EFFECT OF GELCOAT THICKNESS ON LAMINATE COMPOSITE STRUCTURE AND STRENGTH

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) (Hons.)

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DECLARATION

I hereby, declared this report entitled 'Effect of Gelcoat Thickness on Laminate Composite Structure and Strength' is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the Degree of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory committee is as follow:

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(MOHD YUHAZRI BIN YAAKOB)

ABSTRAK

Tujuan kajian ini adalah untuk menilai kesan ketebalan *gelcoat* berbeza pada struktur lamina komposit dan kekuatan. *Gelcoat* ini disediakan dengan kaedah bengkalai tangan dan terus dengan gentian kaca komposit bertetulang di atas *gelcoat* dengan proses pembalut vakum. Sifat-sifat mekanikal dan kekuatan antara pelbagai tebal *gelcoat* pada lamina komposit telah diuji dengan menggunakan tiga mata ujian lenturan dan ujian tegangan. Perbandingan lanjut telah dibuat atas kekuatan mekanikal yang berbeza ketebalan *gelcoat* lamina komposit. Sebab kegagalan di antara ketebalan *gelcoat* yang berbeza akan dimantau di bawah mikroskop elektron imbasan untuk menentukan jenis kegagalan yang berlaku selepas ujian mekanikal. Dari ujian dua hala lenturan dengan meletakkan sampel di mana lapisan *gelcoat* menghala atas dan bawah menunjukkan bahawa 0.30 mm adalah kekuatan mekanikal yang paling tinggi. Lapisan *gelcoat* menghadap atas yang ditekan beban mampatan telah menunjukkan penurunan 54.39 % dan adalah sama dengan lapisan *gelcoat* menghadapi bawah telah mengurangkan 45.07 % apabila mencapai 0.40 mm. Ia adalah disebabkan oleh ketebalan *gelcoat* yang lebih tinggi telah meningkatkan kerapuhan komposit lamina yang patah secara tiba-tiba berlaku sementara menghadapi beban. Ujian tegangan adalah intensif untuk menyiasat ikatan muka di antara *gelcoat* dan lamina komposit telah membayangkan 0.40 mm adalah yang tertinggi mengekalkan daya menarik dan membanding kekuatan ikatan antara muka untuk lamina komposit tanpa *gelcoat* telah meningkat 37.94 %. Punca kegagalan berlaku disebabkan oleh *delamination* matriks antara lapisan di mana *gelcoat* masih kuat terikat dengan lamina komposit. Walaupun tidak ada ketebalan *gelcoat* yang dinyatakan dalam kajian sebelum ini, menambah ketebalan *gelcoat* tidak bermaksud lebih baik kekuatan mekanikal manakala ketebalan sesuai amat diperlukan sebagai reka bentuk bagi perlindungan paling luar.

ABSTRACT

The aim of this study was to evaluate the effect of different gelcoat thickness on laminate composite structure and strength. The gelcoat is prepared by hand lay-up method and continue by fabricate the glass fibers reinforced composites on top of the gelcoat with vacuum bagging process. The mechanical properties and interfacial bonding of the various gelcoat thickness on laminate composite were tested by using three-point flexural test and tensile test. A further comparison was made with the corresponding mechanical strength of different gelcoat thickness laminate composite. The fracture behaviour of different gelcoat thickness is monitor under the scanning electron microscope to determine the type failure occur after the mechanical test. From two-way flexural test in mean by placing the samples where gelcoat layer on facing top and bottom position had shown that 0.30 mm was the highest mechanical strength. The gelcoat layer facing top which was facing the compression load had shown decrease 54.39 % and was similar to gelcoat layer facing bottom had decrease 45.07 % when reach 0.40 mm. It was due to higher the gelcoat thickness had increased the brittleness of the laminate composite that sudden fracture occur in facing load. Tensile test was intensive to investigate the interfacial bonding in between gelcoat and laminate composite had indicated 0.40 mm is the highest in sustain the pulling force and compare interfacial bonding strength to clean laminate composite without gelcoat, it had increased 37.94 %. The failure behaviour occur were caused by the delamination of matrix between the plies where the gelcoat still strongly bonded with laminate composite. Despite there are no significant gelcoat thickness specified in previous study, it was not highest the gelcoat thickness better the mechanical strength while suitable thickness is required as design for outermost protection.

DEDICATION

Dedicated to
my beloved father, Goh Eng Hock
my appreciated mother, Wong Sew Yeng
and my adored sister and brother, Goh Chee Wei and Goh Hooi Lee
for giving me moral support, cooperation, encouragement and also understandings.

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LIST OF ABBREVIATIONS

UV	-	Ultra-violet
SEM	-	Scanning electron microscope
FRP	-	Fiber reinforced panel
PMC	-	Polymer matrix composite
MMC	-	Metal matrix composite
CMC	-	Ceramic matrix composite
FRPC	-	Fiber reinforced polymer composite
CFRP	-	Carbon-fiber reinforced polymer
GFRP	-	Glass-fiber reinforced polymer
MEKP	-	Methyl ethyl ketone peroxide
ASTM	-	American society of testing and materials
ISO	-	International standards organization
T25P	-	Polyester based gelcoat thickness with 25 mm thickness
T30P	-	Polyester based gelcoat thickness with 30 mm thickness
T35P	-	Polyester based gelcoat thickness with 35 mm thickness
T40P	-	Polyester based gelcoat thickness with 40 mm thickness
T45P	-	Polyester based gelcoat thickness with 45 mm thickness
T50P	-	Polyester based gelcoat thickness with 50 mm thickness
T25E	-	Epoxy based gelcoat thickness with 25 mm thickness
T30E	-	Epoxy based gelcoat thickness with 30 mm thickness
T35E	-	Epoxy based gelcoat thickness with 35 mm thickness
T40E	-	Epoxy based gelcoat thickness with 40 mm thickness
T45E	-	Epoxy based gelcoat thickness with 45 mm thickness
T50E	-	Epoxy based gelcoat thickness with 50 mm thickness

LIST OF SYMBOLS

E	-	Tensile modulus
F	-	Force applied
L	-	Length
F_{max}	-	Maximum force
N	-	Newton
°C	-	Degree Celsius
RM	-	Ringgit Malaysia
mm	-	Millimeter
µm	-	Micrometer
%	-	Percentage
GPa	-	Giga Pascal
In/min	-	Inches per minute
MPa	-	Mega Pascal
N/m^2	-	Newton per meter
HV	-	Hardness Vickers
Kg/m^3	-	Kilogram per meter cube
Mm/ min	-	Millimeter per minute

CHAPTER 1

INTRODUCTION

1.1 Research Background

A composite material is a macroscopic blending of two or more distinctive materials which having a conspicuous interface between them. In composite material, the strong adhesion between the fiber and the matrix will prompt to transverse failure of the fiber opposed to failure of the matrix or the interface and interphase region. In addition, the mechanisms and formation of interface and interphase between fibers and resins are needed in the manufacture should have superior performance composite material. According to Shirazi (2012), by consolidating essential material, composites can be intended to provide structural properties and also as additional fundamental materials that have exceptional properties for electrical, thermal, tribological, environmental, and biomedical application. The main advantages of composite materials are their high strength and stiffness, combined with low density considering for weight diminishment in the finished part (Campbell, 2010).

For an instance, Gantayet (2014) expressed the mixture of epoxy and hardener is known as gelcoat that is applied on the mould with a brush. The mixture ought to be applied on mould as fast as it can because generally the mixture may solidify. The quantity of epoxy utilized should be approximately equivalent to the weight of the glass fiber sheets while the quantity of hardener is approximately 8 % to 10 % of the weight of glass fiber sheets. The gelcoat applied is to guarantee a smooth external surface and for the assurance of fibers from immediate exposure to the environment. The procedure proceeds with the subsequent stacking with layers of reinforcement by the application of gelcoat.

Moreover, Karapappas *et al*. (2011) indicated gelcoat is a material used to provide a high-quality finish on the visible surface of a fiber-reinforced composite material. The most widely recognized gelcoat is focused on epoxy or unsaturated polyester resin with thoughtfulness regarding to Scholz *et al.* (2014), Keegan *et al.* (2013), Yardimcia *et al.* (2013). Gelcoat is a modified resin which applied on mould in the liquid state. They are cured to form cross linked polymers and are subsequently backed with composite polymer matrices. Furthermore, Washer and Schmidt (2014) asserted that gelcoat is a thick resin layer on the exterior surface of the laminate which can be applied through spraying or rolling application. The gelcoat also enhances fire protection of the beam and provides an additional barrier against moisture. Research done by Mouritz and Gibson (2007) demonstrates a further issue is that numerous coatings, particularly those that are extremely good insulators but are extravagant. The cost of utilizing the coatings is increased further because they need to be bonded to the composite structure. Many composite applications oblige a gel-coated surface for cosmetic or durability reasons. The most common method of preparation is to paint or spray the mould tool, allow the coating to gel before laminating on the tacky surface. A layer of gelcoat is then sprayed on to the mould to form the outermost surface of the products. The gelcoat is allowed to cure for several hours however remains tacky so subsequent resin layers adhere better. Alternate layers of catalyzed polyester resin and reinforcement material are applied. Each reinforcement layer is wetted out with resin, and then rolled out to uproot air pockets. The procedure proceeds until the desired thickness is attained as highlighted by Dong (2009).

Many current researchers like Gombos and Summerscales (2014), Landowski *et al.* (2014), Salit (2014) and Raghavendra *et al.* (2013) are more to use different gel-coating process or preparation method to fabricate low defect gelcoat in the mould. The main focus is on the performance of gelcoat on their outlined product especially particularly with respect to service period against harsh environment. The best author's knowledge stated that there still no experimental research done about the effect of gelcoat thickness on laminate structure and strength. Thus, this is a very exceptionally topic to be explored in detail to gain deep understanding on roles of different gelcoat thickness affect laminated structure and strength.

1.2 Problem Statement

One of the improvement required for composite properties is by enhancing in gelcoat performance. For example, to get ideal fire retardancy out of laminate, it is imperative that post curing at elevated temperature takes place. The process of post curing diminishes the amount of residual styrene in a laminate. This has shown that previous studies, for example like Sanjay *et al.* (2014) and Nguyen *et al.* (2013) have started alter the substance of gelcoat to reach desired properties.

Sockalingam and Nilakantan (2012) specified chemical reaction occurred in between the first layer of the laminate which is applied to gelcoat that has not completely cured. The two layers were eventually cured together by a chemical bond in between them. In the presence of interface, it should be noted that the fiber sizing region sometimes is referred to the interface while the sizing matrix region is referred to interphase in view of the chemical reactions occurred between the sizing and the resin during consolidation and curing. It is undeniable that brittle gelcoat layer is due to excess of catalyst that cracks with little provocation, while under cure is resulting from excessively little catalyst that produce a flexible gelcoat (Lacovara, 2010). However, more flexible gelcoat is not inclined to cracking, it is slanted toward premature color degradation, loss of gloss, chalking or chemical attack. This is as explored by Mouritz and Gibson (2007) that the filler particles blended into the liquid resin and consistently scattered to guarantee consistent flame retardant properties throughout the polymer. Most polymers require a high stacking of filler to show an appreciable improvement to their flammability resistance. The fillers have different deleterious effects on the properties, including an increase to the viscosity and reduction of gel time for the polymer melt which makes processing more difficult. Numerous filler materials continuously break-down when exposed to moisture by hydrolysis, and this degrades their flame retardant activity.

Capela *et al.* (2013) claimed that there were influence existed of the gelcoat surface layer on fatigue and impact loading performances. The composites coated with gelcoat layer are tested under compression loading exhibit critical higher bending stiffness, static and fatigue strength. The impact response showed a slight variation of the peak load and the elastic recuperation where a significant increased on maximum displacement and absorbed energy with the increasing of incident impact energy. Both energy recovery in rate of the incident impact energy and residual bending strength have shown the linear decreasing with increase of the impact energy for all loading conditions. While the absorbed energy increased with the incident impact energy have reached about 80 % of impact energy for the highest impact energies. In addition, Jones (2007) stated that the interface and interphase in between the gelcoat and laminate composite is similarly imperative in deciding the mechanical performance of the composite. Eventually, the effective advancement of a composite material is characterized by the quality of interface. The interface controls the reintroduction of stress into either component at a damage site.

Based on the research above, the previous studies have generally concentrate on the performance of gelcoat as the protective layer for laminate composite while by adjusting the mixing ratio of catalyst and resin to control the curing of gelcoat. However, there are only few studies are mentioned on the gelcoat thickness used, but not specified on it for optimal purpose. Thus, this research is focusing on gelcoat thickness in order to optimize the performance of laminated composite.

1.3 Objectives

The objectives are as follows:

(a) To study the effect of gelcoat and thickness on the laminate composite strength.

(b) To investigate the interface between the gelcoat and laminated composite after mechanical testing.

(c) To propose the optimum thickness of gelcoat on laminated composite.

1.4 Scopes of the Research

The scopes of research are as follows:

(a) Research on the effects of gelcoat thickness on laminated composite based on the mechanical and physical properties or and related issues. In this research more focus on utilizing distinctive thickness of gelcoat which resulting in term of strength.

(b) Study the potential of using spray up or hand lay-up method on gelcoat application for the purpose of better thickness control, reduce material waste that also can clean the equipment easily. Curing of remaining gelcoat at nozzle is hard to be clean.

(c) Design the different thickness of gelcoat layer on the four plies and 0/90 degree orientation. From testing, result can clearly state the differences in strength and also including the interphase interface between gelcoats and laminated composite.

(d) Identify the appropriate amount of catalyst added into the gelcoat to control the curing behaviour in considering the performance of gelcoat, environment effect to human and surrounding which gelcoat contain hazardous styrene.

(e) Evaluate thickness of gelcoat after each spraying and spraying process to maintain the gelcoat spread evenly on the mould with the use of wet film thickness gauge to measure and control the thickness of gelcoat.

(f) Conduct the comprehensive analysis on experiment data by understanding the interaction between the interface interphase of gelcoat and laminated composite in order to identify the knowledge contribution to sector of gelcoat application.

(g) Propose the optimum thickness of gelcoat thickness on laminated composite with include consideration on the aspect of structure and strength. The performance of the gelcoat is an important role for entire material or product.

1.5 Rational of Research

The rational of research as follows:

(a) Composite product might achieve their highest strength when the bonds between layers of fiberglass are mechanical or primary bonds as opposed stress transferring in between two layers before facing failure. This research is developed to study the mechanical bond in between gelcoat and laminated composite.

(b) Generate scientific information and deep understanding on the role of catalyst in the curing behavior and performance of gelcoat. Gather the useful information on technical data of gelcoat performance after run the experiment approach.

(c) To gain new knowledge behind the experimental research by improve the laminated composite quality and bring the engineering field to higher level especially boat manufacture industry. Develop a new idea by control the gelcoat thickness to enhance composite product with using standard amount of catalyst to design a better product.

(d) Reduce the dependency to use less corrosive catalyst material that suitable to environment and enhance the performance of gelcoat on laminated composite strength such as polyether ether ketone, acetylacetone peroxide, vinyl polymerization peroxide, benzoyl peroxide that are commonly used in the gelcoat.

(e) Compare the different thickness of gel-coated laminated composite with other laminated composite design such as different ply number and orientation. Create a new solution to improve the performance of composite by controlling the gelcoat thickness.

1.6 Research Methodology

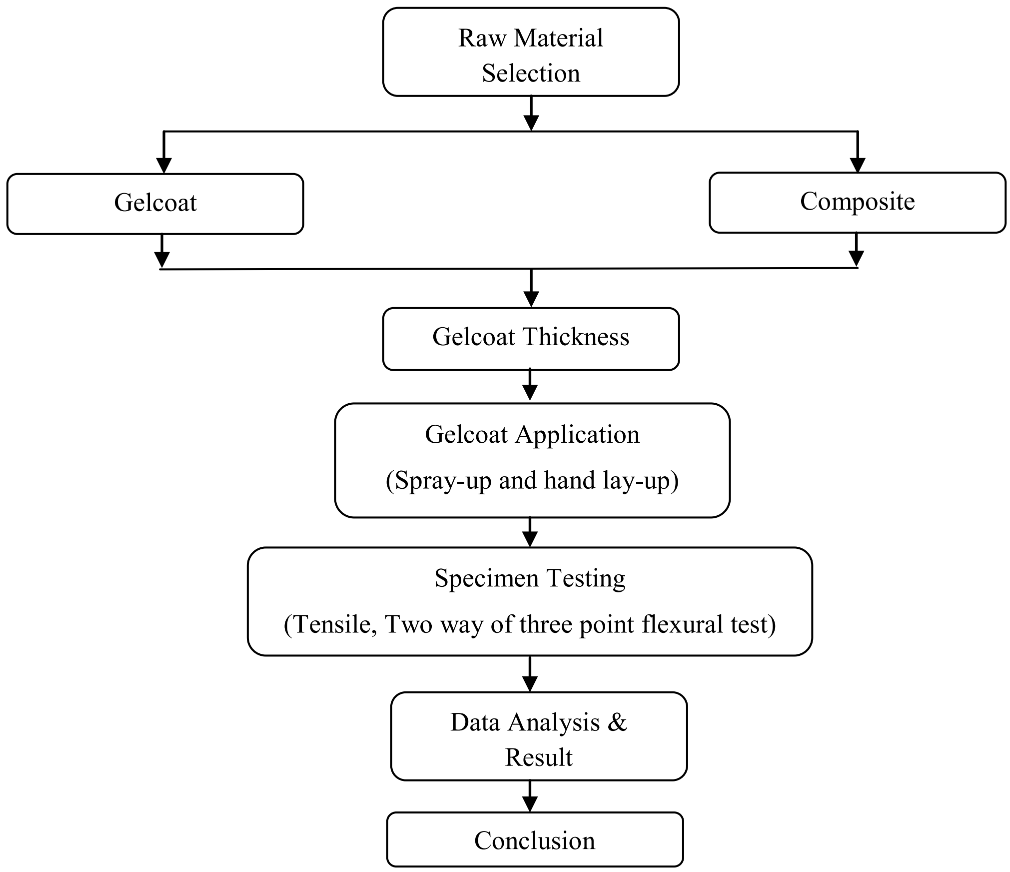

Figure 1.1: Flow chart of framework

The entire research embodies five main parts which are Part 1 is material selection, Part 2 is application of gelcoat on laminated composite, Part 3 is different