Drop weight Impact Response of Woven Natural Silk/Epoxy Laminated Composite Plates


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Abstract: Woven natural silk fabric has been commonly used in textile industries for centuries. Irrespective of their mechanical and environmental merits, their utilizations as reinforcement material for composites structures are very rare. Therefore, this work is focused on the use of woven natural silk as a reinforcement material in composites panels. Since a major concern over laminated composite is their being susceptible to internal damage caused by impact loads; the impact response of woven natural silk fabric reinforced epoxy (WNS/Epoxy) were investigated. Composite panel, prepared in configurations of 10, 15, 20, 25 and 30 layers of WNS and tested under a drop weight impact of 32J, 48J and 64J were analyzed. Load bearing capability and damage fragmentations were investigated. An increased load bearing capability was observed with increase in number of WNS ply. Delamination and surface damage area fragmentation also increased with increase in impact load. The SEM showed failure mechanism as a combination of failures.

Key words: Silk fibre composite, Impact damage, Damage fragmentation

INTRODUCTION

The investigation of fibre reinforced composite plates subjected to impact loads has received good attention from researcher around the globe in recent years. One major concern over laminated composite is that they are known to be highly susceptible to internal damage caused by impact loads. The damage incurred may range from matrix cracking, delamination, and lamina splitting and fibre breakage; sometimes to catastrophic failure. Therefore, the dynamic impact response of composite plates should be fully investigated for the understanding of causes and prevention of impact damage. Material properties, impactor mass and velocity; plate and impactor geometry are likely factors that can influence the impact behavior of composite plates Mishra and Naik, (2009). Many research efforts on low velocity impact are aimed at reducing the extent of damage and to improve the integrity and damage tolerance of polymer matrix composite structures. Often times, internal damages are induced on composite structures by light impact while their surface may appear undamaged to visual inspections Peng and Cao, (2000), the presence of these internal damages in composite structures most often lead to a sudden catastrophic failure. In proffering solutions, woven synthetics materials like Kevlar and Carbon fibres were introduced and used (Okenwa and Ainullofti, 2002; Cho and Zhao, 2002; Aslan et al., 2003). The unfriendly nature of carbon materials to our environments led to a number of research works on natural fabric composites as alternative fibre reinforcement materials. Among previous works were Dhakal et al. (2007), they investigated the impact properties of non-woven hemp fibre reinforcement subjected to drop weight impact test and their results compared with chopped strand mat E-glass fibre reinforcement with an equal fibre volume fraction equivalent. The impact test results show that the total energy absorbed by 0.21 fibre volume fraction (four layers) of hemp reinforced specimens is comparable to the energy absorbed by the equivalent fibre volume fraction of chopped strand mat E-glass fibre reinforced unsaturated polyester composite specimens. Sapuan and Maleque, (2005), worked on the design and fabrication of banana woven fabric reinforcement epoxy composite for household telephone stand. Herrera-Franco et al, (1997) illustrated the feasibility of coir (coconut fibre) as reinforcing fibre in different thermosetting and thermoplastics matrices such as phenol–formaldehyde, unsaturated polyester, epoxy, polyethylene and natural rubber. Sapuan et al. (2001) carried out investigation on the mechanical properties of coconut fibre reinforced epoxy laminated composites. The fibres were treated with acetyl enes, peroxide, stearic acid and potassium permanganate. Flexural and tensile properties were the focus point of their experiment. Though, plant fibres are considered eco-friendly, one major
Problem is their hydrophilic nature which often impend their choice in composite structures Cicala et al., (2009). The present studies then introduced Bombyx mori woven natural silk (WNS) as a reinforcement considering its environmental and mechanical properties. It is among the strongest fibres produced in nature, high specific-strength and high specific-stiffness; extremely elastic and resilient. Previous studies (Bledzki A., Gassan J., 1999; Craven et al., 2002; Perez-Rigueiro et al., 2000) showed that bombyx mori silk is better than Kevlar or steel in terms of elongation at failure. It has a good capacity to absorb energy and to dissipate this energy in a very controlled manner as the silk deforms Perez-Rigueiro et al., (2000). Because of these advantages, improved resistance to impact is expected. Besides their advantageous mechanical properties, woven fabrics composites are easy to handle and have excellent formability Dasgupta and Agarwal, (1992). Therefore, understanding the behaviour of woven natural silk fabric in an impact event by studying the formation of damages and analysing the load bearing capability under low-velocity impact will lead to improving their damage-resistance characteristics and enhance their employment in air, sea and land transport industries.

MATERIALS AND METHODS

Three materials were involved in this experiment. The resin used was Epoxy, type (DER 331). A Jointmine hardener, type (905-35) was employed to facilitate curing. Both items were supplied by DkComposites Maleka. The properties of the epoxy as given by the supplies are listed in Table 1. Bombyx mori plain woven natural silk fabric (supplied by Ankasa Indonesia) has been used as the reinforce material. The mechanical properties which are listed in Table 2 were given by the supplies. Plain woven silk was chosen because interlacing of fibre bundles in woven fabrics composites can prevent the growth of damage and hence provides an increase in impact toughness compared with unidirectional composites.

The composite specimens were made by hand-lay – up. This method provided high quality composite samples plates with minimal defects. To create the laminated samples, a layer of epoxy resin was applied before each layer of woven natural silk fabric was placed. Special care was taken to ensure the correct amount of epoxy was used in addition to being evenly spread out. The vacuum bagging was carefully spread over the sample ensuring no wrinkles would form when the vacuum was applied. Any wrinkles that form on the vacuum bagging will affect the surface finish of the sample. A rubber squeeze was used to remove the extra epoxy and trapped air. The mould was closed and the composite plate was left to cure in a hydraulic press at a room temperature and at a pressure of 10bar for 3hr. After being taken out from the hydraulic press, the plate was left to cure at a room temperature for 24h before being removed from the mould. The plate was then cut into the specimen size for a drop weight impact test using a diamond cuter.

<table>
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<th>Table 1: Properties of DER 331 epoxy</th>
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<td>Density</td>
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<td>Compressive strength</td>
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<td>Tensile strength</td>
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<td>Cure time</td>
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<th>Table 2: Properties of bombyx mori plain woven natural silk fabric</th>
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<td>Elongation</td>
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<td>Modulus of elasticity</td>
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<td>Thickness</td>
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<td>Ultimate strength</td>
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Impact Testing:

The tests were performed using an instrumented drop weight testing system, Instron-Dynatup 9250 HV. This system is suitable for a wide variety of applications requiring low to high impact energies. The hemispherical nose tup used was 12.7 mm Diameter. It was assumed to be perfectly rigid. The testing machine has a force transducer with capacity of 22.24 kN. The total mass of the impactor used was 5.5 kg. The composite specimen with dimensions of 100 mm by 100 mm was clamped via a hydro operated clamp on a fixture along a circumference having a 76.2 mm Diameter.

RESULTS AND DISCUSSIONS

Effect of Number of Ply on Maximum Load:

Fig. 1 shows load versus time behaviour of different configurations of WNS layers under impact loads
(a) 32J, (b) 48J and (c) 64J respectively. Each profile represents the average load bearing capability of its configuration, under a designated impact load. Numbers (1 – 5) were used to distinguish between sample specimens.

Fig. 1: Profiles of impact load versus time of woven natural silk fabric composite plates. (a) Impact load of 32J (b) Impact load of 48J (c) Impact load of 64J

The value of maximum load is a function of the damage resistance of a material Razi and Raman, (2000), in other words, more resistant material will have higher value of maximum load/peak. Fig.1a showed a clear peak increase between each configuration of WNS layers as the number of layers increases. The 30 layers specimen showed the highest peak load value of approximately 1.35kN. In Figs. 1b and 1c the profiles trends were similar to that observed in Fig. 1a with 30 layers specimen having the highest peak values of approximately 1.5kN in Fig. 1b and 1.6kN in Fig. 1c respectively. It could be established here that an increase in the number of WNS layers increases the peak load. Since the difference between each specimen was an additional 5 layers of WNS, the rational of increase could not be determined as increase between specimens were not evenly distributed as thought. The first peak point on the maximum load curve corresponding to the radial fracture damage point. This point marks the onset of failure in the material as this initiation of damage induces a decrease in material stiffness, resulting in a drop in the load time profile. This damage is usually matrix failure, with very little or no visible damage observed upon superficial inspection of the specimen Siow and Shim, (1998). In this study, these points were initiated almost at the onset of the profiles and determination of the type of failure at this point was not possible due to the apparatus used.

A second major peak is the load corresponding to circumferential fracture or complete failure Ude, et al., (2010). Figs 1b and 1c, showed that 30 layers specimen reached circumferential fracture point before specimens 20 and 25 layers. A longer curve profile shows the ability to withstand load for a more period of time; this
was observed for 25 layers specimen in Fig. 1b and 1c respectively. It was generally observed as expected, that peak load increases with increase in the number of woven natural silk fabric layers. The rational of increases in all the specimens could not be clearly quantified; inconsistency and defects associated with composite laminate could be a factor.

The Effect of Increased Load on Load Bearing Capability of the Composite Plates:
The effect of increased loads on each composite configuration were examine, the results show that values of peak loads increases with increase in impact load. Fig. 2 showed 30ply configuration increasing from 1.35 to 1.72 (kN) under 32J, 48J and 64J impact load respectively. Other configurations almost maintained a straight line; there was not much difference, thought it increased.

Characteristics of Composite Plates under 32J Impact Load:
Fig. 3a – 3e show the (front & back) surface fragmentation of WNS/epoxy composite plates impacted with 32J impact load. In general, circumferential and radial damages were predominant. 10 layers configuration showed front damage area approximately 157mm², back damage area was 157.0mm² and 80mm horizontal crack. 15layers configuration showed approximately front damage area of 141.4mm², back damage area of 141.4mm² and horizontal 78mm. In the case of 20layers specimen, it showed front damage area of approximately 125mm², back radial damage of 125mm² perforation hole and 10mm crack on one side, 25layers specimen showed approximately front damage area was 94.2mm², back radial and perforation damages were also sustained. 30layers specimen (Fig. 3e), showed 50mm horizontal crack and 30mm vertical crack as front damage and 70mm horizontal and 30mm vertical crack length were measured as back damage. Except for 30layers, all other configurations suffered perforation damage. This implies that thin specimens had more surface damage and thick specimens less surface damage.

Fragmentation Characteristics of Composite Plates under 48J Impact Load:
Fig. 4a – 4e, shows the (front & back) surface fragmentation of WNS/epoxy composite plates impacted with 48J impact load. 10layers specimen showed perforation hole of approximately 10mm, front surface damage area of 94.2mm² and 98mm crack damage. The back surface showed radial and circumferential
damages. 15layers specimen showed 5mm perforated hole with front damage area of 113.6mm$^2$ and 95mm crack. The back of this specimen also suffered a combination of radial and circumferential damages. 20layers specimen showed front damage area of 102.1mm$^2$, 7mm perforation hole. The back of this specimen showed prism shape damage. 25layers specimen showed front surface damage areas of 125.6mm$^2$, the back also showed prism shape fractured damages of the specimen. 30layers specimen showed front damage areas of 106.8mm$^2$, and the back showed prism shape fractured damages. It was observed that the back damages of Fig. 4c, 4d and 4e were similar in shape; thickness of these specimens is believed as the cause. It was also noted that the entire specimen under 48J impact load suffered damages up to perforation, indicating that damage areas increasing in WNS/epoxy composite plate as the impact energy increases. The pattern of damage in the entire configuration was similar with radial and circumferential damage being dominant. The surface area of damages decreased as the thickness of the specimens increased.

![Fig. 4: Specimens under 48J impact loading. (a) 10ply (b) 15ply (c) 20ply (d) 25ply (e) 30ply](image)

Fragmentation Characteristics of Composite Plates under 64J Impact Load. Fig. 5a – 5e show the (front & back) surface fragmentation of WNS/epoxy composite plates impacted with 64J impact load. 10layer specimen the specimen splitting into two and front damage area of approximately 141.4mm$^2$. 15layers showed front damage area of approximately 94.5mm$^2$, 20mm perforation hole and 90mm crack line. 20layers specimen showed perforation hole and surface area damage of approximately 90mm$^2$. The back of this specimen had one side of the prism shape damage open; this may be due to impact force. 25layers specimen showed front surface damage areas of 80mm$^2$ and 30layers specimen showed front surface damage 70.6mm$^2$ respectively, the back damages of these two specimens showed a prism shape. It was observed that the specimens under 64J impact load suffered more damages than the previous two. A comparison of 10layers specimen under the three categories of impact load shown in Fig.6a – 6c, was done to ascertain extent of surface area fragmentation. As expected, the extent of damage increases with increase in impact load.

![Fig. 5: Specimens under 64J impact loading. (a) 10ply (b) 15ply (c) 20ply (d) 25ply (e) 30ply](image)
Fig. 6: Damage formation on 10 layers of WNS/Epoxy under varied loads (a) 32J (b) 48J (c) 64J

**Failure Mechanisms:**
Fig. 7a – 7e shows the SEM micrographs of specimens impacted with 64J impact load. These set was chosen because all incurred notable damages up to perforation. Fig. 7a and 7b, showed matrix cracking, matrix splattering, delaminations, fibre pull-out and fibre breakage. In Fig. 7c and 7d, there were voids, fibre pull-out, matrix cracking and fibre breakage. In Fig. 7e, a combination of matrix cracks, delaminations, fibre breakage and fibre pull-out were seen.

Fig. 7: SEM of the specimens 500X (a) 10ply (b) 15ply (c) 20ply (d) 25ply (e) 30ply

There appears strong evidence from these micrographs that combination of matrix cracking, delamination and fibre breakage were the predominant failure modes. These failure mechanisms agreed with the impact damages reported in (Corum et al., 2003; Rio et al., 2005) for chopped glass fibre composites and Carbon fibre reinforced Epoxy matrix composites. Further inspection of the micrographs shows that their modes of failures were similar irrespective of the number of WNS layer in the composite plate. They all involved a combination of failures. This behaviour seems to be one of the advantages of using woven fabrics other than unwoven fabrics. It was reported by Ude et al. (2007), that low volume of fibre creates vacant spaces, and there is not enough fibres to restrain matrix; causing resin rich areas present which can lead to highly localised strain. Authors like Yoldas, (2009), Mohamed et al. (2010) also reported that as the fibre weight fraction increase, the wettability of fibre with resin decreases and weak interfacial bonding potentially occurs. These short coming reported by these authors, were not true for woven natural silk laminated composites plates as were proved by these micrographs.

**Conclusions:**
An investigation has been conducted to study the impact response of plain woven natural silk (WNS)/Epoxy composite. Parameters used for the study were load bearing capability, resistance, surface damage fragmentation and failure mechanism characteristics. The findings of this research include:

- Woven natural silk (WNS) could be used as a reinforcement fibre in composites.
- Load bearing capability increases as the number of WNS layers increases.
With an increase in the impact energy, there is an increase in peak loads.

The composite material incurred more damages with increase of impact load.

The SEM revealed the combination of matrix cracking, delamination, fibre debonding; fibre pull-out and fibre breakage as the failure mechanism irrespective of the number of layers.

REFERENCES


