Passive Damage Detection of Natural Fibre Reinforced Composites using Sensor Response Data

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Abstract. This paper presents the detection of impact damage in a natural fibre reinforced composite plate under low velocity impact damage. Lead Zirconate Titanate (PZT) sensors were placed at ten different positions on each plate in order to record the response signals. The response signals captured from each sensor were collected for impacts performed by a data acquisition system. The impacted plates were examined with optical microscope to examine the damaged areas. It was found that the damaged size grew proportionally with impact force. The results also revealed that PZT sensors can be used to detect the damage extent with the waveform of sensor signals implying the damage initiation and propagation which detected above the damage force of 150N.

Introduction

In recent years, natural fibres gained a considerable attention due to their properties such as renewability, low density, high specific strength, non-abrasivity, lightweight, non-toxicity, low cost and biodegradability. Natural fibres are increasingly being considered as an environmentally friendly substitute for synthetic fibres in the reinforcement of polymeric based composites. The use of these fibres instead of glass and carbon is, for example, under consideration in the transportation industry [1-2]. However, Natural Fibre Composites (NFC) tend to fail by most common types of damages in fibre composites such as delamination, matrix cracking, fibre breakage, fibre pull out and fibre–matrix debonding. Among the various types of damage, delaminations are probably the most frequently occurring damage [3]. Delaminations are caused due to imperfect bonding, crack in matrix materials, separation of adjoining plies, broken fibres, impact loads or fatigue loading of the structure. The presence of this sort of damage can severely degrade the mechanical properties of composite structures, and if it is not detected in the incipient stage, it may result in a tragic failure of the structure. So, understanding the introduction of impact damage and its evolution in NFC materials is of great importance and is a major challenge to designers and end-users of advanced composite structures.

Therefore, numerous experiments have been developed to better understand the mechanisms and mechanics of impact damage in composite laminates [4–8]. Several techniques for monitoring the impact response of composite structure with sensors were proposed by many researchers. Naidu and Tseng [9], performed tests on PZT transducers with changes in damage location, damage extent and damage size on simple specimens of aluminium. It was found that the damage index with respect to the pristine state signatures can detect the increase in damage extent. In the other hand, the upward and downward trend lines of the relative state RMSD index serve as an indicator to distinguish approaching or receding damage sequences. It can reveal whether the damage growth approaches or recedes from the transducer which can be understood by the fact that the energy dissipation of the elastic waves generated by the PZT with the increase of the number of holes is higher. Another researcher Kim et al. [6] used polyvinylidene fluoride (PVDF) and lead zirconate titanate (PZT) sensors to predict damage in laminated panels made of Graphite/Epoxy (Gr/Ep) unidirectional prepreg. It was found that both types of piezoelectric sensors were very sensitive to the vibrations and stress wave generated by low velocity impact events. It shows the
possibility of correlating the extent of impact damage, failure mode with sensor signal. The work also seeks to characterize the impact based on the response data from permanently installed piezoelectric sensors. Bhalla et al. [10] investigated a wave propagation-based technique to detect and localize damages in structures and machines. It utilizes commercially available low-cost PZT patches as transmitters and receivers of elastic waves through the monitored component. The results have demonstrated a higher sensitivity for damage detection as well as simplicity of application as compared to the conventional NDE methods.

Another experimental investigation using piezoelectric sensor was carried by Lestari et al. [11]. The study was conducted by using carbon/epoxy laminated composite beams and the curvature mode shapes are measured by using surface-bonded piezoelectric sensors. Several different types of damages are introduced in the beams which is delamination, impact and saw-cut damages to simulate possible damage scenarios. It was concluded that delamination with larger size caused more stiffness loss than the smaller one. While for the saw-cut damage caused the largest stiffness loss about 22.5% as compared to impact damage. Overall, the various damages in laminated composite beams can be identified by the curvature mode shape methods. On the other hand, Naidu and Soh [12], demonstrated the application of the electromechanical (EM) impedance using smart piezoelectric transducers at aluminium beams. Two aluminium beams of the same dimensions were surface bonded with two pairs of piezo transducers each and damages were induced by drilling 5 mm diameter holes. It was observed that damage quantification indices obtained from the EM admittance signatures can characterize localized increase in damage severity and damage propagation.

The objective of this paper is to investigate the damage severity using only response data from the PZT sensors since very limited findings have been reported available for information and data dealing with the impact damage for natural fiber reinforced composite (NFC).

Methodology

Sample Preparation

The selected raw material of the fibre for this research was kenaf short fibre and the matrix was selected from epoxy resin group. The dimensions of the kenaf fibre composite boards were 300mm (L) ×300mm (W) and 3mm thickness. The composites with fibre loading 10% of volume fraction were fabricated using compression technique. The internal surfaces of the mould were sprayed by a release agent (Silicon), in order to facilitate easy removal from mould. Initially, epoxy resin and hardener were mixed with ratio 2:1 to form a matrix. Then the short kenaf fibres and matrix was mixed together using a mixer for 10-20 minute to disperse the fibres in the matrix. After that, the mixture was poured into the mould and the mould was closed before manual compression took place and it was left about 24 hours for curing at room temperature. Care was taken to evenly distribute the fibres in the mould to ensure a uniform sample since natural fibres have a tendency to clump and tangle together when mixed. Lastly the sample was taken out of the mould and post-cured in the air for another 24 h.

Experimental set up

An impact hammer, as used for modal testing, was applied to produce impacts on the natural fibre composite plate. The experiments were conducted on a laboratory, where the plate was positioned on foam without any mechanical constraints. PZT sensors were chosen for detecting the impact, ten for each plate. The diameter and thickness of each sensor was equal to 6.5 and 0.25 mm, respectively. The sensors were placed at ten different positions on each plate in order to sample responses at different distances from the impact as shown in Fig. 1. The DEWEsoft oscilloscope was used to capture and display all strain data from the impact events with a sampling frequency of 5 kHz.
Results and Discussion

A series of low-velocities, low-energy impacts were performed at different force for 40 plate as illustrated in Fig. 2. The resulting strain waves of 2s were acquired by sensors S1 until S10. The impact strain data were acquired using the DEWEsoft oscilloscope. The sampling frequency used was equal to 5 kHz. The strain data were stored on a PC’s hard disc for further analysis. The PZT sensor signals for sensor 1 until 10 are recorded during impact and their filtered signals for sensor 1 are plotted in Fig. 3 as an example. PZT sensor signals show higher frequency signal components relevant to impact damage. When damaging impacts occur, the various fracture events generate high frequency waves. Fig.3(d) shows the peak strain magnitude for damaging impacts is much larger compared with the others and the profile shows more structure as the damage propagates, which is clearly shown that damage occur in the sample. The results agreed well with the result from previous researcher [13].
Fig. 3: Examples of filtered strain wave for (a) 50 N (b) 100N (c) 200N (d) 250N captured by S1
To gather the appropriate data regarding the extent of the damage, two different methods were used to estimate the damage area which is used the naked eye and considered only visible surface damage. The damage area was assumed to be in length and measured with vernier calliper. The second method used optical microscope which is the damage area was measured as a length of damage. An example of images used for extraction of these estimates damage area is shown in Fig. 4. Since the sample was NFC, so the area of the damage will be classified in term of ‘length’. Table 1 summaries the estimated value of the damage area for impact force 100N, 125N, 150N, 175N, 200N, 225N and 250N. Generally, the results indicate that the higher of impact force the larger of the damage area. However, for impact force below than 150N, no damage was detected due to the low energy impacts did not allow sufficient entry to penetrant into the sample. From Table 1, it can be concluded that the damage area estimated from the test plate and microscope produced approximately linear correlation between the impact force and damage area. Fig. 5 clearly illustrated the behavior of visible damage estimates, which show the same trend for plate 1, plate 2, plate 3 and plate 4.

![Region of visible surface damage on the sample](image1)

![Region of images on optical microscope](image2)

Table 1. Estimated values of damage area in the plate

<table>
<thead>
<tr>
<th>Impact Force (N)</th>
<th>Damage area(mm) measured directly from test plate</th>
<th>Damage area (µm) measured from microscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>No Damage</td>
<td>No Damage</td>
</tr>
<tr>
<td>125</td>
<td>No Damage</td>
<td>Dented</td>
</tr>
<tr>
<td>150</td>
<td>1.2</td>
<td>560.2</td>
</tr>
<tr>
<td>175</td>
<td>2.0</td>
<td>1221.56</td>
</tr>
<tr>
<td>200</td>
<td>5.0</td>
<td>3481.50</td>
</tr>
<tr>
<td>225</td>
<td>5.4</td>
<td>4925.10</td>
</tr>
<tr>
<td>250</td>
<td>6.2</td>
<td>5870.34</td>
</tr>
</tbody>
</table>
Fig. 5: Linear correlation between (visible surface) damage area and impact force

Conclusion

This paper presents an experimental methodology aimed at the identification of damage size of sudden impacts on NFC plates using PZT sensor. The impact was generated by an instrumented hammer and response data was collected at a set of sensor locations. It was found that PZT sensor attached at the specimen can provide the information regarding the characteristic of the wave, time of arrival, force, maximum amplitude and minimum amplitude. The experimental results demonstrated that the damage extent appeared above 150N started with a small delamination. Then the damage size increase with the increasing of force. Overall the results indicate the effectiveness of using the sensor for the impact applications, as the PZT could measure strain with good accuracy. Further work is needed to classify the correlation of signal processing with the impact damage since the PZT can provide enough information to allow the development of diagnostics for impact damage extent. Also it can be established the application of neural network techniques on this particular diagnostics especially in NFC.

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References


