INVESTIGATION OF THE CONCRETE SHRINKAGE USING AN EMBEDDED LONG PERIOD FIBER GRATINGS (LPFGs)

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SEPTEMBER 2015

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATION OF THE CONCRETE SHRINKAGE USING AN EMBEDDED LONG PERIOD FIBER GRATINGS (LPFGs)"** was prepared by **WONG SU KHEN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _________________________

Supervisor : Mr. Daniel Yong Yun Thung

Date : _________________________

Specially dedicated to

my beloved grandmother, mother and father

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Mr. Daniel Yong Yun Thung for his valuable advice, guidance and his enormous patience during the planning and development of the research work. Besides, Mr. Daniel always giving some idea for my final year project and discuss together when face some problem and find out the solution.

Moreover, I will take this opportunity to thanks for Dr. Kwan Wai Hoe which help to complete my final year project on how to use the Demec Strain Gauge equipment and plot the graph according to the data collected.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement to complete this final year project. They always give some moral support and financial support in order to complete my final year project.

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ABSTRACT

Measurement of concrete shrinkage is an important parameter for civil industry to ensure that the structure of concrete is capable to support the building requirements. In this project, some research works carried out to investigate of the concrete shrinkage using an embedded Long Period Fiber Gratings (LPFGs). A LPFGs will be used in this project in order to provide an alternative way to measure concrete shrinkage as comparing with the conventional way to measure concrete shrinkage which using strain gauge. By using LPFGs to measure concrete shrinkage might be a better way as compared with conventional way. The main advantage of this method is LPFG embedded inside the concrete which can detect the shrinkage changes internally. Apart from that, LPFG can measure the concrete shrinkage start from liquid state as nowadays there is no technology is able to measure the concrete shrinkage in liquid state. In this study, the main focus is how to measure the concrete shrinkage by using LPFG as a sensor.

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CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 History of Long Period Fiber Gratings

Fiber grating is one of the most widely used devices that in optical communication and optical fiber sensing. In the communication field, it performs the operation such as wavelength-selective filtering, optical switching and other function, where for optical sensing, it mostly used in temperature sensing, pressure sensor, refractive index and as a chemical mixture sensor. The reason why optical fiber is widely used because of its immune to electromagnetic interference, resistance to corrosion, sensitivity high and low attenuation.

According to Vengsarkar A M, Lemaire P J, Judkins J B, Bhatia V, Erdogan T and Sipe J E 1996, the Long Period Fiber Gratings were invented in mid-1990s. The period of LPFG in an optical fiber was about 200-500 µm by James S W and Tatam R P in 2003. The journal written by Professor Benjamin J. Eggleton stated that the LPFG technology has been introduce in 1996. The structure of the LPFG is based on the coupling co-propagating modes. This concept come from a textbook, Amnon Yariv that he had been discover for many years on the integrated waveguide structures. As implemented in LPFG, it provides phase matching between core guided modes and co- propagated modes in the cladding region.

There is another groups of researcher where they found a similar type of LPFG structure before Vengsarkar paper. This groups of people found that by changing the mode from lower mode to a higher order mode will occurs "core guided" mode. Furthermore, from Vengsarkar paper, it also described the LPFG sensitivity to temperature and strain.

Therefore, there are many methods or techniques available to fabricate Long Period Fiber Gratings (LPFGs) including laser writing, ultraviolet (UV) irradiation, periodic relaxation of residual stress, mechanical deformation, microbending and electric arcing. The fabrication through UV irradiation was widely used to fabricate LPFG as compared with other method, but the refractive index changed inside an optical fiber and it can only sustain in low temperature. Thus the fiber that fabricated through UV was not suitable for high temperature application.

1.2 Aims and Objectives

The aims for this Final Year Project is to investigate an alternative method to monitoring the concrete shrinkage. In this project, we will using Long Period Fiber Gratings (LPFGs) as a sensor to monitor the shrinkage.

The objective for the thesis are shown in the following:

i) To study the fabrication method of Long Period Fiber Gratings (LPFGs).
ii) To fabricate the Long Period Fiber Gratings (LPFGs) for an application as strain gauge detection on concrete.
iii) The comparison of sensing performance between conventional way and Long Period Fiber Gratings (LPFGs).

1.3 Problem Statement

Many man-made building structure in the world are made of concrete. It is widely used for making architectural structure, bridges, roads and etc. Concrete is composed of water, cement and aggregate. Aggregate is generally coarse gravel or crushed rocks such as limestone or granite. Cement is composed of a combination of calcium, silicon, aluminum, iron and small amounts of other materials. The most common cement used for today is Portland cement.

Thus, many civil or construction engineering is using the convention way to measure the concrete shrinkage which is strain gauge. Strain gauge is used to measuring the drying shrinkage of concrete autoclave expansion of Portland cement and potential expansive reactivity of cement aggregate combinations in mortar bars during storage on self-drying. As using strain gauge to measure concrete shrinkage, the problem face is every time we take and measure the mould, it is not always the same point we measure before. Apart from this, using strain gauge to measure the shrinkage, it cannot be real time monitoring as the shrinkage was measure by manually. Due to this reason, I have proposed another way to measure it which using long period fiber gratings (LPFG) as a sensor to measure the concrete shrinkage. As we will embedded the LPFG in the middle of the mould and measure its shrinkage.

CHAPTER 2

LITERATURE REVIEW

2.1 Fabrication of Long Period Fiber Grating Using a Tilted Amplitude Mask in a Flexible Fabrication.

Long Period Fiber Grating were couple the core mode and cladding modes propagating at certain resonant wavelengths. It can act as attenuating filters for gain equalization of erbium-doped fiber amplifiers without reflection. In order to fabricate LPFG for gain equalization, the gain peak was controlled by the resonant wavelength whereas the sensitivity was depend on the order of cladding modes. Thus, the selected wavelength must be in the range of interrogation system and the most important in LPFG fabrication was the tuning process.

In the experiment, the fiber was irradiated vertically with UV-laser (KrF excimer laser) beam through an amplitude mask. The grating period was cause by angle ϴ. The resonant wavelengths given by

$$\lambda_c^m = \Lambda_a \cos\Theta\,(n_{core} - n_{clad}^m).$$

The n_{core} is the effective index for the core mode and n_{clad}^m is the effective index for $LP_{0,1+m}$ for cladding mode. The parameter for the amplitude mask had period of 460 µm, effective area of 20 x 5 mm^2 and a total size of 40 x 24 mm^2. The grating can be fixed as 14 mm when the slit was place before the amplitude mask and this require no using of lens. Before started, the energy density was 0.07 J/cm^2 per pulse with rate 20 Hz. The optical fiber used was single mode fiber with 1.3 µm, diameter 9.3 µm and cut-off wavelength of 1.19 µm. A pressure of 100 atm was performed for hydrogen loading at room temperature. The figure below show how the fiber was fabricated.

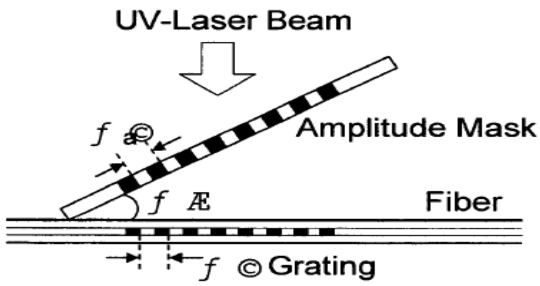


Figure 2.1.1: The Fabrication of LPFG using titled amplitude mask (Toru Mizunami, n.d.).

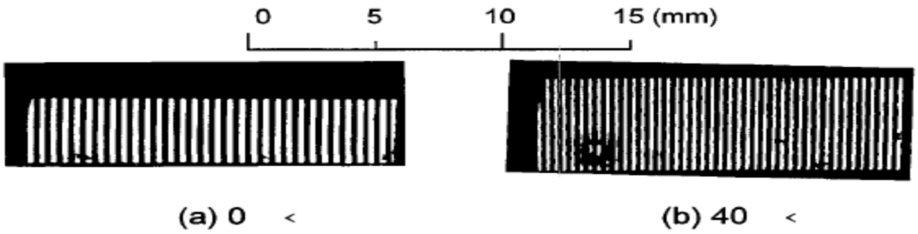


Figure 2.1.2: The burned patterns of laser beams through a titled amplitude mask (Toru Mizunami, n.d.).

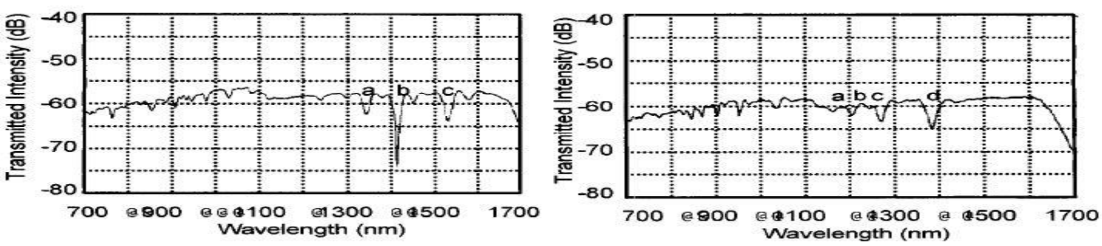


Figure 2.1.3: LPFG fabrication without amplitude mask show on left and with amplitude mask on right (Toru Mizunami, n.d.).

The figure 2.1.3 (left) above is the results without using tilt. From the graph, three loss peak occur and its wavelength were 1344.8, 1415.5, 1532.8 nm for peaks ‘a’, ‘b’, ‘c’ respectively. Besides the graph shows that the exposure time from 5 to 15 minutes has caused the wavelength increase linearly and loss increase until 17 dB then decrease. As for figure 2.3 (right) with tilt angle of 40 ° from the graph four peaks was observed which were 186, 212, 264 and 1382.8 nm for ‘a’ to ‘d’.

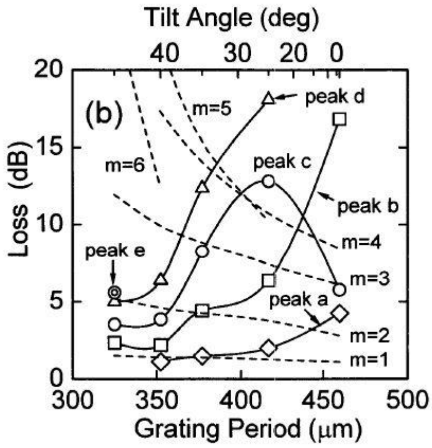


Figure 2.1.4 : Dependence of loss on grating period and a tilt angle of amplitude mask (Toru Mizunami, n.d.).

The figure 2.1.4 shows that if the angles more than 40 °, the losses were less than 10 dB. This conclude that decreasing of the grating period will affect the losses increase, the reason behind this was when the grating length constant, the number of index modulation increases.

Therefore, LPFG can be fabricated at tuning range of 329 nm by changing the tilt angle of an amplitude mask. The exposure time increase for angle exceeding 35 ° can obtain a transmission loss more than 10 dB at any wavelength.

2.2 Highly Sensitive Temperature-Independent Strain Based on a Long Period Fiber Grating with CO^2 Laser Engraved Rotary Structure.

Long Period Fiber Gratings (LPFG) had been widely used in band-rejection filters, fiber amplifier gain equalizers, optical fiber communications and also sensors such as temperature, strain, torsion and refractive index. As the LPFG fabricate by ultra-violet, it have been reported their strain sensitivity (~0.0015 nm/μƐ) was low. On the other hand, fabrication of LPFG with CO^2-laser pulses, the strain sensitivity had increase to 0.12 nm/μƐ which in the range from 0 to100 μƐ. Therefore a new fabrication method had been found which consist of rotary grooves with carved by high frequency CO^2 laser pulses.

The experiment setup for the LPFG fabrication shown below:

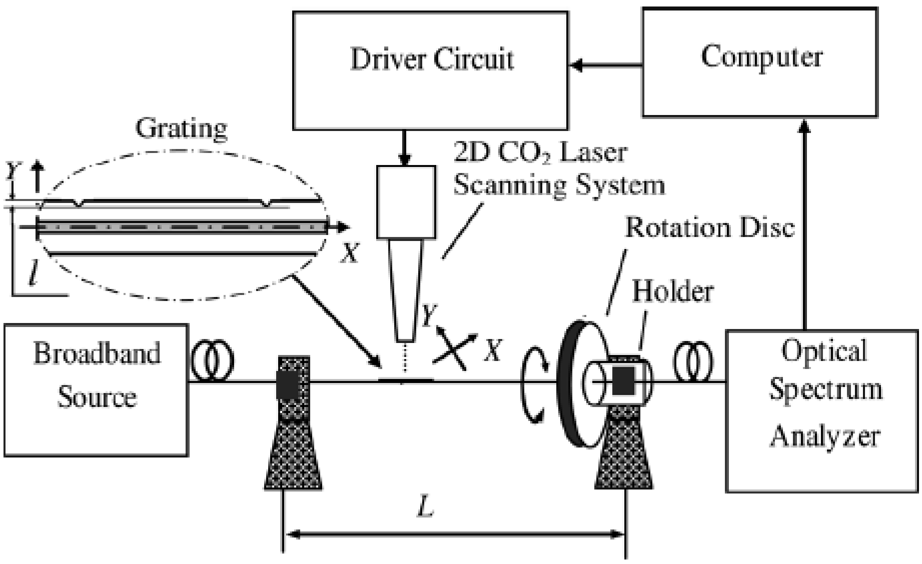


Figure 2.2.1: The experiment setup for the fabrication of LPFG (Tao Zhu, April 15, 2009).

Figure 2.2.1 above show the experiment setup for the fabrication of LPFG with rotary grooves by using high frequency CO^2 laser pulses. A fiber (SMF-28) with L=20 cm was mounted its two ends and fixed at the two holder, one near the broadband source another one to rotation disc. The fiber was focused by the laser beam at a spot of ~100 μm in diameter along the fiber. The laser beam scanned across the fiber to a depth of 10-35 μm in each step and this step was equal to the grating period. After the scanning process complete, the fiber will name as T-LPFG because the fiber was under twisting condition. The fabrication process was fully controlled by computer and after the fiber untwisted, the fiber will name as G-R-LPFG. The main different of this type of fabrication that the laser power is less than 0.4 W compare with other method is more than 0.8 W.

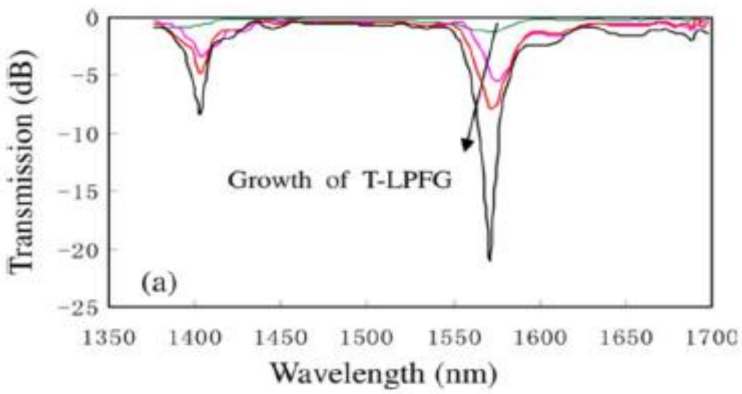


Figure 2.2.2: Growth of the resonance peak of T-LPFG as the number of scanning cycles increase (Tao Zhu, April 15, 2009).

As from the graph above, it was the notch of the T-LPFG for the grating. Besides the notch shifted as the number of scanning cycles increase.

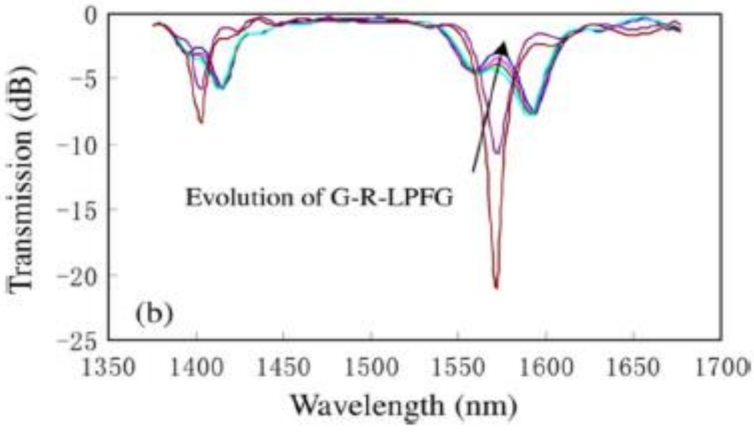


Figure 2.2.3: Evolution of transmission of G-R-LPFG after the torsion released (Tao Zhu, April 15, 2009).

This graph shows the fiber after untwisted, the two original notch of T-LPFG was split into two.

2.3 Loop effect on Long Period Fiber Gratings Produced by electric arc.

In this article, it was explaining how the LPG was fabricate by using electric arc. The reason using this method because it was simple, low cost, harmless compare with other technique like UV irradiation. The figure below show the schematic diagram of the LPGs. The function of cladding was give protection for the core and the grating period was Λ.

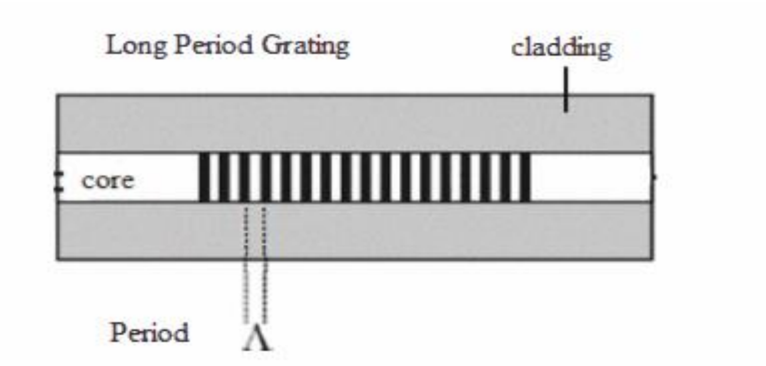


Figure 2.3.1: LPG schematic diagram (J.M. Estudillo-Ayala, 2011).

The grating period happen when an arc discharge was applied at several point with same distance. There was external motor to take controlled the electric arc and a fixed weight was attached on the opposite end of the fiber to keep it under tension during fabrication. The experiment setup for the electric arcing was show below.

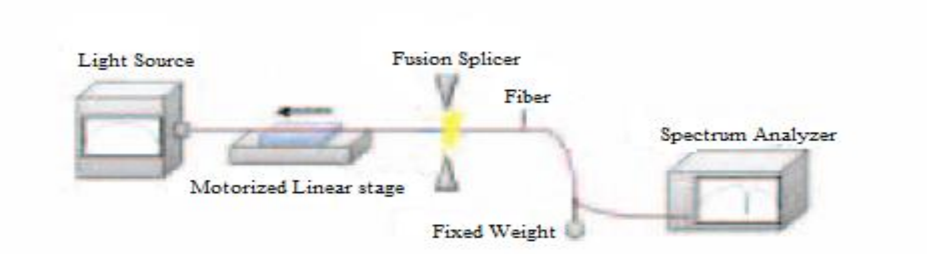


Figure 2.3.2: Experiment setup for the fabrication of LPG (J.M. Estudillo-Ayala, 2011).

The figure shows how the LPG fabricated which the results of success or fail can see from spectrum analyzer to see for its grating and the high notch will occur. The grating of the fiber can be controlled by changing its parameter which were electric current, arc duration, and the weight applied that pull the fiber.

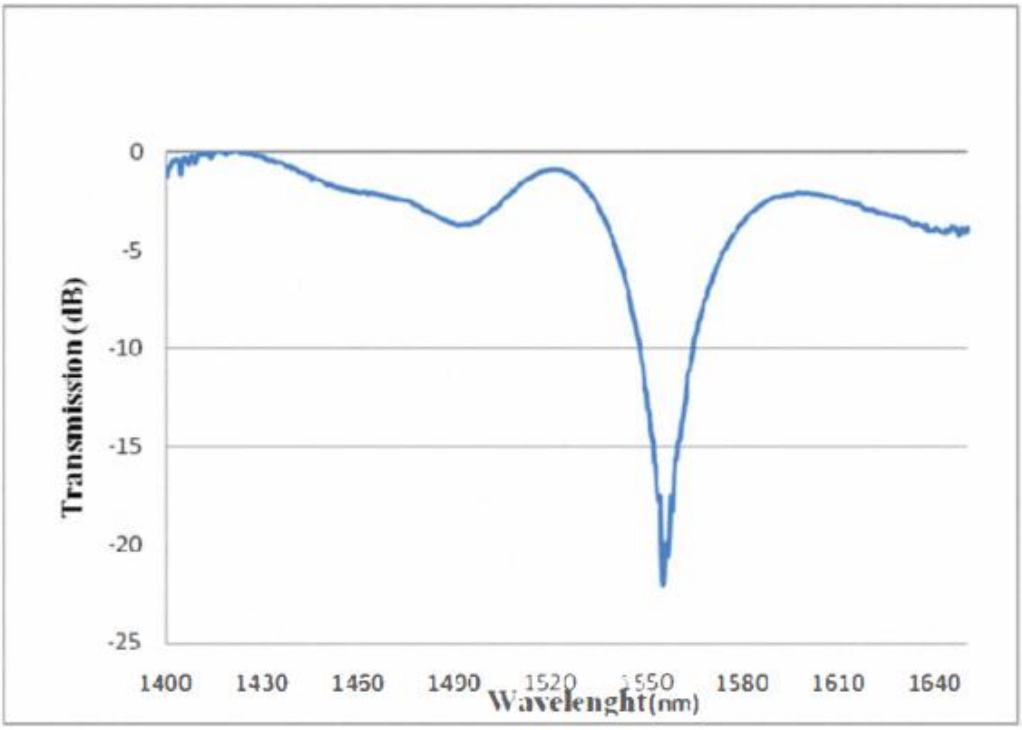


Figure 2.3.3: Transmission spectrum of a LPFG with period (Λ) of 628 nm with center of band-rejection at 1555 nm (J.M. Estudillo-Ayala, 2011).

The mode propagation in the core of the fiber and forward-propagation cladding mode for phase matching was achieved at the wavelength, λ.

$$\lambda = \Lambda(n_{eff(\lambda)} - n^{i}_{clad(\lambda)})$$

Λ was the period of the LPFG, $n_{eff(\lambda)}$ was the effective refractive index of propagating core and the refractive index of the *i*th cladding mode was $n^{i}_{clad(\lambda)}$.

2.4 Development and Longer Term In Situ Evaluation of Fiber Optic Sensors for Monitoring of Structure Concrete.

The uses of fiber optic was continue develop in many way such as amplitude filter, band-rejection and also as a sensor. Fiber optic also takes place in monitoring the pouring of the concrete to form the structure. This application of fiber optic on monitoring concrete had be take serious to new, existing structures and specially structures of the 1960s era but the in situ concept was not consider to use. As many problem arising, there was needed these monitoring to develop a plan maintenance schedule to monitoring the structural.

The first application of the fiber optic was temperature sensors. This design call itself “tried and tested” device, it was for conventional industrial monitoring application. The temperature sensor design was to gain experience of embedding and evaluating single-ended probe-type FOSs in the concrete itself. Besides it also help in collecting temperature data by monitoring the temperature over time.

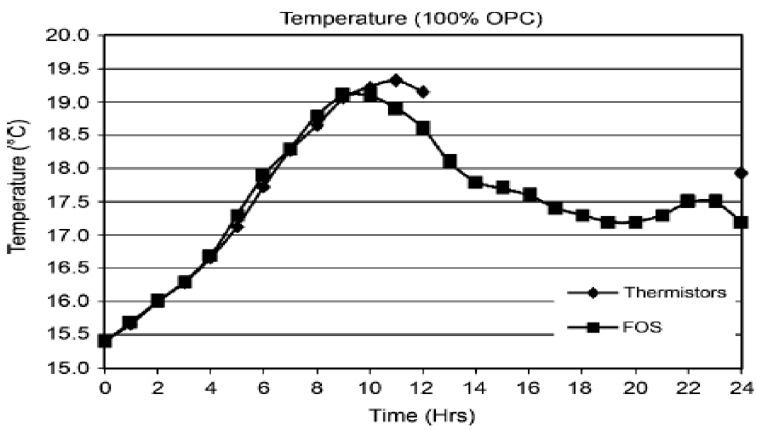


Figure 2.4.1: Temperature monitoring using both FOS and thermistor devices, showing heating during the curing process and a subsequent falloff of temperature (Daniel O. McPolin, November 2009).

This was the results get as monitored by one of the two FOSs over the first 24 hours period. From the graph we can observed that temperature rise at the beginning due to the hydration reaction of the cement. The temperature keep varying after 12 hours where from 15.5 ℃ to 19 ℃. After 12 hours, as the reaction of hydration slow the temperature start decreasing.

2.5 Early Age Autogenous Shrinkage of Concrete.

Concrete shrinkage were divide into many part which were drying shrinkage, autogenous shrinkage, plastic shrinkage and etc. From time to time, the shrinkage induces cracking and lead to short life for the concrete. Autogenous shrinkage was related to the change in volume of a concrete without moisture transfer to the environment. It was the relationship between chemical and structural reactions which this was not take as serious in the past. Recently, with the increasing use of high performance concrete they start reconsider autogenous as the mixtures use was "special" cements, multiple admixtures and less of water will be used. Mostly autogenous shrinkage were more focus in high performance and strength of concrete (>40 MPa or 6000 psi). Therefore, concrete shrinkage was the most important in the early age as it responsible for cracking if the concrete not gained sufficient of strength to withstand the load.

Two distinct stage for autogenous shrinkage early ages and later ages. The early ages which also call as first day where the time cement start poured in. The reason call it as first day because this was the critical time for cement start to setting and starting to hardening around 24 hours. The early stage shrinkage started when the cement was in liquid condition after placing up then undergo early stiffening to form a skeletal frame and finally hardening happen when concrete was rigid and the molds removed. The figure below shows the early age phases.

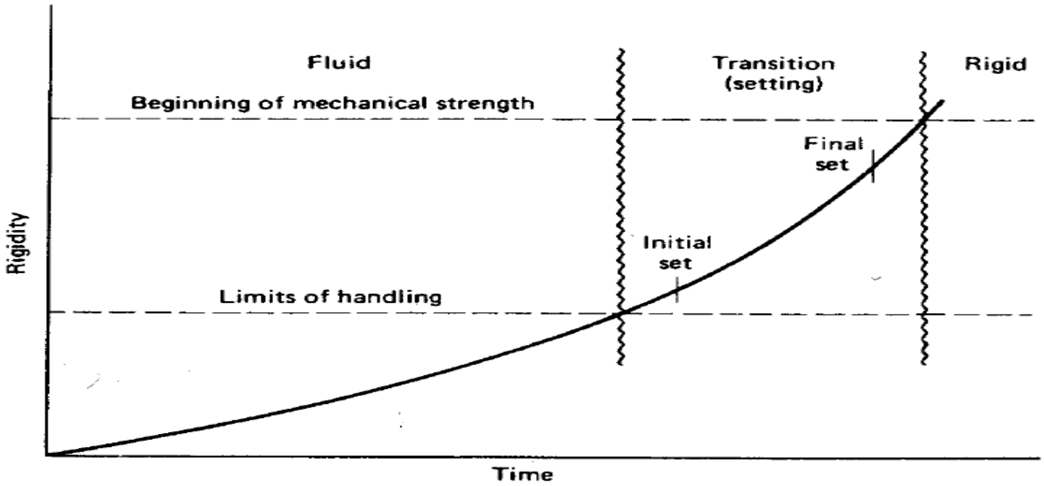


Figure 2.5.1: Liquid, hardening transition with setting and rigid hardening (Mehta & Monteiro 1993).

As from the figure shows the left hand side was the graph plotted when the concrete still in liquid forms. The middle was hardening transition setting where the cement will start the hardening process and the right hand side was the rigid hardening which occurs after the molds removed. As the early ages shrinkage important because the concrete still not gain strength, so a small force applied on it will results shrinkage strains.

After the concrete form the skeleton, and can withstand some forces, this mean the rate of autogenous shrinkage and rate of drying have been slow down. According to Kronlof and other in 1995 at VTT, the concrete only can withstand the drying shrinkage force after 2 hours from the initial time and this statement was verify by Holt [2001]. This will shows on figure below.

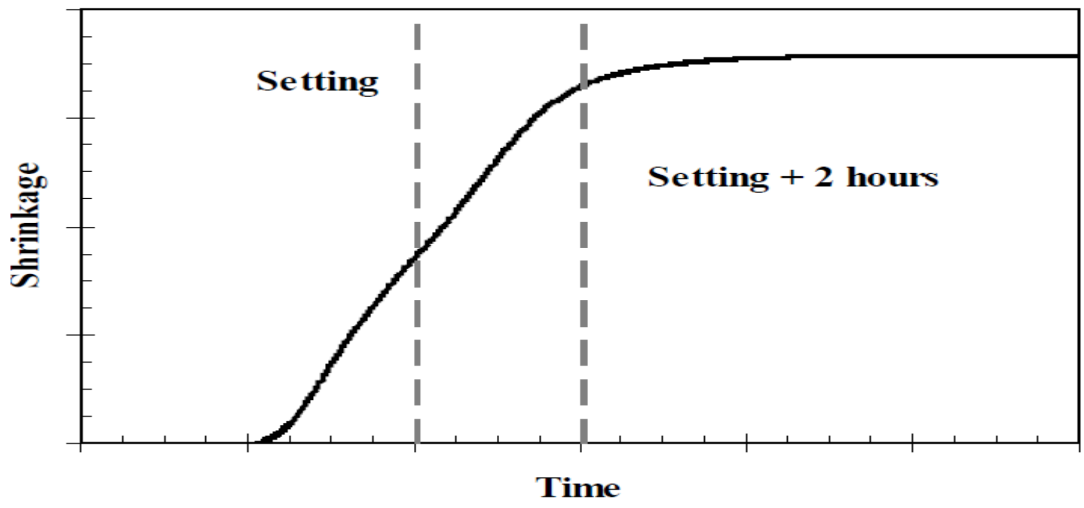


Figure 2.5.2: Hardening phase where this happen at the end of early age drying shrinkage due to hardening of concrete after initial setting time (Holt, October 2001).

The results for the autogenous shrinkage shows in figure below where the y-axis was plotted autogenous shrinkage with unit mm/m where 1 mm/m = 1000 µƐ.

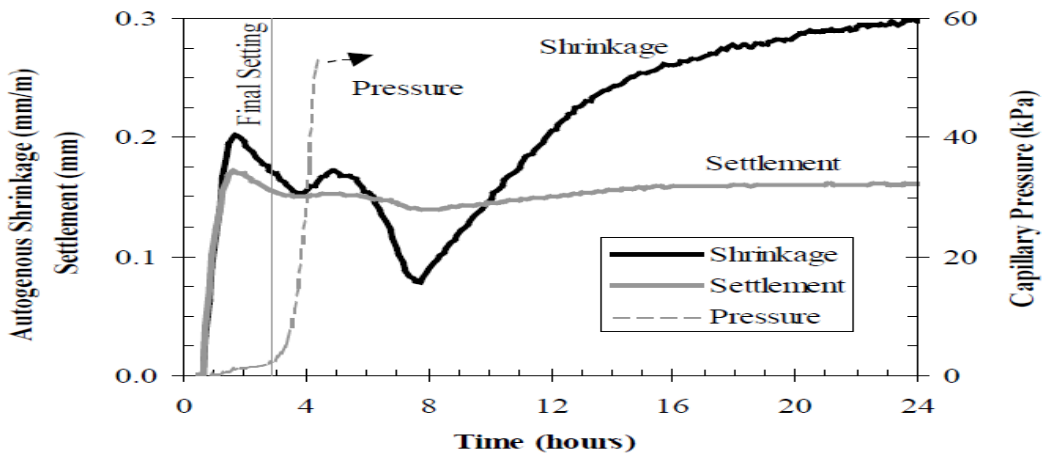


Figure 2.5.3: Typical early age autogenous shrinkage result (Holt, October 2001)**.**

From the experiment results in figure above, the vertical line was about 3 hours which was the final setting time. The reason of this was many preparation and hand work during the first 3 hours so, the vertical line was represent the setting time. As for x-axis will explain in another figure which magnified the x-axis between 0 to 12 hours.

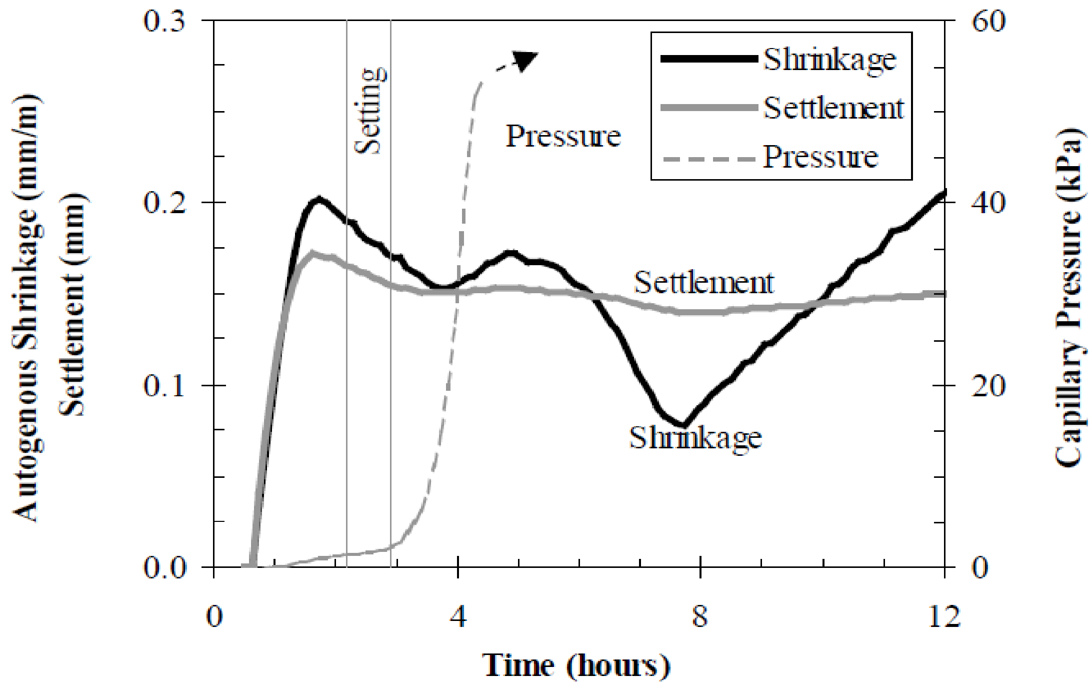


Figure 2.5.4: First 12 hours of the early age autogenous shrinkage which magnified from Figure 2.5.3 (Holt, October 2001)**.**

When time about 30 to 90 minutes, first deformation of settlement and horizontal shrinkage occur. When these happen, the capillary pressure also start to develop and a slightly peak over 50 kPa occurs at 4 hour and 30 minutes. From the graph above, a large amount of vertical shrinkage was measured in the first four hour when the equipment was setting up or in an arranging process. This happen because of the chemical shrinkage between the cement paste and the settlement of aggregate. When the time reach about 90 minutes, the rate of vertical shrinkage slows down because of the formation of internal skeleton that prevent the increment of vertical shrinkage.

Besides that, the horizontal shrinkage can divided into 5 stage which were equipment limitation, bleed water absorption, pressure, thermal expansion and thermal contraction. The figure below show all the five stage.

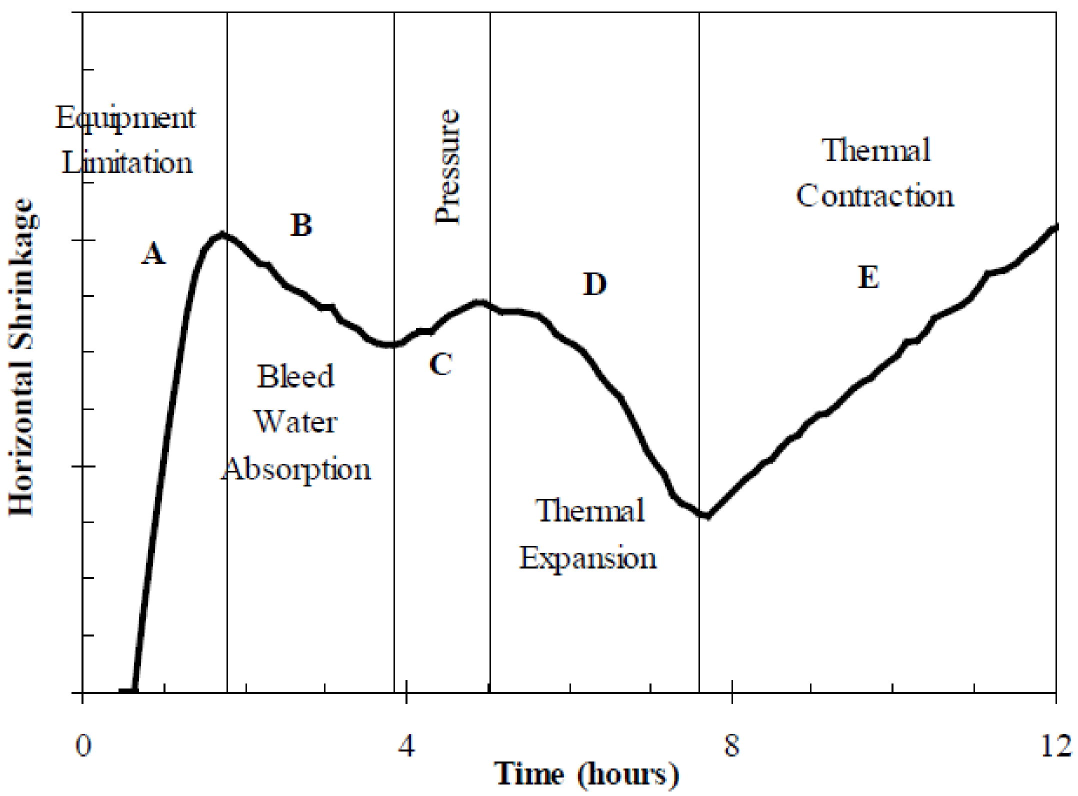


Figure 2.5.5: Various horizontal shrinkage stages in a typical early age (Holt, October 2001)**.**

Stage A: Very early stage: Equipment limitation due to settlement forces. (30-90 minutes)

At the beginning of the experiment, setting up the experiment will measure a large horizontal shrinkage. The mortar was still liquid form and was impossible to displace the results on xy-plane. The reading that acquired maybe accurate and may not accurate as this reading taken when the experiment was in setting up process.

Stage B: Bleeding controlled stage: Bleed water absorption causes expansion. (90minutes – 4 hours)

In this stage, the aggregate and cement particle will settle down where the excessive water will appear on the mortar's surface. In a short time, where the stage A was settle down, the excessive water will drawn back into mortar through small capillary suction. This phenomena cause the mortar to expand.

Stage C: Pressure controlled stage: Development of pressure causes shrinkage. (4 + hours)

As the bleed water has been re-absorpted by the mortar, a pressure will develop. The pressure develop was a result for the cement hydration and it also generate a stress that autogenous shrinkage to happen. The shrinkage that appear can be detected in x and y directions. The pressure will continue to initiate autogenous shrinkage into stage D and E but it maybe reduce by the temperature change.

Stage D: Thermally controlled stage: Cement heat hydration causes thermal expansion. (5 to 8 hours)

The hydration process between cement and water generates heat. As the temperature increase, the mortar will thermally expand and the pressure in stage C will causes the expansion exceeds the amount of shrinkage. Thus, the measurement will results us a change in volume.

Stage E: Thermally controlled stage: End of cement heat generation causes thermal contraction. (8 + hours)

This stage was the reverse of stage D where the heat generate by the cement through hydration was low due to the mortar was cooled. This cooling results in a contraction of mortar and register as a shrinkage. Autogenous shrinkage still continue at a slow rate which call as long term autogenous shrinkage.

2.6 Long Period Fiber Gratings as Band Rejection Filters.

This article is describe how the Long Period Fiber Gratings use as a band rejection filter. They fabricate the fiber by using ultraviolet (UV) light. The UV light range is from 242 to 248 nm.

Apart from that, the article mention about how the operation of the Long Period Fiber Gratings. The fiber want to couple from a forward propagating guided mode to backward propagating modes the phase will be large. The equation is show below

$$\beta 01.\beta cl = \frac{2\pi}{\Lambda}$$

The Λ is the grating period that to couple the fundamental mode to nth-cladding mode. A long Λ will be form is because by the phase matching and the order of hundred microns will form

There is another technique to find the wavelength separation between the cladding modes which by using the wavelength λ_{cut}. The equation is shown below

$$\beta_{cl}^2 + k^2 = \frac{w^2 n_{cl}^2}{c^2}$$

Throughout this equation the difference in the wavelength which the guided mode couples to the different cladding modes. The picture below shows the setup for the fabrication process on how to fabricate a LPFG.

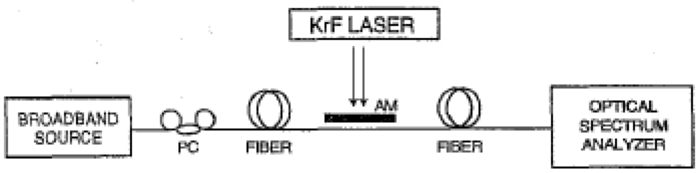


Figure 2.6.1: The experiment setup use to fabricate the LPFG (Ashish M. Vengsarkar, January 1996)**.**

At first, a KrF laser with wavelength 248 nm were exposed by hydrogen germanosilicate through an amplitude mask. One inch long of the grating will be print on the mask and the energy of exposure is 250mJ/pulse, the frequency is 20 Hz were used.

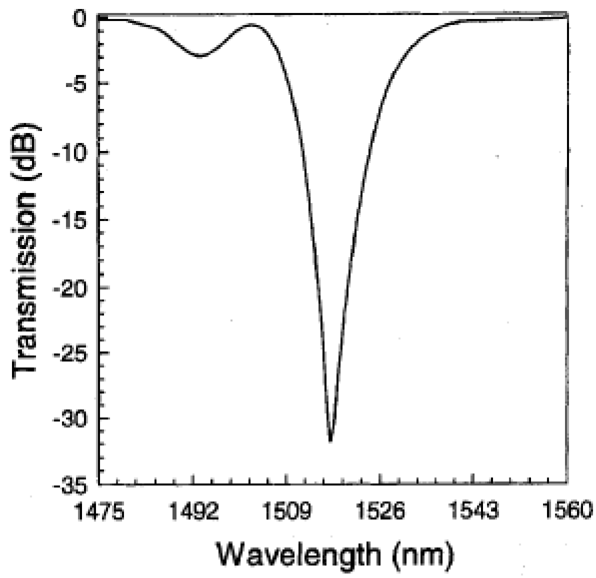


Figure 2.6.2: The band-rejection filter in a tranmission spectrum (Ashish M. Vengsarkar, January 1996)**.**

The figure above is shown a grating period of 402 um in a tranmission spectrum of length 2.54cm. The loss around 32 dB with wavelength of 1517 nm. Besides, the insertion loss is less than 0.20 dB for the wavelength between 1480 to 1545 nm.

2.7 Feasibility of Fiber Bragg Grating and Long-Period Fiber Grating Sensors under Different Environmental Conditions

The performance of the infrastructures are very important to monitoring by using real- time non-destructive evaluation (NDE) but it is difficult to carry out on-line infrastructure monitoring using conventional NDE methods. Thus, fiber optic sensors (FOSs) has been introduce to enable the real-time multiplexed monitoring the infrastructure. Mostly the FOSs were embedded inside or bonded on the surface of the subject.

FOSs more advance than NDE because it is more feasible in the measurement of a subject, the lifetime of using FOSs longer as compare with NDE. Furthermore, fiber optic sensors have more advantage in weight, size, geometrical versatility, electromagnetic immunity and bandwidth larger. Nowadays there are some industrial has been trying to use FOSs in structural monitoring and infrastructure assessment.

In this article, it was describe the Fiber Bragg grating (FBG) and Long Period Fiber Gratings use for structural monitoring for temperature, strain, and liquid-level measurements. The outcome for this article include temperature fluctuation and stability tests using FBG and LPFGs. As my project was research more on LPFG as a sensors, I will more focus on LPFG information in this article.

The figure 2.19 below shows the experimental setup for the LPFGs sensing system. This experiment using ASE as a light source then connected to LPFG either as temperature measurement or as a liquid-level measurement. After that, the other end of the LPFG was connected to Optical Spectrum Analyzer (OSA) to see the output spectrum. LPFGs responsible for the temperature and liquid-level response in the structure monitoring. The five LPFGs with different wavelength were cascade together and used as temperature sensor or a liquid-level sensor.

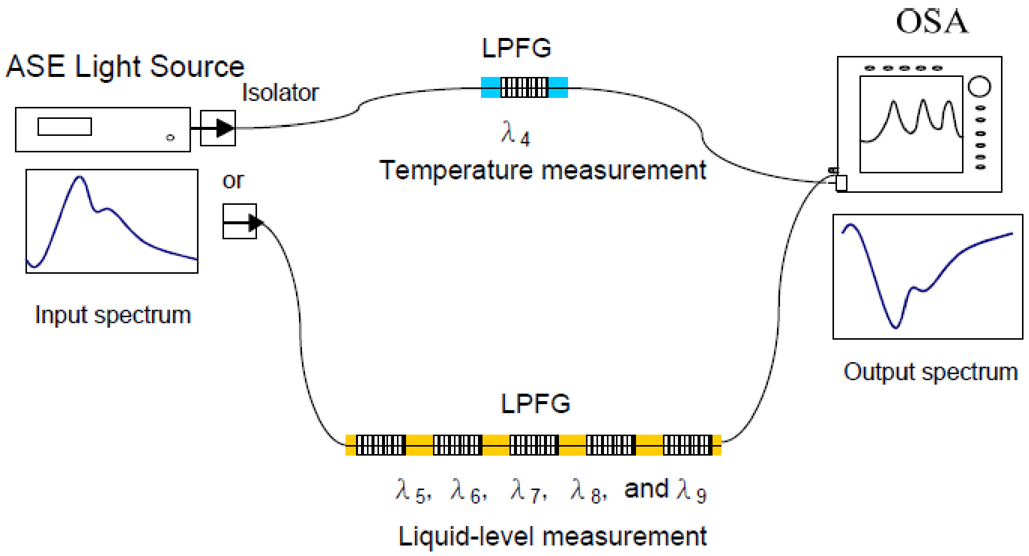


Figure 2.7.1: LPFGs as a sensors either use for temperature or liquid-level measurement (Tang, November 10, 2010)**.**

Long Period Fiber Gratings (LPFGs) usually has a photo-induced periodic modulation of reflective index. It mostly along the core of the single mode fiber. The LPFG perturbation is around 10^{-4} with period between 100 um to 1000 um and the length of the whole period is about 2 to 4cm. The principle of LPFG on how it works where the light is couple with a guided fundamental core mode (LP01) to different forward propagating cladding modes. The phase matching equation for the LPFG shown below:

$$\beta_{core}^{01} - \beta_{cladding}^{1m} = \frac{2\pi}{\Lambda}, where\ m = 2,3,4 \ldots$$

The β_{core}^{01} and $\beta_{cladding}^{1m}$ were the propagation constants for the fundamental mode as for mth is cladding mode and Λ is the grating period that on the LPFG. A series of resonant bands will be generates as the light coupling into cladding region at certain wavelength in the transmission spectrum.

In the experiment, the material using were Portland cement and asphalt mixture which mostly is infrastructure materials. Thus, the specimen used was 150 mm diameter and 300 mm height. The size for aggregate was 19 mm and all were crushed siliceous materials. A cylinder specimens was fabricate by follow the parameter above and it will observe for 28 days.

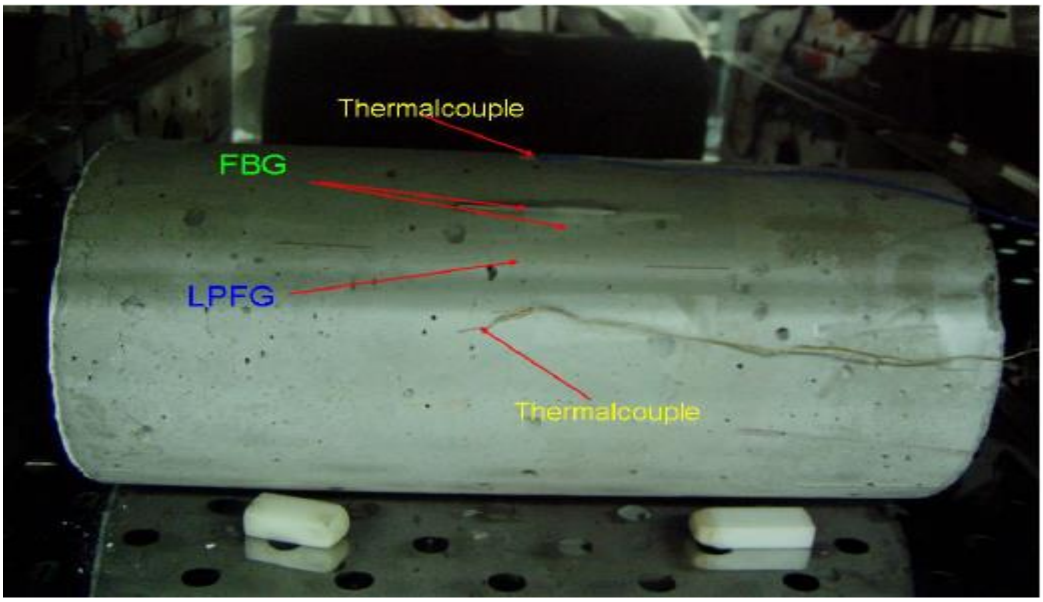


Figure 2.7.2: A cylindrical concrete specimen (Tang, November 10, 2010)**.**

The results for this specimen show below:

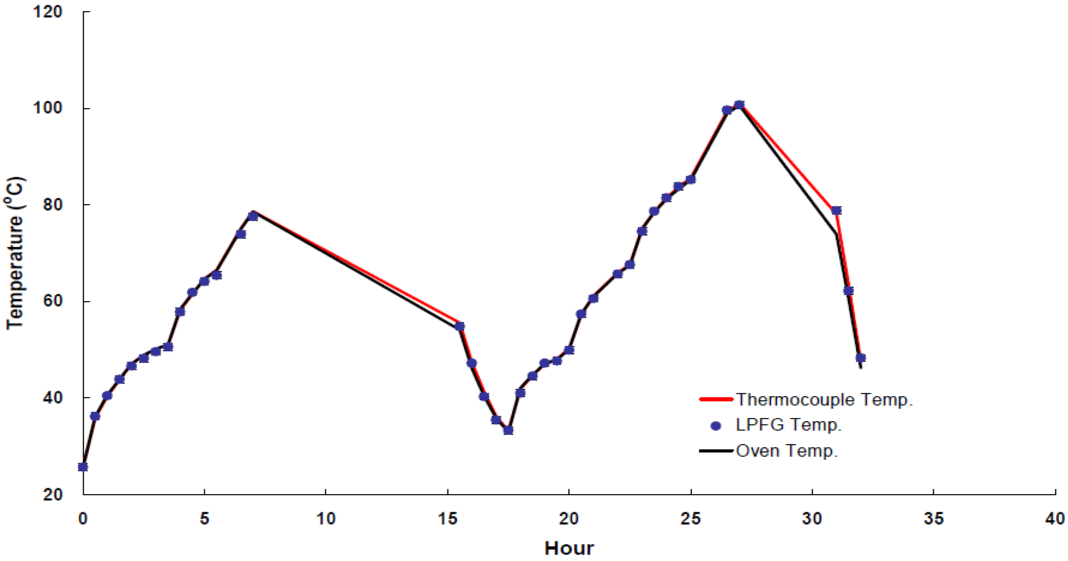


Figure 2.7.3: The response of temperature test using LPFG sensor surface bonded on a cylindrical concrete specimen (Tang, November 10, 2010)**.**

CHAPTER 3

METHODOLOGY

3.1 Tools and Equipment

3.1.1 Preparation of an Optical Fiber

- A Single Fiber Mode (SMF-28) Standard Fiber using in this project
- Glass cutter
- Alcohol
- Stripper spanner
- Two connectors

3.1.2 Fabrication Process

- Laser source
- Optical Spectrum Analyzer (OSA)
- Weight of 14 g
- DC Power Supply and Function generator
- Ignition coil (Bosch) with 30 kW, 12 V
- X-Y Translation stage with Electrodes
- Two fiber clamp

3.1.3 Experiment for the concrete shrinkage

- Fabricated fiber
- Conventional way mould dimension (L = 160 mm, W = 40 mm, H = 40mm)
- A small container with LPFG embedded for the concrete shrinkage test (L = 50mm, W = 13.4mm, H = 13.4mm)
- Strain gauge (Demec strain gauge)
- Water
- YTL Castle Cement
- Sand
- A fiber use for spice for LPFG

3.2 Fabrication of Long Period Fiber Gratings (LPFG)

A SMF-28 of optical fiber will be using in my final year project. Long period fiber grating (LPFG) formed using SMF-28 which is low cost, low attenuation, and widely uses in many application. In my final year project, the technique that I have chosen to fabricate LPFG by using electric arcing method. The advantages of using this method are basic setup requirement and low cost to fabricate the LPFG. Among all of the method available for LPFG fabrication, electric arcing is the most safe and harmless to our healthy compare with other method like UV and etc. In order to fabricate LPFG, the experiment setup show as below.

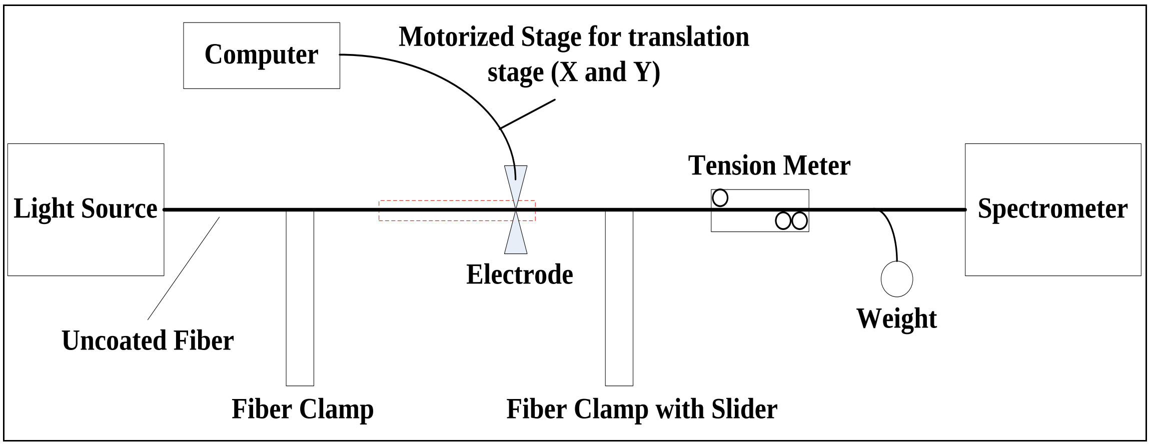


Figure 3.2.1: Experiment setup for the fabrication of LPFG using electric arcing technique.

A fiber with the length of about 1 metre is cut by using fiber cutter, then the coating was removed for both ends for connector installation and centre for grating formation by using stripper spanner. After removing the coating, it needed to clean up the removed part of the optic fiber by using alcohol. The reason remove the coating is to let the electric arcing on the optic fiber to produce grating and the purpose of clean using alcohol is to make sure there is no remaining coating on the optic fiber to avoid the burning of coating during fabrication.. In order to fabricate LPFG, the equipment used in this experiment consist of an ignition coil (Bosch 30 KW 12V) with a pair of electrode, two fiber clamp (one unmovable another one movable with slider), a tension meter with weight, a light source and an optical spectrum analyzer (OSA).

Before starting of fabrication, the optic fiber has to cut by the fiber cleaver before insert into bare fiber connector. This is to make sure the both ends of the fiber have a flat dimension for the light source to pass through. After fiber is inserted into connector, the both ends must check to make sure the light can pass through it. After that, put the optic fiber onto the fiber clamp. One end of the fiber is connected with a light source (laser) and another end connect to OSA. When the setup is completed, the optic fiber is ready to fabricate and the fabricate process is controlled by a computer. A constant force is applied during the fabrication process to create a constant axial tension. In this experiment, the current is 9 mA and supply by power supply to fabricate the optic fiber. During the grating process, the translation stage in x direction is controlled by signal generator with 650 µm period and discharge every 1 seconds to form grating. The grating results will be observed from the Optical Spectrum Analyzer (OSA) to determine the most sharp notch appear, the fabrication has to be stop. The parameters used to fabricate LPFG is show in table 1 below.

Table 1: The parameter for the LPFG fabrication

Optic fiber type	SMF-28
Frequency	500 Hz
Period	650 µm
Grating duration	1 second
Weight apply on the fiber	14g

3.3 Experiment for the concrete shrinkage

In this research work, the conventional way to measure concrete shrinkage was using strain gauge which it can measure the length changes of the concrete until 0.001 mm resolution. By using stain gauge, it have some limitation whereby it cannot have real-time monitoring for the shrinkage of the concrete. Besides that strain gauge needs to measure and record the data manually. During taking the reading, the position of the strain gauge on the concrete could be offset due to not the same position as this is done manually.

Thus an alternative method has to be apply to provide another solution for the concrete shrinkage. In my thesis, the method that I used to measure concrete shrinkage by using an embedded LPFG inside the concrete to monitoring and measure its shrinkage. This method not only can have real-time monitoring for concrete shrinkage, it can also provide a fix position for measuring concrete shrinkage as the Long Period Fiber Gratings (LPFG) which is embedded inside the concrete. Therefore, there is a need to have some research works on this to identify whether this method can function well or not.

In this thesis, I will conducting two types of experiment testing which the first one is using the conventional way to measure concrete shrinkage. The second experiment is using an embedded LPFGs as a sensor to measure concrete shrinkage.

3.4 First experiment: Measuring concrete shrinkage using strain gauge.

The purpose of this experiment is to investigate the concrete shrinkage by using Demec strain gauge to measure where it is the most common equipment using in construction. Demec strain gauge can measure up to 0.001 mm changes, besides it consist of a digital dial gauge that attached to an Invar bar.

Before start conducting the experiment, I need to learn how to use the Demec strain gauge. The Demec strain gauge have a fixed conical point is mounted at one end of the bar, and a moving conical point is mounted on the other end. Furthermore, a setting-out bar is used to position pre-drilled stainless-steel disc which are attached to the structure using a suitable adhesive. When a reading is taken, the conical point are inserted into the holes of the discs and the reading will show on the dial gauge.

Figure 3.4.1: The Demec strain gauge that use to measured concrete shrinkage.

3.4.1 Experiment Procedure

First, get a mould with a dimension of 160 mm x 40 mm x 40mm from workshop. After that, the cement mixture were prepared by following the standard ratio of 1:2:0.35. In my case, I was using cement 1Kg, sand 2Kg and water 0.350Kg for my concrete shrinkage experiment. The cement mixture was mix well manually and pour into the mould. The mould with cement mixture was put aside 1 day for drying purpose.

After 1 day of drying, demould it and start measuring the concrete shrinkage. The day when start demould cement specimen count as day one and recorded twice a day (9am and 5pm), this needed to record for 2 weeks data. The figure below shows the method on how to measure concrete shrinkage by using Demec strain gauge.

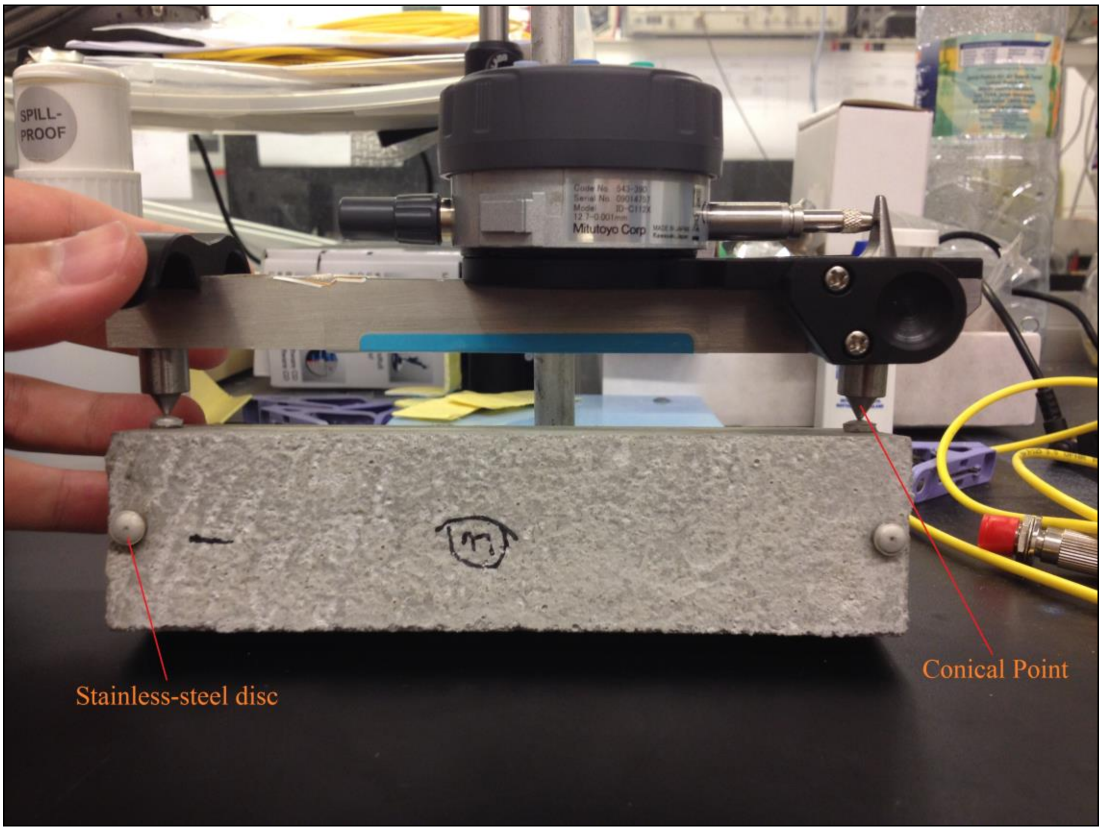


Figure 3.4.2: Measuring the concrete shrinkage using Demec strain gauge.

Figure 3.4.3: The mould use to preparing for cement specimen.

Figure 3.4.4: The mould is fill up by cement after cast cement into it.

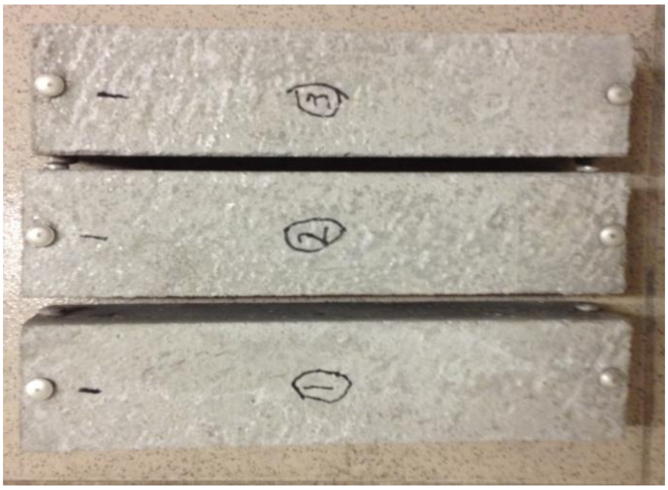


Figure 3.4.5: Three cement specimen were ready for the experiment.

3.5 Second experiment: Measuring concrete shrinkage using an embedded LPFG as a sensor

As for this experiment, the dimension for the container that use to measure concrete shrinkage is 50 mm x 13.4 mm x 13.4 mm. This dimension was scale down from the normal dimension (160 mm x 40 mm x 40 mm) with the scale factor of three. After that, the container was inserted with LPFGs that fabricated from final year project 1 (FYP 1) then the two side of the container were adhesive by silicon gum. This is to make sure the gratings of the LPFGs remain stay inside the container. The experiment setup to measuring concrete shrinkage using an embedded LPFGs show in figure below.

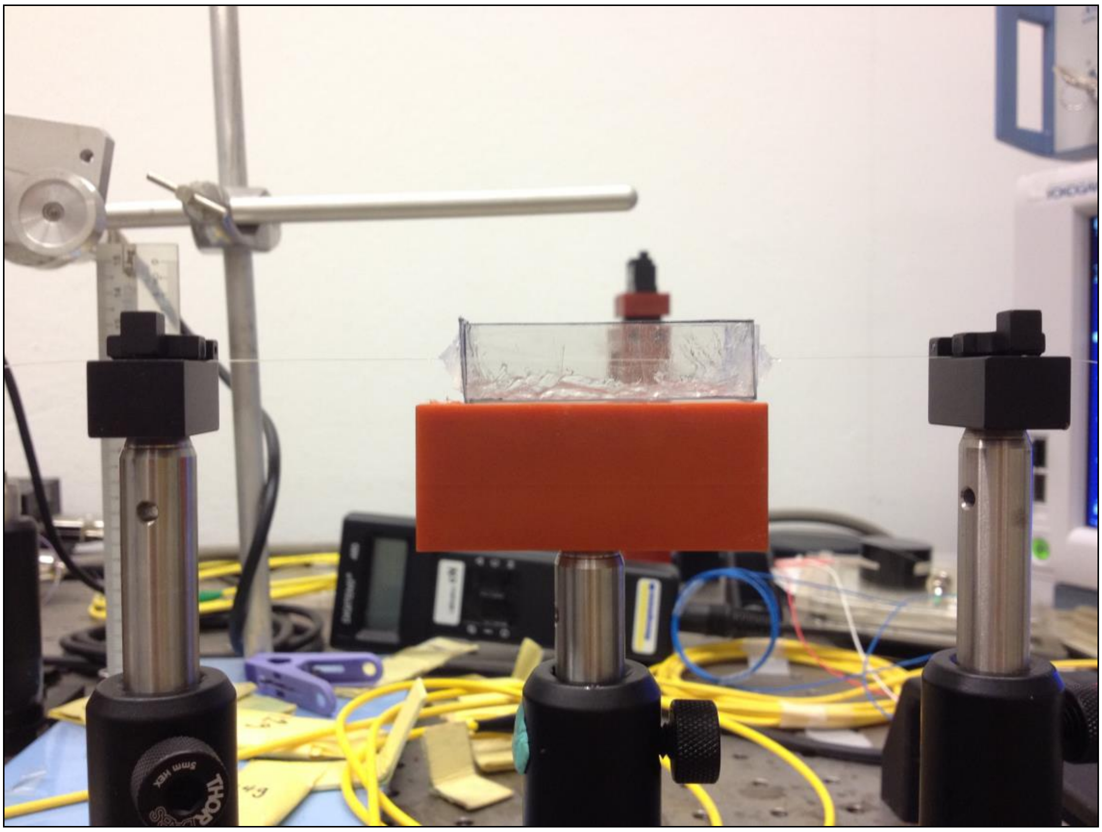


Figure 3.5.1: The experiment setup for measuring the concrete shrinkage using LPFGs.

3.5.1 Experiment procedure

Before start for the cement test, we test the container that embedded with LPFGs with water. This test was to find out the concept correct or wrong. Besides, it also to make sure the condition for the container was in good condition where there is no leakage. This test was carry out and recorded the data every 15 min for 6 hours to observe any changes happen.

After conduct the test with water, the same container with LPFGs embedded was use for the testing for concrete shrinkage. The experiment setup shows in figure 3.4 is the alternative method that use to measure concrete shrinkage. The same ratio 1:2:0.35 use in this experiment to mix the cement mixture. As to avoid the waste of resources, I choose to use 14g of cement, 28g of sand and 5g of water for my cement mixture. The cement mixture was mix manually and pour into the container with LPFGs inserted and start recording the data.

The data was recorded every 15 min for 6 hours. After recorded for 6 hours, the data still have to continue collecting but it recorded twice a day (9am and 5pm) for 2 weeks. The data collected was plotted in a graph and analyse it.

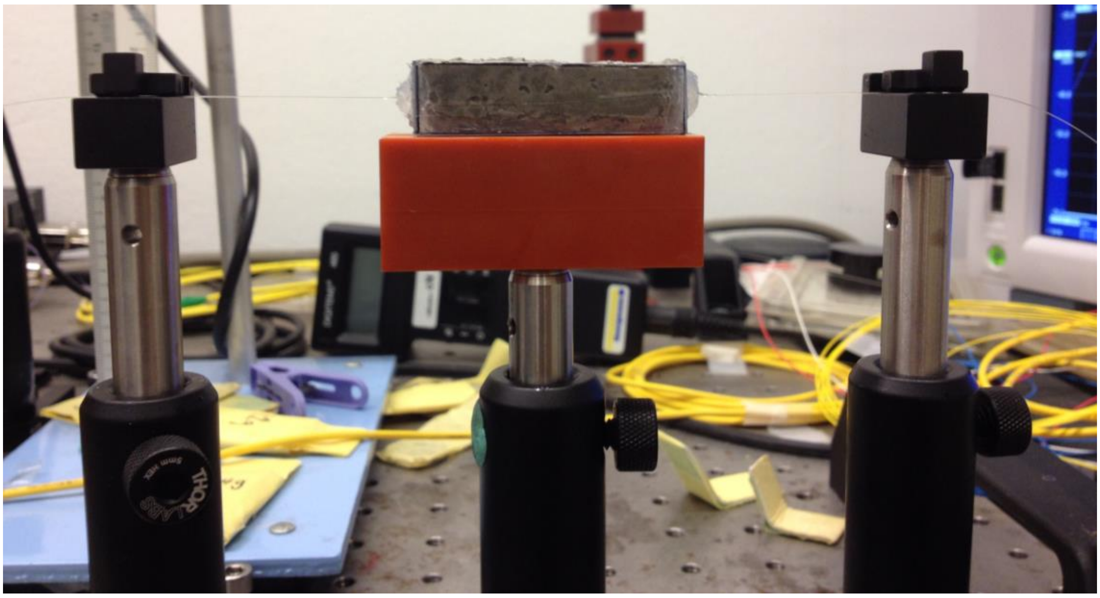


Figure 3.5.2: The cement mixture was pour into the container with LPFG embedded inside as a sensor.

The figure 3.5.2 above shows the cement mixture was fill up into the container with LPFGs embedded. As we can observed, the two side of the LPFGs were clamp by the two fiber clamp. This is to make sure the LPFGs is in straight lines condition when the cement mixture was pour into container.

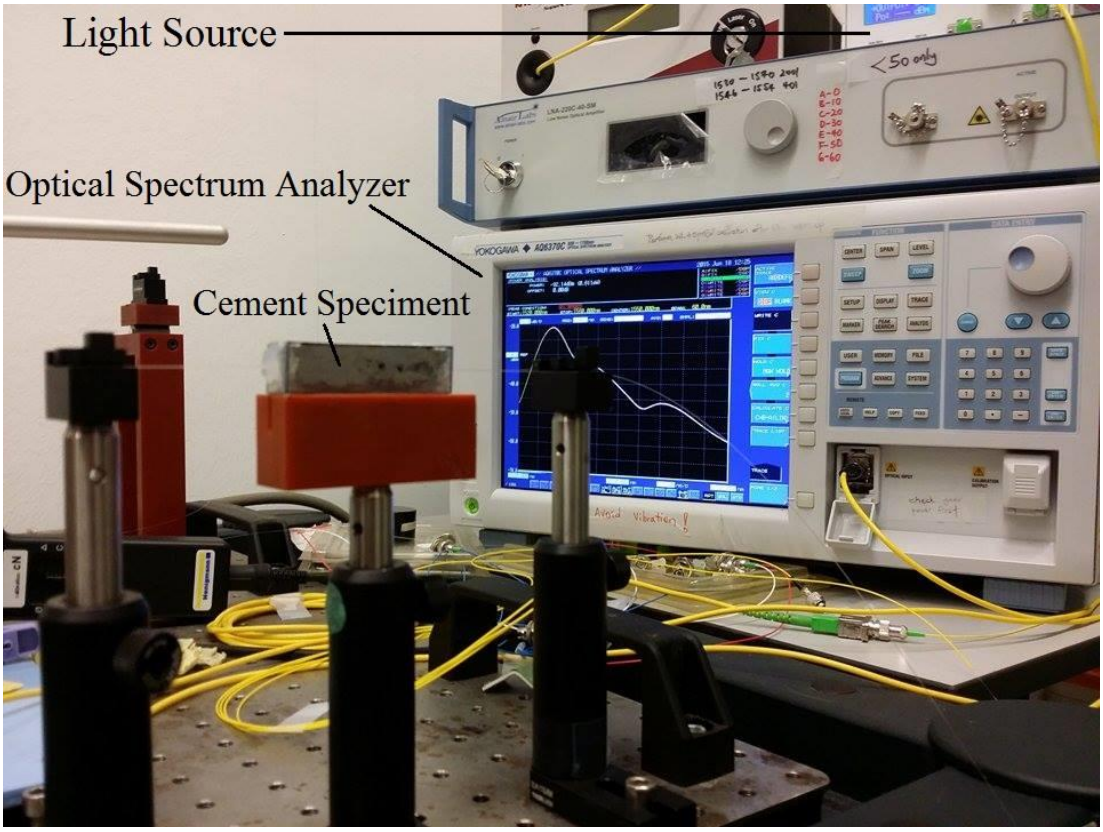
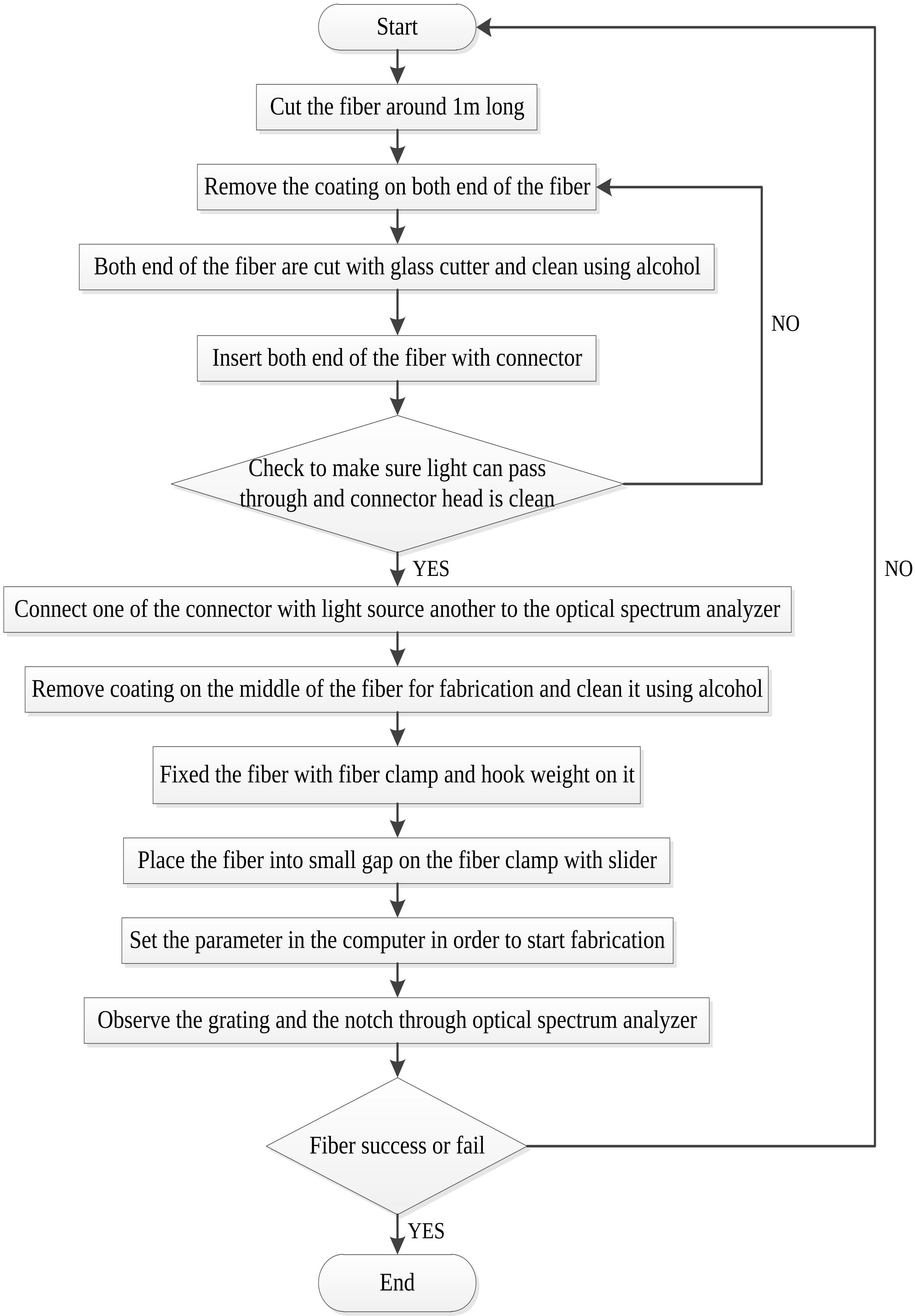


Figure 3.5.3: The cement specimen under testing for concrete shrinkage.

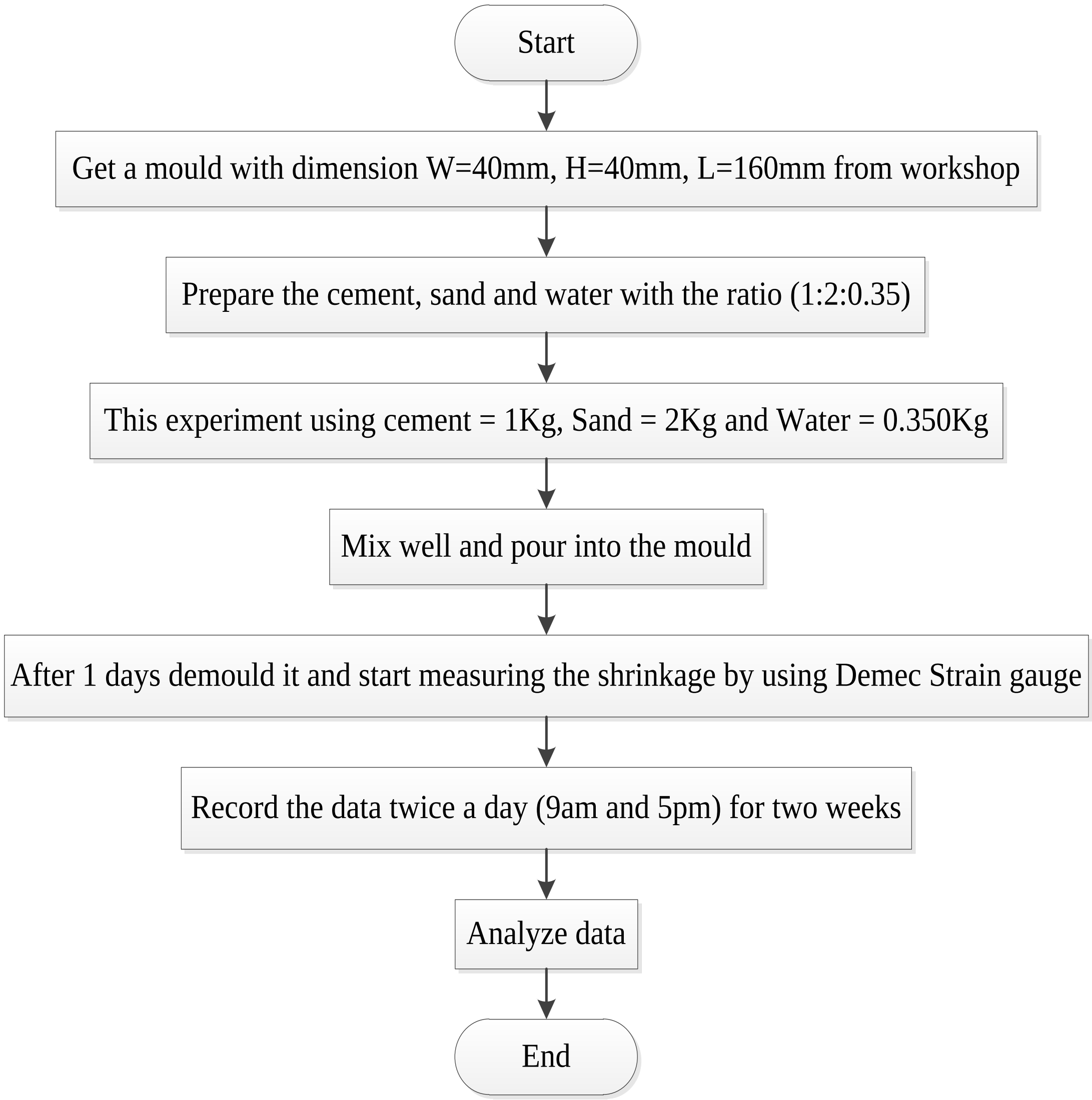
The figure 3.5.3 shows how the cement specimen was tested in order to measure the concrete shrinkage. From the figure, one end of the LPFGs was connected to light source and the other end was connected to the optical spectrum analyser (OSA) for the data recording to find out the shrinkage.

3.6 Flow Chart

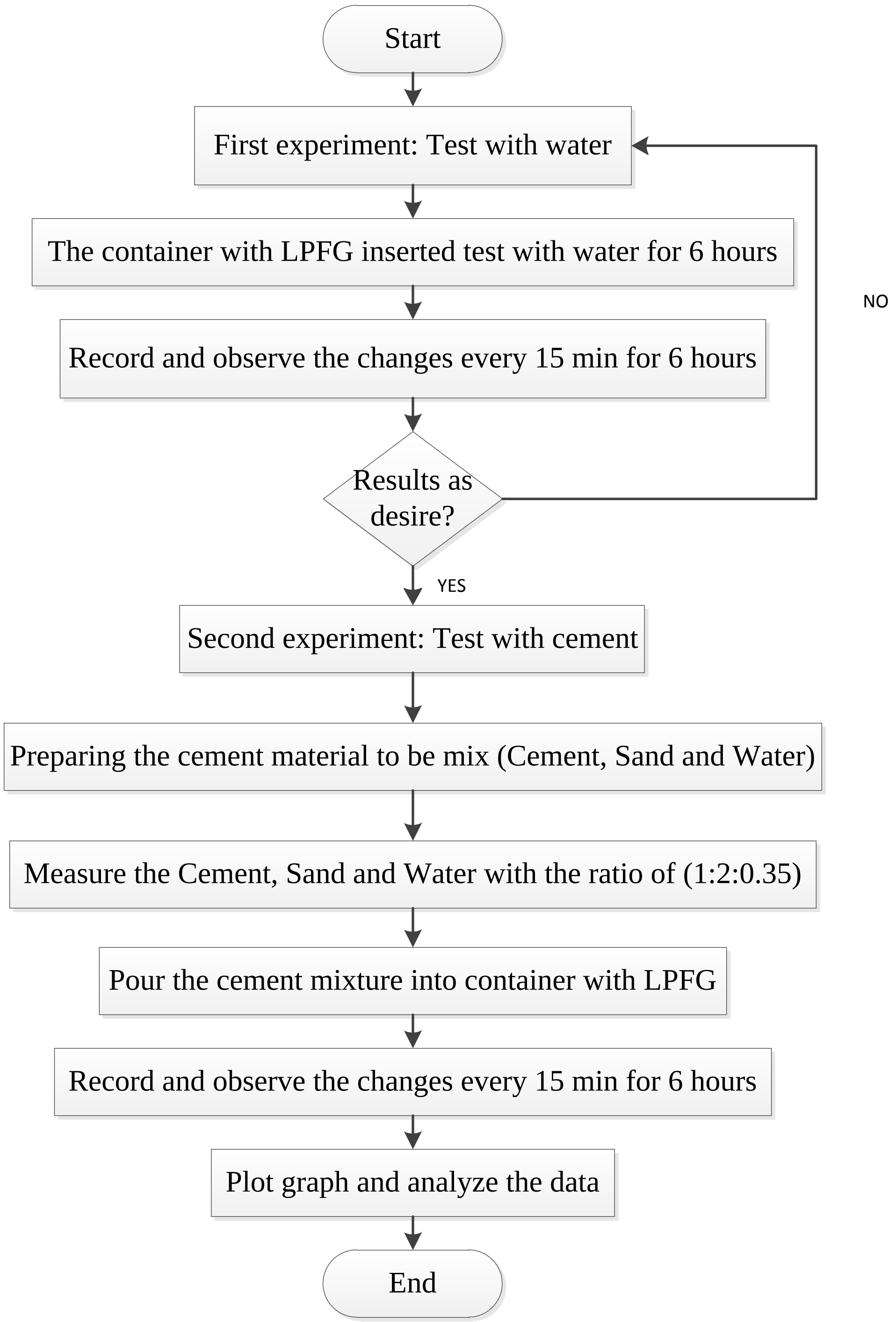
3.6.1 Fabrication of Long Period Fiber Gratings (LPFGs).



3.6.2 Process flow for the conventional method to test measure concrete shrinkage



3.6.3 Process flow for the embedded LPFGs as a sensors to measure concrete shrinkage.



CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Fabrication results

A. The name for this fiber is 160715-650-1-14-37-E-02. The meaning of those number where the fiber is fabricated on 16 March 2015 with the grating period of 650 µm, arcing time 1 second and the puling tension using is 14 g. The notch formed is determine through Optical Spectrum Analyzer (OSA) which it form at the number of 37 gratings at trace E.

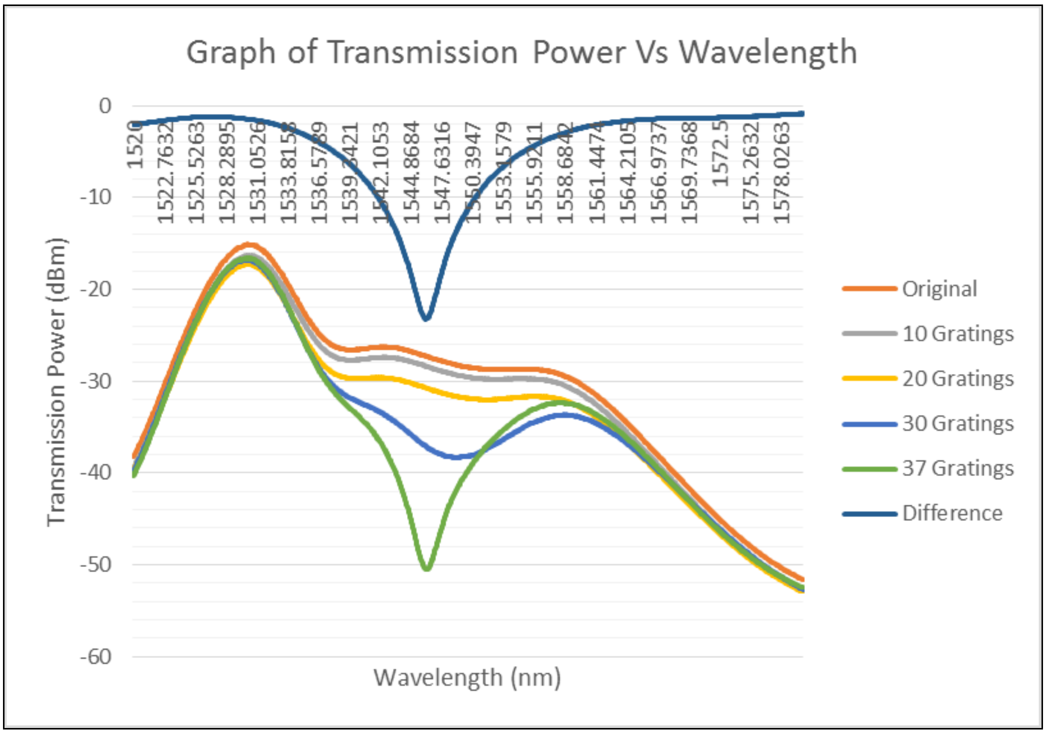


Figure 4.1.1: Fabricated LPFG with 37 number of gratings.

The figure above shows the grating form slowly as the number of grating increases. The notch appeared at the 37th grating. Besides, the difference between the original and last notch form shows in the graph which is dark blue color. This fiber has the attenuation peak at 1546.29 nm in wavelength and -50.498 dBm of transmission power.

B. As for this fiber name is 160715-650-1-14-49-F-07. This fiber was fabricated on 16 July 2015 with the grating period of 650 µm, arcing time 1 second with the pulling tension of 14 g. The notch form for this fiber observed through OSA which form at the 49th of gratings at trace F.

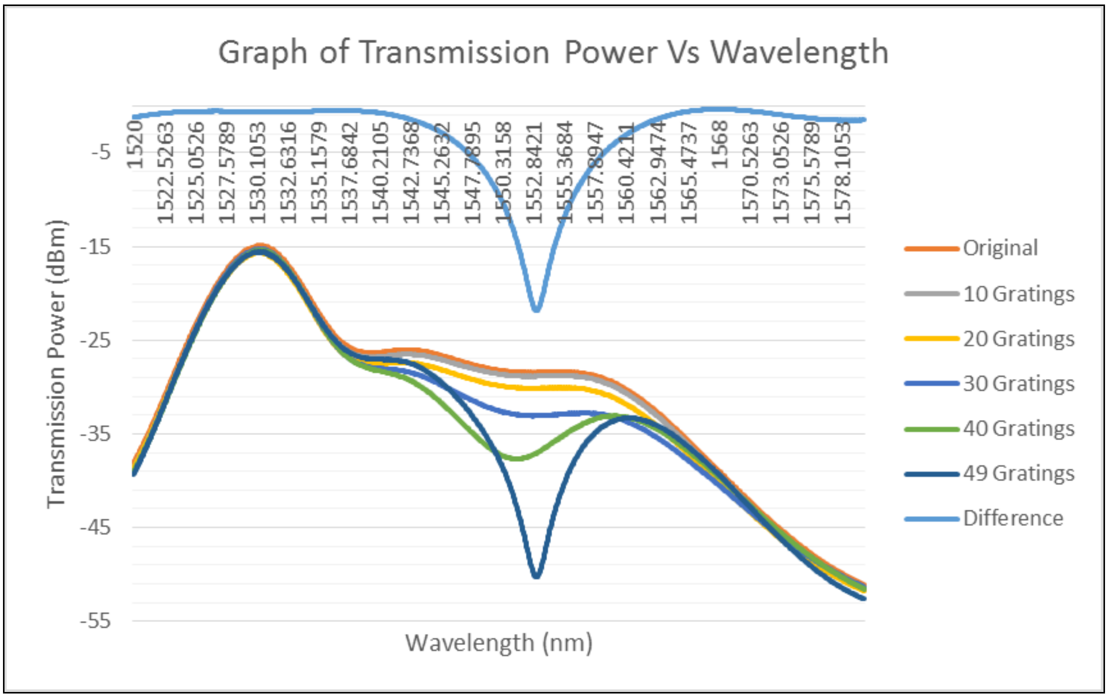


Figure 4.1.2: Fabricated LPFG with 49 number of gratings.

The figure above shows the graph of transmission power vs wavelength for the seventh fiber that fabricated on 16th July 2015. From the graph, we can observed the notch start to form slowly when the number of gratings increasing and the final notch appear at 49th of gratings. This fiber has the attenuation peak at 1553.04 nm in wavelength and -50.29 dBm of transmission power.

C. The fiber for this name is 160715-650-1-14-40-E-05. This fiber was fabricated on 16th July 2015 with the period of 650 μm, 1 second of arcing time and 14 g of pulling tension. The notch form at trace E with the number gratings of 40.

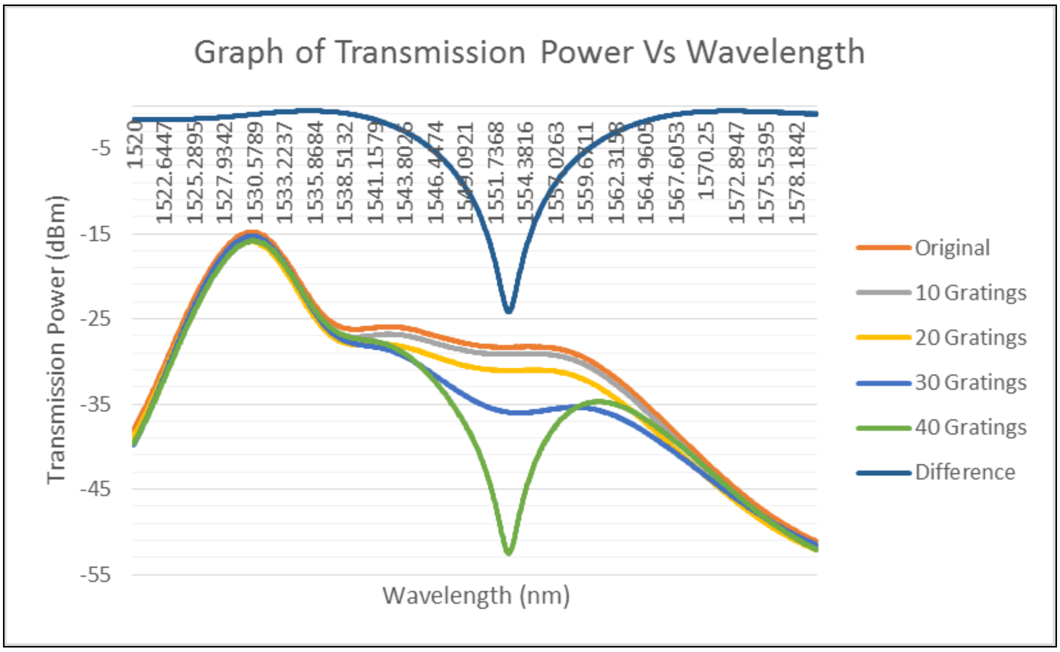


Figure 4.1.3: Fabricated LPFG with 40 number of gratings.

The figure above shows the graph of transmission power vs wavelength for the seventh fiber that fabricated on 16th July 2015. From the graph, we can observed the notch start to form slowly when the number of gratings increasing and the final notch appear at 40th of gratings. This fiber has the attenuation peak at 1552.961 nm in wavelength and -52.543 dBm of transmission power.

D. As for this fiber 160715-650-1-14-36-E-08, it was fabricated on 16th July 2015 with the grating period of 650 µm, arcing duration 1 second with the pulling tension of 14 g. As to determined its condition, we observe the results from OSA where looking for the sharp notch will appear during fabrication. When the notch shows in the OSA, the fabrication process has to be stop. Therefore the LPFG was fabricated. AS for this fiber, the notch appear when the number of grating comes to 36 gratings.

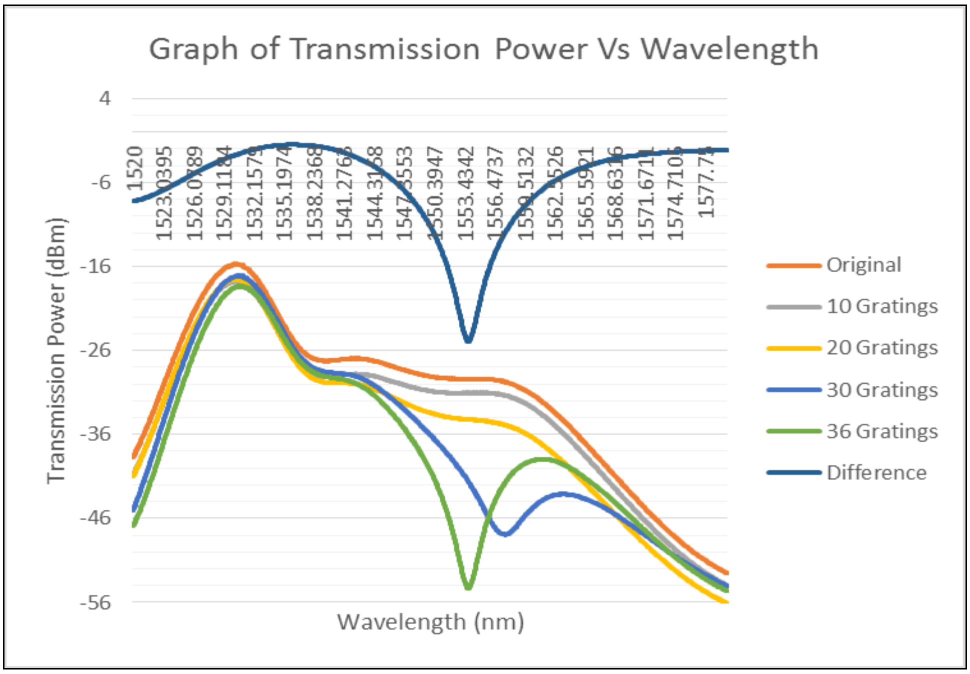


Figure 4.1.4: Fabricated LPFG with 36 number of gratings.

From the figure above, this fiber has the attenuation peak at 1554.026 nm in wavelength and -54.098 dBm of transmission power.

Comparison of the fiber from 4.1 (A) to 4.1 (D).

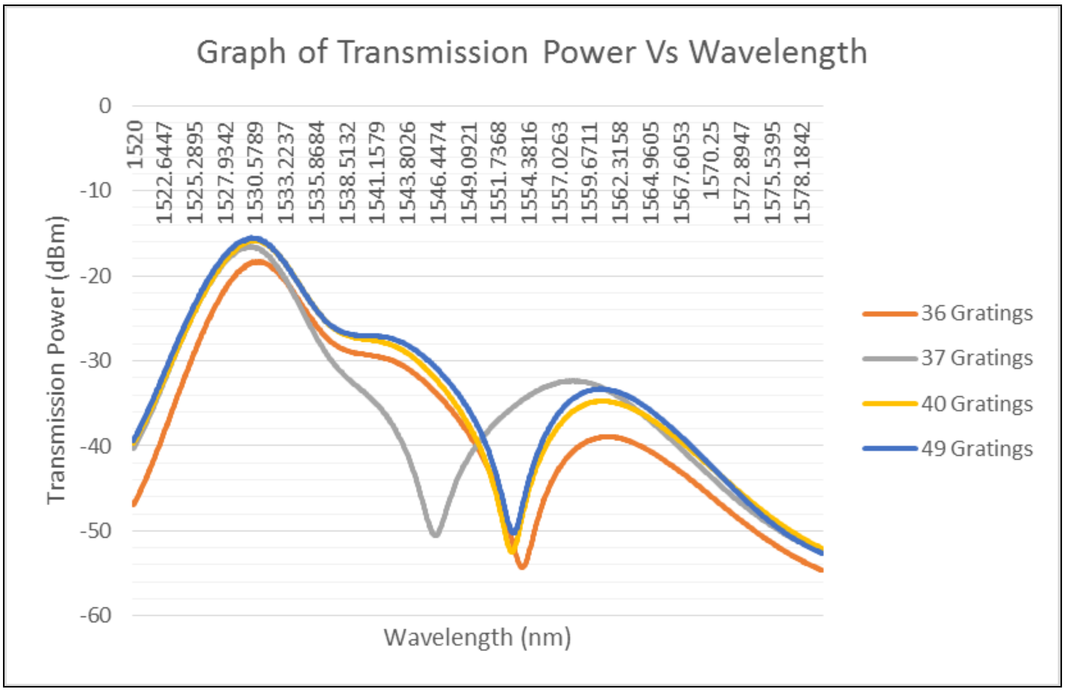


Figure 4.1.5: Comparison of four fabricated fiber.

As from the graph above, we can summarise that most of the attenuation peak range was from 1546.29 nm to 1554.026 nm wavelength and the transmission power for four of the fabricated fiber were over -50 dBm of transmission power.

4.2 Testing Results

In my research work, I have conducted two type of experiment in order to complete my thesis. The first experiment was to measure the concrete shrinkage using conventional method. The equipment that use to measure the shrinkage called Demec strain gauge. As the second experiment, the concrete shrinkage was measure by using an embedded LPFG as a sensor. The LPFG was fabricated by ourselves and use in my experiment.

4.2.1 Experiment one results: Conventional method

Table 2: Data collected from three cement specimen

Cumulative time(hrs)	Microstrain Sample 1	Microstrain Sample 2	Microstrain Sample 3
0	0	0	0
8	0	0	63.3
24	63.3	0	63.3
32	126.6	0	63.3
48	189.8	0	126.6
56	253.1	63.3	126.6
72	316.4	63.3	126.6
80	316.4	63.3	126.6
96	316.4	63.3	126.6
104	316.4	63.3	126.6
120	316.4	63.3	126.6
128	316.4	63.3	126.6
144	316.4	63.3	126.6
152	316.4	63.3	126.6
168	316.4	126.6	126.6
176	316.4	126.6	126.6
192	316.4	126.6	126.6
200	316.4	126.6	126.6
216	379.7	126.6	189.9
224	379.7	126.6	189.9
240	379.7	126.6	189.9
248	379.7	126.6	189.9
264	379.7	126.6	189.9
272	379.7	126.6	189.9
288	379.7	126.6	189.9
296	379.7	126.6	189.9
312	379.7	126.6	189.9
320	379.7	189.9	253.2
336	379.7	189.9	253.2
344	379.7	189.9	253.2
360	379.7	189.9	253.2
368	379.7	189.9	253.2

The figure below shows the graph of microstrain vs cumulative time for the three cement specimen. The graph data plotted according to the data collected from experiment which shows in Table 2.

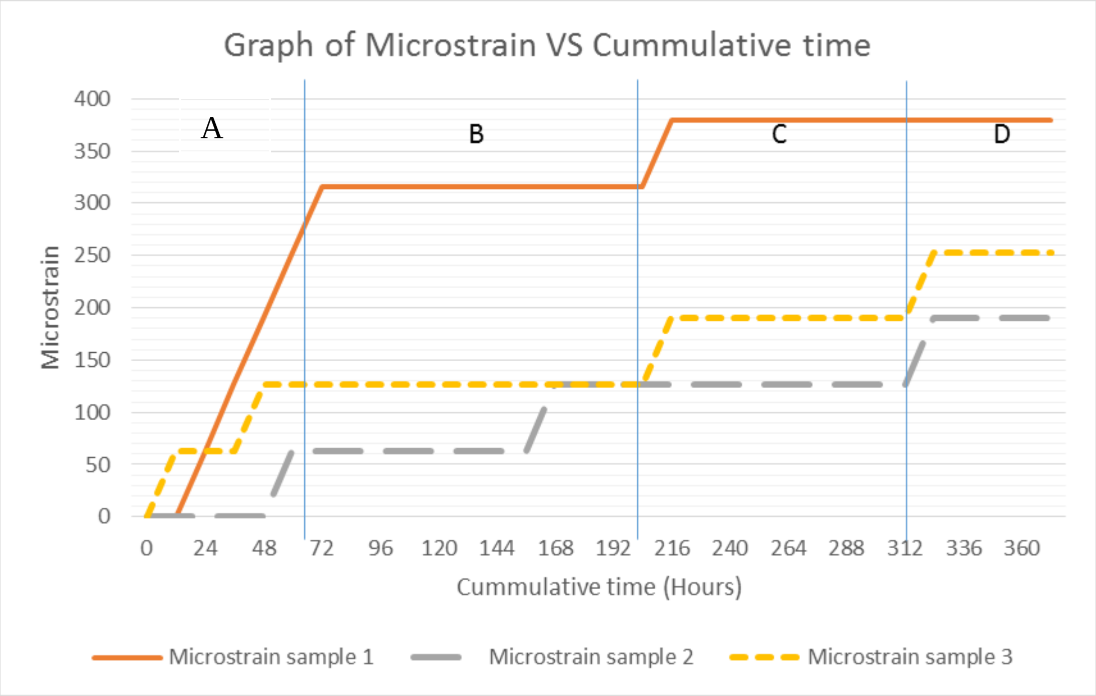


Figure 4.2.1: The three cement specimen shrinkage graph.

The graph above was the microstrain vs cumulative time, where we can observed that the shrinkage start measure the first 72 hours as show at column A. We can see that, the graph was increasing linearly from the beginning of the experiment. As for column B, there is no shrinkage measured until 192 hours. As the data keep recording, the shrinkage was measured at the 192 hours later as we can observed from column C, the graph rise slightly compare with the reading taking at the beginning. The reason is because as from time to time, the chemical reaction between cement and water become slowly and soon those reaction will stop. For the column D, the shrinkage start to remain unchanged as see from the graph.

4.2.2 Experiment two results: An embedded LPFG method.

Before continue for concrete shrinkage, test the plastic container that embedded with LPFG under water.

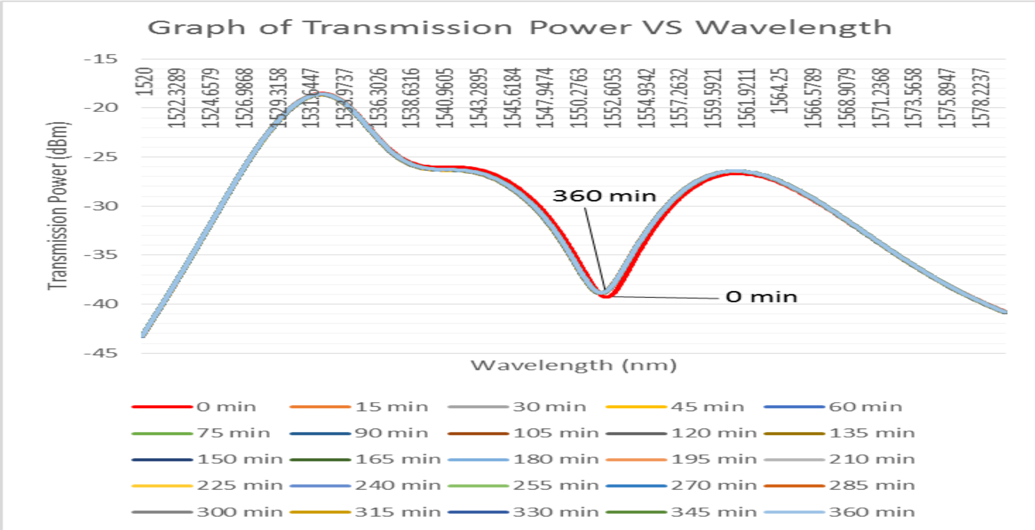


Figure 4.2.2: The six hours results for the testing under water.

The graph above shows the results for the container that embedded with LPFG under water testing. As from the graph, before water pour into container, the transmission power was -39.227 dBm. After that, when water pour into the container, the transmission power shift upward to – 38.858 dBm. A total of 0.369 dBm of power drop.

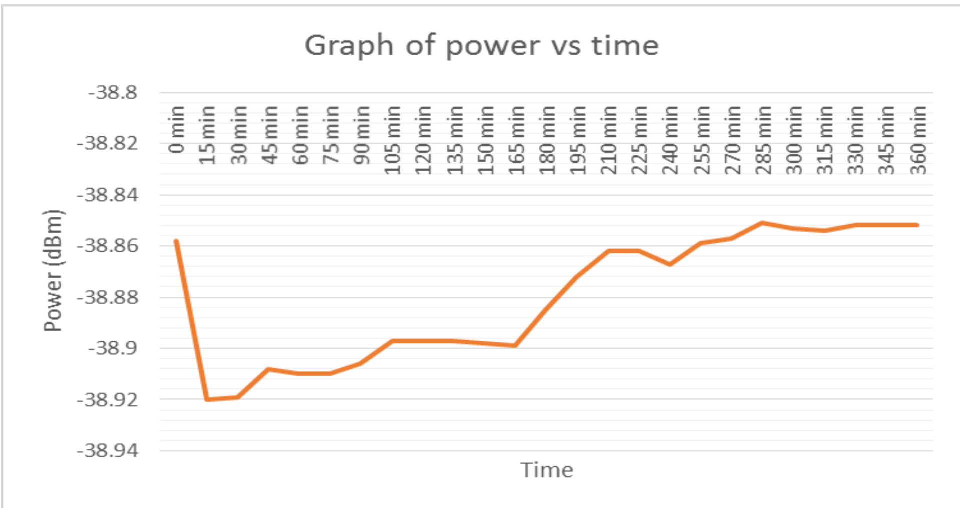


Figure 4.2.3: The graph of power vs time for the testing under water.

As from the graph above, we can observed that the maximum power was -38.851 dBm and minimum power was -38.920 dBm and the difference power changes for the graph was 0.069 dBm.

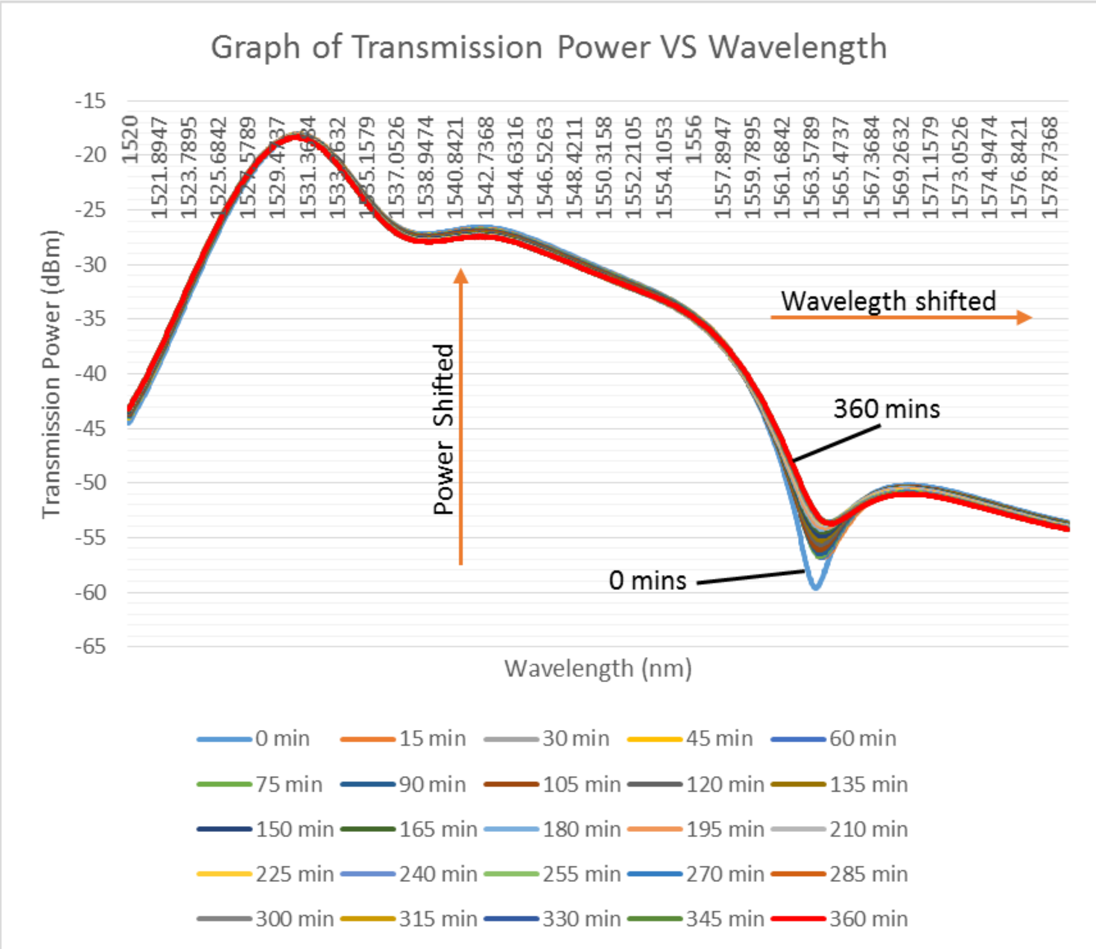


Figure 4.2.4: The six hours results for monitoring the cement specimen.

The graph above shows the transmission power vs wavelength where it was the results for the six hours monitoring for the cement specimen. The results were recorded every 15 minutes and last for six hours which was from 0 minutes to 360 minutes. Thus, from the graph, we observed the transmission power shifted as from time to time. The transmission power initially was -59.632 dBm and start to shift when the LPFG was contact with the cement specimen. After six hours of recording data, the transmission power was -53.732 dBm. There was power drop within this six hours which have a total of 5.9 dBm of losses.

Furthermore, the wavelength of the graph also shifted from time to time. At the beginning of the experiment the wavelength was at 1563.855 nm, after six hours of the experiment the graph shift to the right with 1565 nm. A 1.145 nm of difference wavelength was being shifted.

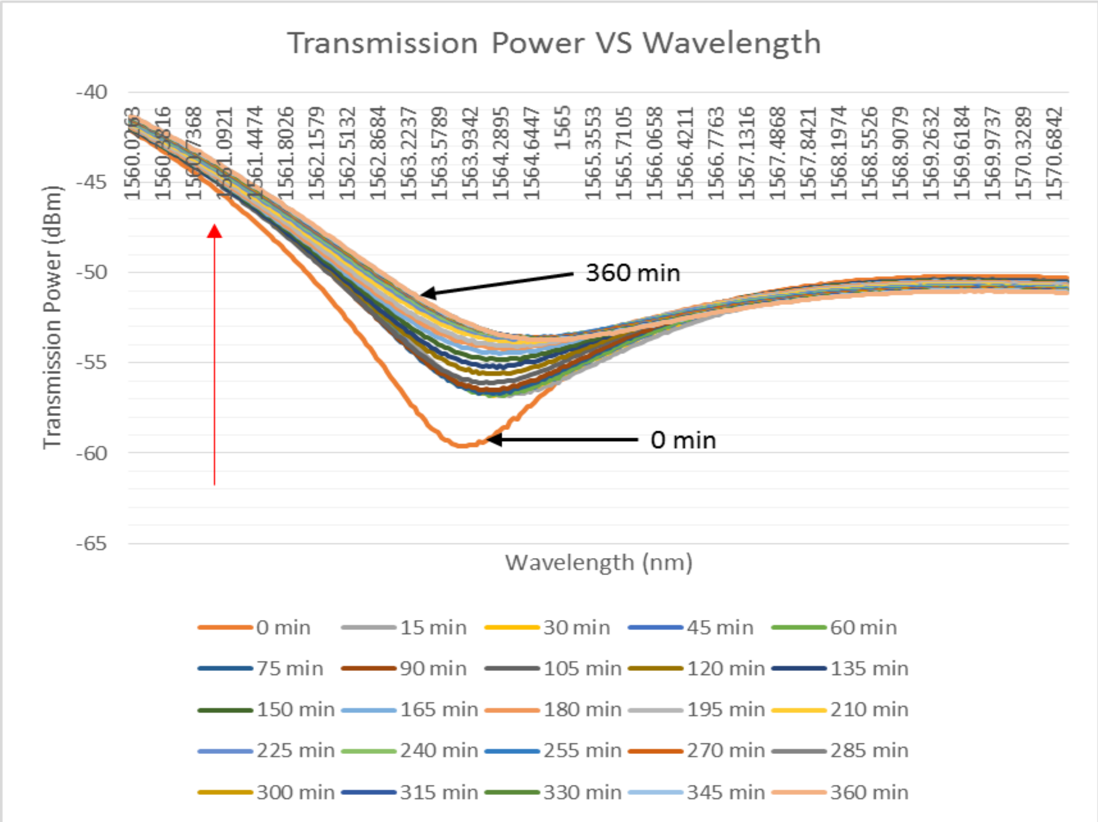


Figure 4.2.5: Zoom in for the Figure 4.2.4

The figure above was the same graph for figure 4.2.3, as this figure was the zoom in for the notch part of the graph for a better view or clearer vision to read the data.

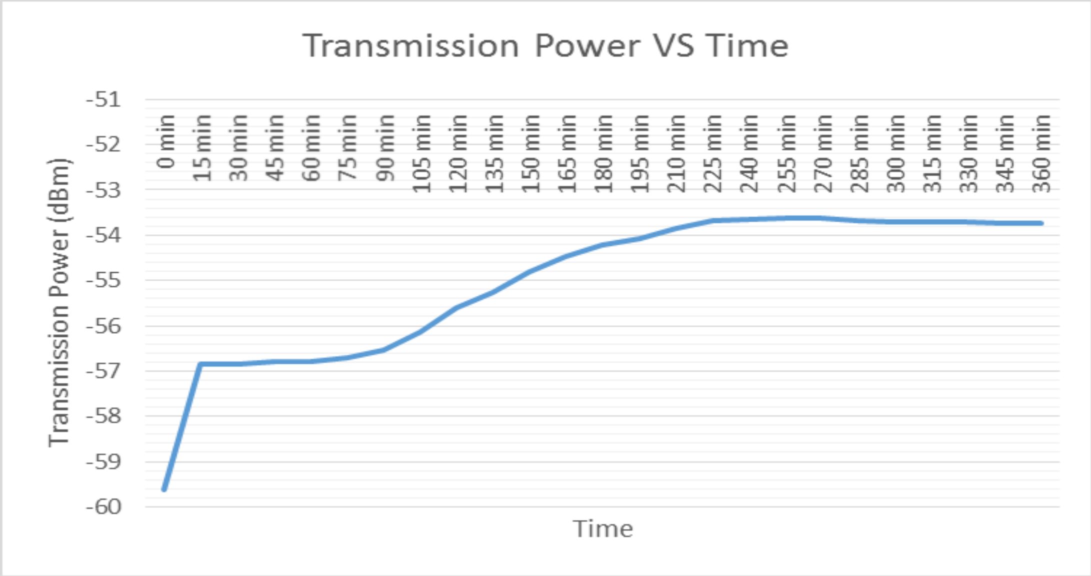


Figure 4.2.6: The graph of transmission power vs time for six hours monitoring.

The figure 4.2.5 was the graph for the transmission power vs time where we observed that at the beginning, the graph was increase sharply between 0 minutes to 15 minutes. This was because when the cement mixture pour into the container with an embedded LPFG inside, the LPFG contact with the cement mixture cause the graph increase. As record the data from time to time, the graph remain unchanged between 15 minutes to 75 minutes. After 75 minutes, the graph started to rise slowly until 240 minutes and remain unchanged after 240 minutes. Thus, the transmission power difference between the initial and the final was 5.9 dBm.

The figure below was the results for the cement specimen which monitoring for 13 days for the measuring of concrete shrinkage.

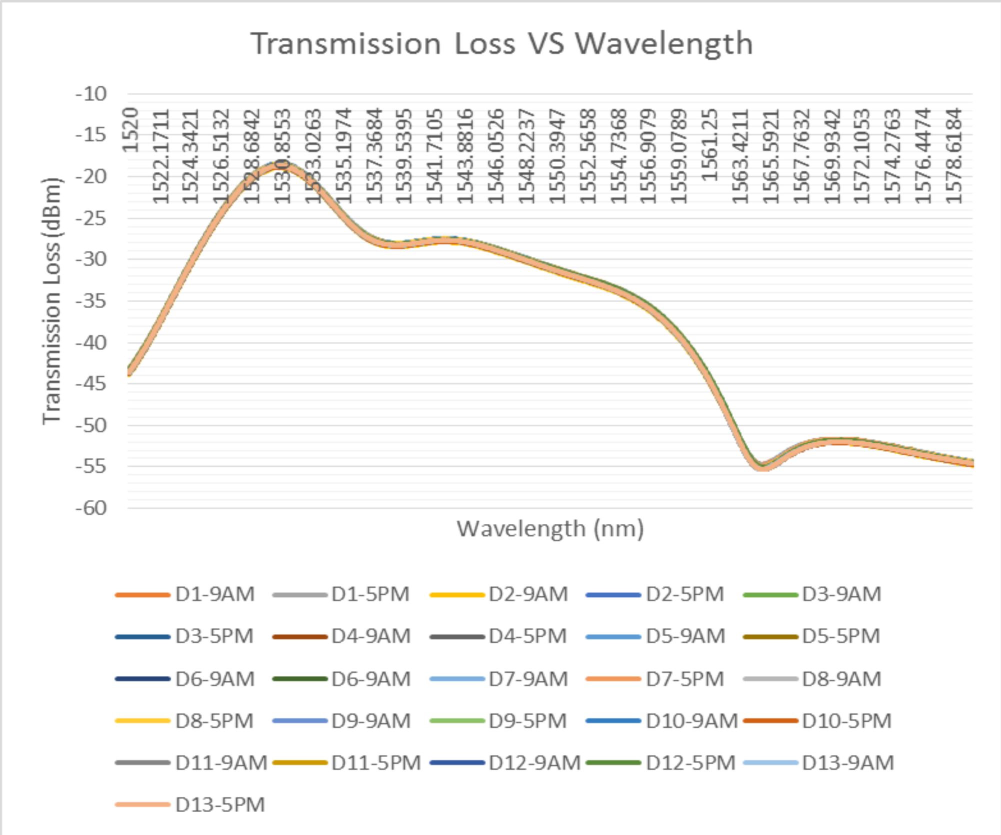


Figure 4.2.7: The thirteen days results for monitoring the cement specimen.

The graph above shows the thirteen days of results for the monitoring of concrete shrinkage. From the graph, we observed that the transmission power and wavelength were remain unchanged for thirteen days.

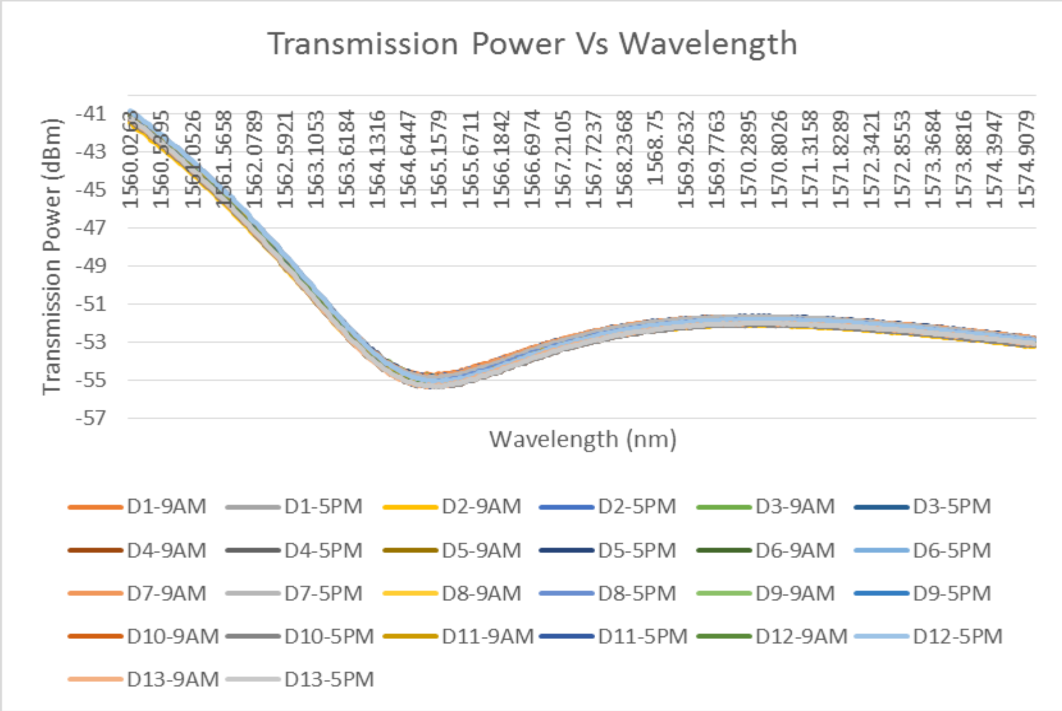


Figure 4.2.8: Zoom in for the Figure 4.2.7.

The figure above was the same graph for figure 4.2.6, as this figure was the zoom in for the notch part of the graph for a better view or clearer vision to read the data.

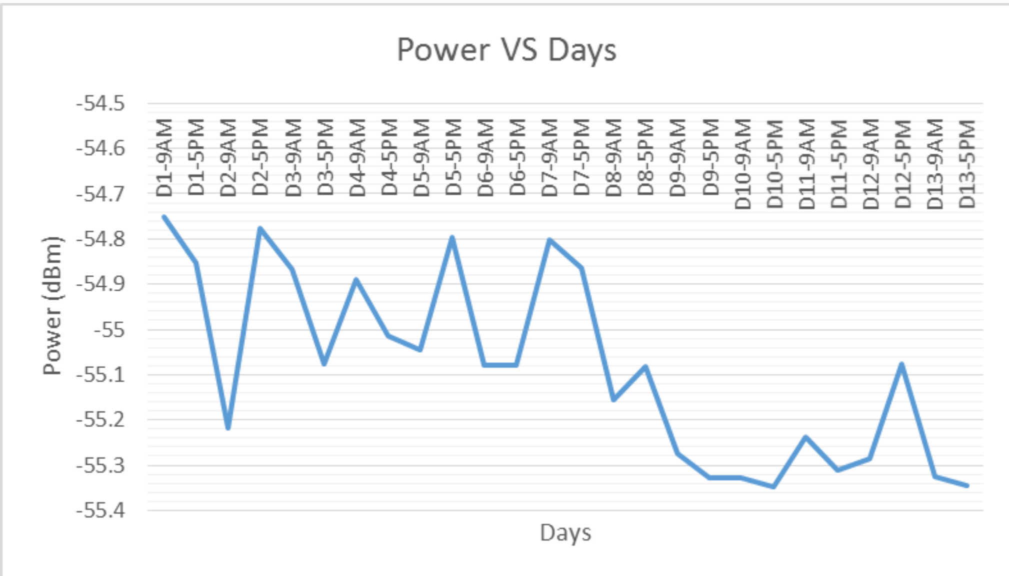


Figure 4.2.9: The graph of power vs days for two weeks data.

The figure 4.2.9 above shows the graph of power vs days for the collected in two weeks data. As from the graph, the power changes from day to day was not significant after the cement specimen turn into the solid form. The maximum power for the graph was -54.751 dBm and the minimum power was -55.348 dBm. Thus, the difference was 0.597 dBm.

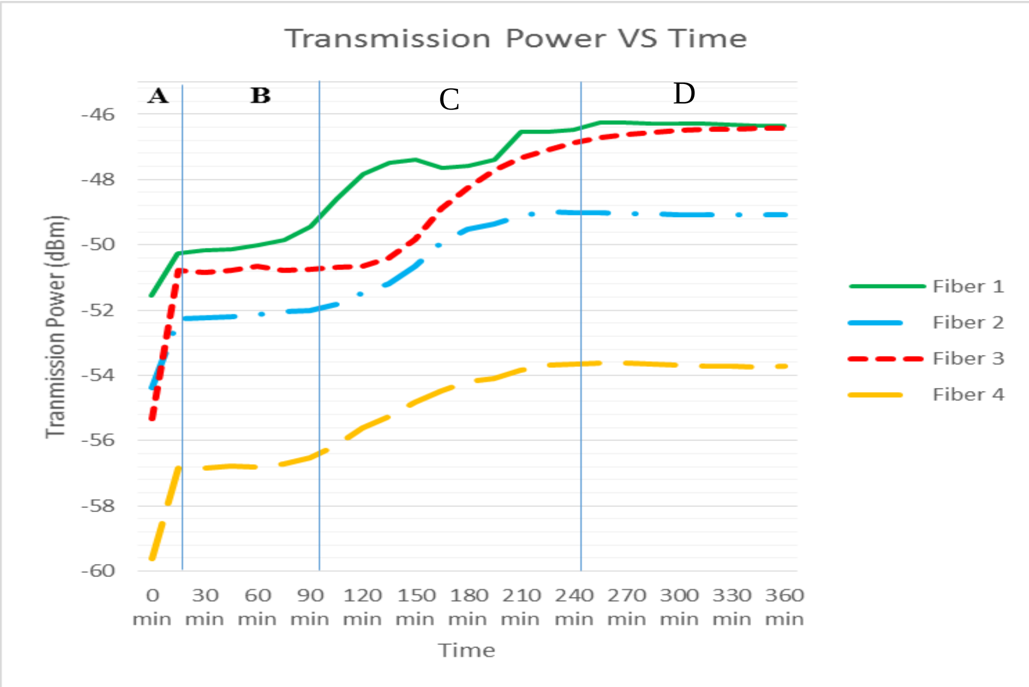


Figure 4.2.10: Graph of transmission power vs time for four fiber results.

The figure 4.2.8 was the graph for the four fiber that used in experiment for the testing of cement experiment in order to measure concrete shrinkage. From the graph, we can observed, at the beginning the graph increase sharply for the first 15 minutes, as this because the fiber were contact with cement mixture that pour into the container. After that, the graph remain unchanged until 90 minutes as because the cement mixture were in liquid form. On the other hand, starting from 90 minutes to 240 minutes, the graph rise again as the cement mixture changing form from liquid slowly turn into solid form. As from 240 minutes onward, the graph remain unchanged because the cement mixture were turn into solid form.

Table 3: Summarises for the difference of transmission power for the four fiber.

Number of fiber	Initial power(dBm)	Final power (dBm)	Difference (dBm)
Fiber 1	-51.551	-46.348	-5.203
Fiber 2	-54.373	-49.084	-5.289
Fiber 3	-55.323	-46.414	-8.909
Fiber 4	-59.632	-53.732	-5.900

Table 3 above summarise out the difference of transmission power for four fiber that use in the experiment to test for concrete shrinkage. The fiber 1 has the difference of -5.203 dBm transmission power after six hours of monitoring for concrete shrinkage follow by fiber 2 has a difference of -5.289 dBm of difference. Fiber 3 has -8.909 dBm and fiber 4 has -5.900 dBm of difference of transmission power. This conclude that, within six hours of monitoring for concrete shrinkage, there were approximately -6 dBm of transmission power loss.

4.3 Discussion

In my final year project, the title that I chose was investigation of the concrete shrinkage using an embedded long period fiber gratings (LPFGs). The fiber use in my project was called Single Mode Fiber-28 (SMF-28). Besides, the long period fiber gratings was fabricated at campus by myself in order to proceed my concrete shrinkage test.

Fabrication of LPFGs was playing an important role in my concrete shrinkage test. The LPFGs fabricated must chose the gratings number that almost the same with the range of ±5 gratings. Therefore during fabrication of LPFGs, the procedure to fabricate and the parameter use to fabricate LPFGs must be correct and precise. For example, during cut the both end of the fiber, it must be cut by using glass cutter so that the fiber end were cut vertically in other word 90 degree. This was to make sure all the light was transmitted into the core.

In my final year project, I have conducted two types of experiment, one of the experiment was measured the concrete shrinkage using conventional method. The second experiment was measured the concrete shrinkage using an embedded LPFGs method. The first experiment, the conventional method to measure concrete shrinkage was using the equipment called “Demec Strain Gauge”. This equipment can measure up to 0.001 mm of changes. It was quite accurate use to measure concrete shrinkage, but there is limitation or disadvantage of using this equipment. By using Demec Strain Gauge to take reading of the cement specimen, not every time we put the Demec Strain Gauge on the specimen was in same position, the different position of the strain gauge, the different reading will be recorded. Next, Demec Strain Gauge cannot have real time monitoring for the concrete shrinkage. As Demec Strain Gauge only start measured when the specimen was in solid form and recorded twice a days which morning 9 am and 5 pm for two weeks continuously. Furthermore, during preparing the three cement specimen, the standard ratio using was 1:2:0.35. For example 1 Kg of cement mix with 2 Kg of sand and 0.350 Kg of water. After cast the cement specimen, cover the three specimen with a big container to let it dry in close air. This was to avoid the natural wind will speed up the drying process and affected our shrinkage value. The whole experiment must done in room temperature. After one day, demould the three specimen and glue the stainless-steel disc on four surface of the specimen and take the four average value for the concrete shrinkage data.

Second experiment was using an embedded LPFGs method to measure concrete shrinkage. This method require a self-design container with a dimension of 50 mm x 13.4 mm x 13.4 mm and embedded the LPFGs into the container. The dimension of the container was scale down from the conventional method mould with a scale factor of three. The reason scale down the dimension because if the dimension was large, the LPFGs cannot cover all of the cement specimen which meant some surface of the specimen reading cannot be detected by the LPFGs. Therefore, a smaller dimension was recommended to use in my experiment. Apart from that, the side of the container was put some silicon gum on it, in order to fix the LPFGs in straight line condition when the cement mixture pour into it. This experiment need to conduct in room temperature same for the conventional method as needed to have standard temperature in order to measure concrete shrinkage.

CHAPTER 5

5.1 Conclusion

Throughout this project, it showed that the proposed of embedded long period fiber grating for concrete shrinkage measurement is workable. During testing, it can classified the stage of concrete shrinkage conditions from liquid to solid. It indicated that most of the samples achieved saturation point (Solid form) after 4 hours. The continuing of two weeks measurement data on one of the sample showed that it is completely solid after saturation point. However the size of the concrete may affect the saturation point which remains as further research study. At this stage, LPFG is only capable to provide qualitative analysis on concrete shrinkage due to the relationship of concrete shrinkage in optical power with the approximate strain value can't be established. This is because lack of measurement technique for comparison especially liquid form.

5.2 Recommendations

The concrete shrinkage measure using LPFGs can be further study by using original dimension (L=160 mm, H=40 mm, W=40 mm) and embedded LPFGs in the middle of the cement specimen for monitoring the shrinkage. Besides, we can also try to add aggregate stone into the cement mixture to see the difference with aggregate stone and without aggregate stone for concrete shrinkage.

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APPENDICES

APPENDIX A: Gantt chart FYP 1

Final Year Project 1

Task Name/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Select FYP Title														
Project Planning														
Literature Review														
Methodology														
Fabrication of LPFG														
FYP 1 Report														
FYP 1 Presentation														

APPENDIX B: Gantt chart FYP 2

Final Year Project 2

Task Name/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Select LPFGs for Final Year Project 2 experiment purpose														
Preparing the container and embedded with LPFGs														
Test under water with an embedded LPFGs in a container														
Test the concrete shrinkage using an embedded LPFGs for first fiber														
Test the concrete shrinkage using an embedded LPFGs for Second fiber														
Test the concrete shrinkage using an embedded LPFGs for Third fiber														
Test the concrete shrinkage using an embedded LPFGs for Fourth fiber														
Understanding how to use Demec Strain Gauge														
Preparing three cement specimen for the conventional method experiment														
Test the three specimen by measuring concrete shrinkage using Demec Strain Gauge														
Summarize Results														
Discussion														
FYP 2 Thesis														
Poster Presentation														
FYP 2 Presentation														