CRUSHWORTHINESS OF POLYMERIC FOAM USED AS CORE COMPOSITE SANDWICH STRUCTURE

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To my beloved family,

The believe in you brings my dreams comes true.

To my hubby, Fakhrin Hakimi Mustofa and sons, Amir Hakim and Luqman Hakim who have brought me love, patience
and understanding into our lives.

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"In the name of Allah that the most Gracious, the most Merciful"

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ABSTRACT

PUR foam has been used extensively as core of sandwich structures in the aerospace and automobile industries. The understanding of their behaviour under crush conditions is extremely important for the design and manufacturing of these engineering structures since crush problems are directly related to structural integrity and safety requirements. In this paper, selected foam cored polymer sandwich beam were subjected to static three point bend tests. The beams were loaded beyond first failure to study the nonlinear post failure behaviour. Provided the beam fails in shear of core and skin delamination. The post failure response is dominated by the crushing of the core and upper skin compression. A theoretical model by Mines and Jones is used to simulate the post failure response of the beams. The model assumes an idealized plastic hinge in the central loading point and relates the beam constituent material properties to the beam overall response. The beams were also subjected with impact test. The impact response of foam based sandwich structures has been investigated using a build-up falling weight impact method and load cell system.

ABSTRAK

Penggunaan ‘PUR foam’ sebagai teras kepada struktur ‘sandwich’ di dalam industri automobil dan aero-angkasa semakin meluas. Oleh itu, pemahaman tentang gayalaku mekanikal di bawah keadaan hentaman adalah sangat penting untuk tujuan rekabentuk dan pembuatan struktur kejuruteraan kerana masalah hentaman berkait secara langsung dengan kekuatan struktur dan keperluan keselamatan. Untuk kertas kerja ini, rasuk ‘foam’ polimer ‘sandwich’ yang telah dipilih dibebankan dengan beban lenturan dalam ujian lenturan sistem pembebanan tiga-titik secara statik. Struktur rasuk itu dikenakan beban sehingga melangkaui kegagalan struktur rasuk yang pertama untuk membolehkan gayalaku selepas kegagalan pertama dikaji. Didapati kegagalan rasuk ialah berlakunya ricihan pada teras rasuk dan ‘skin delamination’. Tindak balas selepas kegagalan yang pertama ialah rasuk mengalami kerenyukan pada teras dan mampatan pada kulit di bahagian atas rasuk. Teori yang diterbitkan oleh Mines dan Jones digunakan untuk simulasi tindakbalas rasuk selepas kegagalan berlaku. Model ini menganggapkan bahawa berlakunya keplastikan penuh secara ideal di tengah-tengah titik tindakan beban dan tindak balas yang berlaku berkait rapat dengan sifat-sifat bahan rasuk itu. Selain itu, sistem rasuk ini juga dibebankan dengan dengan ujian bebanan hentakan. Tindak balas terhadap hentakan oleh foam based struktur sandwich disiasat dengan keadah hentakan pemberat dan sistem ‘load cell’.

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NOMENCLATURES

$\boldsymbol{B}$	Beam width (mm)
$\boldsymbol{c}$	Core thickness (mm)
$\boldsymbol{d}$	Distance between centroidal axis of skins (mm)
$\boldsymbol{h}$	Total beam thickness (mm)
$\boldsymbol{t}$	Skin thickness (mm)
$\boldsymbol{L}$	Beam span (mm)
$\boldsymbol{E}$	Modulus of elasticity (GPa)
$\boldsymbol{v}$	Volume fraction
$[\boldsymbol{Q_{11}}]_k$	Stiffness of kth lamina
$\boldsymbol{v}$	Poisson's ratio
$\boldsymbol{D}$	Flexural rigidity (Nm)
$\boldsymbol{k}$	Beam stiffness (N/m)
$\boldsymbol{F_s}$	Static failure load (N)
$[\boldsymbol{\sigma}]_k$	Faulire stress in kth lamina (MPa)
$\boldsymbol{\tau}$	Shear stress (MPa)
$\boldsymbol{\alpha}$	Axial force component (N)
$\boldsymbol{\beta}$	Moment component (Nm/m)
$\boldsymbol{M}$	Moment of a section (Nm)
$\boldsymbol{F}$	Load or force (N)
ε_f	Initial strain for core crushing
ε_m	Upper core surface strain
$\boldsymbol{z}$	Distance from upper core surface to neutral axis (mm)
$\boldsymbol{g}$	Work hardening index of core (MPa)

$\boldsymbol{l_t}$ Hinge length along core upper surface (mm)

$\boldsymbol{l_o}$ Hinge length along neutral axis (mm)

$\boldsymbol{R}$ Radius of curvature of failed beam (mm)

$\boldsymbol{\theta}$ Angle of curvature of failed beam (radians)

$\boldsymbol{\delta}$ Beam deflection (mm)

$\boldsymbol{\varepsilon_{1,2}}$ Tensile strain in lower skin

The following subscripts can be used with the above notations;

$\boldsymbol{f}$ Fibre

$\boldsymbol{m}$ Matrix

$\boldsymbol{c}$ Core

$\boldsymbol{s}$ Skin

$\boldsymbol{u}$ Upper

$\boldsymbol{l}$ Lower

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CHAPTER 1

INTRODUCTION

The evolvement of material in usage applications has never stopped. Nowadays, the development of structure with the use of polymeric composite material is in rapid progress. One of the important aspects in these structural designs is that the capability of the polymeric composite materials to withstand impact load. Structures are designed in consideration of absorbing energy under impact conditions.

Another aspect needs to be looked into is the replacement of metal, concrete and wood structures with polymer composite materials. Man has moved from using pure materials such as metal to alloy and consequently polymer composite with certain purposes. The main purposes are to achieve weight savings, take advantage of new materials processing methods and improve the properties of the material for certain applications.

Furthermore, in the case of impact response, a complex three dimensional structural behavior of the material occurs. In order to design complex geometry of the structures for impact resistance, it is a need to study a simple structure element of the polymer composite material.

A simple polymer composite structure commonly used today is sandwich structure. The sandwich construction is made up of a lightweight core material sandwiched between high strength and high modulus skins. In most sandwich constructions, core materials include balsa wood, aluminum, paper and plastic honeycombs, cellular foams and Coremat^{R}. The skins are usually resin impregnated glass, aramid or carbon fibres. The matrix resin can be of polyester, vinyl ester, phenolic thermosets and other more recent high performance thermoplastics. In this study, the work is concerned on the sandwich beams with polyester resin impregnated glass fibers for skins and rigid polyurethane foam as the core material. Due to high stiffness and strength to weight ratio of composites and thin walled sectional geometry of FRP shapes, impact is the most likely mode of failure before material failure.

1.1 Background of Project

Studies on impact response of sandwich structures are quite numerous. Previous experimental work [1,2,3] showed that sandwich beams subjected to three point bend test, failed in several different modes. The main modes of failure were upper skin compression failure, upper skin wrinkling, shear of core and lower skin tensile failure. Beams with thin skin and span to depth ratio of 16 or greater mainly failed due to upper skin compression. This is followed by crushing of the core and finally lower skin tensile failure. Figure 1.1 shows the force deflection schematic for the sandwich beams. Up until the first failure, the linear elastic behaviour of the beams can be analysed using the laminate theory which has been extensively covered in most texts and papers. However, little work has been carried out on the post failure behaviour of sandwich beams. A model has been developed by Mines and Jones[1] to simulate the post skin failure response of the beams. The model assumes the idealized plastic hinge. It is under central lateral loading and makes use of simple strength of material concept which relates the material properties to the overall response of the beams. Although highly approximate, the model showed fair agreement with the Coremat^{R} cored beams.

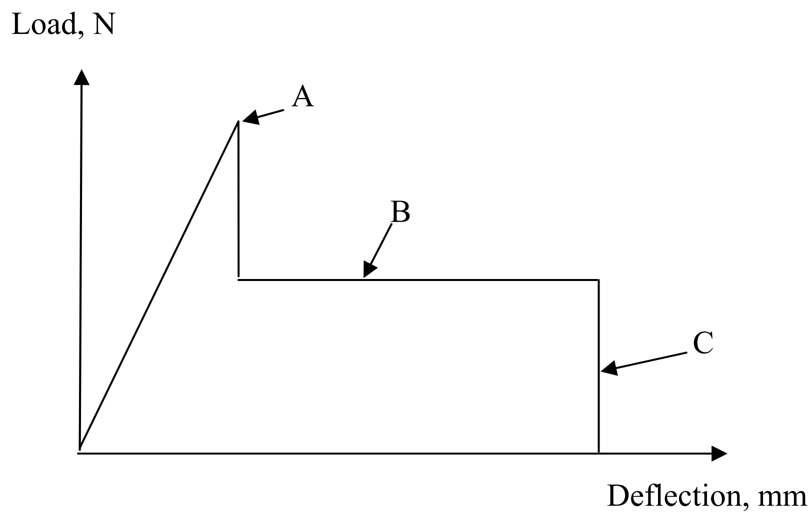

Figure 1.1: Force-Deflection Schematic for Sandwich Beam (A-Upper skin compression, B-Core crushing, C-Lower skin tensile failure)

1.2 Problem statement

Lightweight sandwich constructions are frequently used in a wide range of engineering applications due to their excellent bending properties. In some cases where structures might be subjected to large overloads and impact, residual strength and energy absorption are of equal importance. As in example of large overload, how much energy can the structure absorb until total failure is a major concern. In frontal impact of a car, can the car structure absorb enough impact energy to prevent injury of its occupants? These show the importance on understanding the post failure of sandwich constructions which is in the plastic region where more energy is absorbed.

1.3 Objective

The objectives of this study are:

a) to determine the energy absorbed by the foam from the biaxial test
b) to determine the energy absorbed by the foam as core of composite sandwich structure from the three-points bending test.
c) to investigate the type of the post failure behaviour of this polymeric sandwich structure
d) to investigate the validity of the model with the beam tests.

1.4 Scope of Study

The scopes of this project are as stated below:

1. Study the present technique in producing the polymeric foam: rigid polyurethane foam, as core sandwich structure.
2. Fabricate the foam core using *mixing machine*.
3. Study the characteristics of PUR Foam by performing mechanical tests as below:
    i. Uniaxial Tension Test
    ii. Uniaxial Compression Test
    iii. Pure Shear Test
    iv. Biaxial Test

4. Study the characteristics of glass fibers and polyester resin and to perform tensile tests on the skin of sandwich structure.
5. Study the theory that relates with three-point bending and impact analysis.
6. Perform mechanical tests of the sandwich structure:
    i. Three Point Bending Test
    ii. Dynamic Impact

7. Analyze the experiment data.
8. Carry out the theoretical analysis.
9. Comparison and discussion of data analysis.
10. Conclusion and suggestion/recommendation for future study.
11. Report writing.

1.5 Methodology

The methodology of this project was divided into two parts which are analytical analysis and experimental work. The flow chart in Figure 1.2 below shows the activities for the experimental work.

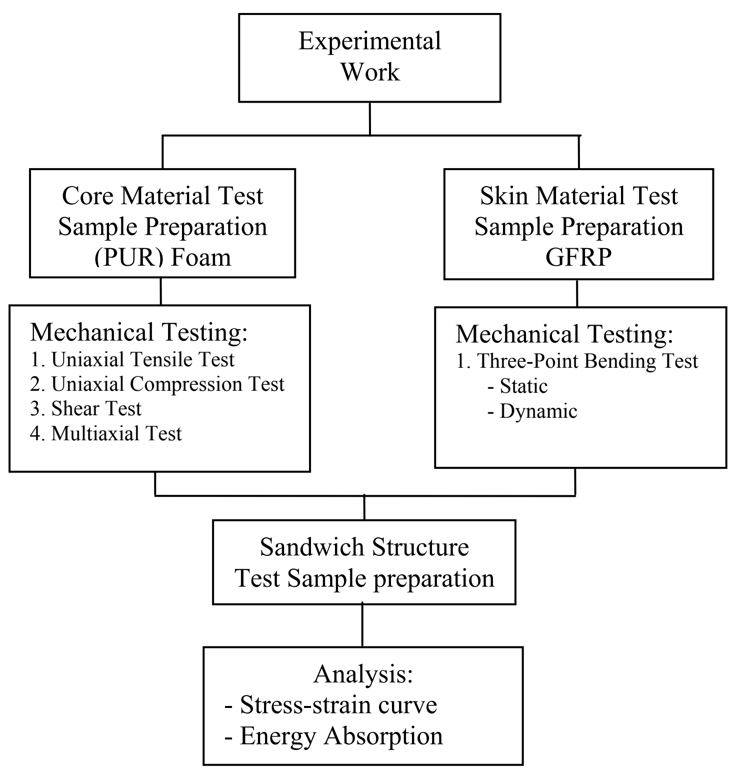

Figure 1.2: A Flow Chart for Experimental Work

The core specimens were prepared by mixing the polyol blend and isocyanate of 1:1 ratio respectively. The determination of the tensile, compression, and shear properties of the PU foam were carried out according to the ASTM C297, ASTM D1621-2000 and ASTM C365-2000, and ASTM C273 standards respectively. The properties of this material used to analyze the failure characteristic of the core sandwich structure. The face sheets were prepared by filament winding process. The determination of the failure characteristic of the GFRP was carried out by the quasi-static and dynamic test and axial test. The sandwich structures were prepared by using in-situ technique. Thus, from the stress-strain curve obtained the energy absorption is analyzed. Apart from that the energy absorption is also being analyzed theoretically.