Jurnal Kejuruteraan Awam 17(1): 13-22 (2005)

OBSERVATION OF CORROSION PROCESS OF REINFORCING STEEL

Mohammad Ismail[1], Erica Dina[1],
Rosly Abdul Rahman[2], Sabirin Ikhsan[2]

[1]*Department of Structures and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai Johor*

[2]*Department of Physics, Faculty of Science Universiti Teknologi Malaysia, 81310 Skudai Johor*

Abstract: Corrosion of reinforcement is one of the major contributors to the deterioration of reinforced concrete structures. The cause of corrosion can be due to carbonation or chloride attack. Early detection of corrosion process can prevent costly repair or structural collapse. The aim of this study was to look at the possibility of using modified fibre optic sensor to monitor the corrosion process of reinforcing steel. The corrosion process was monitored by an unclad plastic optical fibre sensor attached to a steel bar. A fibre optic spectrometer was used to detect the spectrum of the white light. The light spectrum changes in intensity as corrosion develop and progresses on the bar surface. Three samples of mortar prisms with steel bars inserted at the centre were prepared. One sample was immersed in 10% Sodium Chloride (NaCl) solution and another in 20% NaCl. The results were compared with a reference sample. The corrosion process was observed for a 20-day period. The results show that the initial value of the outgoing light from the optical fibre was 4000 counts and reduced to less than 3600 counts after 20 days. The intensity value decreases slowly as the corrosion progresses.

Keywords: *Fibre Optic Sensor, Corrosion of Reinforcement, Chloride, Durability*

Abstrak: Pengaratan tetulang merupakan faktor utama kepada kemerosotan struktur konkrit tetulang. Pengaratan tetulang berlaku akibat pengkarbonatan atau serangan klorida. Mengesan kejadian pengaratan pada peringkat awal dapat mengelakkan kerja pembaikan yang mahal atau kegagalan struktur. Tujuan kajian ini adalah untuk mengkaji kemungkinan menggunakan penderia gentian optik yang diubahsuai untuk mengesan proses pengaratan tetulang. Pengaratan tetulang dikesan menggunakan gentian optik yang dibuang salut dan diikat ke tetulang. Spektrometer gentian optik diguna untuk mengesan spektrum cahaya putih. Spektrum cahaya berubah intensitinya disebabkan produk pengaratan yang terbentuk dipermukaan bar keluli dan semakin likat dengan bertambahnya pengaratan. Untuk kajian ini, disediakan tiga bungkah sampel mortar dengan bar keluli dipasang ditengahnya. Sampel pertama direndam dalam larutan natrium klorida (NaCl) dengan kepekatan 10% dan sampel kedua dalam larutan natrium klorida dengan kepekatan 20%. Keputusan ujikaji dibandingkan dengan sampel kawalan. Pengamatan proses pengaratan diambil selama 20 hari. Hasilnya didapati nilai awal cahaya yang keluar daripada gentian optik adalah 4000 count kemudiannya turun ke paras kurang daripada 3600 count selepas 20 hari. Nilai intensiti cahaya berkurangan dengan pertambahan pengaratan.

Kata kunci: *Penderia Gentian Optik, Pengaratan Tetulang, Klorida, Ketahanlasakan*

1. Introduction

Concrete normally provides reinforcing steel with excellent corrosion protection. Reinforcing steel remains in passive state in highly alkaline pore water, the pH of which is usually higher than 13 (Neville, 1996). In addition, concrete can be designed to have a low permeability, which minimises the penetration of corrosion agents. Low permeability concrete also increases the electrical resistant of concrete, which impedes the flow of electrochemical corrosion current. Corrosion of steel reinforcement, however, can occur if the construction work (workmanship) is not of adequate quality, for example such as detailing not properly designed for the service environment..

Corrosion of reinforcement is a worldwide problem that affects durability and integrity of reinforced concrete structures. Corrosion primarily occurs because of carbonation process that reduced the alkalinity of concrete or chloride that attack the passive layer on the reinforcement (Neville, 1996, Broomfield, 1997; Elsener et al., 1999).

The fibre optic sensors monitoring technology is used to describe the unique marriage of material in structural engineering. This structurally integrated sensing system could monitor the state of a structure's durability throughout its working life. It is necessary to develop a good sensor that has the capability to continuously identify the actual changes in the properties of reinforced concrete structures during curing, ion penetration, and assessing damage or weakness in structural integrity. Therefore, measures to improve the quality control of the reinforced concrete structures during the service life can be carried out. This will enable maintenance works to be carried out from time to time to slow down if not to stop the deterioration of the structures.

Fibre optic sensors have demonstrated the ability to take some of the key structural evaluation and performance measurements (Huston and Fuhr, 1995). Fibre optic sensors are similar to electrical sensors in that the fibre optic sensors use light as both the sensing and information transduction medium. Electrical sensors operate by modifying the voltage, current, frequency, or phase of an electrical signal. Fibre optic sensors operate by modifying the intensity, fast frequency (wavelength), slow frequency (time-modulated intensity), polarisation, phase, and coherence (Huston et al., 1999).

The applications of fibre optic sensors in engineering components and systems have been tested in several laboratories and installed in many sized structures.

The laboratory results have been quite promising, showing potential for further improvement (Eric, 1995). The majority of the field installations are currently of the study or demonstration type. Mendez et al. (1990) first suggested the use of embedded fibre optic sensors to measure physical quantities in concrete. They found that the alkaline nature of a concrete could damage the silicon in glass, but the damage can be avoided by jacketing the glass fibre with plastic buffers.

Huston and Fuhr (1992) and Fuhr et al. (1993) used fibre optic sensors in reinforced concrete. Their studies involved embedding optical fibres of various types inside small reinforced concrete beams (100 mm x 100 mm x 100 mm). The initial tests focused on whether optical fibres could survive the concrete embedding and curing process. Escobar et al. (1992) used bonded fibre optic strain gauges on concrete beams and Kruschwitz et al. (1992) used Extrinsic Fabry-Fizeau Interrerometric (EFFI) strain gauge in concrete beams. Maher and Nawy (1993) reported the successful use of fibre optic Bragg grating strain gauges in laboratory's concrete beam test. The use of fibre optic sensor to determine the physical properties of concrete such as cracking, stress-strain, and temperature has been well developed (Huston and Fuhr, 1995).

Repairing deteriorated reinforced concrete structures at an advanced stage is very costly and time consuming. It is more advantageous if corrosion can be detected at an earlier stage so that some preventive measures can be carried out. The objective of this research was to develop a sensor that can monitor corrosion process by modifying a fibre optic.

2. Materials and Test Procedures

This experiment used samples of cement mortar (40 mm x 40 mm x 90 mm) The mortar was mixed with Cement/Sand (C/S) and Water/Cement (W/C) ratios of 0.36 and 0.64, respectively. 1% NaCl was added to the mixture. A 6 mm diameter mild steel rod was cleaned using sandpaper and immersed in nitric acid until the steel is silvery in colour. Fibre optic was cut into pieces of 450 mm length. About 40 mm at the middle of the fibre was unclad. The unclad plastic optical fibre was tied up to the steel rod and embedded in cement mortar. The glass rod was used to protect the plastic optical fibre from the NaCl solution. The prisms were then immersed in the NaCl solution to enhance the corrosion process. The samples are as shown in Figures 1 and 2.

One prism was immersed in 10% NaCl and another in 20% NaCl solution. A HeNe laser was later used to ensure that the cladding has been properly removed. The experimental setup is shown in Figure 3 and further illustrated in Figure 4.

The intensity of the outgoing white light was recorded using USB2000 Fibre Optic Spectrometer. The spectra obtained before corrosion and during the corrosion process were recorded. For calibration purposes, the light intensity was measured. At the white light source (input), the light intensity recorded was 4000 counts. The range of white light wavelength was from 400 nm to 800 nm, as shown in Figure 5.

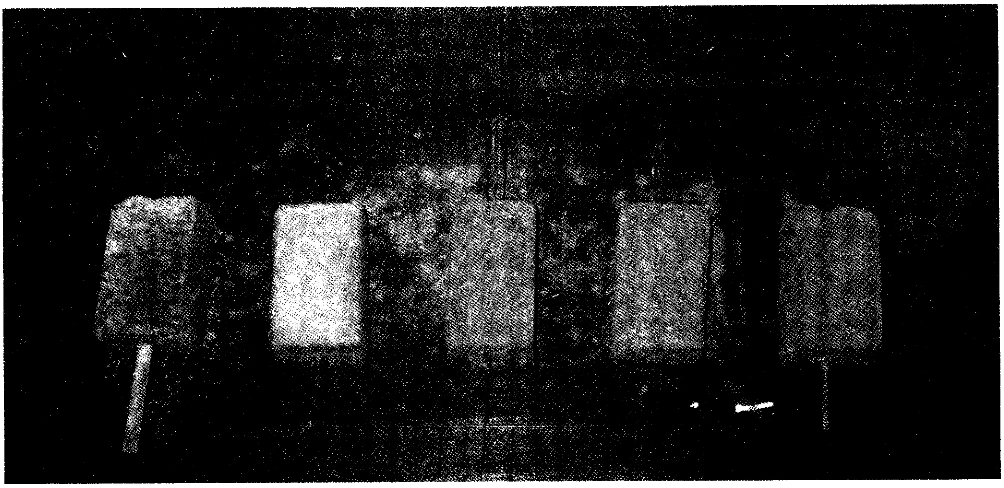

Figure 1: Samples of reinforced mortar prisms

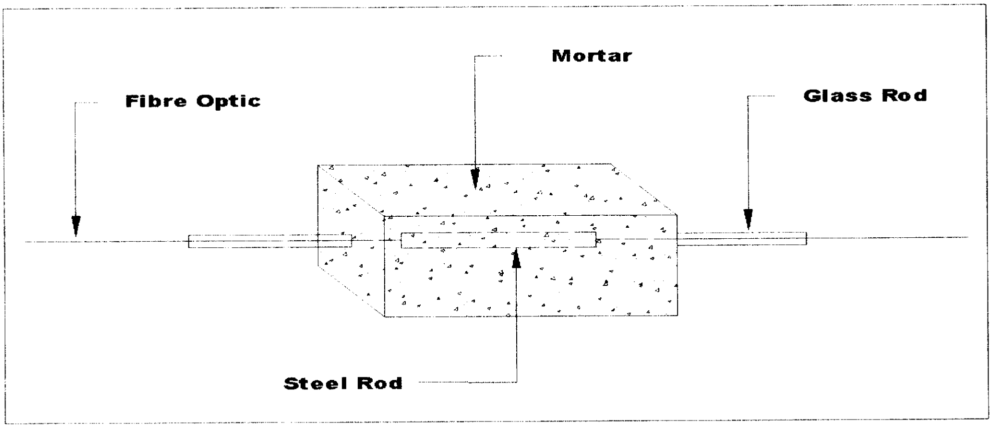

Figure 2: View of sample

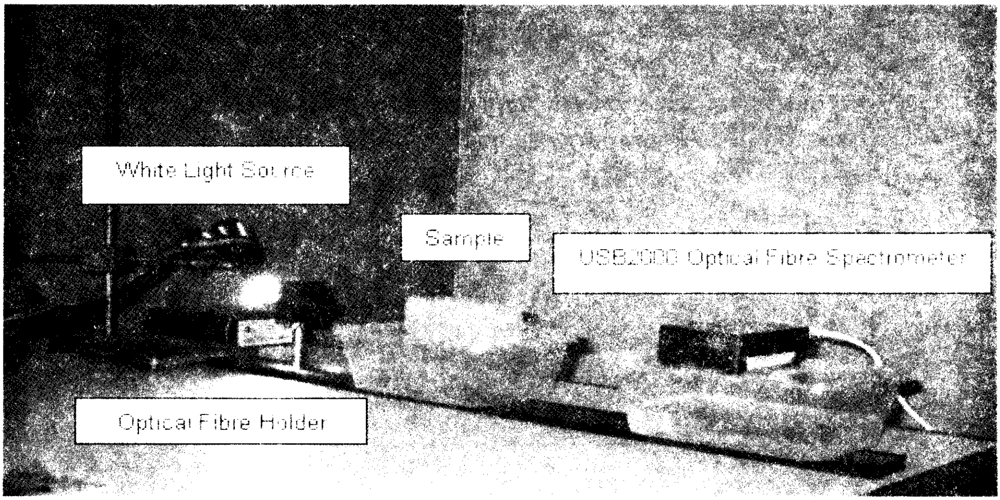

Figure 3: The corrosion monitoring by measuring white light intensity

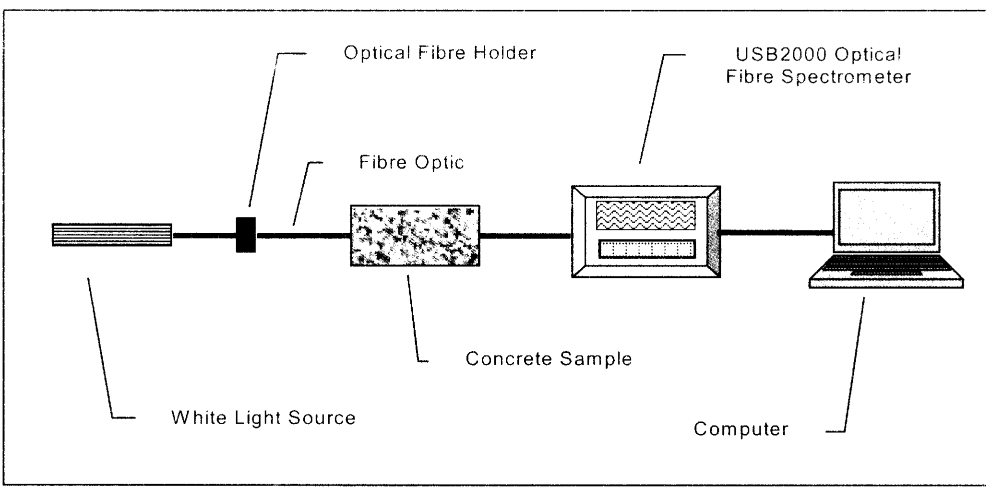

Figure 4: The illustration of experimental Setup

When corrosion of reinforced concrete occurred, it affected the transmission of light through the unclad portion of the plastic optical fibre. The light signals from the fibre was recorded every 24 hours over a duration of 20 days after the mortar prisms had been immersed in the NaCl solution.

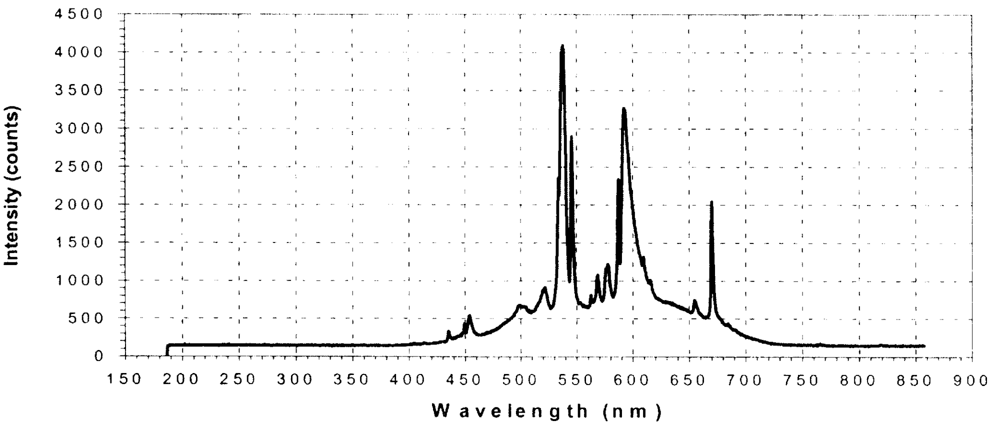

Figure 5: The intensity of white light spectrum

3. Results and Discussion

Figure 6 shows the corrosion curve recorded by the unclad plastic optical fibre corrosion sensor of the controlled sample (sample A). The reinforcing steel was not corroded after 20 days. The curve shows that the average intensity of white light spectrum is always stable for the 20-day period. The intensity of white light spectra for non-corroded reinforcement steel rod fluctuated between 3990 and 4008 counts with average of 3999 counts. There was no pattern to suggest the occurrence of corrosion.

The intensity of light count of sample B (immersed in 10% NaCl solution) for 20 days is shown in Figure 7. From the figure, the transmitted optical power starts to decrease after 9 days. The intensity of white light spectrum reduced probably because of the corrosion product accumulates and change in colour on the reinforcing steel surface. This corrosion product disturbed the light travel along the fibre hence the light intensity reading reduced. This is an important observation of corrosion occurring on the reinforcement.

Figure 8 shows the output of white light spectrum of sample C that was immersed in 20% NaCl. The corrosion influenced the intensity and not the wavelength of the white light spectrum. Figure 8 shows the light intensity curve obtained from unclad plastic optical fibre corrosion sensor after being immersed in 20% NaCl solution for 20 days.

Initially, the corrosion data obtained from sample C by the unclad optical fibre corrosion sensor was similar to the data from sample B. The light intensity of these samples starts to drop at about the same time. However sample B shows a larger reduction at day 20. The reading recorded by sample C was 3200 counts compared to 3600 counts for sample B.

Figure 9 shows different behaviour of curves representing the light transmission of the control sample compared to the sample B and sample C.

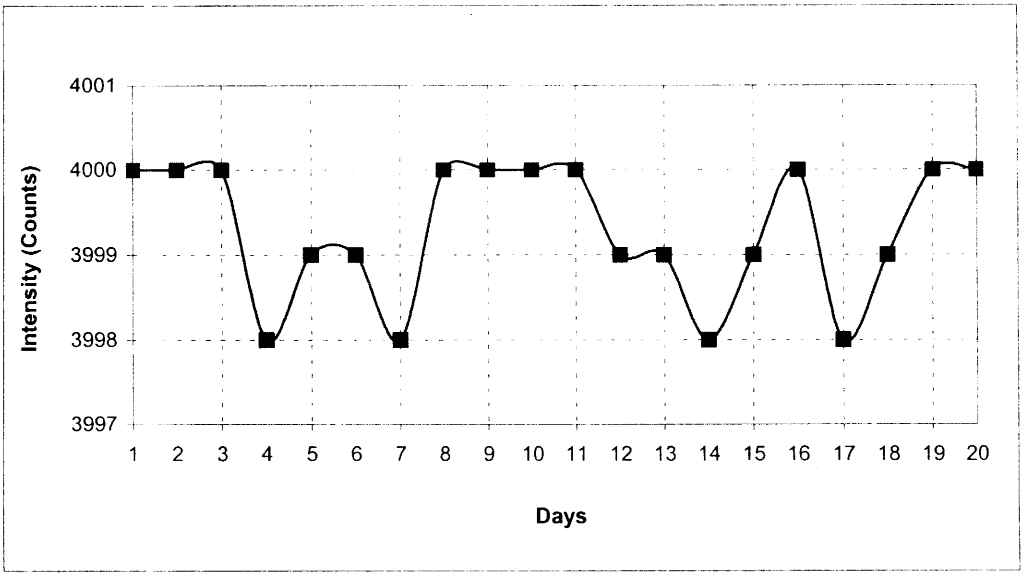

Figure 6: Intensity white light spectrum for sample A (Control Sample)

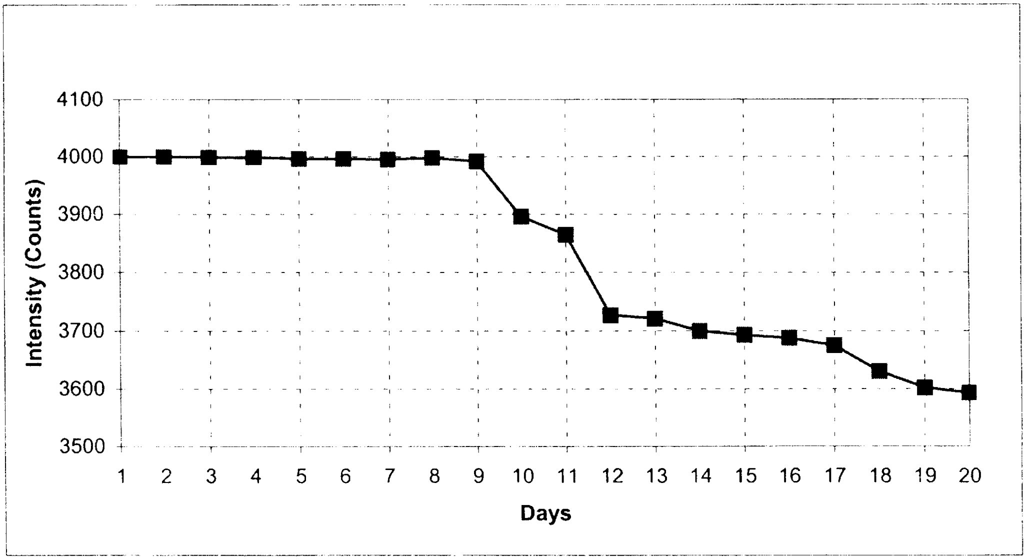

Figure 7: Intensity count against days of Sample B immersed in 10% NaCl solution

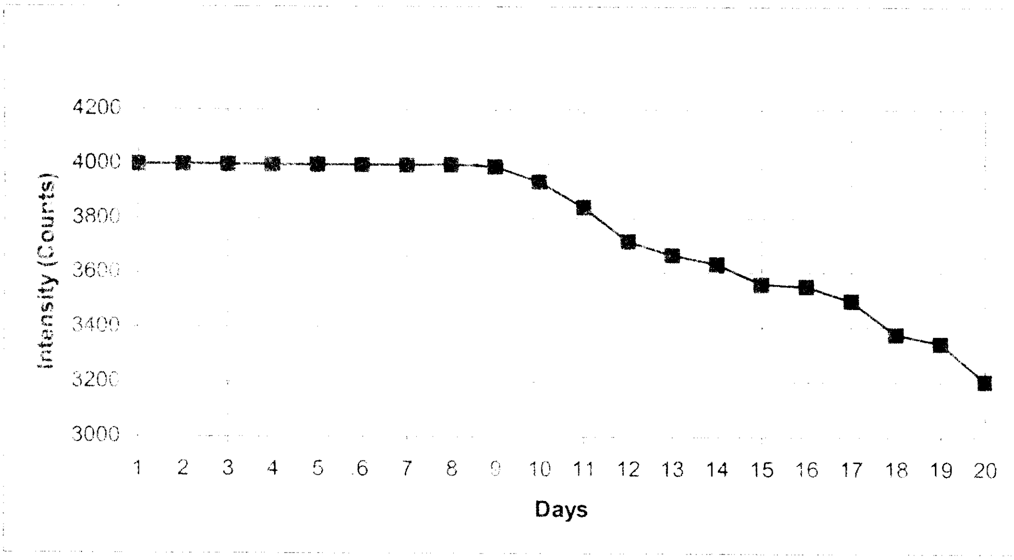

Figure 8: Intensity count against days after immersing sample C in 20% NaCl solution

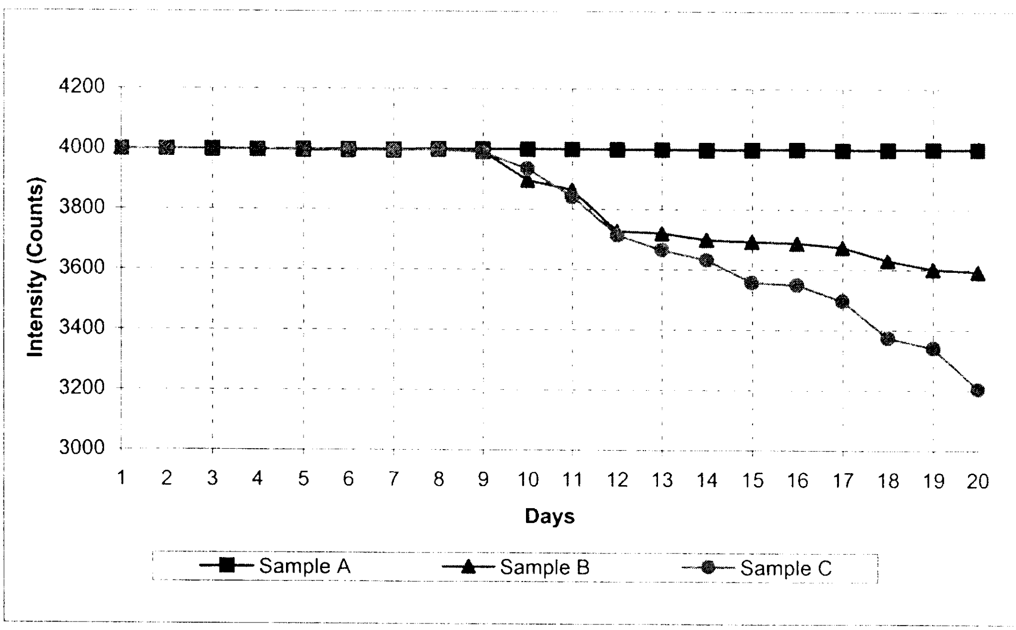

Figure 9: Graphs of intensity vs. days after treatment for the 3 samples

The pattern showed by the curve proved that, the unclad plastic optical fibre corrosion sensor was capable in observing early corrosion process. This finding reinforced work by Siaw et al. (2002) who work on Y-shape fibre bundle to observe corrosion and using power meter to measure light transmitted. From the above observation, the application of optical fibre for monitoring the process of corrosion in concrete is very reasonable and promising.

4. Conclusion

From this study, the application of optical fibre to observe the corrosion process of reinforced concrete structures was encouraging. The changes of white light spectrum intensity tell us about the corrosion intensity of reinforcing steel in concrete.

The following conclusions may be drawn:

i. The unclad plastic optical fibre corrosion sensor can be used as a corrosion monitoring sensor by attaching it to the reinforcement surface.
ii. This type of investigation is very appropriate because the plastic optical fibre can be attached directly to the reinforced surface.
iii. The transmitted optical power going through the plastic optical fibre decreases dramatically with the severity of corrosion in reinforced concrete.

References

Broomfield, J.P. (1997) *Corrosion of Steel in Concrete: Understanding, Investigation and Repair*, E & FN SPON.

Elsener, B., Buchler, M., Stalder, F., and Bohni, H. (1999) Migrating corrosion inhibitor blend for reinforced concrete, *Part 1—Prevention of Corrosion, Corrosion*, Houston, 55(12): 1155-1167.

Eric, U. (1995) *Fibre optic smart structures technology*, *In* Eric U. (ed.) Fibre Optic Smart Structures, New York: John Wiley and Son.

Escobar, P., Gusmeroli, V., and Martineeli, M. (1992) Fibre–optic interferometric sensors for concrete structures, *SPIE*, Vol. 1777.

Fuhr, P.L., Huston, D.R, Ambrose, T.A., and Snyder, S. (1993) Stress monitoring of concrete using embedded optical fibre sensors, *ASCE Journal of Structural Engineering*, 119(7): 2263-2269

Huston, D.R, and Fuhr, P L. (1992) Fibre Optic Monitoring of Concrete Structures, *SPIE*, Vol. 1798.

Huston, D.R, and Fuhr, P.L. (1995) *Fibre Optic Smart Civil Structures*, *In* Eric U. (ed.) Fibre Optic Smart Structures, Wiley - Interscience.

Huston, D.R., Fuhr, P.L., Eric Udd. and Inaudi, D. (1999) Fibre Optic Sensors for Evaluation and Monitoring of Civil Structures, *SPIE*, Vol. 3860.

Kruschwitz, B., Claus, R.O., Murphy, K.A., May, R.G., and Gunther, M.F. (1992) Optical Fibre Sensor for the Quantitative Measurement of Strain in Concrete Structures, *SPIE*, Vol. 1777.

Maher, M. H. and Nawy, E.G, (1993) Evaluation of fibre optic bragg grating strain in high strength concrete beams. *In* Ansari, F. (ed.) Applications of Fibre Optic Sensor in Engineering Mechanic, *ASCE Journal of Structural Engineering*, 119(1): 120-133.

Mendez, A. Morse, T.F., and Mendez, F. (1990) Application of Embedded Optical Fibre Sensors in Reinforced Concrete Bridges and Structures, *SPIE*, Vol. 1170.

Neville, M., (1996) *Properties of Concrete*: Fourth and Final Edition, Addison Wesley Longman Limited.

Siaw W. S., Mohammad Ismail, Madzlan Aziz and Rosly Abd Rahman (2002) Y-shape optical fibre bundle in monitoring corrosion, *Jurnal Kejuruteraan Awam*, 14(2): 47-59.