KOLEJ UNIVERSITI TEKNIKAL KEBANGSAAN MALAYSIA

A Study on UV Curing Process of Polymeric Materials

Thesis submitted in accordance with the requirements of the
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By

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APPROVAL

This thesis submitted to the Faculty of Manufacturing Engineering of KUTKM and has been accepted as partial fulfillment of the requirement for the degree of Bachelor of Manufacturing Engineering (Honours) (Manufacturing Process).

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DEDICATION

For my lovely mother and my family.

ABSTRACT

Polymer material manufacturing techniques have over the years generated tremendous interest in the area of research and development in response to current trends and demands. Bullet proof vests use polymer materials as their constituent in resisting high ballistic impact. One of the section to produce bullet proof vest as personnel protective equipment (PPE) is through a UV curing process to the polymeric materials. Although curing by this technique is relatively slow compared to heat curing, the result is high strength and high impact properties of polymer composites due to crystallinity enhancement of the polymers through cross-linking mechanism. Two types of adhesives materials were used: epoxy and vinyl ester. They were mixed together with different photoinitiator, Bisacyl Phosphine Oxide (BaPO) and Alpha Hydroxyl Ketone Peroxide (AHK). 1.0 and 10.0 per hundred of resin (phr) photoinitiator from the total mixture was added to the adhesive materials. Samples were cured under various times of curing which are 3, 6, 9 and 12 minutes to compare the quality of time exposure under UV light. The mixture of adhesive and photoinitiator was wiped on the fiber layers to act as glue to stick the layers. The laminate was then tested to determine its characteristics such as physical testing like density test, mechanical testing was also performed in order to know its tensile and hardness properties. Morphology study by Scanning Electron Microscope was performed in order to study if proper adhesion has been achieved in each layer. The data obtained was analyzed to determine whether epoxy and vinyl ester give better results.

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LIST OF ABBREVIATIONS

ACGIH	- American Council of Government and Industrial Hygienists
AHK	- Alpha hydroxyl ketone oxide
ASTM	- American Standard Test Method
BAPO	- Phenylbis (2, 4, 6-frmethylbeirzoyl) - Phosphine oxide
IR	- Infrared Radiant
JIS	- Japanese International Standard
MSDS	- Material Safety Data Sheet
NIJ	- National Institute of Justice
NIOSH	- National Institute for Occupational Safety and Health
Phr	- Per hundred of resin
PPE	- Personal Protective Equipment
SEM	- Scanning Electron Microscope
UTM	- Universal Testing Machine
UV	- Ultraviolet
VOC	- Volatile Organic Component

CHAPTER 1
INTRODUCTION

1.1 Problem statement

The curing process of polymeric material by using ultraviolet light has played an important role in polymer material processing since the process is more advantageous than heat cure. One of the applications of the curing process of polymeric material by ultraviolet light can be seen in producing personal protective equipment such as bullet proof vest.

This research is the first stage in producing the bullet proof vest. For this research the main materials that were used were epoxy and vinyl ester and were categorized as thermoset polymer. The matrix was added with photoinitiator materials that act as the energy absorber to start the process of curing. In addition, the curing time has been varied to 3, 6, 9 and 12 minutes. The characteristic of the material cured was analyzed and studied under various analysis methods such as density test, tensile test, hardness test and morphology study by using Scanning Electron Microscope.

Samples were tested under various type of mechanical testing in order to study their response to the applied stress. After the testing process has been done, the data was evaluated and discussed further. This project is hoped can bring a new technique in producing bullet proof vest with better quality and lower cost in its production.

1.2 Research objectives and scope of the project

The objective of this research assesses the ability of the UV light to convert the material to become harden or cure and the properties of the cured material were studied. The objectives of this research are stated as below:

i. To investigate the influence of ultraviolet light in the curing process of thermosetting polymers.
ii. To study the parameter involve in UV curing process of polymeric materials and affect to the properties of polymer materials.
iii. To characterize the effects of epoxy or vinyl ester resin after cured by UV light and the impact of using photoinitiator or accelerator.
iv. To define the effectiveness of the epoxy or vinyl ester resin as a UV cured laminate in application for the bullet proof vest.
v. To investigate the contribution of photoinitiator materials in accelerates the process of curing under UV light.

The scope of the research is to investigate a new technique for producing polymers laminate composites that are excellent in resisting high ballistic impact in the first stage of producing bullet proof vest. Currently, vinyl ester was used as adhesive material to stick the glass laminate. In this research epoxy will be chosen to make comparison between the effectiveness of these two types adhesive materials. In addition, two types of photoinitiator or accelerator was used in this research. Thus, the performance of each adhesive material, time of curing and presence of photoinitiator to stick the glass laminate will be monitored.

1.3 Importance and benefits of the research

This research has its own importance and benefits instead of the study. There are:

1. Fundamental study can be provided in order to pursue more advanced and detailed study regarding the process of UV curing in application process of bullet proof vest.
2. Properties of existing glass laminate composite for bullet proof vest in terms of mechanical properties and durability can be improved. Thus, the quality can be upgraded.
3. Novel method of effective curing process can be developed and introduced. These can benefits to all sectors.
4. Procurement of new equipment related to this project especially regarding to the UV curing process can be equipped and will be useful primarily to the faculty's laboratory.
5. This project is able to contribute to domestic organizational linkages with other research institutions/universities.
6. This project will be beneficial to the local composites manufacturers in terms of collaboration in research and technology exchange.

CHAPTER 2
LITERATURE REVIEW

2.1 Personnel Protective Equipment (PPE)

Personal Protective Equipment (PPE) includes all clothing and other work accessories designed to create a barrier against workplace hazards. Examples include safety goggles, blast shields, hard hats, hearing protectors, gloves, respirators, aprons, and work boots. For army, its include bullet proof vest, helmet, boot and etc. For this research, the main objective is to develop a bullet proof vest for army where the material that will be used is epoxy resin and polyvinyl ester. The epoxy resin will be cured by UV light and the output characteristics will be studied and analyzed.

2.2 Polymeric materials

Polymers play an enormously important role in modern society. The significance of these materials is often taken for granted, yet polymers are fundamental to most aspects of modern life such as building, communication, signs, housewares, textiles, medical devices, foams, paints, safety shield, toys, appliance, lenses, gears, electronic and electrical product, transportation, clothing and packaging. Thus, an understanding of the structures and properties of polymeric materials is vital.

Polymers are large molecules consisting of a large number of small component molecules. In fact, the name polymers derives from the Greek 'polys' meaning 'many' and 'meros' meaning 'part'. Many polymers are synthesized from their constituent monomers via a polymerization process. Most commercial polymers are based on covalent compound of carbon, although certain synthetic polymers may also be based on inorganic atoms such as silicon (Stuart, 2002).

2.2.1 Basic theory of polymeric materials

Polymers can display a range of different structures. In the simplest case, polymers posses have a linear structure. However, polymers can also be branched, depending on the method of polymerization. They may also display a cross-linked structure. Some more unusual polymer structures include central unit, ladder polymers, which consist of repeating ring structures, and dendrimers, which show a star like structure with branching. These different sorts of microstructures have an affect on the properties of the polymer. Polymers are often commonly referred to as 'plastics'. However this is somewhat of a misnomer. The term 'plastic' refers to one class of polymers known as thermoplastics. Polymers are also characterized as thermosets and elastomer (Stuart, 2002).

Because of their unique and diverse properties, polymers have increasingly replaced the applications of metallic components such as automobiles, civilian and military aircraft, sporting goods, toys, appliances, and office equipment. These substitutions reflect the advantages of polymers in terms of the following characteristics:

i. Corrosion resistance and resistance to chemicals
ii. Low electrical and thermal conductivity
iii. Low density
iv. High strength to weight ratio, particularly when reinforced

v. Noise reduction

vi. Wide choice of colors and transparencies

vii. Ease of manufacturing and complexity of design possibilities

viii. Relatively low cost

ix. Others that may or may not be desirable, depending on the application, such as low strength and stiffness, high coefficient of thermal expansion, low useful temperature range, and less dimensional stability in service over a period of time.

The word polymer was first used in 1866. The earliest polymers were made of natural organic materials from animal and vegetable products where cellulose is the most common example (Kalpakjian, and Schmid, 2001).

2.2.2 Types of Polymeric materials

There are three types of polymers which are thermoplastics, thermoset and elastomers. All these types are discussed as follows.

2.2.2.1 Thermoplastic

Polymers in this category show a wide range of different properties, but a simple definition is to describe these as polymers that melt when heated and resolidify when cooled. Thermoplastics tend to be made up of linear or lightly branched molecules, as such structures enable the polymer chains enough freedom of movement to change form as a function of temperature. Thermoplastics are polymers that require heat to make them processable. After cooling, materials will retain their shape. In addition, these polymers may be reheated and reformed, often without significant changes to their properties. Many thermoplastics contain long main chains consisting of covalently bonded carbon atoms. Several types of thermoplastics are including polyethylene, polypropylene, polyvinylchloride, polystyrene, polymethylmethacrylate, polyamide and etc (Stuart, 2002).

2.2.2.2 Thermoset

Thermoset are polymers that do not melt when heated, but decompose irreversibly at high temperatures. Thermosets are crosslink, with the restrictive structure preventing melting behavior. Thermosets have a networked (crosslinked) structure types. Such a structure may be formed by heating or via a chemical reaction. Thermosets tend to posses excellent thermal stability and rigidity. Several types of thermosets are including phenolic resins, epoxy resins, amino resins, polyester resins, and polyurethanes resin (Stuart, 2002).

Thermosetting plastics generally possess better mechanical, thermal, and chemical properties, electrical resistance, and dimensional stability than do thermoplastics. A typical thermoset is phenolic, which is a product of the reaction between phenol and formaldehyde. Common products made from this polymer are the handles and knobs on cooking pots and pans and components of light switches and outlets. The polymerization process for thermosets generally takes place in two stages. The first occurs at the chemical plant, where the molecules are partially polymerized into linear chains. The second stage occurs at the parts producing plant, where crosslinking is completed under heat and pressure during the molding and shaping of the part. Thermosetting polymers do not have a sharply defined glass temperature. Because of the nature of the bonds, the strength and hardness of a thermoset are, unlike those of thermoplastics, not affected by temperature or by rate of deformation. If the temperature is increased sufficiently, the thermosetting polymer instead begins to burn up, degrade, and char (Kalpakjian, and Schmid, 2001).

In this research, the materials that will be used for cured by UV light are epoxy and vinyl ester. The photoinitiator that will be used are benzoyl peroxide (BAPO) and alpha hydroxyl ketone peroxide (AHK). Details about the material are described as follows.

2.2.2.2.1 Epoxy

Epoxy resins, like polyesters, can be formulated to give a wide range of properties. When compared with polyesters, epoxies generally have better resistance to alkalis and solvents but slightly poorer weathering resistance. Their electrical properties, wear resistance and thermal stability are excellent. Epoxies, when reinforced with aramid or carbon fibres, are the standard matrix for high performance aerospace applications. Fibre reinforced epoxies are used in the sport and leisure industry, and they have also replaced reciprocating metal components, particularly in the weaving industry.

Reinforced epoxies can be processed by all the normal thermoset techniques. Fibre, either in the form of continuous filaments or woven fabric that has been pre impregnated with resin (prepregs) can be processed by automated tape laying, vacuum bag moulding or autoclave moulding. Prepregs are usually produced by passing the fibres either through a solvent/resin mix, with subsequent solvent removal, or a hot melt of resin. In both cases, the resin contains the necessary hardeners and catalysts. Though more expensive, prepregs tend to give more reliable results when compared with hand impregnation, with a greater degree of control over properties such as fibre volume fraction and matrix porosity. One disadvantage with epoxy prepregs is their limited shelf life, even when stored at 25°C. They also require elevated temperatures to cure (Charles and Edward, 2003).

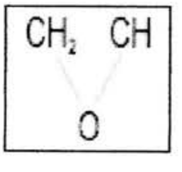

Figure 2.1: Chemical structure of a simple epoxy (ethylene oxide).

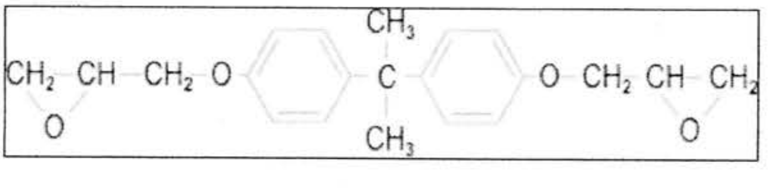

Figure 2.2: Chemical structure of a typical epoxy (diglycidyl ether of bisphenol-A).