UNIVERSITI PUTRA MALAYSIA

AXIAL AND RADIAL LOADING EFFECTS ON QUASI-STATIC CRUSHING OF GLASS/EPOXY COMPOSITE TUBES

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An experimental and finite element investigation of glass fiber/epoxy composite tubes were carried out under axial compressive and radial loading. A filament winding equipment has been used for the fabrication process of the specimens. These composite tubes were fabricated with 2, 4, 6 and 8 layers, keeping the fiber orientation angle of 90°, the tubes inner diameter is 50mm and the height is 100mm for all the specimens. Steel cones, of semi cone angle of 10, 20, 30 and 40 degrees were used to develop the axial and radial-loading cases. In addition, flat plate was used for pure axial crushing cases. The Volume fraction of glass fiber and matrix used was 70% and 30% respectively. The required properties for the composite used were obtained from a tensile test specimens and used for the theoretical part of this study to calculate the first crushing loads. The experimental tests for all the crushing tests of the composite tubes and the tensile specimens tests were performed at room temperature of $20^{\circ}C$.

Three composite tubes were fabricated and tested for each number of layers and each loading case. Tests were carried out at a crushing speed of 2.5mm/min using a digital Instron testing machine of 250 kN capacity.

The results obtained from this study include the experimental results of the load-displacement relations, the first crushing load, average crushing load, crushing load gradient and the energy absorption. On the other hand, only the buckling load has been obtained from the finite element part of this study.

The experimental results show that the first crushing load and the energy absorption increase when the number of layers increases for the same loading mode. They also increase as the loading cone semi cone angle increases, for each number of layers. This was applicable for the change in the average load values. Furthermore, it has been observed that the increase of the loading cone semi angle would decrease the crushing gradient for each set of composite tubes of the same number of layers.

For the first crushing load, the change from two to eight layers for the different semi cone angles shows an increase of 53.3% to 64.9% load. While, the average load increases by 51.0% to 63.4%. Furthermore, the energy absorption increases by 52.2% to 59.3% as the number of layers increases from two to eight layers for all the cases studied. On the other hand, crushing gradient decreases by 89.5% to 73.8% as the semi cone angle increases from 10° to 90°. For tubes loaded using flat plate, first crushing load increase by 60.8% when the number of layers increase from two to eight layers.

The main factors affecting the first crushing load and the energy absorption are the number of layers, semi cone angle and the fiber to matrix ratio.

In addition, the finite element analysis has been carried out for similar composite tubes implementing the buckling analysis. The buckling load evaluated then compared to the average first crushing load for each three similar experimental tests for all the cases. From the comparison, it was found that the percentage difference was in the range between 18.13% to 37.72%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

KESAN BEBAN PAKSI DAN RADIAL KE ATAS KEHANCURAN QUASI-STATIK TIUB KOMPOSIT KACA/EPOXY

Oleh

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Experimen dan kajian unsur terhingga bagi tiub ‘fiber glass’ dan komposit telah dijalankan dibawah beban mampatan dan beban radial. Alat filamen telah digunakan untuk proses pembikinan spesimen. Tiub komposit yang dibikin mempunyai 2, 4, 6 dan 8 lapisan, sudut pusingan ‘fiber’ adalah sudut 90°, diameter dalam silinder ialah 50mm dan tinggi silinder ialah 100mm untuk semua spesimen. Kun besi yang mempunyai sudut separuh kun 10°, 20°, 30° dan 40° sudut telah digunakan untuk menjalankan kajian bebanan ‘axial’ dan ‘radial.

Plat datar digunakan untuk kes hancuran paksi. Pecahan isipadu gelas ‘fiber’ dan matrik yang digunakan masing-masing adalah 70% dan 30%. Ciri-ciri yang diperlukan untuk komposit adalah diperolehi daripada ujian ttegangan spesimen dan digunakan untuk bahagian teori dalam kajian ini untuk mengira ‘crushing load’ pertama. Ujian bagi semua ujian ‘crushing’ untuk tiub komposit dan ujian ttegangan spesimen dijalankan pada suhu bilik 20°C.

Tiga tiub komposit telah dibina dan diuji bagi setiap lapisan dan setiap kes bebanan. Ujian dijalankan pada kelajuan hancuran 2.5mm/min dengan menggunakan mesin ujian Instron berdigital muatan 250 kN. Keputusan yang diperolehi daripada kajian ini merangkumi keputusan eksperimen bagi hubungan beban-anjakan, beban hancuran pertama, purata beban hancuran, cerun beban hancuran dan tenaga serapan. Hanya beban lengkukan (buckling), diperolehi daripada hasil kajian keadah unsure terhingga.

Keputusan eksperimen menunjukkan beban hancuran pertama dan tenaga terserap meningkat apabila jumlah bilangan lapisan bertambah bagi mod bebanan yang sama. Ianya juga meningkat apabila sudut separuh kon meningkat bagi setiap lapisan. Ini adalah munasabah bagi perubahan didalam nilai purata beban.

Selain itu, adalah diperhatikan bahawa peningkatan beban sudut separuh kon akan menurunkan cerun hancuran bagi setiap set tiub komposit yang mempunyai bilangan lapisan yang sama. Pada beban hancur pertama, perubahan dari dua kepada lapan lapisan bagi sudut separuh kon yang berlainan menunjukkan peningkatan 53.3% kepada 64.9% ‘load’.
Diperhatikan juga bahawa purata ‘load’ meningkat dari 51.0% kepada 63.4%. Tenaga serapan meningkat dari 52.2% kepada 59.3% bila bilangan lapisan meningkat dari dua kepada lapan lapisan bagi semua kes kajian.

Manakala, cerun hancuran menurun dari 89.5% kepada 73.8% apabila sudut separuh kun meningkat daripada 10° kepada 90°. Bagi tiub, dibeban menggunakan plat rata, beban hancur pertama meningkat sehingga 60.8% apabila bilangan lapisan meningkat daripada dua kepada lapan lapisan. Factor utama yang memberi kesan kepada beban hancur pertama dan tenaga serapan adalah bilangan lapisan, sudut separuh kun dan 'fiber' kepada nisbah matrik. Analisis unsure terhingga telah dijalankan untuk tiub komposit menggunakan analisis lengkuk (buckling). Beban lengkuk yang ditentukan kemudian di sebandingkan dengan purata beban hancur pertama bagi setiap tiga ujian eksperimen yang serupa untuk setiap kes. perbandigan menunjukkan peratus perbezaan adalah di antara 18.13% hingga 37.72%.

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NOMENCLATURE

Symbol

E	Young's Modulus (GN/m^2)
E_f	Young's Modulus of fiber (GN/m^2)
E_m	Young's Modulus of Matrix (GN/m^2)
V_f	Fiber Volume Fraction
V_m	Matrix Volume Fraction
ν	Poisson's Ratio
ν_f	Major Poisson's Ratio of Fiber
ν_m	Major Poisson's Ratio of Matrix
K	Bulk Modulus
K_f	Bulk Modulus of Fiber
K_m	Bulk Modulus of Matrix
G	Shear Modulus (GN/m^2)
G_f	Shear Modulus of Fiber (GN/m^2)
G_m	Shear Modulus of Matrix (GN/m^2)
E_s	Specific Energy Absorb (N.m/kg)
$\bar{\sigma}$	Mean Crush Stress (N/m^2)
P	Mean Crush Load (N)
ρ	Density of the Composite (kg/m^3)
A	Cross-Sectional Area (mm^2)
M/L	Mass per Unit Length of the Composite Tube (kg/m)
D_1, D_2	Internal and External Diameters (mm)
P_F^C	Critical Buckling Load of Tubes (N)
β	Semi Cone Angle
σ_{sb}	Bending Stress (N/m^2)
M	Bending Moment (N.m)

CHAPTER ONE

INTRODUCTION

1.1 General

Among the major developments in materials in recent years are the modern composite materials. In fact, composites are now one of the most important classes of engineered materials, as they offer several outstanding properties as compared to conventional materials.

Composite materials are made by combining two or more materials, on microscopic scale, to form a useful material. Composite materials are in general not isotropic as compared to the conventional materials such as metals. Structures made of such materials are called composite structure. Some properties are improved in this way that could be important depending on the use of these materials such as strength, stiffness, corrosion and wear resistance, fatigue life and thermal insulations. Because of the advantages such as weight, strength, wear and corrosion resistance, composite materials have a wide range of applications from simple parts, automobile parts to aircraft body and parts.

One of the interesting aspects of composite material is the freedom to select the precise form of the material to suit the application. Along with this freedom is the responsibility of making design decisions on the material aspect.

Recently, the development of the finite element analysis (FEA) software has made the quantitative analysis of composite materials possible and convenient to be used.

Therefore, this FEA has been seen, as the necessity for a vigorous prediction needed for comparison with the experimental results to improve the mechanical characteristics of composite components.

Composite materials are made at least of two materials; a reinforcement material and matrix material. The reinforcement may be in the form of particles, short fibers (whiskers) or continuous fibers. The matrix can consist of metal, ceramic, glass, concrete, gypsum or resins and the reinforcement can be metal rods or filaments, whiskers of silicon carbide or nitride, carbon fiber, boron fiber and various types of glass asbestos and cellulose fiber. The matrix is generally of lower density, stiffness and strength than the fibers or whiskers.

In practical design engineering, the analysis of composite materials is usually done on some typical structures and specimens having the shape of plane, ring, tube, cone and sphere.

Usually the relations of micromechanics are intended first and foremost for initial estimates and qualitative analysis of the effect of micro structural parameters on the composite material properties. Such estimates are necessary for the solution of various problems of materials science associated with property modification and development of new materials.

1.2 Types of composite materials

Composite materials could be classified as; Particulate composite, which are composite of particles in a matrix, fibrous composites, which consist of fibers in a matrix and laminated composites, which consist of layers of various materials. In a particulate composite, particles are added to a matrix. Particles can have various effects on a matrix depending on the properties of the two constituents. Ductile particles added to a brittle matrix increase the toughness as cracks have difficulty passing through the particles. The rubber-modified polystyrene is a common example for particulate composite type. Particles of hard and stiff (high E) material added to a ductile matrix increase its strength and stiffness. An example for that type is the carbon black added to rubber. As might be expected, hard particles generally decrease the fracture toughness of a ductile matrix and this limits the usefulness of some composites of this type. In the fibrous composites, fibers of different length mostly stronger than the matrix are used. Fibers are used in composites because they are of a lightweight, stiff and stronger. Fibers are stronger than the bulk material that constitutes the fibers. This is because of the preferential orientation of molecules along the fiber direction and because of the reduced number of defects present in a fiber compared to the bulk material. The most common fibers used in composites are glass, carbon and organic (Kevlar), Boron, Silicon carbide (Sic), alumina and other fibers are used in specialized applications.

The fibers carry most of the stress, whereas the matrix holds them in place and in shape. Good adhesion between fibers and matrix is important as this allows the matrix to carry the stress from one fiber to another at the point where a fiber breaks or where one fiber