THE EFFECTS OF FIBRE VOLUME FRACTION OF COMPOSITE PLATE

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ABSTRACT

Composite materials especially glass fibre reinforced plastics (GFRP) are being widely used in many industry nowadays due to its special mechanical properties and light weight. The performance of composite materials is often controlled by fibre volume fraction, V_f. Hence, the main objective of this study is to investigate the effect of V_f onto the mechanical properties of composite plate. The fibre used is chopped strand mat (CSM) type E-glass fibre where the matrix used is based on unsaturated polyester resin. The composite plates were prepared by hand lay-up technique. Rule of mixture (ROM) and modified rule of mixture (MROM) were used to predict the performance of the composite plates. Tensile test according to ASTM D 3039 was carried out to obtain ultimate strength and modulus of elasticity of the composite plate with different V_f. Three different composite systems were tested in this study. The actual V_f of the composite plates were justified by burn out test (SIRIM MS 1390:1995). MROM was found had better validity than ROM to be used to estimate the mechanical properties of specimens after compared with experimental results. The experimental results show that the mechanical properties were improved when V_f is increased. Thus, the influence of fibre volume fraction on the mechanical properties of CSM E-glass fibre/polyester composites has been evaluated.

ABSTRAK

Bahan komposit terutamanya plastik bertetulangkan gentian kaca (GFRP) yang mempunyai sifat mekanikal yang istimewa dan ringan telah digunakan secara meluas dalam pelbagai industri. Kekuatan bahan komposit sering bergantung kepada pecahan isipadu gentian, V_f. Maka, objektif utama kajian ini adalah untuk menyelidik pengaruhan V_f terhadap sifat mekanikal plat komposit. Bahan gentian digunakan adalah *Chopped Strand Mat* (CSM) jenis gentian kaca-E dan resin poliester tak tepu sebagai bahan matriks. Plat komposit adalah disediakan dengan teknik bengkalai tangan *(Hand lay-up)*. Hukum Pencampuran (ROM) dan Hukum Pencampuran Diubahsuai (MROM) dipakai untuk meramal sifat plat komposit. Ujian tegangan berdasarkan ASTM D 3039 telah dilaksanakan untuk menguji kekuatan tegangan dan modulus keanjalan plat komposit. Tiga sistem komposit yang berlainan telah dikaji dalam kajian ini. V_f yang sebenar terkandung dalam plat komposit ditentukan dengan *Burn Out Test* (SIRIM MS 1390:1995). MROM adalah didapati lebih sesuai dipakai untuk meramal sifat mekanikal specimen selepas perbandingan dilakukan terhadap keputusan ujikaji. Keputusan ujikaji menunjukkan bahawa sifat mekanikal plat komposit dapat diperbaikan dengan peningkatan V_f. Dengan demikian, pengaruhan V_f terhadap sifat mekanikal komposit CSM gentian kaca-E/poliester telah dibuktikan.

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LIST OF SYMBOLS

v_f	-	Volume of fibre
v_m	-	Volume of matrix
v_v	-	Volume of void
v_c	-	Volume of composite
V_v	-	Void volume fraction
V_f	-	Fibre volume fraction
V_m	-	Matrix volume fraction
ε_c	-	Strain of composite
ε_f	-	Strain of fibre
ε_m	-	Strain of matrix
ε_a	-	External shear strain
$\bar{\varepsilon}$	-	Average strain
G_i	-	Shear modulus component at *i* phase
G_c	-	Shear modulus composite
V_i	-	Volume fraction component at *i* phase
σ_i	-	Stress component at *i* phase
$\bar{\sigma}$	-	Average stress
σ_c	-	Composite strength
σ_f	-	Ultimate tensile strength of fibre
σ_m	-	Matrix strength at the strain corresponding to the fibre's ultimate tensile stress
σ_1	-	Composite strength at direction 1

σ_{m1}	-	Matrix strength at direction 1
σ_{f1}	-	Fibre strength at direction 1
E_{1c}	-	Modulus of elasticity composite at direction 1
E_{1f}	-	Modulus of elasticity fibre at direction 1
E_{1m}	-	Modulus of elasticity matrix at direction 1
E_c	-	Modulus of elasticity composite
$E_{c\parallel}$	-	Longitudinal modulus of elasticity composite
$E_{c\perp}$	-	Transverse modulus of elasticity
σ_{cu}	-	Composite Ultimate strength
χ_1	-	Fibre orientation factor
χ_2	-	Fibre length factor
η_0	-	Fibre length correction factor
η_L	-	Non-unidirectional reinforcement correction factor
σ_f^f	-	Fibre fracture strength
σ_f^m	-	Matrix fracture strength
σ_y^m	-	Matrix yield strength
σ_{TS}	-	Tensile Strength
σ_{UTS}	-	Ultimate tensile strength
σ_c^f	-	Composite failure stress
ε_f^f	-	Fibre failure strain
ε_m^f	-	Matrix failure strain
V_f^*	-	Critical fibre volume fraction
$\dot{e}$	-	Strain rate
l	-	Initial length
v, $\frac{dl}{dt}$	-	Deformation rate
ρ_m	-	Matrix density
ρ_f	-	Fibre Density

W_f	-	Weight percent of fibre
W_m	-	Weight percent of resin
T_g	-	Glass Temperature
A	-	Cross sectional area
F_u	-	Ultimate force

LIST OF ABBREVIATIONS

AAP	-	Acetyl acetone peroxide
ASTM	-	American Society for Testing and Materials
BPA	-	Bisphenol A
BPO	-	Benzoyl peroxide
CHP	-	Cyclohexanone peroxide
CMC	-	Ceramic matrix composite
CSM	-	Chopped strand mat
CTE	-	Coefficient of thermal expansion
FRP	-	Fibre reinforced plastics
GFRP	-	Glass fibre reinforced
MEKP	-	Methyl ethyl ketone peroxide
MMC	-	Metal matrix composite
MROM	-	Modified rule of mixture
MS	-	Malaysian Standard
PMC	-	Polymer matrix composite
ROM	-	Rule of mixture
RPC	-	Reinforced polymer composite
SIRIM	-	Standard and Industrial Research Institute of Malaysia
SMC	-	Sheet moulding compound
UD	-	Unidirectional
UTS	-	Ultimate tensile strength
WR	-	Woven roving

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Composite material is artificial combination of different materials. It can attain the properties that the individual material cannot attain [1]. Normally, composite is encountered consists of stiff fibres embedded in a more deformable matrix [2]. Hence, they are stiffer, stronger and tougher than conventional materials.

There are many types of composite. In generally, they are classifying according to their matrix materials for example polymer matrix composite which polymer used as matrix. The main classes of composites are polymer matrix, cement matrix, metal matrix and ceramic matrix composites [1].

Polymer matrix composite (PMC) also known as reinforced plastics and fibre reinforced plastics (FRP) [3]. They use a polymer based resin as a matrix material with some form of fibres embedded in the matrix where the fibres provide the strength and stiffness. They are the most common material to be used for lightweight structures such as aircraft and automobile among all types of composite materials [1].

They are having outstanding corrosion resistance, low tooling cost, excellent fatigue and fracture resistance and the potential for rapid process cycles [4]. Hence, their applications are very wide. They can be used in vary sectors such like structural applications, electrical applications, civil structures, aircraft industries and so on.

PMC are the most common, owing to the low cost of fabrication. These types of composites have significant high strength and light weight properties. They can be classified according to whether the matrix is thermoset or a thermoplastic. Thermoset matrix composites are by tradition far more common, but thermoplastic matrix composites are under rapid development [1].

The used of FRP in several industries is increased and become important in this decade due to its special mechanical properties. Even though FRP still cannot totally replace the used of steel and aluminium alloy, but its significance of light weight, high specific strength and lower thermal expansion properties had successfully grab the manufacturers' attention. Interest in the use of polymer composites was highlighted by its use in the aXcess Australia concept car built by Millard Design using a carbon fibre and epoxy resin tubular frame skeleton [4].

Although the composite can attain the properties that individual material cannot attain, however, the improvement of mechanical properties of the composite are dominated by the contribution of the fibre to the composite which also known as fibre volume fraction (V_f) [5].

Fibre volume fraction is the percentage of the fibre contents in the composite. It was found to have significant effects on mechanical properties of the composite including strength, toughness, failure mode and so on. The mechanical properties can be improved by increasing fibre volume fraction [6, 7].

However, the composite ultimate strength will degrade if the fibre volume fraction is too large [7]. Hence, the aim of this project is to investigate the performance of composite plate with different fibre volume fraction. Universal Testing Machine (INSTRON) will be used to perform tensile test where the purpose of this test is to examine the strength, modulus of elasticity of the specimens. The failure code of the specimens will also be determined through this test.

1.2 Problem Statement

Polymer composite is material which is two or more distinct components. It had the capability to attain the properties that individual components cannot attain by themselves. Reinforced polymer materials are composite materials that had being reinforced by fibres, surface treatments, use of coupling agents and etc. [1].

Fibrous polymer composite is the material that containing fibre which provide strength and stiffness to it. Even though composite materials can combine the properties of the component of the mixtures, however, many of the mechanical properties such as strength, stiffness and toughness is weighted by the fibre volume fraction (V_f) of the composite [5]. Fibre volume fraction was also found to have significant effects on important composite properties including failure mode and ultimate strength [7]

Nowadays, the construction industry is concerted effort to use fibre composite as replacement of steel in fibre concrete. It also migrate reinforced polymer composite (RPC) for use in primary load bearing applications due to it shown a lot of potential advantages such as high specific strength [8].

Unfortunately, the use of RPC in construction industry still limited. This is because the absence of proper design codes [8]. Composition of matrix, fibre and resin is not standardized. Hence, RPCs with the greatest mechanical properties such as strength and toughness cannot be presented since the properties of RPCs are much depends on the composition of the mixture components especially V_f.

Besides that, RPCs had wide range of application in automobile and aerospace industry. High specific strength and low mass were often the dominant criteria to be achieved particularly for aerospace applications [4]. RPC is the materials can fulfill this conditions and its' mechanical properties can be improved with increasing fibre volume fraction. However, when the fibre volume fraction was sufficiently large, the composite ultimate strength was degraded [7].

The significant increased of the used of FRP in industry shown that there is a need to improve the properties and quality of polymer composite. In order to maintain and produce polymer composite with greatest mechanical properties, a standard in manufacture polymer composite is very important. Hence, a proper fibre volume fraction which plays an important role on mechanical properties of FRP should be investigated to obtain the best performance.

1.3 Project Objectives

i. To investigate the mechanical properties of composite plate with different fibre volume fraction.

ii. To compare the results obtained by analytical method and experimental method.

1.4 Project Scopes

i. To study about effects of fibre volume fraction of composite plate through literature studies.

ii. To prepare the sample specimen based on different fibre volume fraction.

iii. To examine the strength and modulus of elasticity of the specimen by tensile test method using Universal Testing Machine (INSTRON).

iv. To determine the specimen with the highest ultimate strength.

v. To observe the failure category of the specimens based on Tensile Test Failure Code.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the importance and applications of the composite materials at several sectors will be discussed. The rule of mixture (ROM) and modified rule of mixture (MROM) of composite materials will also be discussed. This chapter will inquired into the general properties of the components that commonly used to produce polymer composite materials which are fibre glass, polyester and epoxy. The effects of fibre volume fraction onto the mechanical properties of composite materials also will be discussed. Through this chapter, the details of the composite materials can be understood in depth. The roles of fibre volume fraction in mechanical properties of the composite materials also can be studied deeply. Hence, a suitable composition of fibre and resin can be investigated to produce composite materials with better performance.

2.2 Composite Materials

Among the major developments of materials in recent years are composite materials [3]. Composites are broadly known as reinforced plastics. Specifically, composites are a reinforcing fiber in a polymer matrix. [9]. Composite materials are the new products of the so-called advance engineering age [10].

In fact, composites are now one of the most important classes of engineered materials, because they offer several outstanding properties as compared to conventional materials [3]. The composite industry, however, is new. It has grown rapidly in the past 30 years with the development of fibrous composites [5].

Composite materials are multi-phase materials obtained by artificial combination of different materials, so as to attain properties that the individual components by themselves cannot attain [1].

A composite material typically consists of one or more fillers (fibrous or particulate) in a certain matrix. The matrix is usually a polymer, a metal, a carbon, a ceramic or a combination of different materials. The fibres provide the strength and stiffness while the polymer servers as the binder [1].

2.3 Classification of Composites

In generally, composites are classified according to their matrix material. The main classes of composites are polymer matrix, cement matrix, metal matrix and ceramic matrix composites [1].

2.3.1 Cement Matrix Composite

Cement matrix composites include concrete, which is once having a fine aggregate (sand), a coarse aggregate (gravel) and optionally other additives (called admixtures). Concrete is the most widely used civil structural material. When the coarse aggregate is absent, the composite is called mortar, which is used in masonry (for joining bricks) and for filling cracks. When both coarse and fine aggregates are absent, the material is known as cement paste. Cement paste is rigid after curing, which refers to the hydration reaction involving cement (a silicate) and water to form a rigid gel [1].

The admixtures can be a fine particular such as silica (SiO_2) fume for decreasing porosity in the composite. It can be a polymer (used in either a liquid solution form or a solid dispersion form) such as latex, also for decreasing porosity. It can be short fibres (such as carbon fibres, glass fibres, polymer fibres and steel fibres) for increasing toughness and decreasing drying shrinkage (shrinkage during curing – undesirable as it can cause cracks to form) [1].

2.3.2 Metal Matrix Composite

Matrix materials in metal matrix composite (MMC) are usually aluminium, aluminium-lithium, magnesium, copper, titanium, and superalloys. Fibres materials can be graphite, aluminium oxide, silicon carbide, boron, molybdenum, and tungsten. The elastic modulus of nonmetallic fibres ranges between 200 GPa and 400 GPa, with tensile strengths being in the range from 2000 MPa to 3000 MPa [3].

MMC are gaining importance because the reinforcement serves to reduce the coefficient of thermal expansion (CTE) and increase the strength and modulus [1]. Typical composition for metal composites materials are as shown in Table 2.1.

Table 2.1: Composition for Metal Matrix Composite Materials [3]

Fibre	Matrix
Graphite	Aluminium, Magnesium, Lead, Copper
Boron	Aluminium, Magnesium, Titanium
Alumina	Aluminium, Lead, Copper
Silicon carbide	Aluminium, Titanium, Superalloy (cobalt-base)
Molybdenum, tungsten	Superalloy

2.3.3 Ceramic Matrix Composites

Composites with a ceramic matrix or ceramic matrix composites (CMC) are another important development in engineered materials because of their resistance to high temperatures and corrosive environments. Ceramics are strong and stiff, and they resist high temperatures, but they generally lack toughness [3].

Although cement is a ceramic material, CMC usually refer to those with silicon carbide, silicon nitride, alumina, mullite, glasses and other ceramic matrices that are not cement [1]. Silicon carbide, silicon nitride, aluminium oxide and mullite (a compound of aluminium, silicon, and oxygen) can retain their strength up to 1700 °C (3000 ^{0}F) [3].

Ceramic matrix fibre composites are gaining increasing attention because the good oxidation resistance of the ceramic matrix (compared to a carbon matrix) makes the composites attractive for high temperature application (e.g., aerospace and engine components) [1].

2.3.4 Polymer Matrix Composite

Polymer matrix composite (PMC) also known as reinforced plastics and fibre reinforced plastics (FRP) [3]. PMC are the most common, owing to the low cost of fabrication. They can be classified according to whether the matrix is thermoset or a thermoplastic. Thermoset matrix composites are by tradition far more common, but thermoplastic matrix composites are under rapid development [1].

Thermoplastics have lower manufacturing cost because it does not need to be cure, have reprocessing possible (for repair and recycling) and fewer risks due to chemicals during processing. They also have high toughness and environmental properties. However, they limitation in processing method, high processing temperature, high viscosity and fibre surface treatments less developed [1].