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ORIGINAL ARTICLE

Creep behaviour monitoring of short-term duration for fiber-glass reinforced composite cross-arms with unsaturated polyester resin samples using conventional analysis

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ABSTRACT – The leading objective of this experimental study is to perform a Short-term Creep Testing on samples (coupon test) obtained from a private company in order to learn the durability of the Unsaturated Polyester Resin (UPR) material with and without Calcium Carbonate ($CaCO_3$) on the applied cross-arm application according to ASTM E139. Through the method of flexural test jig (three point bending test) along with the usage of the furnace chamber HK160, samples then examined with initial temperature of 30°C until it breaks down. Result has been evaluated using conventional method for predicting the life-long purpose of the samples for future reference and analysis. The configurations or the patterns of the failure through (conventional) method recorded for short term test inside HK160 Chamber furnace fails at temperature of 120°C for samples without $CaCO_3$ the samples fails and crack. Therefore, the samples with due to the material of UPE with FRP in a bar shape are said to have Ultimate Temperature for Failure of 120°C. Further details are crucial for advance analysis in the future research purposes.

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Composite material; flexural test jig; mechanical properties; unsaturated polyester composite

INTRODUCTION

The cross-arms are commonly positioned near the top of transmission towers with a higher mean wind speed [1]. Visweswara [2] stated that tallness and the span of the cross- arms is the general shape of the tower that carry electrical conductors which is becoming a whole high voltage transmission line structure system. In China, the composite cross-arms are created and used in the transmission line corridor and the weight is lowered to shape the arm body instead of using the traditional steel components. Cross-arm composite also has advantages such as excellent insulation efficiency, high mechanical strength, light weight, erosion resistance, simple to set up and much more. After the use of composite insulator, composite cross-arm is also said to be innovative in composite material applications in transmission line [3].

The commercial thermosetting resins such as unsaturated polyesters resins are widely used with fillers [4] as a neat [5] and also reinforced by fibers [6, 7]. Murafa et al. [8] indicated that, usually, this unsaturated polyester resins are used to fill up similar and dissimilar materials such as metals, wood, plastics, non-metals or even ceramics. The reduction of surface size occur through curing process at room temperature. With its characteristics of fast curing and also reduction in temperatures, low viscosity, excellent compatibility with mineral fillers and reinforcing fiber products, together with the capacity to be transformed through poly-condensation or polymerization process which reacts to the cross-linked polymers.

The impact of fiber curing on the flexural stress-strain conduct of fiber characteristics, as assessed by Hariharashayee et al. [9] especially on Sansevieria Cylindrical Fiber Reinforced Polymer Composite (SCFP) is presented as the upper and lower surface of the specimen under a three-point bending force, the bending stress (compression and strain) and the axisymmetric plane precisely subjected to shear stress. Flexural test were also conducted on the machine per the ASTM D2344-84 [21] where 150 mm length and 20 mm wide samples were cut and loaded on three point bending with span to depth ratio of 16:1 [10]. Chaudhary et al. [11] mentioned that in the design of composite material, flexural strength is very essential when material is subjected to lateral loads. Nearly identical to flexural modulus in which the rigidity of composite materials is measured. This bending test of three points is widely used to find flexural strength and flexural modulus. This is further discussed by Acharya and Soma [5], where they researched the flexural characteristic of woven jute glass hybrid composite strengthened by natural fiber. They discovered that by incorporating glass fiber as extreme fiber, they might improve the flexural characteristics of jute E-glass epoxy and its composites.

As for creep study, statement by Anand et al. [12] mentioned that creep is defined as the material's plastic deformation at constant stress-temperature over an extended period of time.

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National instrument (NI) has been widely become one of the data logger used for measuring strain as well as recording failure of material for a period of time. This is applied by Constantin et al. [13] where National Instruments NI PXI 4220 data acquisition module has been used in order to measure stress in quasi-static tests with the help of MTS C-45 tensile testing machine (TTM) equipped with a 100 kN load cell and deformation was recorded with a GOM Aramis measuring system.

Strain gauges glued on two opposite sides of each active and dummy specimen used to quantify the compressive strain in the accelerated test and connected in a Wheatstone bridge circuit as shown in Figure 1 [14]. The strain gauges used in the experiment were self-temperature compensating constantan alloy foil strain gauges attached on a plastic backing. The gauges were glued to the wood surface using an epoxy adhesive, AE-10, prepared by strain gauge manufacturer and the glued gauges were protected with a moisture protective coating. The gauge arrangement shown in Figure 1 was planned to measure pure compressive strain and eliminate bending and temperature effects. [15]. The creep strain was quantified and read by a data acquisition system on a portable IBM-PC.

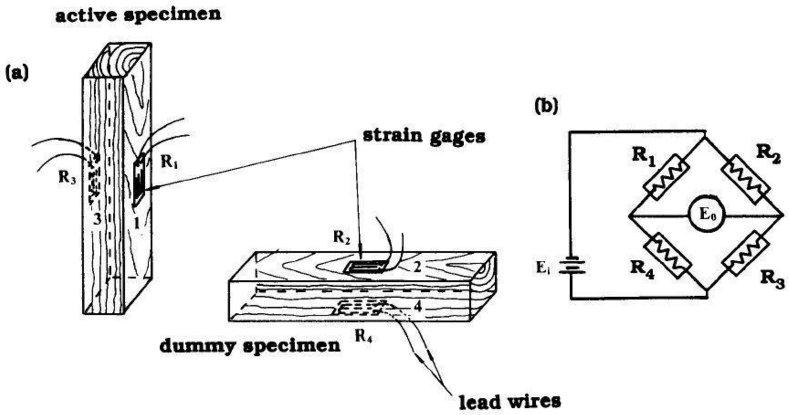

Figure 1. Creep strain measurement [16]: (a) active and dummy specimens and gauges and (b) Wheatstone bridge circuit

Short-term accelerated compression test apparatus. - The short-term accelerated test were conducted in an insulated test chamber. A compression test fixture with a calibrated lever arm producing a lever advantage of 1:20 was developed, and three such test fixtures were assembled in the test chamber as shown in Figure 2 [14]. Spherical seats positioned underneath the specimens minimized the load eccentricity. Five thermometers and a humidity and temperature transmitter were handled to measure the temperature inside the chamber. Creep was accelerated by testing the same specimen at successively higher temperature levels for 17 hours. Three active specimens were arranged in the test fixtures and the corresponding dummy specimens were stationed near each active specimen Figure 2 [16, 17]. Three moisture monitoring specimens were created, were coated with a moisture protective coating. The creep test procedure began by conditioning the specimens at ambient temperature and relative humidity (70 F, 49%RH) for 24 hours. The loads were applied and the creep response [Wheatstone bridge output (EO) in Figure 1 (b)] was recorded for 17 hours.

Figure 2. Sample of short-term accelerated test apparatus test jig [20]

Then loads were removed and 40-hour recovery data were gathered. Next, temperature and relative humidity conditions and the recovery from the previous test was complete as evidenced by the bridge output voltage.

The purpose of the cross arm of the tower structure as a holder holding the insulator that is positioned directly by the insulator. It is also classified as a device used to keep the insulator and the cable to the power tower at a certain height.

Since 1929 TNB has been using the wood cross arm from the Chengal wood (Neobalanocarpus). The preference of wood cross arm is prior to its excellent mechanical strength properties and good arc quenching ability during lightning strikes [18,19]. But it is no longer easily accessible due to ageing factors and the source of Chengal that matures, Alternate solution for material replacement of wood cross arm with fiber reinforcement polymer (FRP) in Malaysia commenced in 1999 in Pekan to Tanjung Batu line on the 132kV line tower with the kick-start pilot projects [18].

Therefore, the gap of this study is some of the installed cross arm transmission tower that were made of fabricated fiber-glass composite cross-arm (Unsaturated polyester resin mixture) has failed due to uncertain reason which was estimated to be caused by the addition of Calcium Carbonate filler ($CaCO_3$). A specific test has been introduced in order to differentiate between two types of samples which are the filler of $CaCO_3$ and without $CaCO_3$ which require data and information for further clarification and improvement.

METHODS AND MATERIALS

In this experimental investigation on the coupon test of unsaturated-polyester composite fibre glass, samples are prepared through the process of pultrusion method. The process itself prepared by Electrius Sdn. Bhd. a joint venture company with Tenaga Nasional Berhad, TNB. The coupon samples are used for further analysis of the characterization and behaviour of the materials which undergoes Short Term analysis procedure.

Based on Figure 3, the composite samples are prepared with two group of materials. One sample is prepared from the material of unsaturated polyester resin, fiber glass and added up with calcium carbonate ($CaCO_3$) whilst another sample without presence of calcium carbonate substances. Both samples with its depth measurement of 8 mm and 7 mm respectively and sample length of 176 mm. There are 4 layers of fiber glass sheets applied.

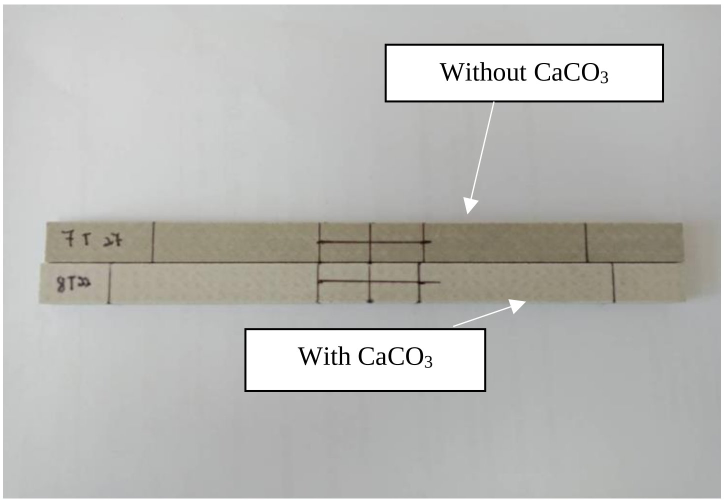

Figure 3. Coupon test bar sample (with calcium carbonate and without calcium carbonate)

Preparation of Experimental (Conventional Method) Set Up on Creep Testing

The preparation of conventional method for testing the coupon test sample bar are carried out and shown based on the following diagrams:

Based on Figure 4, calibration of coupon test set up must first be carried out in order to calibrate the National Instrument (NI 9237, Data Logger) for the next process of collecting the data for the creep deformation on the samples of fabricated cross-arm. 4 NI RJ50 Cables are used. Two of them are dummy cables while another two cables are used to record the data. The reason of having dummy cables are has for completing the circuit for NI Instrument to measure the strain values during the experimentation as referred to the literature review stated with reference to the Wheatstone bridge configurations.

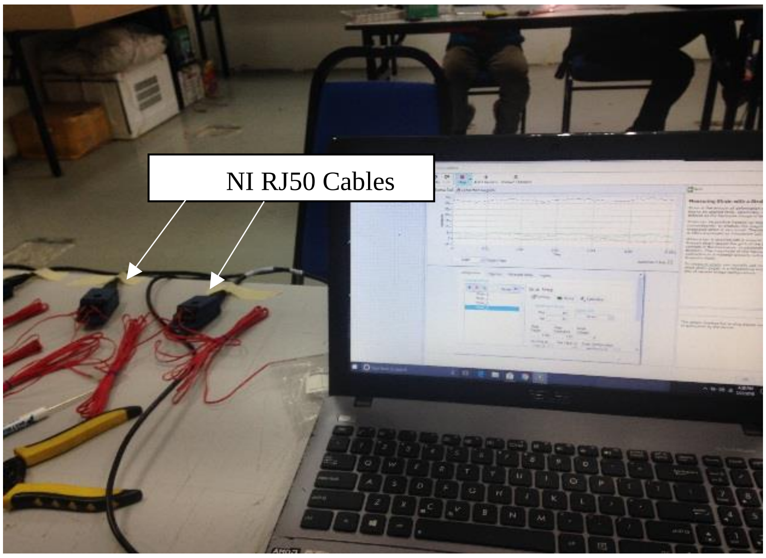

Figure 4. Calibration of coupon test set up

Figure 5 shows the strain-gauge used for mounting onto the RJ-50 (Female) to screw the terminal and thus measure the strain of deflection of the mounted fiberglass sample. The brand used for this strain gauge is KYOWA. The gauge length is 5mm and the lead wire length is 3 meter long with two wire system.

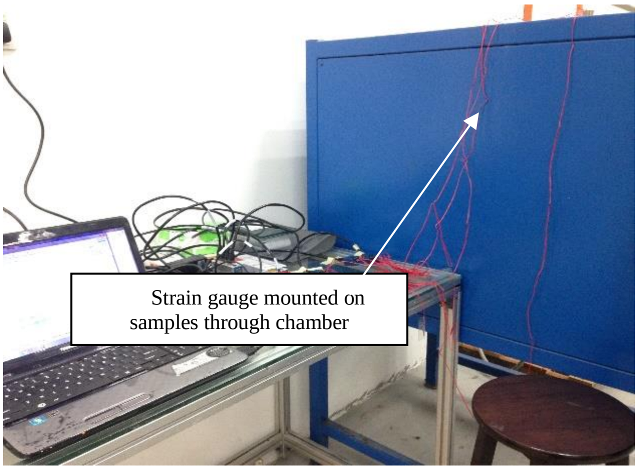

Figure 5. Strain-gauge mounted (red-line wired)

Figure 6 demonstrates a furnace chamber (version: HK160, Linn High Term) used for short-term creep testing on the fabricated fiberglass samples prepared for a different temperature tested from the range of 30°C-160°C which is said to be the ultimate temperature for the sample to fail or fracture.

Figure 6. HK160 Furnace chamber

Figure 7 shows a set of experimental jig with mounted weight which is used to mount the weight onto 4 samples at one time. (two samples are dummy samples and another two samples are the samples that are going to be tested in terms of their flexural strength. For one sample, a column of mounted weight weighs about 10kg per block (1 column; 5 blocks of weight) are used as it sum up to be 40% of the ultimate tensile strength of the material used (Fiberglass-Unsaturated Polyester Resin, with calcium carbonate & without calcium carbonate).

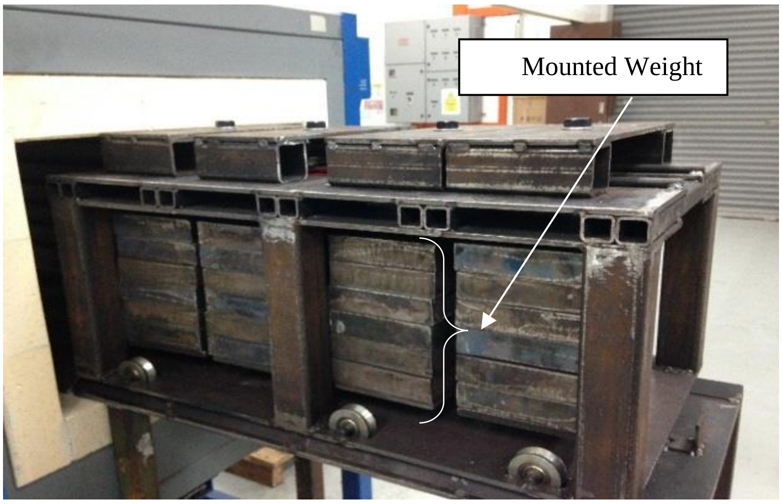

Figure 7. Weight-mounted for flexural test

Figure 8 display the image of the main experimental process undergoes the three point bending (flexural test) before the creep testing implemented using the HK160 Furnace Chamber prepared by the Material Laboratory, Department of Aerospace Engineering, Universiti Putra Malaysia.

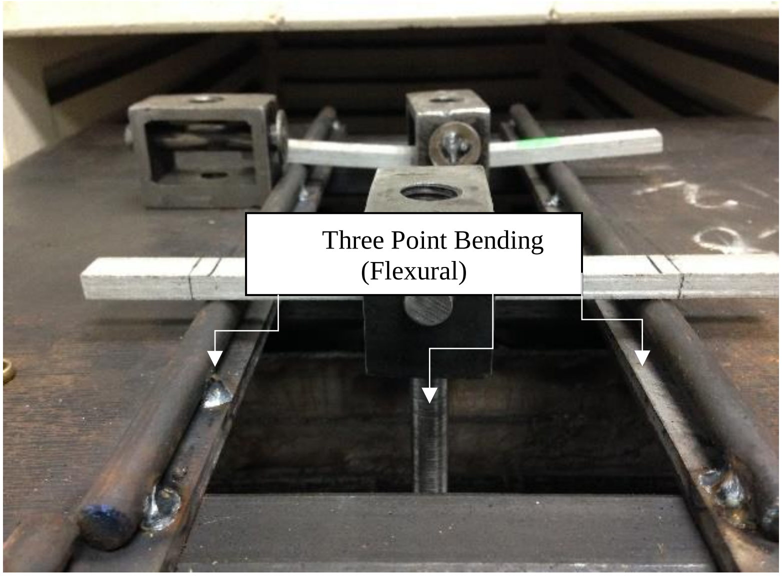

Figure 8. Coupon test samples mounted

RESULTS AND DISCUSSION

Short-term Creep Test Analysis

Figure 9 depicts that the coupon sample of the pultruded composite failed and crack when it reached the ultimate temperature during the creep testing inside the furnace chamber with respect to the flexural load given onto the sample. The temperature of 120°C is the temperature that records the moment of failure of the sample which is said to be the sample without calcium carbonate impregnated within.

Figure 9. Side view of failed-composite coupon sample

Figure 10 shows the sample fracture or fail from the top view. The crack happens to be at the middle of both sample (the dummy and the actual sample) without calcium carbonate ($CaCO_3$) impregnated inside the fiberglass coupon composite sample.

Figure 10. Top view of failed-composite coupon sample

Conventional Analysis

Figure 11 shows the graph of figure (Strain vs. Time in hours). The portions are divided as primary , secondary and tertiary curves. At first, the strain rate is high and then stabilizes due to hardening work. In the second segment, the strain is minimal and almost constant as a result of the balance between annealing and hardening. The tertiary segment is similar to the necking phenomenon seen when the metals are tested for tension in the Universal Testing Machine. Strain vs. time graphs are plotted at a constant load at such a constant increasing temperature. The shape of the creeping curve will depend on the temperature and stress levels involved. If the temperature remains constant, the creeping curves shift upwards and to the left with increasing applied stress. If the creep test is performed at different temperatures but at a constant stress level, the creep rate will increase with rising temperatures.

The graph shows the creep deforming pattern for both samples (with and without the presence of $CaCO_3$). The samples without the presence of $CaCO_3$ experience failure (crack) earlier than the samples with the presence of $CaCO_3$ which was on 8^{th} hours while sample without $CaCO_3$ still continue to deform until it breaks at 13^{th} hours. This shows slightly improvement on the application of $CaCO_3$ on unsaturated polyester resin composite with fiberglass as it was tested as coupon size downsizing from the actual cross arm dimension which suitable on small test jig apparatus. The process undergo repetition of 5 sets and all of the values plotted was subject to the average values of strain with respect to time and variation of constant temperatures.

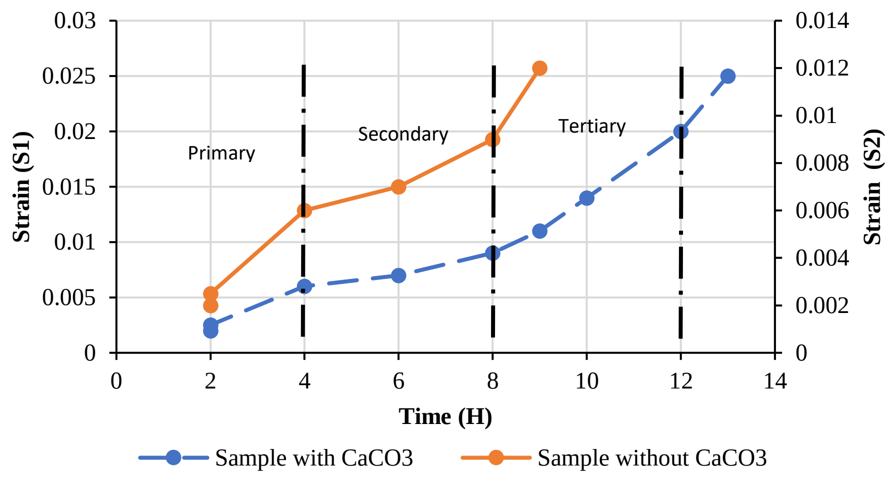

Figure 11. Strain against Time (s) of two sets of sample (one with $CaCO_3$ impregnated and without $CaCO_3$)

CONCLUSIONS

As a result of this conventional method, this experimental process specifies that:

- The pultruded samples which are not impregnated with calcium carbonate ($CaCO_3$) failed at the temperature of 120°C at 9 hours time.
- The pultruded sample with calcium carbonate ($CaCO_3$) impregnated shows good result where the samples were not experiencing failure when the temperature are simultaneously reached 120°C and continue to deform until it reach failure at 13 hours time.
- These experimental setup done to slightly show the significant of having filler such as $CaCO_3$ instead of simply layers of fiber composite without $CaCO_3$ as it strengthen the composite as whole.

Although of these samples are just coupon size, it can be a based reference for actual size set up creep testing for industry applications. All of these data are further investigated on the future experimental research.

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