Materials and Design 59 (2014) 475–485

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Investigation of the behaviour of a chopped strand mat/woven roving/foam-Klegecell composite lamination structure during Charpy testing

A.M.T. Arifin [a,b], S. Abdullah [a,*], Md. Rafiquzzaman [a], R. Zulkifli [a], D.A. Wahab [a], A.K. Arifin [a]

[a] Dept. of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[b] Dept. of Materials and Design Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 27 November 2013
Accepted 3 March 2014
Available online 21 March 2014

Keywords:
Charpy
Chopped strand mat
Failure
Polymer matrix composite
Woven roving

ABSTRACT

This paper presents the investigation of the characteristic behaviour of polymer matrix composites under Charpy impact conditions with different design configurations of the laminate structure. The aim of this study was to evaluate the capability of different lamination designs for composite materials, in term of contact load, energy absorption, deflection and damage behaviour. In this study, laminated panels were fabricated using chopped strand mat (CSM), woven roving fabric (WR) and foam-PVC Klegecell as reinforcement with a combination of epoxy or polyester resin, respectively. Structural panels of composite laminates were produced using a hand lay-up technique. Each configuration design was impact tested to failure. Finite element analyses (FEA) were employed in this study to correlate the experimental value of energy absorption with simulation results. The characteristics of different reinforcement types, matrix type, hybrid type, architecture and orientation type were studied. These characteristics need to be considered, due to their affecting the characteristic behaviour of the composite lamination structures. Based on the results, it was found that differences in configuration design of the lamination structure of the polymer matrix composites do influence the strength and weakness of the materials.

1. Introduction

Polymer matrix composites are one of the three main groups in common man-made composites, with the others being metal matrix composites and ceramic matrix composites. Polymer matrix composites, normally known as composite materials, consist of two or more materials that are combined to produce new materials and to have better properties. Today, among existing materials, composites are among the best materials, due to their advantages, such as high strength and stiffness, low density (lightweight), resistance to corrosion, good electrical properties and ease of manufacturing. Composites have increasingly been used in various applications, for instance in automotive industries, maritime industries, aviation, equipment for sport, fishing and architecture structures. There are two classified groups of composite materials: matrix and reinforcement [1]. As a core component, reinforcement provides strength and is stronger than a matrix. Meanwhile, a matrix is a material that is used to keep the fibre (reinforcement) orientation and to provide protection from ambient conditions. It is important to study impact phenomena in composite materials while keeping in mind that different materials are used and that the structures are unique and usually in a laminated form. Most of the applications that use composite materials are exposed to impact conditions. Examples include marine and aerospace vehicles and ballistic protection in the defense industry. Therefore, it is important to study the behaviour of composite materials that are subjected to impact conditions. Most of the previous work on impact behaviour of composite materials involved evaluating the impact response during experimental failure testing of composite materials, and studying the effect of the material used and of improvements in the composite structure.

Due to the low velocity of impact in the Charpy test, the results are strongly dependent on configuration, fibre type, matrix type (resin), thickness of the sample, loading velocity and type of projectile. Furthermore, low velocity impact on composite materials is very important to investigate because internal fracture can decrease the effectiveness of materials, without any obvious damage at the impacted surface [2]. For this reason, as reported by Evci and Gulgec [3], the researcher still has considerable work to understand the exact relationship between impact force and damage mechanism. In other words, damage initiation and propagation are dependent on both impact properties and the material's response. The impact properties include impact force, velocity and

* Corresponding author. Tel.: +60 3 89118411; fax: +60 3 89259659.
E-mail addresses: mubarak@eng.ukm.my (A.M.T. Arifin), shahrum@eng.ukm.my (S. Abdullah), rafiqbitr@yahoo.com (Md. Rafiquzzaman), rozli@eng.ukm.my (R. Zulkifli), dzuraida@eng.ukm.my (D.A. Wahab), kamal@eng.ukm.my (A.K. Arifin).

http://dx.doi.org/10.1016/j.matdes.2014.03.005
0261-3069/

energy, and the material's impact response depends on material strength, deflection of force, duration of impact and energy dissipation [4]. The impactor of the Charpy test also influences the damage characteristics of the sample in a manner related to the design and mass of the impactor [5].

Ghasemnejab et al. [6] mention that the natural characteristic of composite materials is to be brittle. Therefore, the energy absorption under impact is linked to other mechanisms, such as fibre breakage, matrix cracks, debonding of fibre–matrix interface and delamination of plies. In composite material structures, if delamination of plies occurs between each layer, this means that a progressive failure mode has occurred, and the composite shows a capability for energy absorption. According to Sohn and Hu [7], in their investigation of delamination mechanisms and energy dissipation of carbon fibre epoxy composites, the failure mode was separated between mode-I and mode-II delamination when the composites were tested in two extreme conditions. Shyr and Pan [8] found that the first layer in composite lamination is a key parameter for dissipation of energy in the structure, as reported in his study of impact behaviour and damage characteristics in different fabric structures with various laminate thicknesses. Chan et al. [9] identified that the efficiency works to improve energy absorption in composite lamination structures through the thickness direction and can indirectly control delamination of the structures. Ulven and Vaidya [10] noted that the impact response in polymer matrix composite laminates can be divided into three stages: damage initiation, penetration and total perforation. They also mentioned that the contact response of the PMC and sandwich types under impact conditions is different because of sandwich structures having a core material that significantly increases the rigidity of the composite.

Hristov et al. [11] investigated the impact behaviour of modified polypropylene/wood fibre composites, and found that the behaviour of composite materials is different, due to differences in material used, even for a small modification of the material content. Fu et al. [12] investigated the fracture resistance of short-glass-fibre reinforced and short-carbon fibre reinforced composites, and reported that the impact energy of composite materials depends on the fibre length. In optical systems, Zang and Zhang [13] identified that the fibre length are strongly affect the width of the hysteresis loop and threshold switching power, whereby the polymer matrix composites has also been employed in the fibre grating to improve the operation of optical switching. In the field of carbon fibre reinforced composites, Choi and Chang [14] mentioned impact failure of the structure from matrix cracking, and this can trigger delamination at others ply interfaces before fracture. Kwon and Wojcik [15] found that the failure load of the composite material increases with a presence of small lamination cracks compared with non-delaminated structures. Pegoretti et al. [16] analysed the fracture behaviour in an epoxy carbon laminate system using a correlation of interlaminar fracture toughness and impact energy absorption. Erkendirci [17] concluded in his work using plain weave S-2 glass/HDPE thermoplastic composite that impact energy of the composite structure increases upon increasing the thickness and volume fraction of the composite.

Available literature indicates that the characteristics of composite materials in terms of Charpy impact behaviour have been investigated by a large number of researchers [2–16]. However, numerical analysis combined with experimental investigation on Charpy impact behaviour with different design configurations has not received much attention. Therefore, the aim of this study is to fabricate chopped strand mat/woven roving/foam-Klegecell composite lamination structures with different design configurations, and investigate the behaviour of these composites both experimentally and numerically. It is believed that knowledge on the Charpy impact behaviour of these composites would have an essential role for many structural applications, such as marine boat structures. Laminated panels are fabricated using CSM, WR and foam-PVC Klegecell with a combination of epoxy or polyester resin for reinforcement. In this study, six groups of design configurations are used, Types-A–F. Structural panels of the composite laminates are produced using a hand lay-up technique. Each configuration design is impact tested to failure. Finite element analysis (FEA) is then employed to correlate the experimental values of energy absorption with the simulation results.

Due to the brittle behaviour, which is one of the weaknesses of composite materials, this investigation has been carried out. This disadvantage causes problems for composite structures that experience collision. The expected outcome from this study was to evaluate the behaviour of different lamination structures under various Charpy impact conditions, particularly in terms of load, energy absorption and deflection behaviour with respect to the use of different materials. Hence, it is important to identify resistance to failure of composite materials with different design configurations, especially at sudden applied loads.

2. Theoretical background

2.1. Charpy testing

The Charpy impact test is commonly used to evaluate the impact energy and toughness of materials, and usually used in quality control processes, whereby it is one of the economical tests [18]. Impact energy is defined as the energy that required to fracture a standard test specimen under impact loading. In the Charpy impact test, the energy absorption of the specimen is determined from the change in the height of a pendulum before and after the impact [19]. When the pendulum strikes the specimen, the specimen absorbes the energy until it yields and it begins to undergo plastic deformation. As reported by Nita et al. [18], at that condition, the specimen continues to absorb the energy. Fracture occurs at the point when it can no longer absorb any more energy.

According to Ali et al. [19] the impact velocity of the pendulum when it strikes at the specimen is given by the Eq. (1), respectively.

$$v = \sqrt{2gH_1} \tag{1}$$

where g is the acceleration due to gravity and H is the change of elevation in the centre of the strike. The energy absorbed when the specimen is fractured, which is energy lost by the pendulum is given by, as shown in Eq. (2).

$$U = mg(h_1 - h_3) = mgr(\cos\beta - \cos\alpha) \tag{2}$$

where m is the mass of the pendulum, and h_1 and h_2 are elevations of the mass centre, as shown in Fig. 1.

3. Methodology

3.1. Materials

CSM 450, woven roving WR 300 and foam-Klegecell were used as received from the supplier as reinforcement. The matrix was epoxy resin (ADR 246 TX) cured with Hardener ADH 160 and polyester resin (Polymal VE-P310P) with Methyl Ethyl Ketone Peroxide (MEPOXE) supplied by a local supplier. The hardener was used as a curing agent and to improve the interfacial adhesion and impact strength of the composites. The materials used in this investigation are based on the same material used in a Malaysian-based marine boat [20]. To obtain the optimum matrix composition, a resin and hardener mixture of 5:1 was used. The properties of each material employed in the investigation are shown in Table 1, and a flowchart of the experimental and FEA procedure is shown in Fig. 2.