INFLUENCE OF $CaCO_3$ IN GLASS FIBRE/UNSATURATED POLYESTER COMPOSITE ON THERMAL AND FLEXURAL CREEP BEHAVIOUR

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By

AHMAD NAZRIN BIN JOHARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

December 2019

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DEDICATION

This thesis is dedicated to my beloved parents;
Hj. Johari bin Hj. Zakariah
And
Hjh. Hamidah binti Ayub Uthman
And to my special one, (RZ) who keep on believing and supporting me for every second of my life. Thank you very much for all your love and support that contributes to the publication of this thesis.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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December 2019

Chair : Mohamad Ridzwan Bin Ishak, PhD
Faculty : Engineering

The main objective of this experimental study is to investigate the influence of applying Calcium Carbonate ($CaCO_3$) on the flexural creep behavior of the coupon sample and to predict the service life of the composite samples. One of the test was short-term testing. Flexural test jig has been used along with furnace chamber HK160 for samples tested with different temperatures until it fails while the Long-term test has been done using constant temperature of 30°C.

Master curve generated through the Time-temperature Superposition Principle via TRIOS software purposely done to predict the longevity of the sample. The patterns of the failure through conventional method shown consistent increment of temperature for short term test inside furnace until it reached 120°C, the sample for UPE with fiber-glass (without presence of $CaCO_3$) fails and fracture. For long term test results of creep in room temperature set up to be consistent at (30°C). The results shown small deformation on the center for both of the specimen (with $CaCO_3$ and without $CaCO_3$) with respect to time for 45 days of testing.

Master curve produced displayed different results for UPE samples (with the presence of $CaCO_3$) for 95°C and 160°C respectively. The longevity of the sample of coupon test which can reach up to 25 years of services for long-term (conventional testing) under consistent room temperature (30°C). Using master curve method for TTS, results were at consistent form (without failure) for both UPE coupon sample (with and without $CaCO_3$ reinforced) at 30°C but fractured at 120°C for coupon sample (without $CaCO_3$), and TTS

master-curve prediction for temperature 95°C fails on the 111th Day while for temperature 160°C, it fails on the 11th Day. Therefore, the use of $CaCO_3$ shows significant benefits to the longevity of UPE coupon samples rather than absence of $CaCO_3$ in the samples.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGARUH $CaCO_3$ DI DALAM GENTIAN KACA/KOMPOSIT POLIESTER TIDAK TEPU PADA UDARA PANAS DAN SIFAT LENTURAN SECARA PERLAHAN MELALUI SUHU TINGGI

Oleh

AHMAD NAZRIN BIN JOHARI

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Pengerusi : Mohamad Ridzwan Bin Ishak, PhD
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Objektif utama kajian ini dijalankan adalah untuk melakukan penyiasatan terhadap pengaruh penggunaan kalsium karbonat ($CaCO_3$) pada sifat lenturan secara perlahan melalui suhu tinggi sampel kupon dan akhir sekali untuk membuat jangkaan jangka hayat komposit pada sampel-sampel. Salah satu ujian tersebut ialah ujikaji masa pendek, jig ujikaji lenturan bersama ruang relau HK160 digunakan, sampel-sampel diuji dengan suhu yang berbeza sehingga rosak manakala ujikaji jangka masa panjang telah dijalankan menggunakan suhu yang sama iaitu 30°C. Lengkung Perdana menggunakan prinsip Masa-Suhu Kuasa Posisi (TTSP) telah dihasilkan menggunakan perisian TRIOS bertujuan untuk menjangka jangka hayat sampel.

Corak pola melalui kaedah ujikaji (konvensional), sifat pada sampel kupon menunjukkan peningkatan yang konsisten bagi ujikaji jangka masa pendek di dalam ruang relau HK160 sehingga mencecah suhu 120°C, sampel UPE bersama gentian-kaca (tanpa kehadiran $CaCO_3$) rosak dan patah. Bagi hasil dapatan ujikaji jangka masa panjang di dalam suhu bilik secara konsisten (30°C), hasil menunjukkan pengubahan bentuk yang kecil pada kedudukan tengah kedua-dua specimen (bersama kehadiran $CaCO_3$ dan tanpa kehadiran $CaCO_3$) pada jangka masa selama 45 hari ujikaji.

Lengkung perdana yang telah dihasilkan menunjukkan hasil yang berbeza bagi sampel UPE (dengan kehadiran $CaCO_3$) pada suhu 95°C dan 160°C. Jangka hayat sampel kupon bagi ujikaji jangka masa panjang (ujian konvensional) untuk UPE dan gentian-kaca boleh mencapai tahap sehingga 25 tahun penggunaan dibawah suhu yang konsisten (30°C), bentuk yang konsisten (tanpa kegagalan) untuk kedua-dua sampel kupon UPE (hadir dan tanpa kehadiran $CaCO_3$) pada suhu 30°C tetapi sampel gagal (rosak) pada suhu 120°C bagi sampel kupon (tanpa kehadiran $CaCO_3$), dan jangkaan

Lengkung Perdana TTS menjangkakan akan gagal pada suhu 95°C pada hari yang ke 111 manakala pada suhu 160°C gagal pada hari yang ke 11. Oleh yang demikian, penggunaan $CaCO_3$ menunjukkan kelebihan ketara berbanding tanpa penggunaan $CaCO_3$ pada sampel tersebut.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
CO_2	Carbon Dioxide
CFRP	Carbon Fibre Reinforced Polymer
CSM	Chopped Strand Mat
DMA	Dynamic Mechanical Analysis
DTG	Derivative of Thermogravimetric
DAQ	Data Acquisition Board
DEA	Dielectric Analysis
DTA	Differential Thermal Analyses
DSC	Differential Scanning Calorimetry
FRP	Fiberglass Reinforced Polyester
GFRP	Glass-fiber Reinforced Plastics
GPIB	General-Purpose Interface Boards
INTROP	Institute of Tropical Forestry and Forest Products
LVDT	Linear Variable Differential Transformer
MCMC	Malaysian Communication and Multimedia Commission
PCCA	Pultruded Composite Cross Arm
PMMA	Poly Methyl Methacrylate
PVA	Polyvinyl Alcohol
SIM	Stepped-Isothermal Method
TNB	Tenaga Nasional Berhad
Tg	Glass Transition Temperature
TTSP	Time-temperature Superposition
TG	Thermogravimetric
TGA	Thermogravimetric Analysis
UPM	Universiti Putra Malaysia
UPE	Unsaturated Polyester Resin
UTM	Universal Testing Machine
VI	Visual Instrument
WLF	William-Landel-Ferry

CHAPTER 1

INTRODUCTION

1.1 Background of study

Malaysia is a renovating nation that has been respectfully known for her rapidly expanding economy in various industries. As demand for energy increases every year, the maintenance of the existing power transmission lines cannot be completely ignored. Today, a private company which supplies electrical energy throughout Malaysia has been powering the nation since the day electricity came into existence in Malaysia. It is well understood that electricity is generated at the power plant, then transmitted with voltage stepped down and finally distributed to the end users.

From the beginning of time, the transmission of electricity has been achieved using the transmission towers from the power plant. The transmission tower bodies are usually made of galvanized steel and the cross arms, for certain reasons, can be constructed either from steel or wood. Recently, a private electrical company division found out that most wooden cross arms are degrading and deteriorating because they have been in operation in the tropical climate of Malaysia for more than 40 years. The problem now arises in Malaysia is our country running out of trees that supply the wood for the replacement of the cross arms.

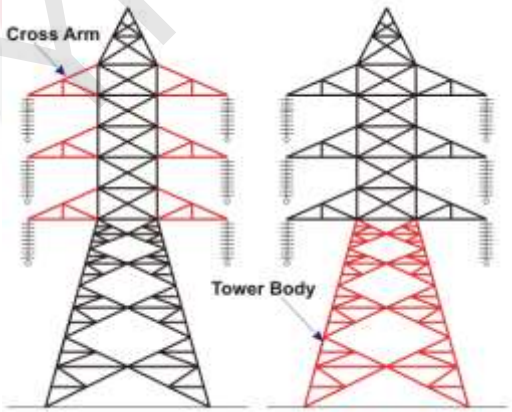

Figure 1.1: Transmission tower with cross arms. (source: Electrical4U, 2018)

Therefore, a proposal entitled 'Influence of $CaCO_3$ In Glass Fibre/ Unsaturated Polyester Composite On Thermal and Flexural Creep Behavior' is introduced to the study and focusing the durability of the fabricated cross arm material shown in figure 1.1, which further will be tested with flexural and creep test. The tropical climate which

indicates or focusing on the equatorial of the earth, experiences hot and humid weather throughout the year. Huge rainfall due to the vertical uplift or convection of air that takes place, as well as thunderstorm happens certain days.

The temperature varies and might surpass 35°C during sunny day while at night abundant cloud regulate amount of heat loss and the temperature might fall lower than 22°C. Presence of water and sometimes extreme heat might affect the behavior of material especially the composite adapted on the cross arms. From the perspective of eco-friendliness, the selection of materials of composite must be acceptable to not affect the readiness of the green eco-system of the earth. This research also includes the robustness of the cross arm overall structure that suits to certain size of transmission line tower. This is due to some failure that occur to current Tenaga Nasional Berhad (TNB)'s cross arms, which breaks after months of installments and give impact to the labor, cost and loss of assets of TNB property.

1.2 Problem statements

Failure happens to the new fabricated composite cross-arm by the industries that use Calcium Carbonate ($CaCO_3$) as the fillers. This brings the significance of the study on the 'Behavior' of the material itself. The study is expected to present the best information on the characteristic of the current fabricated composite cross-arms in terms of their flexural strength and some testing which defines the real lifelong of the current used composite cross-arm.

Due to lack of information on flexural creep of the pultruded composite cross-arm, less study has been done on the effect of using $CaCO_3$ with Unsaturated Polyester Resin Reinforced with fiber-glass, less comprehensive study has been done to study the behavior using both Short-term and Long Term test on the effect of calcium carbonate and fewer research has been carried out on the prediction of the service life of the Pultruded Composite Cross-Arm (PCCA) using Time-temperature Superposition (TTS) which is the latest theoretical method in order to support the whole experiment and the result obtained.

1.3 Objective of study

The overall aim of the study is to carry out investigation through some experimental procedures on the fabricated pultruded composite cross-arm samples which is commercially prepared and used to obtain the desired outputs (i.e., flexural strength, longevity of the sample and relevancy of the material usage). Therefore, this study addressed the following objectives:

1. To do investigation on the thermal analysis of the fabricated pultruded composite cross-arm samples.

2. To investigate the influence of applying Calcium Carbonate ($CaCO_3$) on the flexural creep behaviour.

3. To predict the service life of the composite samples.

1.4 Scope of study

This research will be conducted to study the characteristic of current fabricated pultruded cross arm composites sample. This whole process will cover the research of past works or literature review on the past, mechanical testing and thermal analysis that will be carried out at the Aerospace Engineering Lab, Faculty of Engineering, Universiti Putra Malaysia (UPM).

In Chapter 1, the background of the study, problem statement, objectives of research, scope and significance of study. Chapter 2 discussed the literature review of relevant research. The chapter started with the topic of composite cross arm and continued by topic of Pultruded fiber-glass Reinforced Plastics, Mechanical testing for creep behavior, principle applied for material service life, data logger application for strain measurement and ended with thermal analysis for samples testing. Chapter 3 presents the material and methodology used in the study.

This chapter describes the techniques of material preparation and standards used for mechanical and physical testing. Results and discussions are discussed in Chapter 4. The conventional analysis data of sample and the theoretical analysis using TRIOS software will be further discussed and evaluated in this Chapter. Chapter 5 presents the conclusions and recommendation for future studies.

1.5 Significance of study

As mentioned on the title of the research 'Influence of $CaCO_3$ in Glass Fibre/Unsaturated Polyester Composite On The Thermal and Flexural Creep Behaviour' by highlighting the word of 'Behaviour', means the character and behaviour of the material used in order to withstand wear, pressure or any sort of damages on the cross-arm of the power transmission line for a short and long duration of time and also by applying variation of heat or temperature (creep). Therefore, some significant studies have been done, specifically on the aspect of material that are used will be discussed thoroughly on this research journey.

As for the current fabricated and existing composites, that could not really work well with its strength properties, become major reference for future modifications and benefits for the future researchers to deal with the installation of pultruded composite cross-arm for all power transmission line tower throughout the world. Besides, the

material used will be considered and called 'eco-friendly' which has features of the whole production of new, future modified cross-arm and will become crucial to be one of the most important goals of this project. The research which includes the significant factor; range of temperature (actual; environmental temperature which varies) dealing with the quality and standard of the whole behaviour of the cross-arm.

All of the aesthetic values of the future modification will be put into account as the primary objective of this project is to investigate the durability of the current fabricated pultruded cross-arm which later will become a main supporting parts of the transmission tower that carry huge amount of energy to be supplied domestically. Temperature control testing also needed to get focus on testing the fabricated pultruded cross-arm in order to see the reaction of the cross-arm on certain situation so that the term 'Behaviour' could be achieved successfully. Figure 1.2, shows how important to study every single aspect of cross arm, so that the distribution of voltages can be delivered to the community successfully in Malaysia.

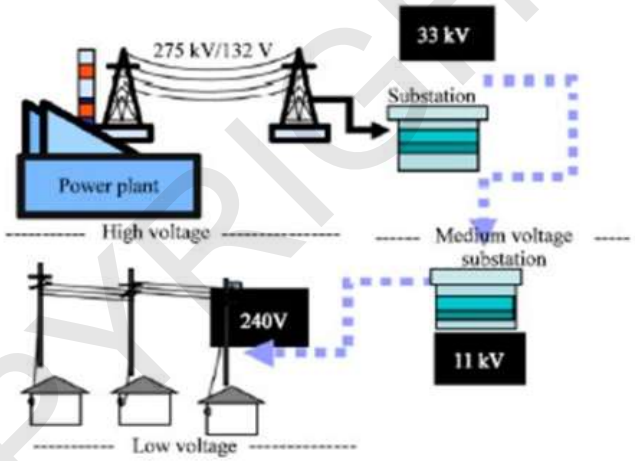

Figure 1.2: The distribution voltages over power lines in Malaysia (source: MCMC, 2005)

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