THE EFFECT OF THERMAL AGEING ON LOW VOLTAGE CROSS-LINKED POLYETHYLENE INSULATED CABLE

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Forensic Engineering.

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JANUARY 2019

DEDICATION

This thesis is dedicated to my parents
for their love , endless support
and encouragement.

ACKNOWLEDGEMENT

"In The Name Of Allah, The Most Beneficient,The Most Merciful"

I would first like to thank my main supervisor, Dr. Mohd Azreen bin Mohd Ariffin for his continuous support, motivation and encouragement. I am forever grateful for his kind advice and guidance in helping me for the completion of this thesis.

My research would have been impossible without the aid and support of Ir. Dr. Lau Kwan Yiew from School of Electical Engineering. His guidance and immerse knowledge helped me in all the time of research experiment.

My sincere thanks also goes to the Jabatan Perkhidmatan Awam for the study opportunity and providing the financial support for me to further my studies at the Universiti Teknologi Malaysia, Johor. Not to forget, my current employer, Jabatan Kerja Raya Malaysia for the opportunities and providing me the access, data and sample for the this research. Financial assistance from the Universiti Teknologi Malaysia for my research work is highly appreciated.

Finally, to my families and friends, thanks you for being there with your unconditional love and continuous support.

ABSTRACT

This research presents some results and discusses the investigation on thermal ageing of low voltage cross-linked polyethylene (XLPE) insulated cable rated at 0.6/1(1.2) kV. This type of cable was found to experience premature degradation within three to five years of service. The objective of this investigation is to study the characteristic of XLPE insulated cable under thermal conditions. A number of tests were conducted to investigate the chemical properties, electrical properties and mechanical properties of unaged and aged XLPE insulated cable. Samples were thermally aged using air ventilated oven at temperature of 90 ^{o}C. The breakdown strength of XLPE materials were measured for each samples. The structural changes due to the formation of carbonyl groups were observed using Fourier Transform Infrared (FTIR) spectroscopy. The application of Differential Scanning Calorimetry (DSC) revealed the effect of thermal ageing on the crystallinity variation on XLPE insulated cable. Mechanical properties were observed through tensile strength test. Experimental findings in this study suggests that thermal ageing induces significant degradation on XLPE insulated cable.

ABSTRAK

Kajian ini menerangkan hasil siasatan dan ujian terhadap kabel voltan rendah jenis *cross-linked polyethylene* (XLPE) dengan kadaran penebat pada 0.6 / 1 (1.2) kilo volts. Kabel jenis ini didapati semakin kerap mengalami kerosakan akibat pereputan awal dalam tempoh operasi antara tiga hingga lima tahun. Objektif siasatan ini adalah untuk mengkaji ciri-ciri kabel jenis XLPE apabila diletakkan dalam keadaan berhaba tinggi. Beberapa siri ujian telah dibuat untuk mengkaji sifat kimia, elektrikal dan mekanikal kabel jenis XLPE dalam keadaan baru dan lama. Kabel dipanaskan pada suhu 90 ^{O}C di dalam ketuhar sebagai kaedah penghasilan kabel lama / tua. Kekuatan dielektrik untuk setiap sampel XLPE diukur. Perubahan struktur bahan akibat pembentukan kumpulan karbonil turut diteliti menggunakan teknik spektroskopi *Fourier Transform Infrared* (FTIR). Penggunaan teknik *Differential Scanning Calorimetry* (DSC) membolehkan kesan penuaan haba terhadap perubahan pada penghabluran bahan XLPE. Ciri mekanikal bahan diuji melalui ujian kekuatan tegangan bahan. Hasil dari kajian ini mendapati bahawa kesan penuaan haba telah menyebabkan kemerosotan jangka hayat kabel jenis voltan rendah XLPE.

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LIST OF ABBREVIATIONS

XLPE	-	Cross-linked polyethylene
PVC	-	Polyvinyl chloride
EPR	-	Ethylene propylene rubber
IEC	-	International Electrotechnical Commission
JKR	-	*Jabatan Kerja Raya*
EMAL	-	Electrical Material Approved List
FTIR	-	Fourier transform infrared
DSC	-	Differential scanning calorimetry
DCP	-	Dicumyl peroxide
ATR	-	Attenuated total reflectance
AC	-	Alternating current
Hz	-	Hertz
C-H	-	Carbon-hydrogen
OH	-	Oxygen hydrogen (Hydroxy)

LIST OF SYMBOLS

E_B - Breakdown field

V_B - Breakdown voltage

d - sample thickness

$F(x)$ - Cummulative probability of failure

exp - exponential

x - Breakdown voltage

α - Scale parameter

β - Shape parameter

χ_c - Crystallinity

ΔH_0 - Enthalpy corresponding to the melting of 100% crystalline material

ΔH - Heat of fusion

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Cross-linked polyethylene (XLPE) is manufactured from polyethylene (PE) plastic with a three-dimensional molecular bond that is created within a structure of a plastic. Manufacturing process of XLPE is done by adding small amounts of chemical additives (such as antioxidants) to the polymer. Additives help improve the flow properties of a polymer that will be moulded. This process allows the molecular chains to form a lattice formation by cross-linking the polymer under appropriate treatment after extrusion (Reeves and Heathcote, 2003).

The process of cross-linking changes its original state from thermoplastic to thermoset (Tamboli et al, 2004). As a thermoset polymer, it consists of long chain of molecules that form bonds between the chains during polymerisation. This forms a single network of polymer chains that are generally not straight, but a tangled mass.

XLPE is commonly used in electrical cable construction for a wide range of voltage. A study by Dilip K and Das Gupt (1997) had shown the benefis of using XLPE as insulation material in general are due to their great physical, chemical and dielectric properties. XLPE is favoured over other insulation material, such as polyvinyl chloride (PVC), ethylene propylene rubber (EPR) and silicone rubber due to its toughness against high temperature. This material also has high insulation resistance, excellent dielectric strength and a low dissipation factor at all frequencies.

Low voltage is a voltage between the range of 50 volts and 1,000 volts alternating current, as defined by the International Electrotechnical Commission (IEC). Low voltage XLPE insulated cable are used in low voltage (600/1000 volts) applications. In Malaysia, this type of cable is designated for general use and for underground cabling, where lightness and convenience of terminating are major considerations. XLPE insulated cable also withstands smaller radius bending, allowing for easy and reliable installation.

The design of low voltage XLPE insulated cable must conform to IEC 60502 (2004) and rated at 600/1000 (1,200) kilovolts. It has plan circular conductors made of compacted stranded copper or stranded aluminium. The XLPE insulation layer is rated at temperature of 90 ^{O}C. A typical construction of a low voltage XLPE insulated cable is illustrated in figure 1.1 and figure 1.2.

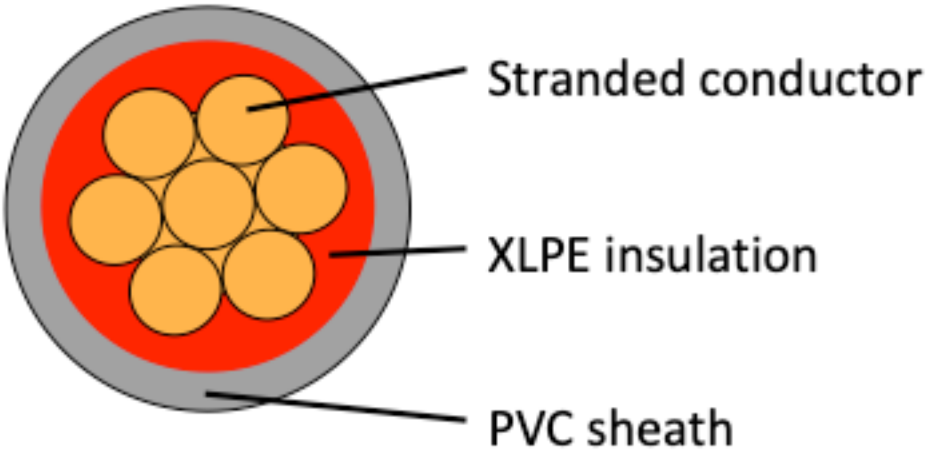

Figure 1.1 A single core low voltage XLPE insulated cable.

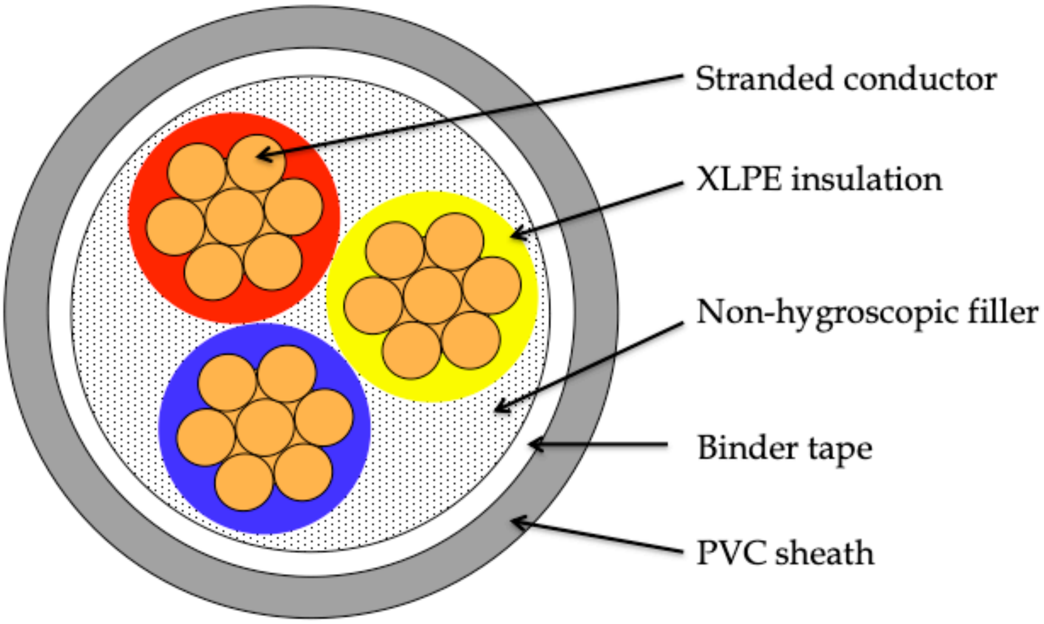

Figure 1.2 A multi-core low voltage XLPE insulated cable.

1.1 Problem Background

Previous studies and researches showed that XLPE cable has a great performance over high temperature and could last 40 years or more (Anwar ul-Hamid et al, 2015). However, there are increments in the number of complaints for insulation failure in low voltage XLPE insulated cable within 5 years of service. This leads to a temporary suspension in the usage of XLPE insulated cable. The approval for this type of cable from sizes between 1.5 mm^2 up to 25 mm^2 has been withdrawn from the *Jabatan Kerja Raya* (JKR) Electrical Material Approved List (EMAL).

During installation, cables are subjected to repeated bending or random flexing causing its copper conductors to be stressed. Mechanical stresses during installation are generally more severe than those encountered while in service. Physical damage caused by mishandling of the cables may cause injury to the insulation layer. Degraded cable can often be found in the electrical switch board is as shown in figure 1.3

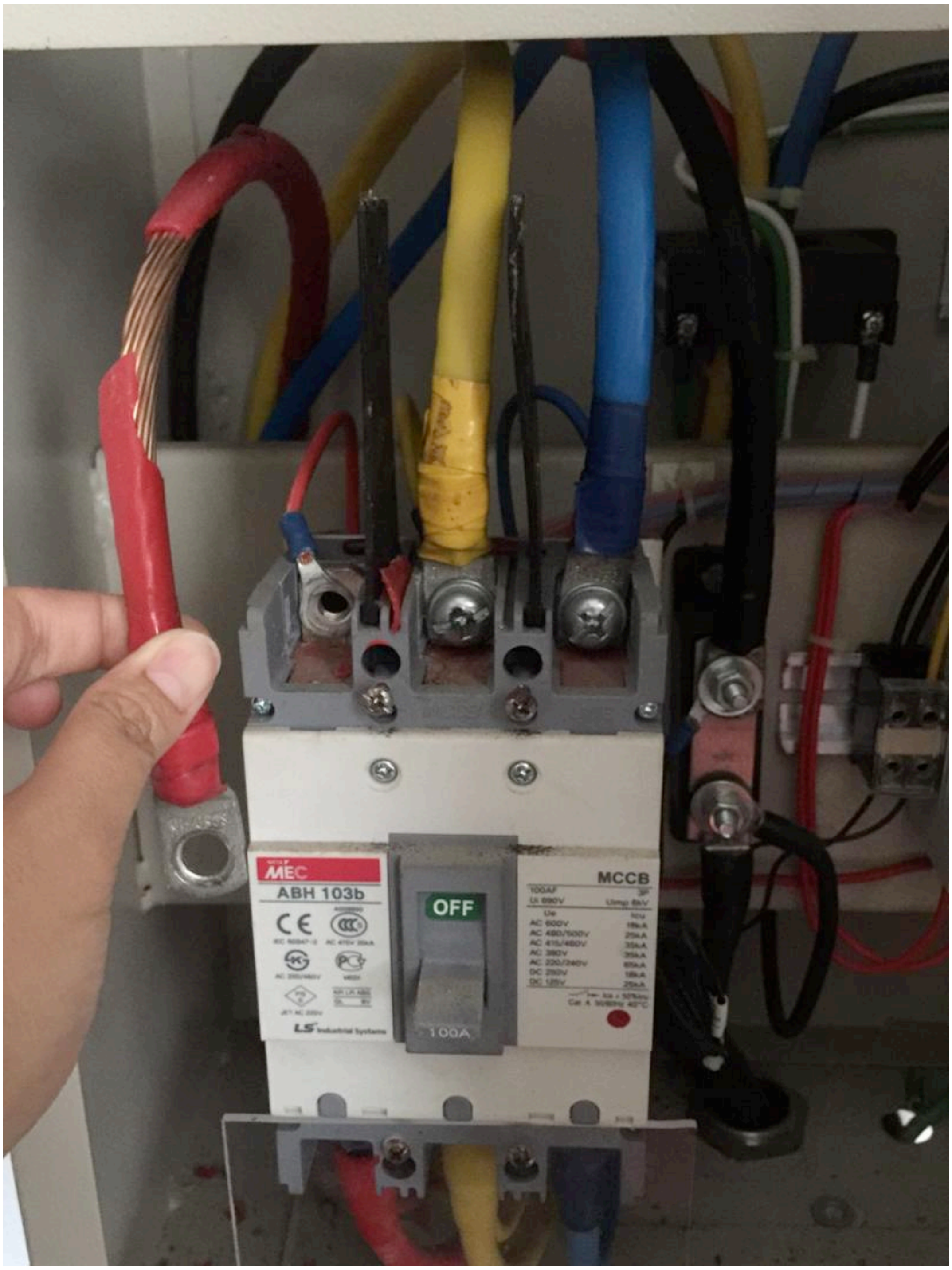

Figure 1.3 Degraded red core XLPE cable found in switchboard.

In the operating environment, constant abrasion of the cable by other cables could cause failure in cable insulation. Environmental factors such as high humidity and elevated temperatures can also degrade XLPE insulation layer. Moisture may exist in cable surroundings and it could affect the basic characteristics of the XLPE insulation and the realibility of XLPE insulated cables (Mecheri et al, 2010). According to Jong-Il Weon (2009), the degradation of XLPE is also caused by exposure to heat, ultraviolet radiation, discolouration among others. Figure 1.4 shows the degraded XLPE insulated underground cable.

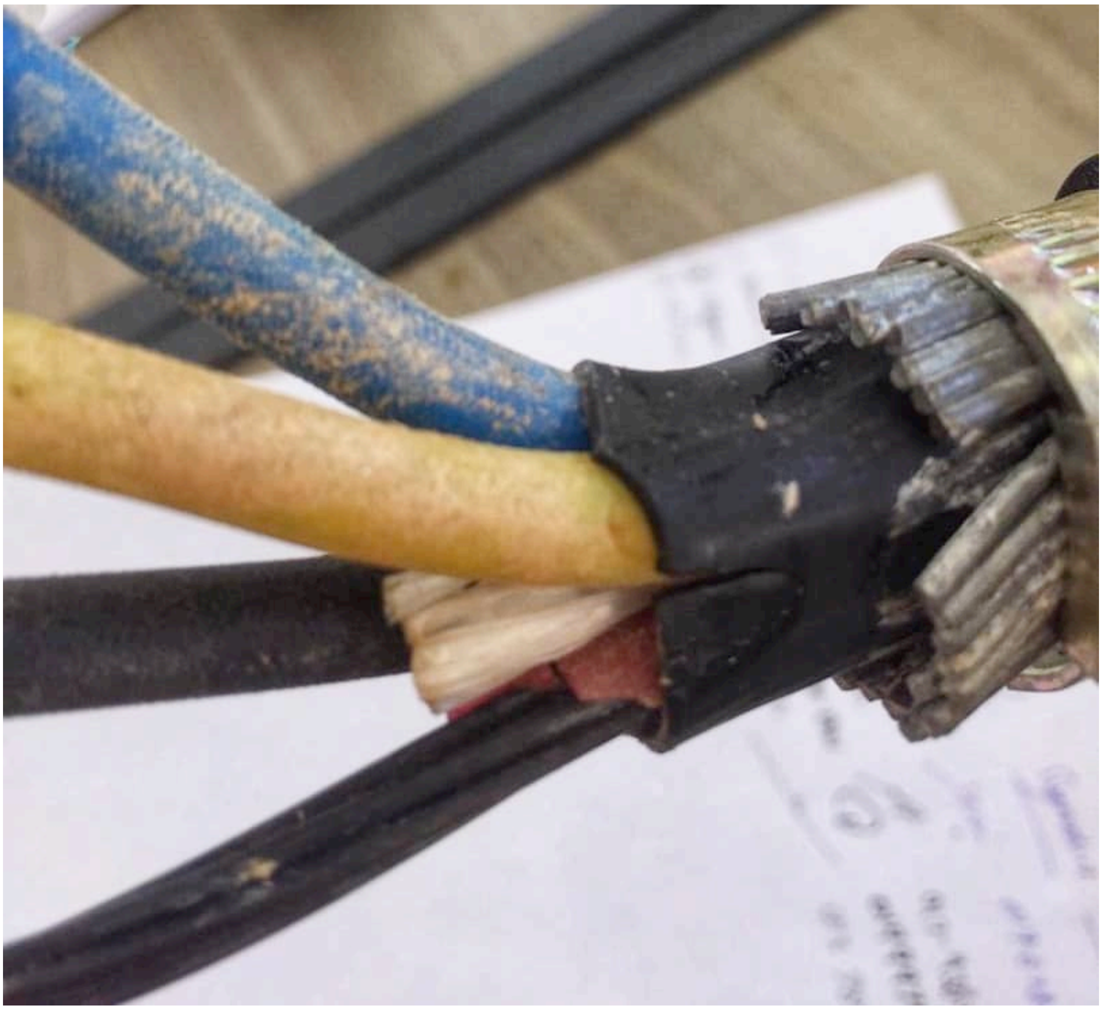

Figure 1.4 Degraded XLPE insulated underground cable.

1.2 Problem Statement

A reliable study on understanding how the degradation mechanism especially on low voltage system is still lacking although there area high numbers of published papers related to degradation of XLPE material. A reliable method of investigating the insulation failure, failure analysis and failure origin must be studied. The degradation on low voltage XLPE insulated cable is investigated using several methods comprise of the study of chemical, electrical and mechanical properties of the XLPE material.

1.3 Research Objectives

This work aims to fabricate a forensic investigation process for cable insulation failure. Therefore, there is a potential for improvement in identifying the cause that made the material fails to perform its intended function. The specific research objectives are as follow;

i) To identify the primary degradation and failure mechanism of low voltage XLPE insulated cable.

ii) To characterize and compare the properties of the XLPE materials under different thermal conditions.

iii) To provide thermal ageing analysis for cable failure.

1.4 Research Scope

The scope of research for this experimental study includes;

i) Insulation layer of low voltage XLPE insulated cable was used in this experiment to study the electrical, mechanical and chemical properties for both fresh and aged conditions.

ii) Insulation layer of low voltage XLPE insulated cable that had experienced degradation was also used in this study for reference and comparison purposes.

iii) The properties and behaviour of each samples were compared and characterized using breakdown strength test, tensile strength test, Fourier infrated (FTIR) spectroscopy and differential scanning calorimetry (DSC).

1.5 Significance of the Study

Eventhough many experimental works have been done to investigate the degradation of XLPE insulated cable, not much research and publication have been done particularly for cable degradation in the low voltage cable. Therefore, the benefits expected from this research are;

i) To determine the condition of low voltage cable failure with the application of forensic engineering in the investigation.

ii) The use of research information helps to provide forensic engineers a proper method of doing forensic investigation on cable failure.

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