 4.15: Flexural strength test for different percentage of PVA.

CHAPTER 5

CONCLUSION& RECOMMENDATION

5.1 CONCLUSION

Improving the performance of ECC is of great importance for modern construction material. The objectives of this project are to develop ECC mixtures satisfying the self-compacting requirements and to evaluate the hardened properties of self-compacting ECC mixtures. In this study, PVA had been added in order to improve the performance of concrete. A total of 10 successful mixes had been achieved for this project. All the 10 mixes had been tested for fresh concrete and for hardened concrete test, the test which already been conducted is compressive strength for 7 days and 28 days, tensile strength as well as flexural strength. Based on the results presented in this paper, the following conclusion can be drawn.

1. Increase of PVA in the ECC affect the workability of the concrete. In the fresh concrete test which including all four test, slump flow, slump T50, V-funnel and L-box, it showed that as the percentage addition of PVA into ECC increase the result will decrease. It shows that increase in PVA addition will affect the flowability of ECC.
2. The compressive strength of ECC giving high different between normal concrete. From this test also, it shows that as the PVA increase, the compressive strength will decrease in the same time the results still higher than the normal concrete.
3. Higher strength in both tensile and flexural strength showing that adding of PVA will increase the ductility of engineered cementitious composites (ECC).The concrete has higher strength to stand splitting flexural stress.
4. A new equations to predict the compressive, splitting and flexural strength of ECC F_c = -2.0943 PVA (%) + 107.79, F_s = 0.1759 PVA (%) + 5.6787 and F_f = 0.792 PVA (%) + 4.768 respectively has been developed in this study.
5. The coefficient of determination (R^2) for the compressive, splitting and flexural strength of ECC 0.7404, 0.31, and 0.9025 respectively has been obtained in this study.

5.2 RECOMMENDATIONS

The following is the recommendations in dealing with ECC, which are proposed for future researches.

1. The research shall tests for PVA incorporated concrete up until 90-days to get more accurate and higher result, since in this project, 7-28 days concrete showed lower strength but still higher compare to the normal concrete. The 90-days concrete will have the potential to obtain higher result.
2. To study the effect of PVA on SCC at constant water to cement ratio, a wider range of SP dosage is needed.
3. During the mixing of ECC, tests of moisture content should be carried out more frequently, since ECC is more sensitive than normal concrete to variations. Aggregate moisture should be kept constant for all mixes.
4. Further study for 90days and 120 days compressive strength can be done for determining better strength.

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