

## **LOAD SUSTAINED RIG FOR BOND DURABILITY STUDY**

Shukur Abu Hassan<sup>\*</sup>, Yob Saed Ismail<sup>1</sup>, Abd Rahman Mohd. Sam<sup>2</sup>

<sup>1</sup>Department of Applied Mechanics,  
Faculty of Mechanical Engineering,  
Universiti Teknologi Malaysia,  
81300 Skudai, Johor Bahru,  
MALAYSIA

<sup>2</sup>Department of Structure and Materials,  
Faculty of Civil Engineering,  
Universiti Teknologi Malaysia,  
81300 Skudai, Johor Bahru,  
MALAYSIA

### **ABSTRACT**

*This paper describes the development of a special-built experimental rig used for bond durability study of composites specimen under combination of sustainable mechanical load and weathering effects. The specimen under study was Carbon Fibre-Reinforced Plastic (CFRP) plates bonded with special structural epoxy adhesive to a concrete prism. The fully mechanical rig was designed to create and sustain pull-push load configuration to the specimen. From setting-up process, laboratory monitoring works and CFRP plate strain data, it shows that the rig performed well without any maintenance throughout the period.*

**Keywords:** *Bond durability, CFRP plate-concrete bonded system, experimental rig, load sustainable.*

### **1.0 INTRODUCTION**

Several experimental and testing rigs have been produced and used to investigate either for short-term or long-term bond performances of steel or fibre-reinforced plastic (FRP) plate-concrete system since 1970's by known researchers around the world. These include four point flexural loads and pull-out test rigs that used for normal experimental size reinforced concrete beams or small scale concrete prism respectively. Most of the designs were related to investigation into either bond performances or bond durability and other mechanical performances studies of steel and FRP system bonded to concrete. In the early age of the durability study, an investigation into the flexural performances of steel plate-concrete beam bonded system exposed to outdoor environmental condition under sustained load

---

\*Corresponding author : shukor@fkm.utm.my

had been successfully conducted by numerous researchers [1-8]. They have used fully mechanical experimental rig as shown in Figure 1. The rig was designed to create a sustainable four points flexural load imposed onto a pair of externally steel plate-concrete beam bonded system. The rig was used without any maintenance for bond durability studies of reinforced concrete beam that externally bonded to mild steel plate. The specimens were exposed for more than 15 years to an aggressive environment industrial area around Sheffield, United Kingdom. Apart from that, the geometries and the loading configuration that assigned to the FRP or steel plate-concrete bonded specimen can be referred to numerous researches works, for example Nakaba, *et al.* [9] in studying bond characteristics under various loading effects such as bending, single face shear, direct tensile and double face shear. From their study, it shows that the double face shear was the preferred test method that provided a significant result. These were proven by Swamy, *et al.* [2], Mukhopadhyaya *et al.* [10], Maeda, *et al.* [11], Brosens and Van Gemert [12], Horiguchi and Saeki [13] and Toutanji and Ortiz [14]. From literatures, it shows that no experimental rig has been developed specifically for bond durability study under pull-push loads configuration. Therefore, it is very important in this research to develop the rig that can create and sustain the mechanical load for long-term bond durability study.

This paper discusses the methodology of how a simple mechanical rig has been developed, produced and tested for bond durability study of CFRP plate bonded to concrete prism using structural type epoxy adhesive. The mechanical performances of the rig also has been discussed to proof the mechanics of the overall rig-specimen integration in terms of load transfer and sustainable.

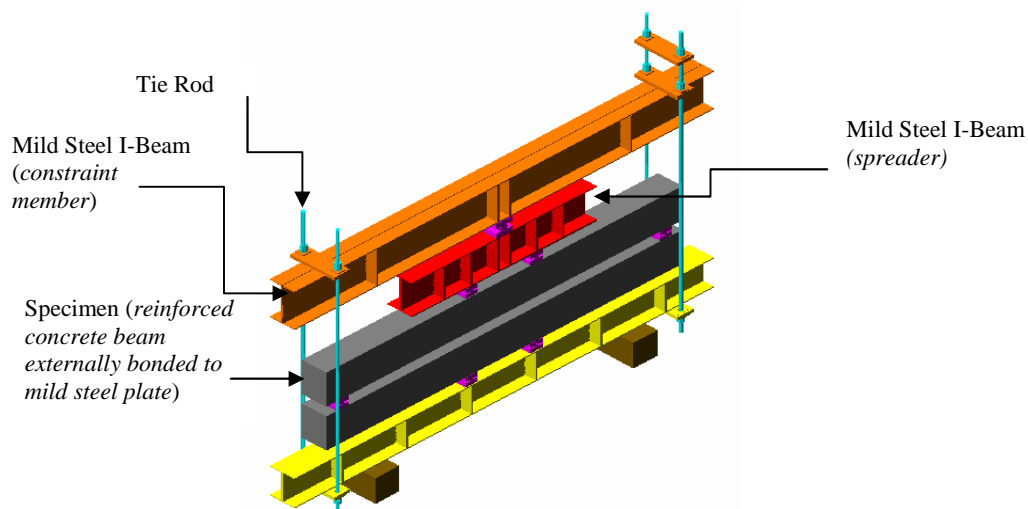


Figure 1: Four points flexural load sustained rig

## 2.0 DESIGN OBJECTIVE AND METHODOLOGY

The main objective of developing the experimental rig was to create a sustainable pull-push loads that can be imposed on CFRP plate bonded to concrete specimen (Figure 2) for bond durability assessment. The first stage in the design process was to establish the problem statements which focuses to the critical needs of the product. In this study, the critical parts of the rig design is to counter the problems that related with specimen's geometry and loading configuration that need to be assigned to the specimen's respected individual material. After completing the parametric study of the specimen, three rig design concepts have been produced. Finally, the design concept based on the ability in meeting most of design criteria has been selected and develop for further technical evaluation. Apart from that, the mechanical testing was also performed on individual rig components and specimen materials in order to determine load and stresses limit state. The specimen materials test data are very important for the overall rig-specimen design consideration.

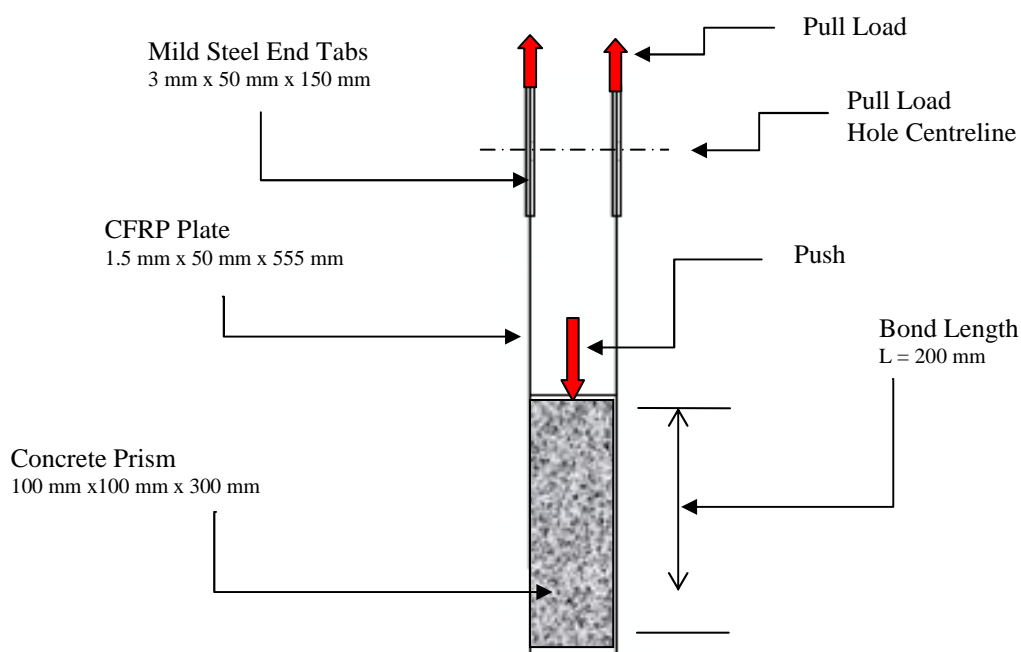


Figure 2: Specimen configuration under study

## 2.1 Design Solution

Apart from developing the rig, the analysis and investigation of the ultimate limit state of the bond joint between mild steel end tabs to CFRP plate was also considered as a top priority in the overall design process. This is important because the failure in the bond region is not acceptable within certain load limit. This was to ensure the specimen would not fail in the clamping region rather than in the CFRP plate-concrete bonded area [15, 16]. The application of mild steel plate as end tabs was to prevent or to overcome the weakness of orthotropic

properties of CFRP plate under tensile stress [17, 18]. Mukhopadhyaya, *et al.* [10] in their experimental study of Glass Fibre-Reinforced Plastic (GFRP) plate-concrete specimen had used mild steel plate geometry of 150 mm x 90 mm x 1.2 mm bonded on both side of GFRP plate in order to ensure the GFRP plate did not tear off prematurely due to reduced cross section across the drilled hole. No failure along the bonded area of GFRP plate-mild steel end tabs bonded area was reported in their study. Therefore, performing both bond numerical analysis and bond test was the best approach to reach the conclusion in determining the load and stress limit around the pinhole region within the end tabs. From pull-push load test shown in Figure 3, it can be seen that the weakness in shear properties of orthotropic CFRP plate was the main factor that initiated the failure in end tabs bond region. The test result shows that the debonding of mild steel end tabs from CFRP plate was due to excessive local bond stress which was developed at specimen loaded end interface (i.e. tensile) bond region [19, 20]. This can best be referred to strain distribution around pin hole under various applied load level as shown in Figure 4.



Figure 3: Close-up view of shear-out bond failure within mild steel end tabs CFRP plate under pull-pull load.

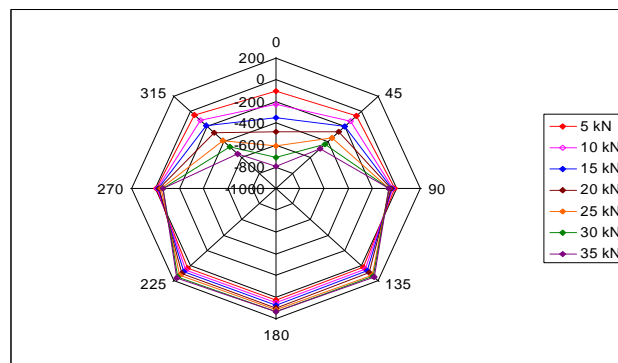


Figure 4: Typical strain distribution around end tabs pinhole at various load levels.

The rig final design is shown in Figure 5 which consists of an upper constrain plate, lower constrain plate, bearing block, guide block, pin, bolts and tie rods. All the mechanical design calculation was referred to design handbooks [21-24]. In this design, the safety factor of 1.5 has been used for all critical components. This was based on material testing and numerical analysis. The assumption made in this design analysis was that the rig and the specimen were in the state of equilibrium. The design analysis started with first identifying the most critical rig components and specimen material (i.e. specimen area that subjected to critical stress under load). To overcome the constraint in identifying the correct loading mechanism which able to produce higher limit load and also able to fit the specimen loading point configuration, a mini-hydraulic jack with 50 kN maximum load capacity has been selected (Figure 6). The load applied to the rig-specimen was measured by a load transducer with the maximum capacity of 50 kN brand TML supplied by Tokyo Sokki Kenkyujo Co. Ltd. [25]. The load transducer was first calibrated to confirm it mechanical performances prior been used for load measurement during rig-specimen set-up (Figures 7 and 8).

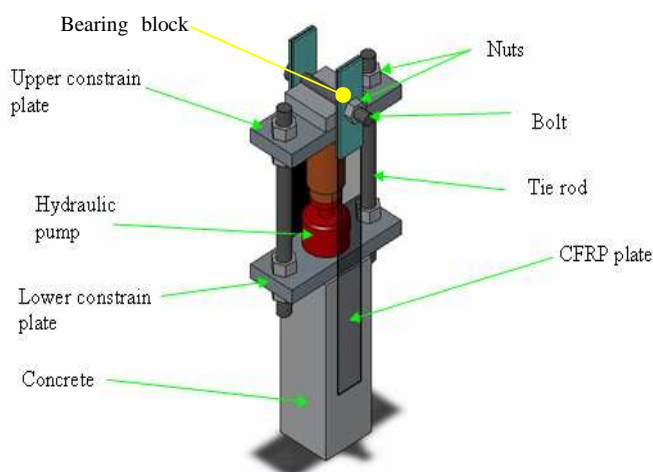


Figure 5: Final design of load sustained bond experimental rig spring under compression load test.



Figure 6: Mini hydraulic jack with capacity of 50 kN.



Figure 7: Calibration of 50 kN load cell using 100 kN Instron Universal Testing Machine.

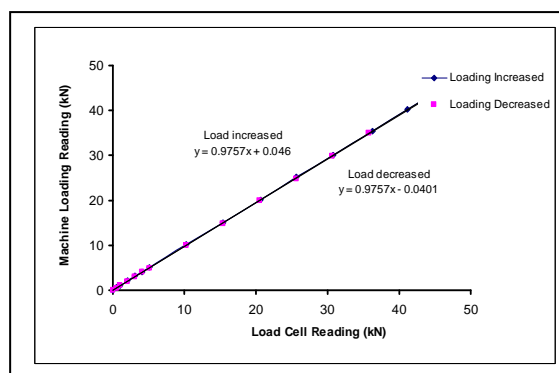


Figure 8: Graph of machine load versus load cell load reading under increment and decrement of applied machine loads.

### 3.0 RIG-SPECIMEN SET-UP DESCRIPTIONS

The rig-specimen set-up started with the assembly the rig components configuration prior to the installation of the specimen to the rig itself. After the completion of setting-up works the mini hydraulic jack was installed onto the lower plate follow by the installation of load transducer in between hydraulic jack and the upper constraint plate. The lateral movement of hydraulic jack and load transducer was constraint by a circular holes depth of 3 mm in depth and 50 mm in diameter were formed at both lower and upper constraint plates. Both tie rods were subjected to full compression load after the specimen reached it limit load. This was achieved by tighten both rods using double system nuts. Finally, the torque wrench was used to lock the nuts prior to releasing the hydraulic load. At the early stage, observation on the rig-specimen performances were monitored through data logger TDS-302 on the CFRP plate strains output. The monitoring was performed in every 15 minutes for the first 24 hours, followed by every 30 minutes for the next 48 hours and finally by every 24 hours for the duration of 45 days. There are three rig-specimens used in this experiment, namely;

BOLTALS50-C1, BOLTALS50-C2 and BOLTALS50-C3. The complete rig-specimen set-up are shown in Figures 9 to 12.



Figure 9: Rig initial set-up.

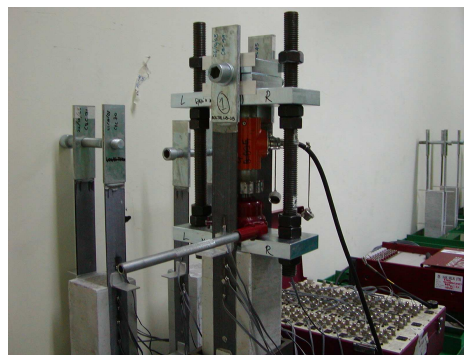


Figure 10: Full set-up and ready to be loaded.



Figure 11: Applying hydraulic load.



Figure 12: Rig-specimen performance monitoring through strain reading.

#### **4.0 DISCUSSIONS**

The complete performances of the rig-specimen during pre-stressing and during sustainable load are shown in Figures 13 to 16 for BOLTALS50-C1 specimen. The curve shown in Figure 13 demonstrates the three stages of loading conditions experienced by the specimen, namely; stressing (stage 1), locking (stage 2) and applied load released (stage 3). It can be seen that during the stressing stage, the CFRP plate local strains were non-linear up to the limit load. This non-linearity was due to the mechanically controlled mini hydraulic jack pumping system which occurs at non-constant rate. This non-linearity can best referred to CFRP plate strain curve along bond length as shown in Figure 14. The next locking stage was considered the critical part during the setting-up process by which the limit load imposed was set by the applied torque (i.e. determined by design calculation) and this need to be workout in a fast mode and both tie rods must be in a balanced load condition. This could be verified and confirmed by monitoring the strain readings of both sides (Side A and Side B) of the CFRP plates. From Figure 15, it can be seen that the difference between strain readings along the bonded length can be

used as a standard benchmark to evaluate the balancing between both sides of the specimen in terms of load transfer from the applied hydraulic load. The results show that the different strain readings between each pair (i.e. reading of strain gauges at the same location, for example SG2A and SG2B etc.) for BOLTALS50-C1 ranged from 0.5% to 30% for the three loading stages and 3% to 85% for low load level condition. The same results were also recorded by BOLTALS50-C2 where the readings ranged from 0 to 20% for the three last stages and 20 to 85% for low load level condition. Finally, BOLTALS50-C3 showed a larger difference between those two specimens whereby the difference ranged from 20% to 125% for the last three stages and 7% to 19% for low load level condition. It could be said that at low to higher load levels the rig-specimen slowly adjusted their loading condition until they reached the final state of equilibrium. In the final stage, it could be seen that strain readings dropped to the final value (i.e. less than the value just after locking) just after the applied hydraulic load had been released (i.e. load equal to zero). The rate of strains decreased along the bonded length in linear mode. The reduction was due to the loss of support provided by the hydraulic jack used during pre-stressing. Therefore, it could be seen that the rig worked successfully as designed and capable of sustaining the stressed load imposed to the specimen.

During the performance observation in the laboratory environment for 45 days it can be seen that the CFRP plates strain readings were almost constant after reaching their full statics equilibrium (Figure 16) just about after two weeks time period. The laboratory room temperature and humidity parameters had not significantly affect the stressed conditions due to very small fluctuation of the overall strain readings during the monitoring periods. Finally, the rig-specimen was exposed to outdoor condition for the period of six months. During the exposure period, the rig-specimen performance was regularly monitored through strain reading measured at CFRP plate and concrete.

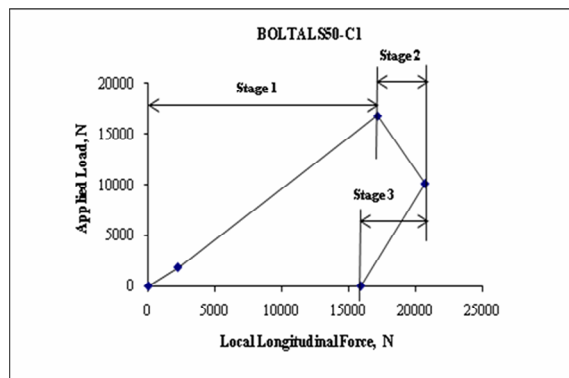


Figure 13: Three load conditions during pre-stressing stages.



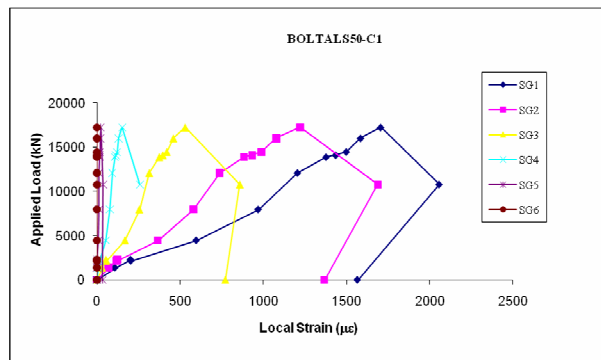


Figure 14: CFRP plate strain along the bond length at various load levels during pre-stressing.

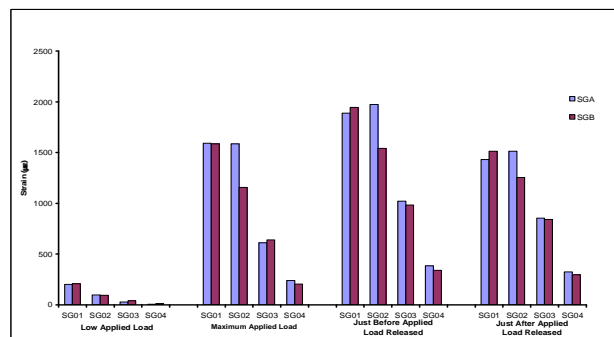


Figure 15: Strain readings between Side A and Side B for CFRP Plate after applied load released.

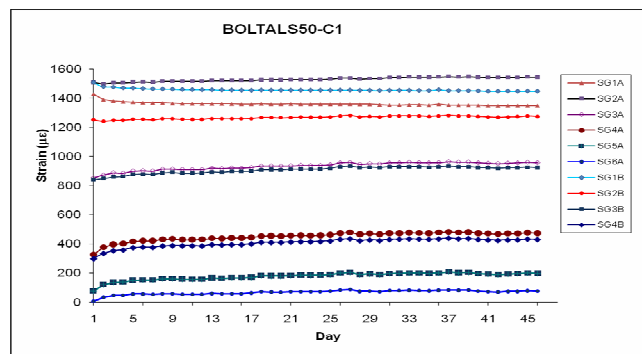


Figure 16: Graph of CFRP plate local strains versus time (days).

## 5.0 CONCLUSIONS

The first design and fabricated load sustainability test rig was successfully produced. The rig successfully produced pull-push loading configuration on the CFRP plate-concrete prism adhesive bonded specimen. The rig was capable of transferring the load-stresses onto the specimen and sustained the load up to 50% to 65% of the control specimen ultimate failure load. The reliability of the rig was technically proven during the observation periods under laboratory condition.

## ACKNOWLEDGEMENT

The authors wish to thank Ministry of Science and Technology of Malaysia for funded the research project and UTM Research Management Centre (RMC) for managed the research activities under Vote 74180. The authors also wish to acknowledge the assistance of Mr. Rizal Khaus (Materials and Structural Laboratory, Faculty of Mechanical Engineering, UTM) for his technical support in rig prototype development and testing.

## REFERENCES

1. Macdonald, M. D., and Calder, A. J. J., 1982. Bonded Steel Plating for Strengthening Concrete Structures, *International Journal of Adhesion and Adhesive*, Vol. 2, No. 2, pp. 119-127.
2. Swamy R.N., Jones R, and Charif A., 1986. Shear Adhesion Properties of Epoxy Resin Adhesives, *Proceedings of International Symposium on Adhesion Between Polymers and Concrete*, pp. 741-755.
3. Calder, A.J.J., 1979. *Exposure Tests on Externally Reinforced Concrete Beams – First Two Years*. Transport and Road Research Laboratory, Supplementary Report 529, Berkshire, UK: Crowthorne.
4. Calder, A.J.J., 1982 *The Microstructure of Epoxy Bonded Steel-to-Concrete Joints*. Transport and Road Research Laboratory, Supplementary Report 705, Berkshire, UK: Crowthorne.
5. Calder, A.J.J.,1988 *Exposure Tests on Externally Reinforced Concrete Beams–Performance after 10 Years*. Transport and Road Research Laboratory, Supplementary Report 129, Berkshire, UK: Crowthorne.
6. Calder, A.J.J.,1989 *Exposure Tests on 3.5m Externally Reinforced Concrete Beams The First 8 Years*, Transport and Road Research Laboratory, Supplementary Report191, Berkshire, UK: Crowthorne.
7. Calder, A.J.J.,1990 Durability of Steel Plates Bonded to Concrete with Structural Epoxy Adhesive *International Seminar on Structural Repairs Strengthening by the Plate Bonding Technique*, University of Sheffield, SIRIUS.
8. Swamy, R.N, Hobbs, B. and Roberts, M.,1995 Structural Behaviour of Externally Bonded Steel Plated RC Beams after Long-Term Exposure. *Structural Engineer*, pp. 255-261.

9. Nakaba, K, Kanakubo, T., Furuta T. and Yoshizawa H.,2001. Bond Behaviour between Fibre-Reinforced Polymer Laminates and Concrete. *ACI Structural Journal*, pp. 359-367.
10. Mukhopadhyaya, P, Swamy, R.N., and Lynsdale C.J.,1998 Influence of Aggressive Exposure Conditions on the Behaviour of Adhesive Bonded Concrete – GFRP Joints, *Journal of Construction and Building Materials* 12, pp. 427-446.
11. Maeda T., Asano Y., Sato Y., Ueda T. and Kakuta Y.,1997 A Study on Bond Mechanism of Carbon Fiber Sheet, Non-Metallic (FRP) Reinforcement for Concrete Structure, *Proceeding of the Third International Symposium*, Vol.1, pp. 279-286.
12. Brosens, K and Van Gemert, D., 1997 Anchoring Stresses Between Concrete and Carbon Fibre Reinforced Laminates, Non-Metallic (FRP) Reinforcement for Concrete Structures, *Proceeding for Third International Symposium*, Vol. 1, pp. 271-278.
13. Horiguchi, T. and Saeki, N.,1997 The Effect of Test Methods and Quality of Concrete on Bond Strength of CFRP Sheet, *Proceeding of Non-metallic FRP Reinforcement for Concrete Structure*, pp. 265-274.
14. Toutanji, H. and Ortiz, G.,2001 The Effect of Surface Preparation on the Bond Interface between FRP Sheets and Concrete Members, *Journal of Composite Structures*, pp. 457-462.
15. Abdul Rahman M. S. and Shukur, A. H. 2005 Fibre Reinforced Polymer Composites in Construction”, *National Civil Engineering Conference 2005 (NACEC2005)*, KUITTHO, Johor.
16. Hodgkinson, J.M. *Mechanical Testing of Advanced Fibre Composites*. Woodhead Publishing Limited, Cambridge England, 2000 pp. 121.
17. Shukur, A. H., Abdul Rahman, M. S. and Yob, S.I. 2002 Tensile Behaviour of CFRP and GFRP Reinforcements. *Research Seminar on Materials and Construction*, UTM, Malaysia.
18. Hojo, M., Sawada, Y. and Miyairi, H, 1994 Influence of Clamping Method on Tensile Properties of Unidirectional CFRP in 0° and 90° Directions – Round Robin Activity for International Standardization in Japan, *Journal of Composites*, Vol. 8, No. 1-4.
19. Shukur, A.H., Abdul Rahman, M. S. and Yob Saed, I., 2003 Bond Behaviour of CRFP Plate Bonded of Concrete. *Malaysia Science and Technology Congress*.
20. Shukur, A. H., 2007 *Mechanical Performance of Carbon Fibre Reinforced Vinyl Ester Composite Plate Bonded Concrete Exposed to Tropical Climate*, PhD Thesis, UTM.
21. Shigley, J.E., Mischke, C.R. and Budynas, R.G., 2003 *Mechanical Engineering Design*. 7<sup>th</sup> edition, pp. 24.
22. Juvinall, R.C. and Marshek, K.M., 1991 *Fundamental of Machine Components Design*. Second Edition, John Wiley & Sons, pp. 190.
23. Swanson, R.S.,1997 *Introduction to Design and Analysis with Advanced Composite Material*. Prentice-Hall International, Inc.
24. Clarke John L., 1996 *Structural Design of Polymer Composites: Eurocomp Design Code and Handbook*, E and Spon.

25. Tokyo Sokki Kenkyujo Co., Ltd: 2003 *TML Strain Gauge Test Data*. Tokyo, Japan.