Optimization of Stress Intensity Factor for Natural Rubber Toughened Glass Fiber

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Abstract: ***In this project natural rubber is used as a matrix material and glass fiber as reinforcement material that are fabricated using hand layup process. Then comparing the stress intensity factor of composites made of glass fiber with natural rubber and glass fiber with epoxy. The objective of the project is to determine the fracture parameter 'k' by Crack Tip Opening Displacement Method (CTOD). To study the effect of dispersing elastomer into the polymer on 'k', the thermography and radiography testing's have done.***

Keywords: natural rubber, glass fiber, epoxy, stress intensity factor

1. Introduction

Aerospace as well as aeronautic applications, both commercial and military, are accounting for a large share of the growing market value. The Composite materials offer many properties that have enabled composites manufacturers to gain significant market share in a variety of industries. Increased usage of composites in military and space systems, as well as in commercial aircraft development is expected to continue far into the foreseeable future.

A composite material contains a reinforcement (fibers) supported by a binder (matrix) material. The reinforcement components commonly used in the fabrication of composite structures are Carbon, Aramid, Glass and Ceramic fibers. The matrix or resin material can be Polyester, Vinyl ester, Epoxy, etc.

By blending quarry products (sand, kaolin, limestone, coleminate) at 16000^0 C, liquid glass is formed. The liquid is passed through micro-fine bushings and simultaneously cooled to produce glass fiber filaments from 5-24 μm in diameter. The filaments are drawn together into a strand or roving and coated with a "size" to provide filament cohesion and protect the glass from abrasion. The different types of glass can be produced by variation of the "recipe". For structural reinforcements, the types used are E-Glass, C-Glass, T-Glass, etc.

The resin systems used to manufacture advanced composites are of two basic types: Thermosetting and Thermoplastic. Thermoset resins require addition of a curing agent or hardener and impregnation onto a reinforcing material, followed by a curing step to produce a cured or finished part. The part cannot be changed or reformed if it once cured. Thermosets include epoxies, phenolic and amino resins. Of these, epoxies are the most commonly used in today's PMC industry. Thermoplastics currently represent a relatively small part of the PMC industry. They require only heat and pressure to form the finished part.

Natural Rubber also called India rubber or an elastomer that was originally derived from latex. An incision made into the bark of the tree and the milk coloured latex is collected and refined into a usable rubber. The purified form of natural rubber is chemical polyisoprene. Natural rubber is used in many applications and products. It is very stretchy and flexible and water proof. Abu Bakar et al proved that Liquid Epoxidised Natural Rubber (LENR) is used to overcome the disadvantage of brittleness and low toughness of Epoxy resin. By addition of Liquid Epoxidised Natural Rubber (LENR), flexural modulus, flexural strength and fracture toughness are improved. S.K.Tan et al (2013) stated that rubber-toughened epoxy resins were prepared using the mechanical stirring method and molded into samples. The aim of is to modify the brittleness of epoxy matrix by adding discrete rubbery phases to improve the toughness. Liquid natural rubber and liquid epoxidized natural rubber were used as toughening agents in the epoxy resin to compare the properties of the modified networks. The toughness of the epoxy was improved by adding the rubbery phase into the epoxy resin. The composite with 3 wt% of LENR possessed the highest mechanical properties for both flexural and impact properties. The scanning electron micrograph (SEM) demonstrated the discrete rubbery phases between the epoxy and the rubber particles. H.Ku et al found that natural fibers have recently become attractive to researchers, engineers and scientists as an alternative reinforcement. Because of their low cost, high specific strength, good mechanical properties, non-abrasive, and bio-degradability characteristics, it is used as a replacement for the conventional fiber such as aramid, carbon and glass. Tensile properties of natural fiber reinforce polymers are influenced by the interfacial adhesion between the matrix and the fibers. Some modifications are employed to improve the interfacial matrix-fiber bonding resulting in the enhancement of the tensile properties of composites. The tensile strengths of natural fiber reinforced polymer composites increase with fiber content up to an optimum value. After that the value will then drop. The Young's modulus of the natural fiber reinforced polymer composites increases with increase in fiber loading. LEE YIP SENG et al found the effects of liquid natural rubber (LNR) on the morphology and mechanical properties of rubber modified epoxy. Epoxy composites were prepared in four different compositions of LNR (3, 5, 7 and 9phr) by using twin screw extruder. The samples for tensile, impact tests and fracture toughness were prepared according to ASTM D 638, D 5045 and D 256. The elastic nature of rubber can act as energy dissipating centre to cause the ductile fracture. There was an increment of fracture toughness where maximum value was observed with 3 phr LNR. A good increment of impact strength at 3 phr LNR was observed. When the amount of LNR was increased the SEM micrographs shows an increment of rubber particle and caused the mechanical properties to drop.

2. Properties of Natural Rubber

Natural rubber is having high resilience, high tear and tensile properties. Toughness of rubber can change by varying the mechanical and physical properties. The mechanical and physical properties of rubber are shown in below tables.

Table 1: Mechanical Properties of Natural rubber

Quantity	*Value*	*Unit*
Young's Modulus	1-5	MPa
Tensile Strength	20-30	MPa
Elongation	750-850	%

Table 2: Physical Properties of Rubber

Quantity	*Value*	*Unit*
Thermal expansion	6.7	e-6/K
Thermal conductivity	0.13 - 0.142	W/m.K
Specific heat	1880	J/kg.K
Glass temperature	70	^{0}C
Density	910-930	Kg/m^3
Resistivity	1e+21	Ω.mm^2/m

3. Fabrication of composites

Moulding is the process of manufacturing by shaping pliable raw material using a rigid frame or model. The major molding process are hand layup process, vacuum bag moulding, pressure bag moulding, filament winding. Hand layup process is used here. It is a simple method for composite production. A mould must be used for hand layup parts unless the composite is to be joined directly to another structure. The mould can be as simple as a flat sheet or have infinite curves and edges. For some reasons the moulds must be joined in sections so they can be taken apart for part removal after curing. Before layup, the mould is prepared with a release agent to ensure that the part will not adhere to the mould. Resin must then be catalyzed and added to the fibers. A brush or roller can be used to impregnate the fibers with the resin. The layup technician is responsible for controlling the amount of resin and the quality of saturation. Hand layup or contact moulding is the oldest way of making fiber glass-resin composites. Applications are standard wind turbine blades, boats, wing rudders, etc.

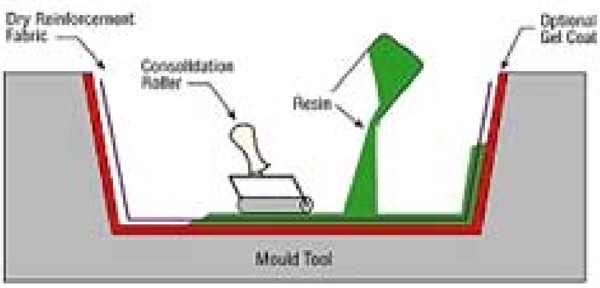

Figure 1: Hand layup process

4. Testing Methods

4.1 Thermography testing

Infrared and thermal testing is one of many non-destructive testing techniques designated by the American Society for Non-destructive Testing (ASNT). Infrared thermography is the science of measuring and mapping surface temperatures. It can detect internal voids, delamination and cracks. An infrared thermo graphic scanning system can measure and view temperature patterns based upon temperature differences as small as a few hundredths of a degree Celsius. Depending on environmental conditions and the desired results, infrared thermo graphic testing can be performed.

4.2 Radiography testing

The thicker or higher density materials absorb more radiation resulting in less transmission to the film, based on the principle of preferential radiation transmission and absorption.

4.3 Tensile testing

The tensile strength is defined as the maximum tensile load a body can withstand before failure divided by its cross sectional area. This is also sometimes called as ultimate Tensile Stress. Fibers such as glass, Kevlar and carbon fiber are often added polymeric materials in the direction of the tensile force to reinforce or improve their tensile strength. The specimen was trimmed and cut into pieces according to ASTM D3039.

4.4 Crack tip opening displacement testing

Crack tip opening displacement test is usually done on materials that undergo plastic deformation prior to failure. The testing material resembling the original one through dimensions can be reduced proportionally. The notch is created exactly at the center after the specimen is placed on the work table. The crack is produced such that the length of defect reaches a value of about half the depth. A three point bending load is applied on the specimen. The strain gauge is used for measuring the crack opening.

5. Stress intensity factor

The stress intensity factor, 'k' is used in fracture mechanics to predict the stress intensity factor near the tip of a crack caused by a remote load. It is usually applied to a linear elastic, homogeneous material and is useful for providing a failure criterion for brittle materials. It can also be applied to materials that exhibit small-scale yielding at a crack tip.

The magnitude of 'k' depends on the size and location of the crack, and the modal distribution of loads on the material. The stress distribution (σ_{ij}) near the crack tip, in polar coordinates (r, θ) with origin at the crack tip is in the form.

$$K = Y\frac{3PS\sqrt{a}}{2TW^2}$$

$Y=1.9-3.07(a/w) + 14.53(a/w)^2 - 25.11(a/w)^3 + 25.80(a/w)^4$, where ‘P’ is the critical load for crack propagation, ‘S’ is the length of span, ‘a’ is the crack length, ‘T’ is the thickness, ‘W’ is the width and ‘Y’ is the non dimensionless function.

6. Results

The stress intensity factor values of the composites are shown below.

Table 2: Theoretical and experimental values of stress intensity factor

Material	*Theoretical values of stress intensity factor (MPa)*	*Experimental values of stress intensity factor (MPa)*
Fiber	$117.3\sqrt{a}$	$126.75\sqrt{a}$
1% natural rubber	$120.7\sqrt{a}$	$126.75\sqrt{a}$
2% natural rubber	$120.6\sqrt{a}$	$121.003\sqrt{a}$
3% natural rubber	$128.4\sqrt{a}$	$142.36\sqrt{a}$

7. Conclusion

The literature survey confirms that the liquid epoxidized natural rubber is a good potential toughening agent for epoxy resin. A significant increase in the bending properties and impact strength was observed by Tan S K et al, by the addition of liquid rubber to the epoxy matrix. The sample with 3 wt% of LENR toughened epoxy obtained optimum results for both bending and impact properties.

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