UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

EFFECTS OF CURING ANGLE ON LAMINATED UNSATURATED POLYESTER / EPOXY COMPOSITES STRUCTURES

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EFFECTS OF CURING ANGLE ON LAMINATED UNSATURATED POLYESTER / EPOXY COMPOSITES STRUCTURES

TAN TENG TENG

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Manufacturing Engineering

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DECLARATION

I declare that this thesis entitled “Effects of Curing Angle on Laminated Unsaturated Polyester / Epoxy Composites Structures” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………….

Name : Tan Teng Teng

Date : ………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature	:	…..…………………………….
Supervisor"s Name	:	Dr. Mohd Yuhazri Bin Yaakob
Date	:	……….………………………..…

DEDICATION

My late dad, Tan Chu,

For bringing me to this world.

Beloved mum, Lim Meoi,

For taking good care since small and working hard for the family.

Respected guardian, Xavier Rayan,

For precious advice and guidance in life and academic.

My concerned sisters, Tan Poh Ming, Tan Poh Yen and Tan Poh Lin,

For giving support and bringing fun.

ABSTRACT

Small and Medium Industries or Enterprises (SMI/E) in Malaysia that involved in composite industry faced a lot of challenges, ranging from raw materials, processes and product itself. The high production cost was due to the confined production floor as a result of horizontal curing plane for long hours. A solution was proposed by investigating the different curing angles (0˚, 10˚, 20˚, 30˚, 40˚, 50˚, 60˚, 70˚, 80˚ and 90˚) to find out the best curing angle via hand lay-up assisted by vacuum bagging technique at room temperature thus is able to fabricate the composite parts with similar or improved properties besides saving space. A series of four-ply laminated glass fiber composite structures were impregnated with unsaturated polyester and epoxy separately then set to cure at different curing direction. The composite structures were tested with density, tensile, flexural and hardness tests to determine the mechanical performance, and also the SEM images were examined and analysed on fracture samples. Across the samples at different curing angles from curing angles of 0˚ to 90˚, the peak performance found out to be frequently at 40˚. However, the vertically cured 90˚ composite structure found out to have improved mechanical properties (1.089 % to 4.280 %) when benchmarked with horizontal curing plane at 0˚. Curing at a tilting angle is possible to carry out. Therefore, the vertical curing of composite parts can be recommended to SMI/E in view of its improved performance and optimum space management solution.

ABSTRAK

Perusahaan Industri Kecil dan Sederhana (SMI/E) di Malaysia yang terlibat dalam industri komposit menghadapi banyak masalah, bermula dari bahan mentah, proses pengeluaran dan produk komposit itu sendiri. Kos pengeluaran menjadi meningkat kerana lantai pengeluaran terhad disebabkan sudut pengeringan mendatar untuk tempoh masa yang panjang. Satu penyelesaian dicadangkan untuk menyiasat kesan sudut pengeringan bermula dari keadaan mendatar sehingga menegak (0˚, 10˚, 20˚, 30˚, 40˚, 50˚, 60˚, 70˚, 80˚ and 90˚) bagi mengetahui sudut pengeringan terbaik melalui teknik bengkalai tangan dibantu oleh tekanan beg pada suhu bilik bagi mampu menghasilkan ciri-ciri komposit yang serupa atau lebih baik selain menjimat ruangan. Satu siri struktur komposit berlapis yang mempunyai empat lapis gentian kaca dihasilkan menggunakan poliester tak tepu dan resin epoksi secara berasingan lalu dikeringkan pada sudut pengeringan yang berlainan. Struktur komposit itu diuji terhadap ujian ketumpatan, tegangan, lenturan dan kekerasan untuk menentukan prestasi mekanikal, di samping itu, imej SEM dianalisis ke atas sampal patah. Di antara sudut pengeringan dari 0˚ sehingga 90˚, prestasi maksimum didapati kebanyakan berlaku pada 40˚. Walau bagaimanapun, ciri-ciri mekanikal struktur komposit yang dikeringkan pada 90˚ didapati lebih baik (1.089 % to 4.280 %) apabila dibandingkan dengan sudut pengeringan mendatar pada 0˚. Pengeringan pada kedudukan sudut didapati berjaya. Dengan itu, pengeringan menegak bahagian komposit boleh dicadangkan kepada SMI/E memandangkan prestasi yang lebih baik dan pengurusan ruang yang lebih optimum.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
DCPD	-	Dicyclopentadiene
FRP	-	Fiber reinforced plastics
MEKP	-	Methyl ethyl ketone peroxide
PP	-	Polypropylene
PVC	-	Polyvinylchloride
RM	-	Ringgit Malaysia
SEM	-	Scanning electron microscopy
SMI/E	-	Small and medium industries or enterprises
UP	-	Unsaturated polyester
UTeM	-	Universiti Teknikal Malaysia Melaka
UTM	-	Universal testing machine
UV	-	Ultraviolet

LIST OF SYMBOLS

atm	-	Atmosphere
g	-	Gram
GPa	-	Giga Pascal
kN	-	Kilo Newton
m	-	Meter
mm	-	Millimeter
MPa	-	Mega Pascal
N	-	Newton
s	-	Second
%	-	Percent
±	-	Plus or minus
E_a	-	Activation energy
g/cm^3	-	Gram per centimetre cube
kg/m^3	-	Kilogram per meter cube
mPa.s	-	Mili Pascal-second
N/mm^2	-	Newton per milimeter square
^{o}	-	Degree
^oC	-	Degree Celcius
Pa.s	-	Pascal-second
wt %	-	Weight percent
ρ	-	Density

LIST OF PUBLICATIONS

Journals

(a) Jennise, T.T.T., Yuhazri, M.Y., Sihombing, H., Yahaya, S.H., Nirmal U. and Megat Ahmad, M.M.H., 2013. Gravity Effects of Curing Angle on Laminated Composite Structures: A Review on Novel Study. *Journal of Advances in Materials Science and Engineering,* vol. 2013, pp. 1-10.

(b) Yuhazri, M.Y., Jennise, T.T.T., Sihombing, H., Mohamad, N., Yahaya, S.H. and Zalkis M.Y.A., 2013. Water Absorption and Thickness Swelling of Laminated Composite after Cured at Different Angle. *Applied Mechanics and Materials*, vol. 465-466, pp. 86-90.

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(b) Yuhazri, M.Y., Jennise, T.T.T., Sihombing, H., Mohamad, N., Yahaya, S.H. and Zalkis M.Y.A., 2013. Water Absorption and Thickness Swelling of Laminated Composite after Cured at Different Angle. 4^{th} International Conference on Mechanical and Manufacturing Engineering (ICME 2013), Putrajaya, 17^{th} - 19^{th} December 2013.

(c) Yuhazri, M.Y., Jennise, T.T.T., Sihombing, H., Said, M.R., Nirmal, U. and Megat Ahmad, M.M.H., 2013. Tensile Properties of Angle Cured Laminated Composites Structures under Gravity Effects. 4^{th} International Conference on Mechanical and Manufacturing Engineering (ICME 2013), Putrajaya, 17^{th} - 19^{th} December 2013.

(d) Yuhazri, M.Y., Jennise, T.T.T., Sihombing, H., Qumrul Ahsan, Lau, S.T.W. and Mohd Imran Ghazali, 2013. Gravity Effects on the Density of Laminated Composite due to the Differences in Angle Cured. 4^{th} International Conference on Mechanical and Manufacturing Engineering (ICME 2013), Putrajaya, 17^{th} - 19^{th} December 2013.

(e) Jennise, T.T.T., Yuhazri, M.Y., Sihombing H., Zalkis, M.Y.A. and Megat Ahmad, M.M.H., 2013. Gravity Effects on the Flexural Properties of Laminated Composite due to Curing at Angle Position. Seminar Kebangsaan Aplikasi Sains Dan Matematik (SKASM 2013), UTHM, 29^{th} – 30^{th} October 2013.

(f) Jennise, T.T.T. and Yuhazri, M.Y., 2012. A Preliminary Novel Study on the Gravity Effects of Curing or Drying Angle on Laminated Composite Structure. 5^{th} International Conference on Postgraduate Education (5^{th} ICPE), UTM, 18^{th} - 19^{th} December 2012.

CHAPTER 1

INTRODUCTION

1.1 Background

Utilization of high technology and advanced engineering materials such as composites are getting common and its demand is increasing. It is because the usage of composites is very significant and extensively applied in the field of civil, mechanical and aerospace, shipping, automobiles and construction (Topal and Uzman, 2008). The favourable characteristic of composites such as non-corrosive, high stiffness, high strength to weight ratio, environment resistance and ease of processing are the main factors over the selection of conventional materials such as metal, plastics and ceramic (Aktas *et al*., 2011; Kolachalama, 2007). These superior and excellent properties of composites are determined by both of the main constituents in the structure which precisely termed as reinforcement and matrix. The polymeric matrix that is commonly called as plastics in engineering terminology is often work with fibers to form a Fiber Reinforced Plastics (FRP) which is well known for various structural components (Zaid *et al*., 2011). The role of fiber in the composites structure is to provide mechanical support while the matrix is responsible for holding the fibers together (Said *et al*., 2012).

The composite manufacturing is a very active industry and it is gaining much attention and popularity partly due to the material that is able to tailor made its properties according to its function and purpose. Since the demand of such engineering material is very high, small and medium industries or enterprises (SMI/E) in Malaysia are also using various processing methods to manufacture FRP inclusive of filament winding, pultrusion, vacuum bagging, autoclave and compression moulding. However, processing composite structure sometimes can be very expensive and the equipment needed to invest can cost a huge sum of money. Due to this reason, alternative is required to substitute the process that involved large amount of money so that it can be suited into SMI/E taking the economic target as part of the considerations. Although innovation has been taken to change the process in the manufacturing of the composites, the functions of the product should remain the same to provide the best solution to its application fields and performance.

Besides the materials that cost, curing process during manufacturing has always been emphasised and given much attention (Jain and Shaikh, 2012; Wang *et al.*, 2011b; Kim *et al.*, 2012). The curing process of the composites is vital because it is one of the factors that determine the properties of the products. Proper curing applied to the composites will mightily enhance the performance of mechanical and physical of the product. Through curing, the polymer matrix of thermoset is hardened together with reinforcement by cross-linking chains with addition of appropriate hardener. Suitable curing condition and method will influence the degree of cure in the composites thus resulting in the dissimilar mechanical properties (Pochiraju *et al.*, 2012).

The major concern for curing in this context is the curing plane that takes up large area for long curing hours. The production has to be slowed down to suit to the curing process since limited area is available such as in the SMI/E. Commonly and conventionally, the composites are cured on the horizontal plane as it is simple and sensible as shown in the studies of Kumar *et al*. (2014), Tabi (2013), Boopalan *et al*. (2013), Mir *et al*. (2013), Almeida *et al*. (2013) and Tran *et al*. (2013). To the best knowledge of the author, there is no research study reveals the curing is at other angle besides on the horizontal plane. Moreover, the discussion of gravity effect is so far limited to the fields for instances liquid transporting as seen in petroleum transportation, water supply to the housing estates, waste water management in the piping system and dam water to generate electricity which may have involved horizontal, inclined and vertical planes (Deka et al., 2014; Sarghini et al., 2013; Minussi and Maciel, 2012).

During the curing of the thermosetting laminated composites, it is vital to know that the pre-gel resin is driven by the gravity when curing at angle position and vertical plane. Once the catalyst is added to the resin, the chemical reaction takes place such as the exothermic reaction and the formation of cross-linking. It will slowly lead to the decrease of the viscosity of the resin turning into gel form and finally becomes harden once curing process is done. It is curious to know to what extend would the viscous resin that applied in between the layers of reinforcement be influenced by the gravity prior to the resin cure.

In the composites industry, vacuum bagging technique is a common and well-known manufacturing method that used by various manufacturers due to its medium capital cost and high quality composite production. Vacuum bagging assists hand lay-up process for improved properties and it can have various changing parameters according to the desire such as the thickness, irregular and complex shapes, large size and alignment of the long fibers to obtain its controlled orientation quality. Moreover, it is a good solution to the tight budget allocation (Park and Seo, 2011; Boudenne *et al*., 2011).

To achieve full benefit of composites, lamination can be considered in order to gain an optimum structure. There are wide range of composite laminates can be developed such as slab lamination, sandwich lamination, and all laminated structure. Lamination is extensively used as satellite structures, snow skis, bicycles, archery limbs as well as construction and infrastructure for instances beams, columns and walls (Park and Seo, 2011).

1.2 Problem Statement

Curing is very important in composites so that to gain the fully cured and high quality products at a reduced cost. The importance of curing in composites have always been discussed to find improvement to establish optimum curing conditions and parameters (Lührs *et al*., 2014; Palin *et al*., 2014; Shah and Stansbury, 2014; Erickson *et al*., 2014; Randolph *et al*., 2014; Watts and Alnazzawi, 2014; Kim *et al*., 2012).

Gravity-driven fluids on inclined plane has drawn the attention of a great crowd and has been a popular topic for study and discussion (Chinyoka et al., 2013; Hu and Kieweg, 2012; Del-Castillo et al., 2011). Discover the advantage of the gravity and utilise it by incorporating into the industry such as the flow of oil-water in the inclined pipe (Deka et al., 2014; Dasari et al., 2014; Sotgia and Tartarini, 2006), water or liquid flows in an inclined plane (Sarghini *et al*., 2013; Minussi and Maciel, 2012; Song *et al*., 2012; Cremonesi *et al*., 2011), and inclined flow of wastewater (Chen *et al*., 2013; Wang *et al*., 2013; Li *et al*., 2012). However, there is yet any researchers study and discuss on the curing of composite materials on the inclined plane or angle position under the influence of the gravity with the best effort from the author.

SMI/E in the composite sectors that manufacturing high quality composite components via vacuum bagging technique is troubled by some of the problems such as having high production costs and confined production floor. In the case of having limited working space caused by the horizontal curing plane of large composite parts for long hours in vacuum bagging in turns give rise to lower productivity (Gu *et al*., 2014; Mcdonald *et al*., 2014; Nasir *et al*., 2013; Kmetty *et al*., 2013; Giddings *et al*., 2010). The investment in the SMI/E is very limited and often the further development is burdened and restricted by the difficulties faced. Hence, industries are seeking for alternatives or other