DEFORMATION PROPERTIES OF ENGINEERED CEMENTITIOUS COMPOSITE (ECC) WITH NANO SILICA

By

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16714

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DEFORMATION PROPERTIES OF ENGINEERED CEMENTITIOUS COMPOSITE (ECC) WITH NANO SILICA

By

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A project dissertation submitted to the

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MAY 2015

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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MOHD AZIZUL BIN ABU BAKAR

ABSTRACT

In this study, the deformation properties of Engineered Cementitious Composite (ECC) with Nano-Silica (nS) are tested based on four deformation properties with two different tests conducted, all the test conducted are based on the standard testing method following the American Standard Testing Method (ASTM). For this purposed, Initially 20 mixture of ECC were prepared by varying the percentage of Polyvinyl Alcohol (PVA) Fiber (0.5%-2%) and nS (0%-4%). From each mixture, 3 cylinders (100 mm x 200 mm), and 3 prisms (25 mm x 25 mm x 285 mm) are prepared. These samples are then cured in curing tank for 28 days before testing were conducted. The first test were conducted to monitor the shrinking properties of ECC after 28-days samples are cured and the second test were conducted to analyze the ECC strain behavior under applied compressive load. The ECC mixture consist of Fly Ash, Ordinary Portland Cement (OPC), Sand, Water, PVA Fiber and also Super Plasticizer (SP), a percentage of nS is added into the ECC mixture to investigate the effect of the nano size particle material in the ECC mixture towards the deformation properties. It is expected that at some amount of nS will be ideal to fill the pore spaces in the ECC mixture and improves the performance of materials of ECC, thus result in significant improvement in the deformation parameters.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Recently, a class of high performance fiber reinforced cementitious composite known as Engineered Cementitious Composite (ECC) has been developed in University of Michigan by researchers that are lead by Dr.Victor Li for the last few decades but currently being under research and development all around the globe. ECC were developed to overcome and improved the brittleness behavior of normal concrete.

Engineered Cementitious Composite or shortly known as ECC, is a new formulated concrete which act more like a ductile material instead of normal brittle concrete materials. The ECC is formulated like a mortar based composite with short random fibers to improve its ductility. In general, ECC is not a fixed material design but more to an undergoing research and development to find the most ideal mixture of ECC. The material can be considered as an ECC as long as it is design based on micromechanics and fracture mechanics theory to be able to act in ductile behaviors.

The normal ECC mixture were formulated most likely like a normal concrete except the course aggregate is not used in the mixture as it tend to contribute to the brittle behavior and short random fibers is used to improves the mixture ductile properties. As the family of ECC were actually expending from day to day, the development of an individual mixture required to focus more on the systematic engineering at the material nano-composite scale.

While, one of the ways to improve ECC characteristic by looking on the material composite scale is by using Nano-Silica (NS) in the mixture. From the previous study, it is proven that the microstructure of the mortar mixture containing NS was denser and more uniform compared to conventional mortal mixture microstructure and mixture that containing silica fume (Sayed, Sameh, & Ibrahim, 2013).

1.2 PROBLEM STATEMENT

The quest for improving the strength of concrete is associated with increasing brittleness. Highly brittle concrete which is one of the peculiar properties of high strength high-performance concrete has restricted its application in a seismic environment.

In effort to make high strength concrete ductile, some researchers at the University of Michigan initiated a study on engineered cementitious composite (ECC), utilizing a fraction of short discontinuous fibers designed using the principles of micromechanics. The developed ECC is ductile and exhibits micro cracks when subjected to a direct tensile test. The ECC has a low value of Elastic Modulus due to only fine mineral aggregates utilized in its productions and the shrinkage behavior is high due to the high volume of cementitious materials utilized.

The low modulus of elasticity has restricted its application in some structures. The present research is intended to utilize Nano Silica (nS) particles and investigate its effects on the deformation properties of the ECC materials.

1.3 OBJECTIVE

1. To determine the deformation properties of Engineered Cementitious Composite (ECC) with Nano Silica.

2. To determine the Stress-Strain behavior of Engineered Cementitious Composite (ECC) with Nano-Silica.

1.4 SCOPE OF STUDY

This research will be focusing on the deformation properties of ECC (Modulus Elasticity and Shrinkage) with the presence of nano-silica as a part of the mixture and analyze the impact of nano-silica in ECC mixture towards the stress and strain performance of ECC. The deformation properties of ECC mixture with presence of nano-silica will be tested by using two tests which is the Standard Test for Length

Change of Hardened Hydraulic-Cement Mortar and Concrete and lastly the Stress and Strain Compression test.

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To understand the deformation impacts of nano-silica in ECC mixture and to prove the impact of nano-silica in the mixture of ECC, a set of mixture proportion used for this study where ECC reinforced with 0-4% nano silica particle proportional to polyvinyl alcohol (PVA) fiber used for mix ECC range from 0.5-2%. While other common materials used to formulate ECC such as Portland cement, Sand, Fly Ash, Water except Super Plasticizer (SP) remain at constant amount. The percentage of SP adjusted depending on the mixture workability

CHAPTER 2: LITERATURE REVIEW

2.1 ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

The mixture of ECC is quiet similar to the mixture of normal concrete, the difference is it does not contain any course aggregate. ECC mixture contains only water, cement, sand, fiber, and some common chemical additives. The coarse aggregates are not used as they affect ductile behavior of the composite.

The key behind the ductile properties of ECC lies in proportion of short random fiber, cementitious matrix, and the interface (mechanical and geometric) properties must be of a correct combination in order to attain the unique behavior of ECC. From the previous study, it is reported that the compressive strength of ECC varies from 30 to 70 MPa, only by varying the cementitious matrix composition (Li & Kanda, 1998).

2.2 DEFORMATION PROPERTIES OF ENGINEERED CEMENTITIOUS COMPOSITE

Generally, Neville (1995) mention that all the effect of changing the natural shape of the concrete structure is known as the deformation of concrete. The deformation may occurs when load is applied or without application of load.

Deformation properties is one of the main properties in concrete, poor deformation properties were reported will lead to structural/non-structural cracks and distresses and in turn degrade the performance of the structure, generally there are few class of deformation properties such as setting shrinkage (or hardening shrinkage) during initial chemical reactions, thermal deformation due to temperature changes, Elastic deformation due to instantaneous loading and creep deformation due to long-term loading(Yeon, Yeon, Choi, & Min, 2014). Among all these properties, a few will be included and analyze in this research.

2.2.1 Modulus Elasticity

Modulus elasticity is one of the basic parameters that are used to determine the strain and displacement of the structural design, modulus elasticity is usually measured through sample subjected to uniaxial compression loading. (Galobardes, Cavalaro, Aguado, & Garcia, 2014).

The modulus of elasticity is defined as the slope of the stress-strain curve in the elastic deformation region as shown below. There are two types of modulus elasticity that usually measured, tangent modulus (E_{ci}) tangent at a certain point of the curve and secant modulus (E_{cm}) a slope of straight line between the coordinate system origin and a certain point of the curve.

Generally, the research studies nowadays using only the secant modulus of elasticity obtained for a stress equal to 30% of the failure stress as shown in Figure 1, since this is the parameter usually used in the standardize tests. Therefore, the modulus elasticity in this test will be referring to the secant modulus (E_{cm}). (Galobardes et al., 2014)

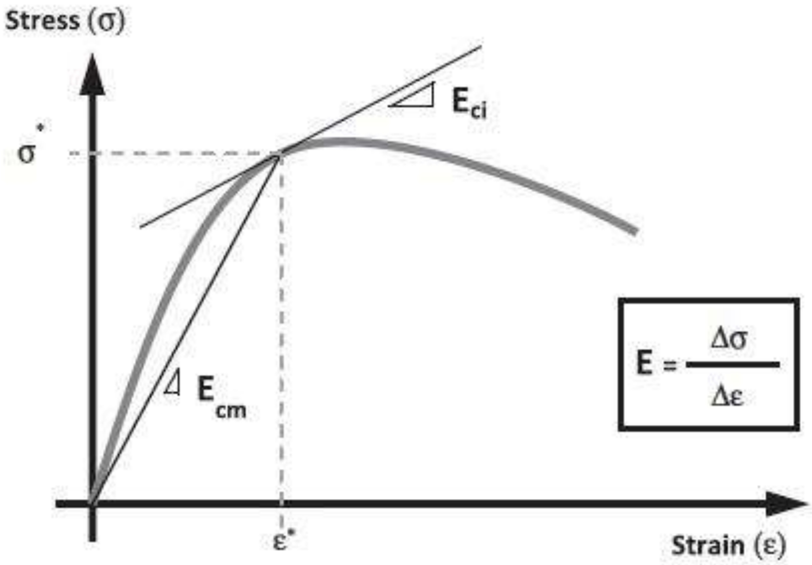

Figure 1: Normal Stress-Strain Diagram (Galobardes et al., 2014)

It is known that, for any types of concrete, the modulus elasticity will be increase with the raise of compressive strength of the sample and for normal concrete the modulus elasticity is directly affected by the modulus elasticity of the aggregates used in the mixture. (Neville, 1995). For normal concrete, several factors were known to be affecting the modulus elasticity of the concrete such as the water ratio content, maximum aggregates sizes and the percentage of fly ash used. (Yıldırım & Sengul, 2011). The effects of water/cement ration, Aggregate Size and Fly Ash towards the Modulus Elasticity are shown in Figure 2, Figure 3 and Figure 4 below.

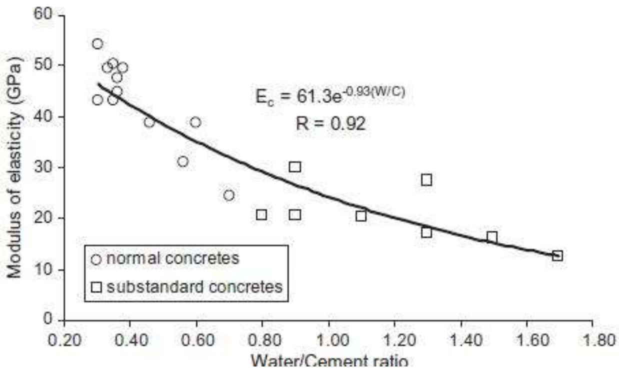

Figure 2:Effect of water/cement ratio on the static modulus of elasticity of concrete(Yıldırım & Sengul, 2011)

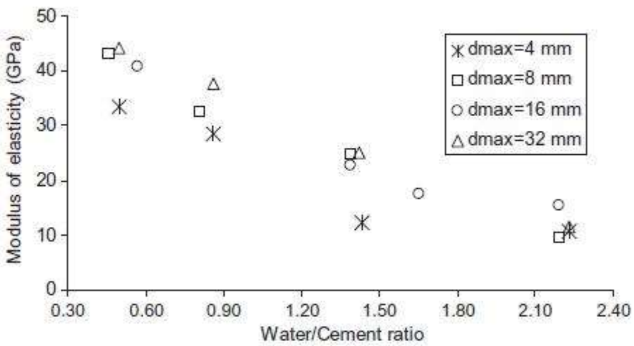

Figure 3:Effect of maximum aggregate size on the static modulus of elasticity of(Yıldırım & Sengul, 2011)

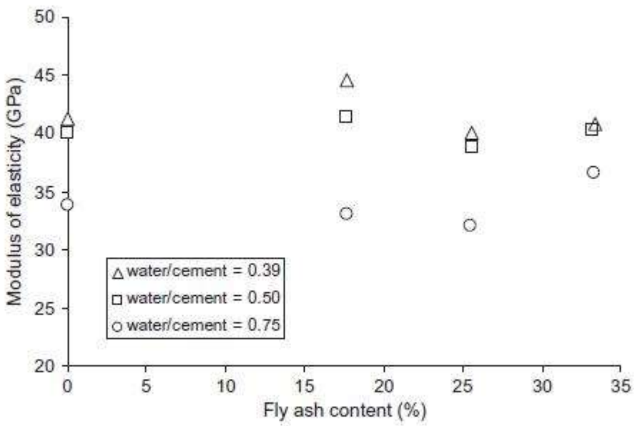

Figure 4: Effect of fly ash content on the static modulus of elasticity of concrete. (Yıldırım & Sengul, 2011)

2.2.2 Shrinkage

According to Neville (1995), shrinkage occurs when no moisture to or from cement paste is permitted. In the industry, the shrinkage may be contributing to other forms of damages in concrete (e.g. corrosion, freezing and thawing) and this will be reducing the structure integrity. (Güneyisi et al., 2014)

From the previous research made, there are generally two most common ways to reduce the impacts of shrinkage, first of all by using a shrinkage reducing admixture (SRA) as shown in Figure5, Figure 6, Figure 7 and Figure 8, which will be reducing the magnitude of capillary stresses and shrinkage strains by lowering the surface tension of concrete's pore fluid, while the other alternatives is to used steel fiber in concrete mixtures as shown in Figure 6, Figure 7 and Figure 8, the presence of steel fibers will enhance the concrete's tensile stress, fracture toughness, impact strength and durability(Güneyisi et al., 2014)

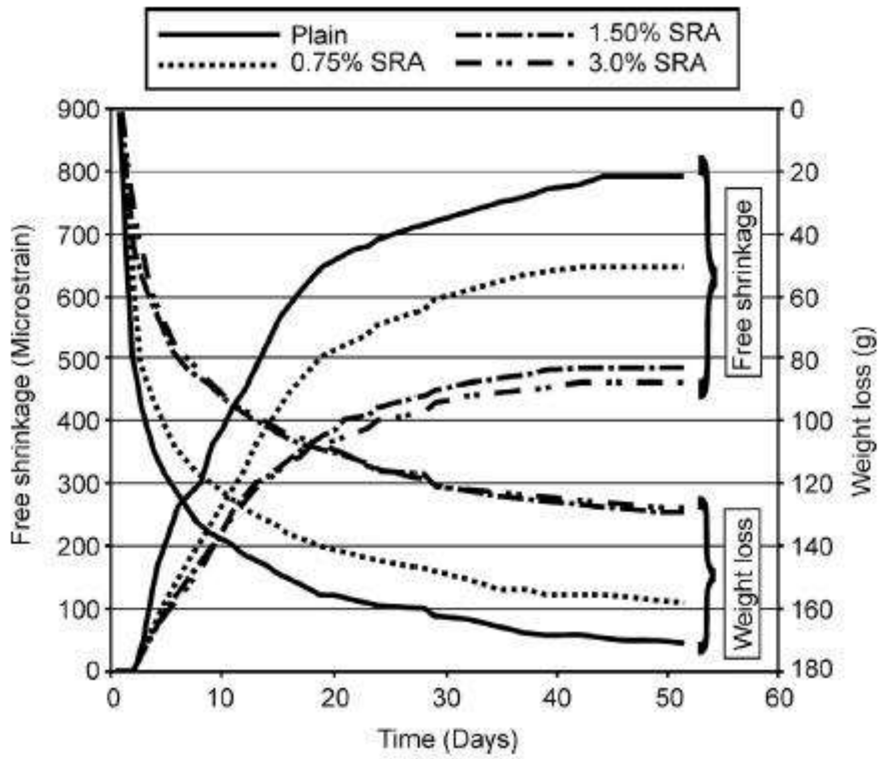

Figure 5: Free shrinkage results with varying SRA values. Güneyisi et al., 2014*)*

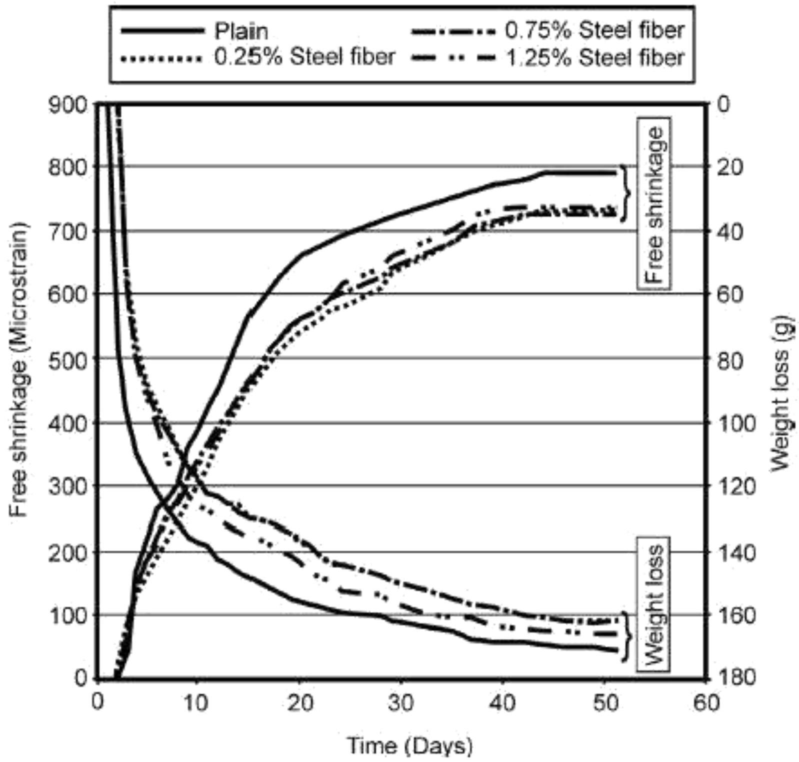

Figure 6: Free shrinkage results with varying steel fiber values. Güneyisi et al., 2014)

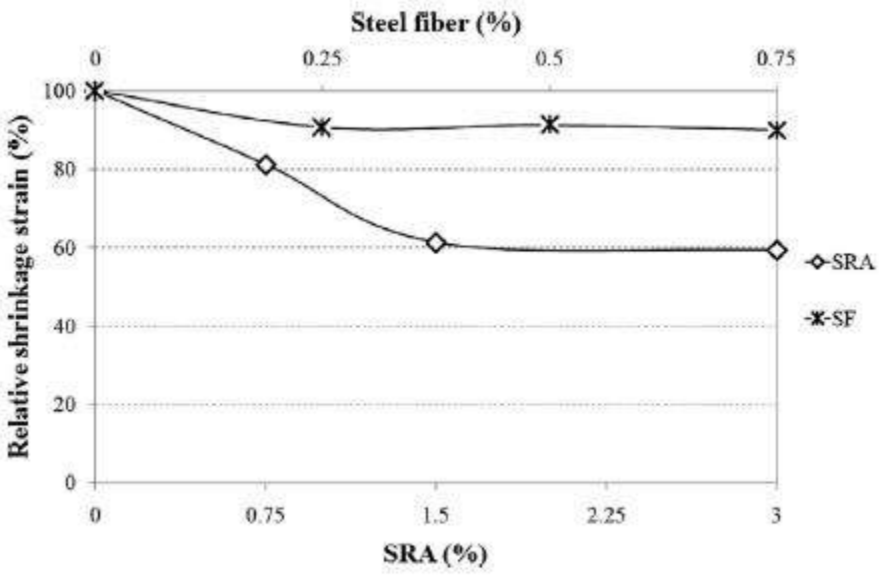

Figure 7: Effect of SRA and steel fiber on final shrinkage strains at the end of drying Güneyisi et al., 2014)

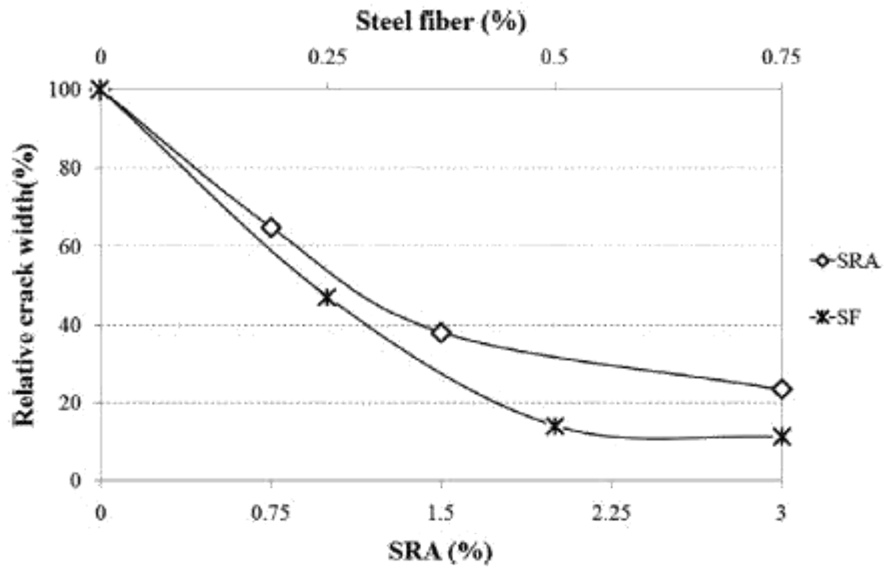

Figure 8: Effect of SRA and steel fiber on final crack widths of restrained specimens at the end of drying period (Güneyisi et al., 2014)

It is known that Engineered Cementitious Composite was formulated without the presence of course aggregate, due to larger amount of cement paste is in the mixture, result in higher drying shrinkage that must be developed during setting and hardening of the composite. For normal concrete, the ultimate drying shrinkage strain with magnitude of 400μm/m to 600μm/m at 20^{O}C and 60% relative humidity. While for normal ECC mixture, the ultimate drying shrinkage was higher with magnitude of 1200 μm/m to 1800μm/m under the same condition. (Zhang, Gao, & Wang, 2013).

For the poor shrinkage deformation properties of ECC, it is expected that there will be significant cracking that were induced by the shrinkage as the ECC is used for the construction purposed.

2.3 NANO SILICA IN CONCRETE MIXTURE

Currently, the nano-particles of high reactivity and advanced properties as compared to the behavior of parent materials have been produced with the developments in nanotechnology(Sanchez & Sobolev, 2010). The usage of nano-particles has been started in the cement based materials and surprisingly has resulting in a positive result, the nano size material seem to be able to provide unique characteristic to the cement based materials (Du, Du, & Liu, 2014).

The usage of nano-SiO_2, TiO_2, Al_2O_3, Fe2O3 as nano-filler in the cement matrix causing the capillary pores to be more smaller and the total porosity were also reported to be decreased (Du et al., 2014).Among all the nano-sized materials that usually used in the mixture, nano-silica seems to have its owned special characteristics Due to its ultra fine particle size, nano-silica can possess a distinct pozzolanic reaction at a very early age. Therefore, one of the promising applications of nano-silica is to promote the hydration of cement blended with fly ash, slag or other pozzolanic materials. (Du et al., 2014).

Compressive and flexural strengths of concrete were also reported can be enhanced by incorporating nS in the mixture (Ghafari, Costa, Júlio, Portugal, & Durães, 2014). While, from the previous studies it is stated that the usage of nano-silica will increased the cement hydration and resulting in the higher cracking potential (Shaikh, Supit, & Sarker, 2014) if they were dispersed uniformly in the composites, or else the benefit will be compromised by the agglomeration of nano-particles.

Currently, the studies on the deformation properties of cement-based materials with nano-silica are still limited, as most of the previous research deals mainly with the dispersion issue and the influence on the fresh state properties (Du et al., 2014)

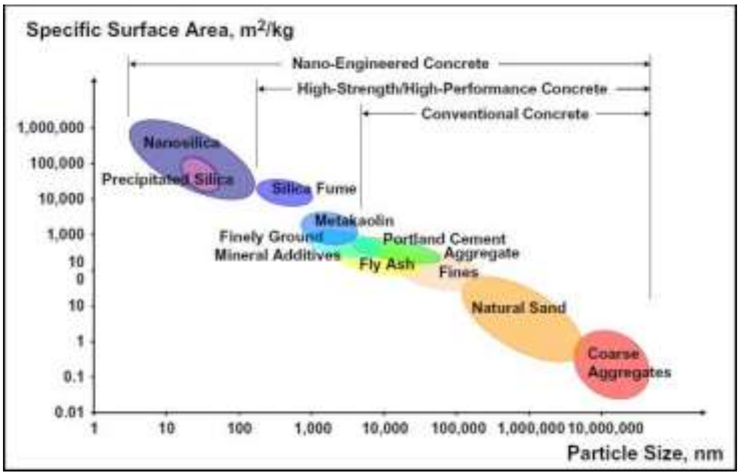

Figure 9: The nano particles sizes used in the industry (Sanchez & Sobolev, 2010)

CHAPTER 3: METHADOLOGY

3.1 RESEARCH METHODOLOGY

This research will be divided into three phases, the first part will be preparing the materials and conducting the mixture for sample testing, the second phase of this research is testing the sample based on three testing method and the last phase is the phase of analyzing the result gained in the testing to conclude the findings of the research, the details of the research methodology is shown in the Figure 10.

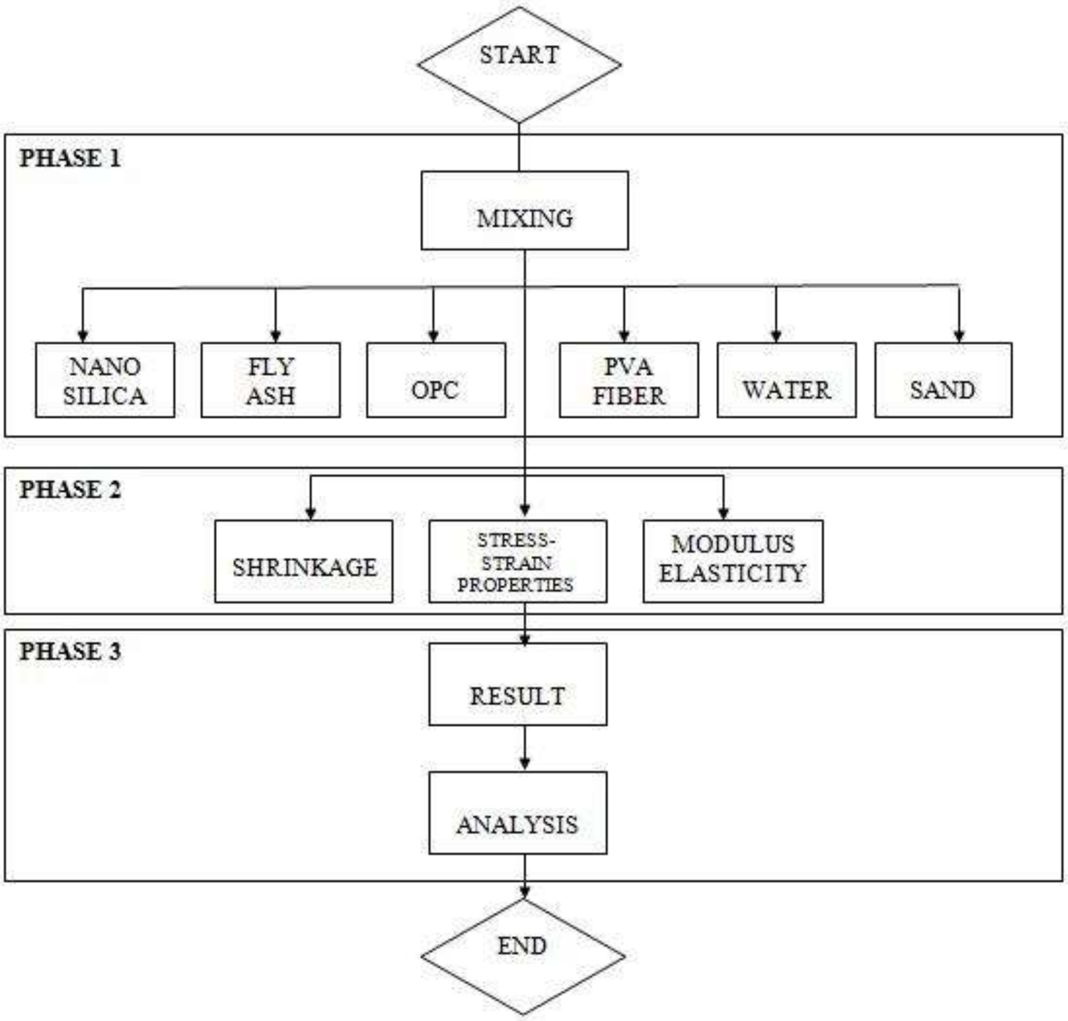

Figure 10: Research Methodology

3.2 PERFORM LITERATURE STUDY AND PRELIMINARY RESEARCH

The research on Engineered Cementitious Composite (ECC) has been conducted for a few decades and there is always new research conducted and contributes to the main research. The purpose of literature study is to get current research information and knowledge and also strengthen the basic fundamental related to the engineered cementitious composite (ECC) using nano silica particle.

While, the preliminary research is made to avoid duplication and ensure same degree of nobility in this research, the literature study and preliminary research is made. Besides, there are also some theories and formulas to be understand from the previous research. To show the significance of this research, the result analyze will be compared with the result from the previous research from numbers of sources including internet, books and also past thesis that is related to the research made.

3.3 MATERIAL PROPORTION

3.3.1 Cement

Ordinary Portland cement (OPC) of 43 grades having a specific surface of 412.92 m2/kg and conforming to Malaysian Standard MS 522: Part 1: 1989 Specifications for Ordinary Portland Cement was used. The cement was kept in an airtight container and stored in the humidity-controlled room to prevent cement from being exposed to moisture. Malaysian Standard MS 522: Part 1: 1989 Specifications for Ordinary Portland cement. OPC consist chemical composition of calcium silicates , aluminum, magnesium and iron containing at clinker phases.

3.3.2 Fly Ash

Fly Ash used is in well graded curve class, between fine silt to fine sand sizes with range of 0.001mm and 0.6mm. Specific gravity of fly ash found to be 2.3 and 1.99 respectively. Density of this material is less than 1Mg/m. The fly ash is a heterogeneous material. The main chemical components are SiO2, Al_2O_3, Fe_2O_3 and occasionally CaO.

3.3.3 Polyvinyl Alcohol (PVA) Fiber

The PVA fibers are made with a high tensile strength with maximum elongation and elastic modulus makes this material applicable for strain-hardening performance. Nominal strength for PVA fiber is 1620 MPa with young modulus of 42.8 GPa. Diameter of this material should be 39 micron and length of 12 mm, while the specific gravity is 1.30. The PVA made were produced from polymerization of vinyl acetate to poly vinyl acetate which a simple chemical structure of hydroxyl group.

3.3.4 Nano silica particle

Nano silica is the most crucial material in this research, the impact of nano silica into deformation properties of ECC will be analyze and conclude in this research. Nano silica particle used in this study were having a diameter of 19nm and density of 2.12 g/cm^3, while the Specific surface for this particle is known to be 160 m^2/g.

3.3.5 Fine aggregate (sand)

The sand used in this study was natural sand or river sand which use in commercial available. The specific gravity of this material is 2.68 with fineness modulus of 3.42. This material is dried at room temperature for 24 hours to control the water content in the concrete. Fine Aggregates should passing No.4 (4.75 mm) sieve and predominately retained on the No. 200 (75 μm) sieve according to BS 882: 1992

3.3.6 Water

In this study, normal tap water available in the concrete laboratory was used. Water conforming to the requirements of water for concreting and curing

3.3.7 Super Plasticizer

Super plasticizer Conplast SP430A1 based on commercial available produced in Bangalore was used to produce high workability in concrete and reduce the water cement ratio. The Specific gravity of the Conplast SP430A1 is 1.18 to 1.20 at 20 C.

3.4 MIX DESIGN AND PREPARATION OF SPECIMEN

3.4.1 Mix Design

In order to understand the impact of Nano Silica towards deformation properties of ECC, 20 samples of mixture were prepared. The mixtures were prepared by varying the percentage of PVA fibers from (0.5-2) % and Nano Silica particle for (0-4) %. The formula of the sample mixtures is shown in the Table 1.

Table 1: ECC with Nano Silica mixing formula

Sample /unit	**Sand** *kg/m3*	**OPC** *kg/m3*	**Water** *kg/m3*	**FA** *kg/m3*	**PVA** *%*	**nS** *%*	**SP** *kg/m3*
M1	467	583	187	700	0.50%	0%	9.5
M2	467	583	187	700	1.00%	0%	9.5
M3	467	583	187	700	1.50%	0%	9.5
M4	467	583	187	700	2.00%	0%	9.5
M5	467	583	187	700	0.50%	1.00%	9.5
M6	467	583	187	700	1.00%	1.00%	9.5
M7	467	583	187	700	1.50%	1.00%	9.5
M8	467	583	187	700	2.00%	1.00%	9.5
M9	467	583	187	700	0.50%	2.00%	9.5
M10	467	583	187	700	1.00%	2.00%	9.5
M11	467	583	187	700	1.50%	2.00%	9.5
M12	467	583	187	700	2.00%	2.00%	9.5
M13	467	583	187	700	0.50%	3.00%	9.5
M14	467	583	187	700	1.00%	3.00%	9.5
M15	467	583	187	700	1.50%	3.00%	9.5
M16	467	583	187	700	2.00%	3.00%	9.5
M17	467	583	187	700	0.50%	4.00%	9.5
M18	467	583	187	700	1.00%	4.00%	9.5
M19	467	583	187	700	1.50%	4.00%	9.5
M20	467	583	187	700	2.00%	4.00%	9.5

In order to prepare for all the specimens required in each mixing, a total of 0.03 m^3 of ECC were prepared, the amount needed for each mix is shown below. The percentage of all materials are fixed, except for PVA fiber and nS, the variation is made from a range of 0.5%-2.0% for PVA Fiber and 0%t- 4.0% for Nano Silica in order to identify the optimum amount and range of these two variable in the mixing and also to identify the relationship between PVA fibers and also nS.

Table 2: ECC with Nano Silica mixing proportion

Sample	Sand	OPC	Water	FA	PVA	nS	SP		
							Initial	Add	Total
/unit	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*Kg*		
M1	14.01	17.49	5.61	21.00	0.192	0	0.285	0	0.285
M2	14.01	17.49	5.61	21.00	0.385	0	0.285	0	0.285
M3	14.01	17.49	5.61	21.00	0.577	0	0.285	0	0.285
M4	14.01	17.49	5.61	21.00	0.770	0	0.285	0.04	0.325
M5	14.01	17.49	5.61	21.00	0.192	0.385	0.285	0.04	0.325
M6	14.01	17.49	5.61	21.00	0.385	0.385	0.285	0.06	0.345
M7	14.01	17.49	5.61	21.00	0.577	0.385	0.285	0.08	0.365
M8	14.01	17.49	5.61	21.00	0.770	0.385	0.285	0.09	0.375
M9	14.01	17.49	5.61	21.00	0.192	0.770	0.285	0.18	0.465
M10	14.01	17.49	5.61	21.00	0.385	0.770	0.285	0.12	0.405
M11	14.01	17.49	5.61	21.00	0.577	0.770	0.285	0.14	0.425
M12	14.01	17.49	5.61	21.00	0.770	0.770	0.285	0.14	0.425
M13	14.01	17.49	5.61	21.00	0.192	1.155	0.285	0.24	0.525
M14	14.01	17.49	5.61	21.00	0.385	1.155	0.285	0.30	0.585
M15	14.01	17.49	5.61	21.00	0.577	1.155	0.285	0.34	0.625
M16	14.01	17.49	5.61	21.00	0.770	1.155	0.285	0.42	0.705
M17	14.01	17.49	5.61	21.00	0.192	1.540	0.285	0.60	0.885
M18	14.01	17.49	5.61	21.00	0.385	1.540	0.285	0.70	0.985
M19	14.01	17.49	5.61	21.00	0.577	1.540	0.285	0.74	1.025
M20	14.01	17.49	5.61	21.00	0.770	1.540	0.285	0.80	1.085

3.4.2 Specimen Preparation

In the mixing process, all the dry material are mixed first for about 1-2 minutes in the concrete mixer (Figure 11), water and SP are combined together in one bucket and slowly added to the mixture to avoid sample coagulation. The mixing process will be conducted for about 5-10 min. Flow test were conducted to ensure the workability of all mixture are consistent, SP will be added if needed based on mixture workability. The sample is then will be placed inside an iron mould based on the required sample dimension (Figure 12) for about 24 hours before being removed and cured for 28 days inside a curing tank (Figure 13).

Figure 11.a

Figure 11.b

Figure 11: Concrete Mixer & Concrete Workability Test

Figure 12a Figure 12b

Figure 12: Concrete moulds used

Figure 13: Samples molded are cured for 28 days before testing

3.4.3 Workability Test

Workability is one of physical parameter for fresh concrete perfectly mix. It is useful indicator to determine the amount of internal work needed without bleeding or segregation. It is important to conduct this test because very significant effect on strength of concrete due to presence of void. However, ECC unlike normal concrete which has properties of self-compacting So, ECC must have require sufficient workability to achieve a possible density in order to achieve a good result on deformation properties of ECC, Flow table test is used to determine the workability of each sample prepared as shown in Figure14.

Figure 14: Flow table test to measure sample workability

3.5 STANDARD TEST METHOD FOR LENGTH CHANGE OF HARDENED HYDRAULIC-CEMENT MORTAR AND CONCRETE

This test was conducted to monitor the shrinking properties of ECC, the initial sample length are measured and compare with the final length after 28 days of curing, the percentage of shrinking is then calculated and analyze.

3.5.1 Scope

This test method covers the determination of the length changes that are produced by cause's other then externally applied forces and temperature changes of hardened hydraulic cement mortar and concrete specimens.

3.5.2 Test Specimens

The test specimen for this experiment is a prism of (25mm) square cross-section with approximately (285mm) in length. Three specimens are prepared for each mixture.

3.5.3 Procedure

The test was conducted using the procedure as follows:

3.5.3.1 Sample Mixing

i. All the materials used for mixing are place in environment with temperature of (18-24) Degree Celsius.

ii. The mixing process is conducted in a laboratory mixer in accordance of Practice C192/C 192M.

iii.

3.5.3.2 Molding Specimens

i. The sample is placed in the mold in approximately two equal layers. Each layer is compacted with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, the mortar flush is strike off using the top of the mold, the surface is smoothening by using trowel.(as shown in Figure 15)

3.5.3.3 Curing Specimens

i. The test specimens in the mold is cured inside a room and protected from dripping water.

ii. The specimens were removed from its mould after $23^{1/2}$ ± ½ hour after the addition of water during the mixing operation.

iii. The sample is then placed inside lime-saturated water for a minimum of 15 minutes before the initial comparator reading is taken.

iv. The specimen is then stored in the lime-saturated water until they reach the age of 28 days including the period in the molds

v. Final comparator reading is then taken.(as in Figure 16)

Figure 15: Shrinkage sample

Figure 16: The comparator used to measure change in sample length

3.6 TEST FOR STRAIN & STRESS ANALYSIS FOR CONCRETE UNDER COMPRESSION

There is no specific standard for Stress and Strain analysis, this test were conducted by installing strain gauge across 100 mm x 200 mm cylinders samples, this sample is then applied with compression load, the stress and strain data were recorded and tabulated

3.6.1 Scope

Determine the relationship between stress applied on ECC sample and the strain on the ECC sample

3.6.2 Test Specimen

Molded Cylindrical Specimens- Mold test cylinders is in accordance with the requirement for compression test specimens in Practice C192/C 192M (100mm x 200mm)

3.6.3 Procedure

A standard concrete in compression test will be conducted with the strain gage installed on the concrete sample as in Figure 17, the load applied and the strain will be measured simultaneously. The strain value will be recorded via a data logger as in Figure 18 and Figure 19, while the stress reading will be calculated from load distribution as in Figure 20. The result will be plotted to determine the strain-stress relationship between each sample mixture.

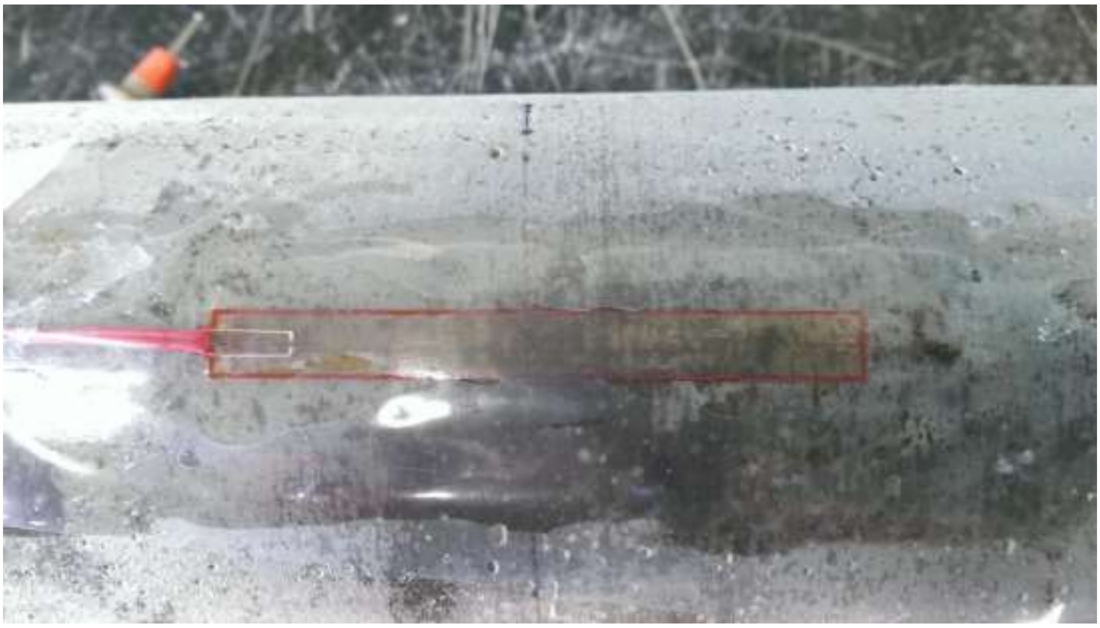

Figure 17: Strain Gauge installed on ECC sample

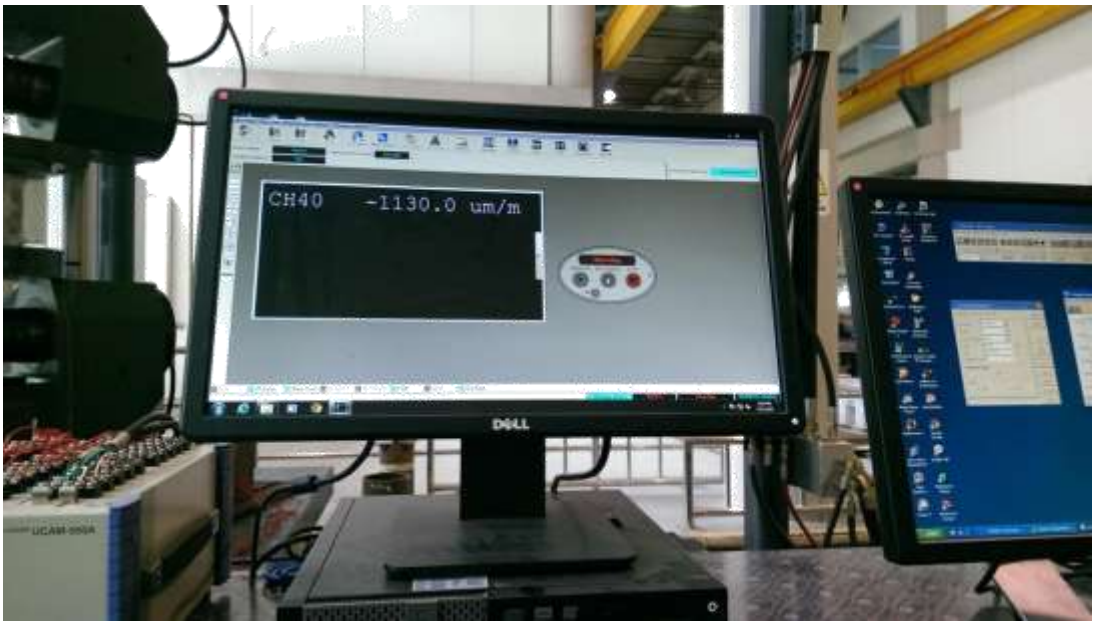

Figure 18: Strain reading is recorded via data logger

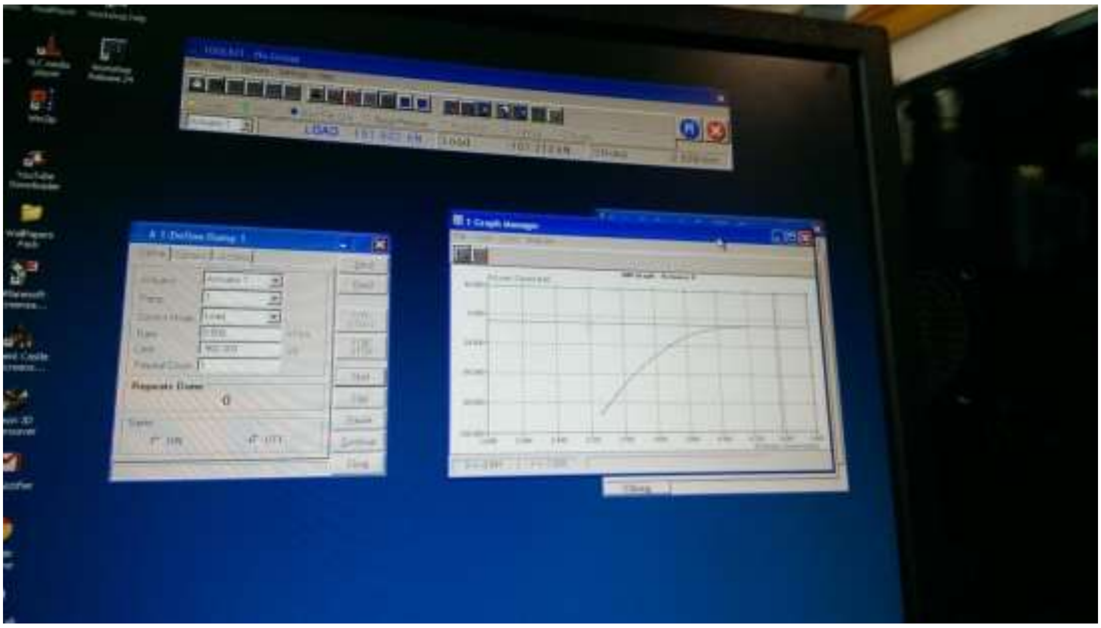

Figure 19: Load Distribution

Figure 20: The equipment used to test sample stress-strain behavior

CHAPTER 4: RESULT AND DISCUSSION

4.1 WORKABILITY

Engineered Cementitious Composite (ECC) is categorized as a type of Self Compacting Concrete (SCC) that known to have a self compacting behavior, for that reason the workability of ECC mixture is a major concern. For each mixture, a flow table test is conducted to test the mixing workability and if the workability is not sufficient, additional Super Plasticizer (SP) will be added into the mixture to increase the mixture workability. The uses of SP has become a common practices in concrete mixture to increase the mixture workability without increasing the water/cement ratio, The presence of SP will increase the mixing workability but at the same time will also increase the overall cost of mix, due to the expensive price of SP in the market. Table 3 is showing the amount of additional SP added into each mix.

Table 3: The additional SP used in ECC mix

Nano Silica (%)	**PVA Fiber**			
	0.50%	*1.00%*	*1.50%*	*2.00%*
	Additional SP(ml)			
0	0.000	0.000	0.000	0.040
1	0.040	0.060	0.080	0.090
2	0.180	0.120	0.140	0.160
3	0.160	0.160	0.200	0.220
4	0.600	0.700	0.720	0.760

In general, the workability of ECC mixture were affected by two main factors, the first one is the percentage of PVA Fiber used in the mixture and the second one is the amount of Nano Silica added into the mixture. From the graph shown in Figure 19, the additional SP needed in ECC mixture increase as the amount of PVA Fiber used is increasing, this is due to the physical properties of PVA Fiber that tend to reduce the material workability. The graph in Figure 19 were also showing.

While at the same time, the presence of nS in ECC mixture were also contributing to the decreasing of ECC mixture workability, this can be clearly seen on the amount of SP added in the mixture as in Figure 19. Nano Silica is known to be a Pozzolanic Materials and it reacts with Calcium Hydroxide form the Ordinary Portland Cement Chemical Reaction, this reduces the amount of water in the mixture and reduced the mixture workability. The workability decrease slowly as the amount of nS is increasing from 0% to 3, the ECC workability were significantly reduced at 4% of nS used, and for that about 2% (0.75L) of SP were added into the ECC mixture to improved the mixture workability, this amount is significantly high to be considered and the cost is too high to be practically applied for commercial used.

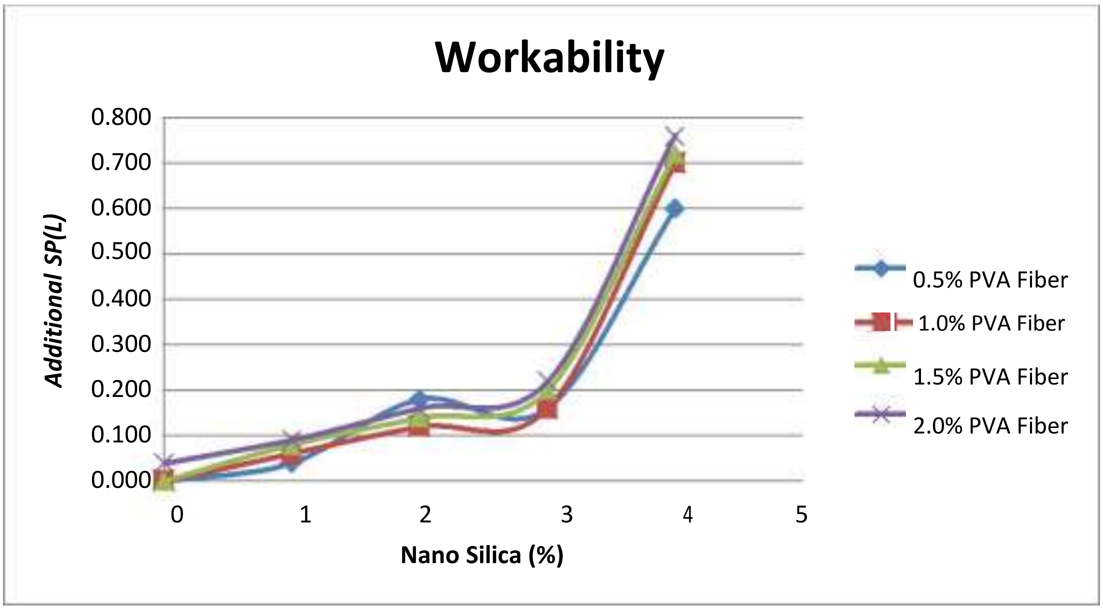

Figure 21: Workability of mixture based on additional SP

4.2 SHRINKAGE

In this study, the main focus is on the deformation properties of ECC with additional of nS and the relationship with the amount of PVA fiber uses. It is known that the uses of PVA Fiber in ECC is to enhance the bonding between cementitious material and other materials, and at the same time contributing ductile properties of ECC, the PVA Fiber will eliminate the microcrack that usually formed in a high cement content mixture.

While the Nano Silica are used to filled the pores between the ECC particle mixture, the ultra-fine size of Nano Silica are capable to fill the pores spaces and contribute to more dense mixture, but the usage of Nano Silica in the previous study were also reported will cause more drying shrinkage in the mixture. Thus, it is expected that the shrinkage percentage will be reduce as the percentage of PVA Fibers are increase, and the shrinkage percentage will be increase as the amount of Nano Silica used increased.

Table 4: Percentage of Shrinkage

Nano Silica (%)	**PVA Fiber**			
	0.50%	1.00%	1.50%	2.00%
	Shrinkage (%)			
0	0.031	0.026	0.020	0.024
1	0.052	0.044	0.042	0.038
2	0.074	0.060	0.058	0.050
3	0.080	0.074	0.062	0.058
4	0.082	0.078	0.070	0.068

The shrinkage test result in Table 4 are showing that the ultimate drying shrinkage were increasing with increasing amount of Nano Silica and decreasing with increasing amount of PVA Fiber. PVA Fiber contains hydroxyl groups (OH) which have the potential to form hydrogen bonds between molecules resulting in a significant change in surface bond strength between PVA fibers and the cement matrix. The Nano Silica properties seem to increase the cement hydration and lead to higher drying shrinkage in mixture.

From the graph plotted in Figure 20 below, it can be seen that the addition of 4% nS into ECC mixture increase the Shrinkage percentage from 0.03%-0.08% for mixture with 0.5% of PVA Fiber, 0.025%-0.078% for mixture with 1.0% of PVA Fiber, 0.02%-0.07% for mixture with 1.5% of PVA Fiber and 0.024%-0.068% for mixture with 2% of nS.

The previous study was showing that the normal concrete were having 0.04%-0.06% of Ultimate Drying Shrinkage at 20^{O}C and 60% relative humidity.

While for normal ECC mixture, the ultimate drying shrinkage was higher with magnitude of 0.12%- 0.18% under the same condition. (Zhang, Gao, & Wang, 2013). The results gained in this study were showing different shrinkage range that maybe due to the differences in room temperature and humidity.

The highest shrinkage percentage is for sample with 0.5% PVA Fiber and 4% nS with shrinkage value of 0.082% and the lowest shrinkage value is for sample with 1.5%PVA Fiber and 0% of nS.

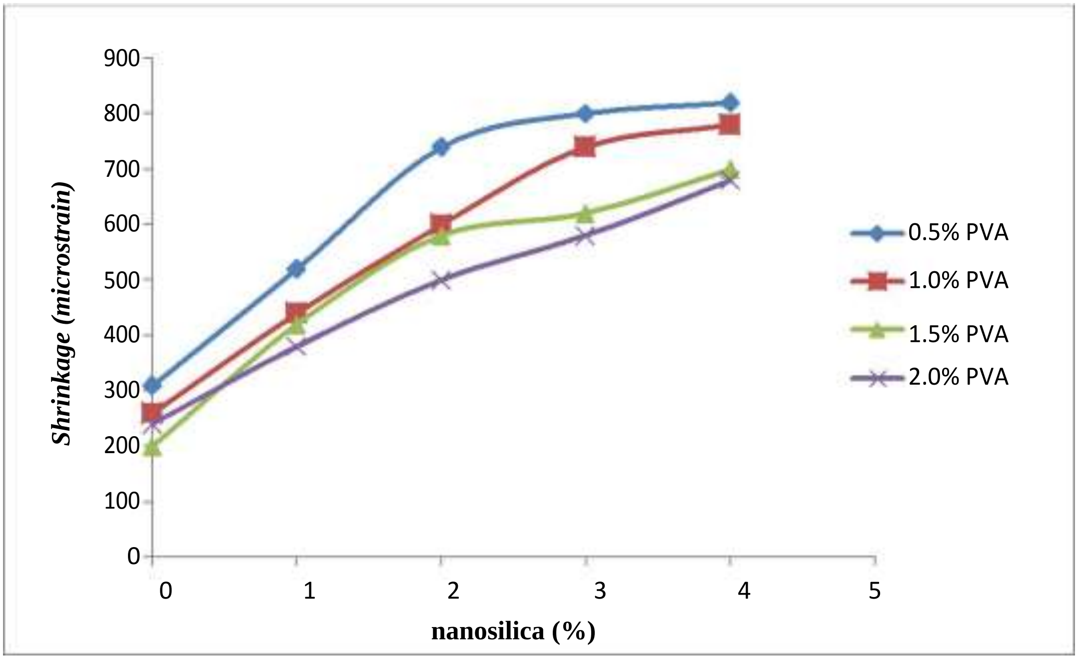

Figure 22: ECC Ultimate Drying Shrinkage

4.3 STRESS & STRAIN BEHAVIOUR

To determine the stress-strain behavior of each ECC mixture, a compression test has been conducted as shown in Figure 23, strain gauge has been installed on each sample before being tested. Both the stress applied and the strains are recorded using data logger. From the result obtained, the compressive strength of ECC mixture are recorded and monitored. The Ultimate Strength of ECC are decreasing with increment of PVA Fiber starting from 0.5% of PVA Fiber to 2.0% of PVA Fiber, while with the presence of nS in the mixture, the Ultimate Strength of ECC are increasing at first when up to 2% of nS has been used and the Ultimate Strength has been slightly decrease when the amount of nS used reached 3.0 % and 4.0 %.

The compressive strength of ECC samples was in a range of 50.0 MPa to 78.8 MPa this variation were result from the variation of percentage of PVA Fiber and also percentage of nS used in the mixture. According to M. Șahraman et al. (2009) mentioned that compressive strength for more than 40 MPa were enough to use in structural application to support loading. The compressive strength depends on two variables of PVA fiber content and nano silica content.

It is known that the increasing of PVA Fiber will decrease the strength of ECC mixture, the maximum amount of PVA Fiber is stated to be at 2% for ECC mixture, excessive amount of PVA Fiber used will change the ECC self healing properties. While, the nS were seem to be able to fill all the pores left behind in the ECC mixture, the Pozzolanic reaction seem to be able to improve the cementitious matrix bonding and the effective amount of nS to be used in ECC mixture is about 2%, excessive usage will then again reduce the strength of ECC samples due to clogging of pores inside the ECC mixture due to excessive amount of filler material.

Table 5: Samples Ultimate Strength &Maximum Strain

Nano Silica (%)	PVA Fiber (%)	Ultimate Strength (Mpa)	Maximum Strain (μm/m)
0%	**0.50%**	59.40	2300
	1.00%	56.30	2420
	1.50%	52.70	2450
	2.00%	50.00	2500
1%	**0.50%**	65.00	2400
	1.00%	63.00	2500
	1.50%	59.70	2550
	2.00%	56.00	2600
2%	**0.50%**	78.80	2500
	1.00%	75.90	2580
	1.50%	73.00	2670
	2.00%	69.80	2700
3%	**0.50%**	75.40	2600
	1.00%	69.80	2700
	1.50%	65.00	2750
	2.00%	62.00	2750
4%	**0.50%**	69.00	2500
	1.00%	63.20	2600
	1.50%	62.20	2660
	2.00%	48.50	2690

While for strain, as expected the usages of PVA Fiber in the mixture were resulting in increasing the strain capacity. PVA Fiber that is known to have elastic behavior increase the ECC samples strain capacity and the strain capacity increment made were in a range of 10% for samples with 0.5% PVA and 2.0% PVA for same amount of nS.

The strain capacity were showing some variation when the percentage of nS used varied, the strain capacity increase when percentage of nS used are from 1-3% and started to decrease when percentage of nS reaching 3% and 4%.

The result in Table 5 were showing that the maximum strain capacity of ECC samples were 2750μm/m for ECC samples with 3% of nS and 2% of PVA Fiber. While the minimum strain capacity are 1920μm/m for ECC samples with 0.5% PFA Fiber and 0% of nS.

Figure 23: Samples Compression Test

Stress-Strain is a unique relationship that represents how the material behaves when subjected to load. Each material will have different stress-strain curve relationship that represents how material deforms when subjected to load. From the shape of the curved it is possible to determine the general characteristic of the material, the most two common types of materials are brittle material and also ductile material. Figure 24 is showing the typical shape of stress-strain curved on aggregate, Concrete and also Cement Paste.

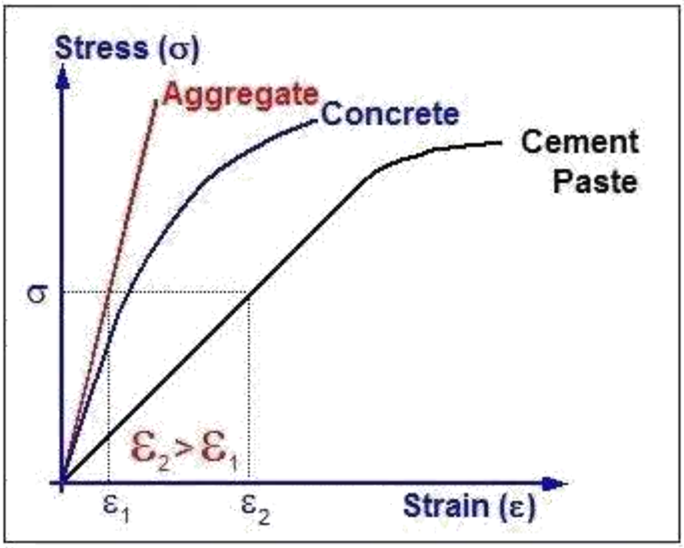

Figure 24: Typical Stress-Strain Curve

In the compression test conducted, all the samples are subjected with load and the data of stress and strain were collected individually, four graphs are being tabulated as in Figure below to show the variation of Stress and Strain curve.

In general, the presence of Nano Silica in ECC mixture does not significantly change the stress-strain behavior of ECC. From the graph constructed below, all the samples curved save similar shape, which mean they behave similarly. ECC tend to have a linear curve before started to have defection after reaching the ultimate strength. This is showing that the ECC have a capability to deform when stress is applied and posses the ductile properties compared to other concrete that mostly having brittle properties. The present of Nano Silica in the ECC mixture were clearly changing the ECC mixture in term of Ultimate Strength and the Maximum Strain as explained before.

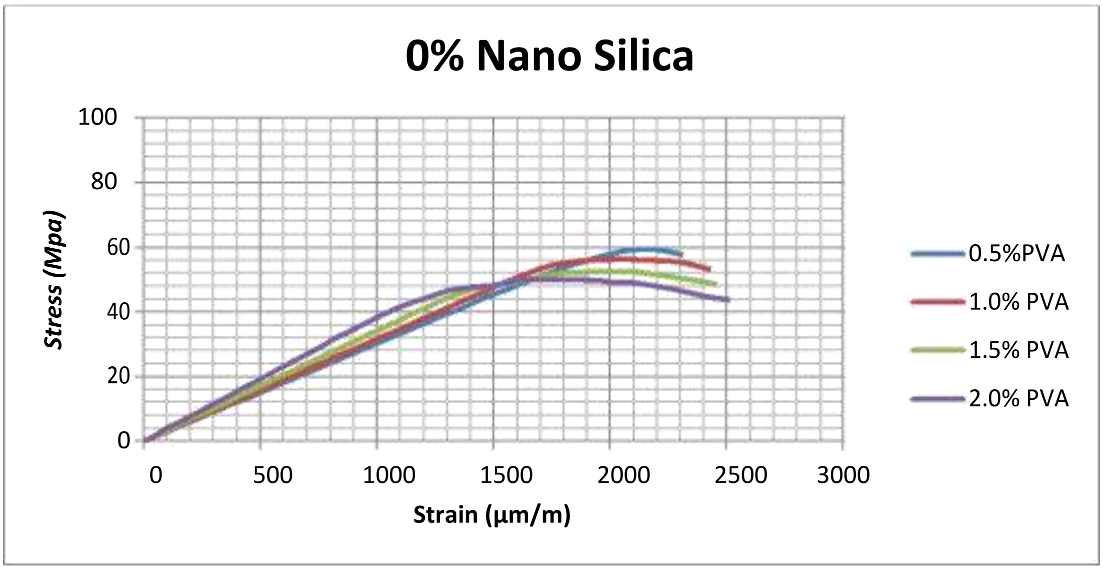

Figure 25: Stress-Strain Relationship for samples with 0% of nS

The first graphs in Figure 26 were showing the stress-strain curved for conventional ECC samples (0% nS). The steepness of the graph slopes before the samples reaching the ultimate strength were increasing slowly as the amount of PVA Fiber used was increased from 0.5% to 2.0%. This indicate the increasing in amount of PVA Fiber used actually turn the properties of ECC to become more brittle instead of making the samples more ductile and also reducing the ultimate strength of ECC samples , but at the same time increasing the strain capacity. As the amount of PVA Fiber increase from 0.5% up to 2.0%, the Ultimate Strength were decreasing from 59.40MPa to 50MPa and the strain capacity were increase from 2300µm/m to 2500µm/m.

The stress-strain curved for this mixture will be the reference to compare with other stress-strain curved constructed with the presence of nS as cementitious filler material in the mixture.

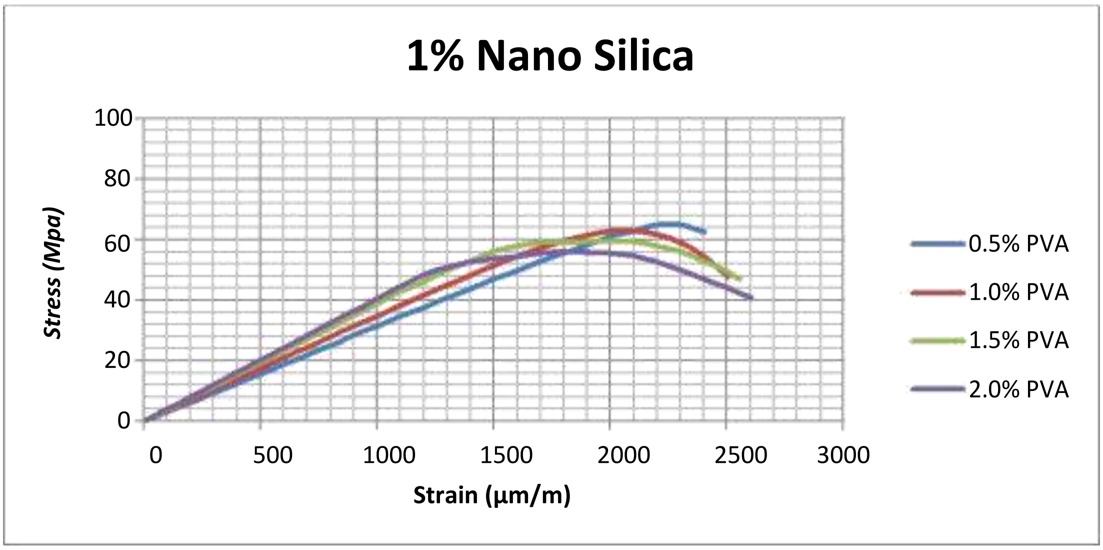

Figure 26: Stress-Strain Relationship for samples with 1% of nS

While in Figure 27, it is showing the Stress-Strain curved for ECC mixture with the lowest amount of nS. In general, the presence of 1% of Nano Silica does not changing the stress-strain behavior of ECC mixture, this could be seen from the shape of stress-strain curved in Figure 26 and Figure 27, both of these graphs are showing similar pattern. The presence of 1.0% of nS seem to be slightly increasing the ECC mixture strain capacity and also the ECC ultimate strength compared to conventional ECC mixture in Figure 26, this mean that at a percentage of 1%, Nano Silica has started to fill the pores inside ECC mixture and started to improved the ECC ultimate strength and also the strain capacity.

In comparison with ECC samples with 0% of nS, the strain capacity for mixture with 0.5% PVA Fiber increased from 2300 µm/m to 2400 µm/m, while for 1.0% PVA Fiber the strain capacity increased from 2420 µm/m to 2500 µm/m, the same goes to samples with 1.5% and 2.0% PVA Fiber, the strain capacity were increased from 2450 µm/m to 2550 µm/m and from 2500 µm/m to 2600 µm/m. While the ultimate strength were increased from 59.40MPa to 65.00MPa, 56.3MPa to 63.0MPa, 52.7MPa to 59.70MPa and 50MPa to 56.0MPa for samples with 0.5% PVA Fiber, 1.0% PVA Fiber, 1.5% PVA Fiber and lastly 2.0% PVA Fiber.

The same effects of PVA Fiber could be noticed in the curved, as the amounts of PVA Fiber were increased from 0.5% to 2.0%, the Ultimate Strength of samples has been slightly decrease and the strain capacity were showing some increment.

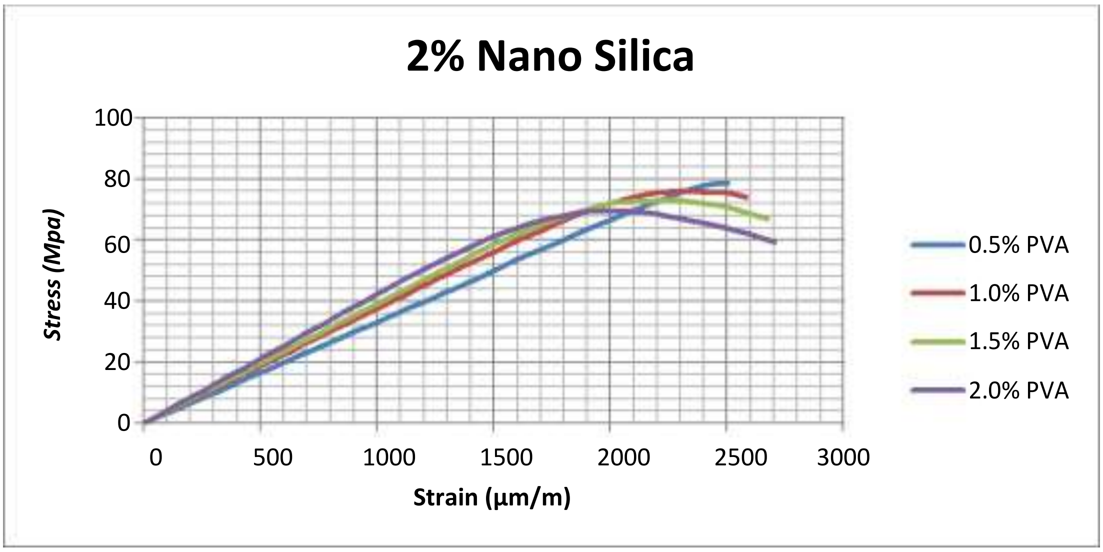

Figure 27: Stress-Strain Relationship for samples with 2% of nS

The third graph in *Figure 28* was showing the variation of stress-strain curved for ECC samples with addition of 2% of Nano Silica. In general, again at 2.0% of nS does not changing the stress-strain behavior of ECC mixture, the graph patterns does not changing compared to the ECC samples without nS in Figure 26. The increment of PVA Fiber also has showing the same impact as in previous mixture.

At 2.0% of nS the ECC samples has showing the highest Ultimate Strength with 78.80MPa, in comparison with the conventional ECC samples the Ultimate Strength has increase from 59.40 MPa, the Ultimate Strength increment were about 32.65%. The increment were a result of nS as the cementitious filler material inside ECC samples, at 2% of nS it seem to be the ideal amount to fill all the pores inside the ECC mixture and improves the cementitious bonding between particles inside ECC samples.

While at the same time, the strain capacity were also showing the same patterns of increment compared to the previous ECC samples with a lower amount of nS.

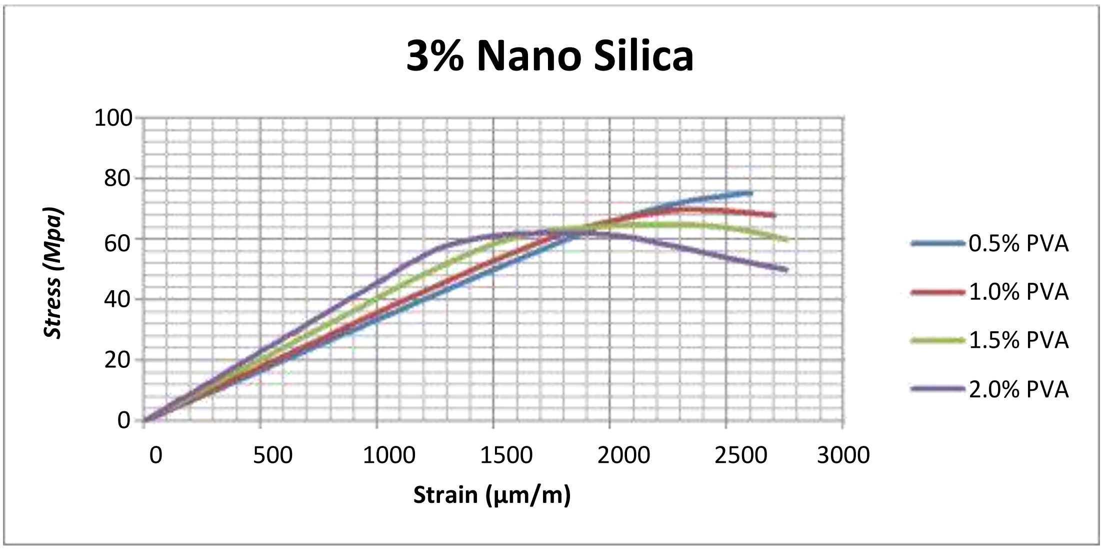

Figure 28: Stress-Strain relationship for samples with 3% of nS

The fourth graph in *Figure 29* was showing the stress-strain variation for ECC samples with 3% of Nano Silica addition. First of all, since 2.0% of nS seem to be the ideal amount of nS to be used, at 3.0% the nS seem to be in excess amount. The excess amount of filler materials has result in clogging inside the pores and reducing the cementitious matrix performance and at the same time started to affecting the performance of ECC mixture. From the graph obtained in figure 29, we could see slightly decrement in the ultimate strength of ECC samples compared with the previous samples. The ultimate strength were decreasing from 78.80MPa to 75.4MPa, 75.90MPa to 69.80MPa, 73.0MPa to 65.0MPa, and 69.8MPa to 62.0MPa for samples with 0.5%PVA Fiber, 1.0%PVA Fiber, 1.5% PVA Fiber and 2.0% PVA Fiber.

While at the same time, the effect of PVA Fiber were still remain the same as in the previous ECC samples.

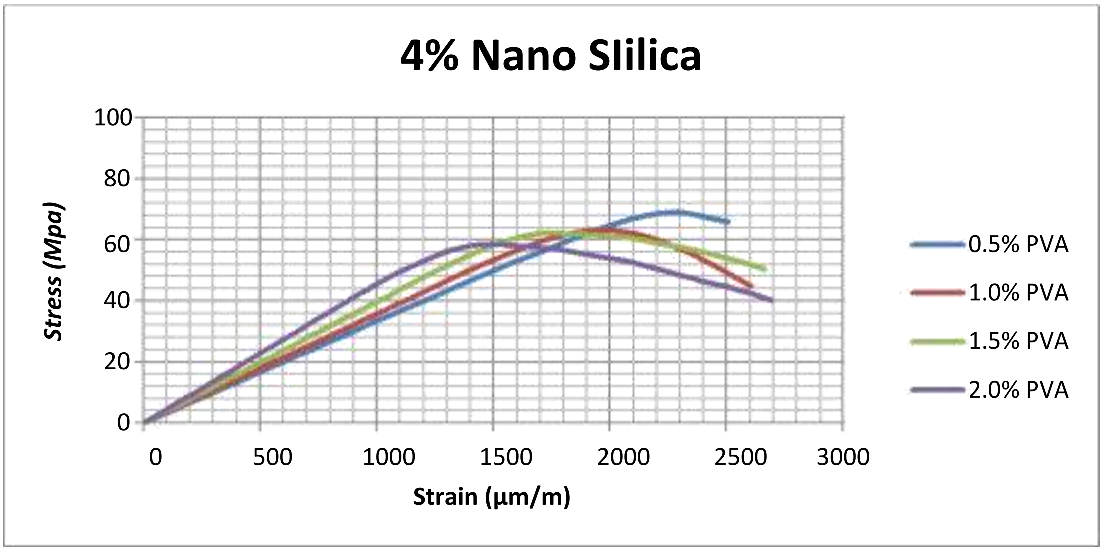

Figure 29: Stress-Strain relationship for samples with 4% of nS

The last graph constructed was showing the variation of stress-strain curve for ECC mixture with the maximum of 4.0% of Nano Silica. The result was as expected, the presence of nS as the filler material in excess amount will cause clogging inside the pores and reducing the performance of cementitious matrix bonding.

From the result obtained there has been slightly decrement in term of Ultimate Strength and also Strain capacity of ECC mixture compared to the previous ECC mixture with 3% of nS as the filler material.

4.5 MODULUS ELASTICITY

In this study, the samples Modulus Elasticity (ME) were calculated at 30% of the ultimate strength of ECC samples from the Stress-Strain curved constructed in the Compression Test. The ME represent the characteristics of a material, it is one of the common method to determine the properties of materials, the ME of concrete mixture depending on the constituents materials and also the amount that being used in the mixture. In ECC itself, the modification that has been made to replace the usage of course aggregate with PVA Fiber is in order to reduce the ME of ECC samples, the presence of course aggregate will contribute to higher value of ME and turn it to be more brittle.

In general, we could see from Figure 31 that the increasing of PVA Fiber has clearly contributing to a higher amount of ME in the mixture, we can say that this is because PVA Fiber is the constituents material that having the highest ME value in the mixture with 42.8GPa. This explained why the presence of more PVA Fiber has significant impact in increase the ME of ECC mixture.

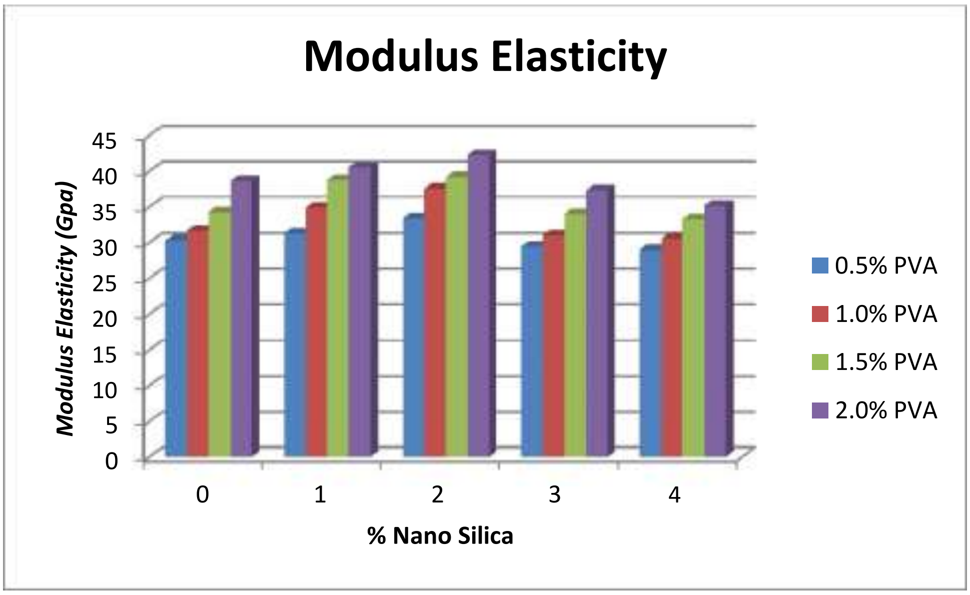

Figure 30: Modulus Elasticity of ECC samples

While, the same pattern of ME variation were observed with the increment of nS in the mixture. The presence of nS that acts as a cementitious filler material in the ECC mixture fill the pores inside ECC mixture, this producing a denser ECC mixture compared to the mixture without nS. We can see that the ME were increasing as the amount of nS is increasing till the ideal of 2.0% of nS and the value of ME started to slightly decrease as the amount of nS used reaching 3.0% and also 4.0%.

CHAPTER 5: CONCLUSION

Engineered cementitious composite (ECC) were known to have excellent properties in durability and ductility. In this study, Nano Silica has been used in the ECC mixture as a filler & cementitious material to improve the particles bonding inside ECC mixture and at the same time improving the material deformation properties. The deformation properties of ECC were determined by measuring the Ultimate Drying Shrinkage, The Modulus Elasticity and Stress-Strain behavior of 20 samples of ECC mixture that were prepared by varying the amount of PVA Fiber and Nano Silica.

The ideal amount of nS in ECC is at 2.0%, at this amount nS could properly fill the pores in ECC mixture and improves the cementitious matrix bonding. Thus, resulting in high value of Ultimate Strength and Modulus Elasticity. As the amount of nS were increased up to 3.0% and 4.0%, the excessive amount of nS were causing clogging in the pores inside ECC mixture and this causing slightly dropping in the performance of ECC.

The presence of nS in ECC mixture improved deformation properties of ECC, beyond 2% nS, there was decline in performance of ECC which was caused by clogging of excess nS.

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