EFFECT OF PAN NANOFIBER INTERLEAVING ON IMPACT DAMAGE RESISTANCE OF GFRP LAMINATES

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Abstract:
Eight-ply composite laminates of plain and interleaved Glass/Epoxy laminates clamped according to ASTM D7136 were impact tested to assess the improvement in impact resistance of composite laminates that have been interleaved by electrospun PAN nanofiber. Composite specimens with stacking sequence [0/90/0/0]s were impacted at two different impact energies: 3 J and 5J. Variation of the impact characteristics such as maximum contact load, maximum deflection, maximum contact time, absorbed energy, damage area are depicted in figures. The results showed that PAN nanofiber is not a good choice for toughening epoxy and improving impact damage resistance of GFRP.

Keywords: Composite materials, Nanofibers, Interleaving, Impact damage.

1. INTRODUCTION:

Compared with more traditional materials such as metals, ceramics, and polymers, fiber reinforced composites have several specific features such as high stiffness and strength to weight ratio, excellent corrosion resistance, and ability in providing both mechanical as well as functional properties. The most common failure mode of this high performance laminated material is delamination as a consequence of low velocity impact, and/or cyclic loading during manufacturing or service life. Insufficient fracture toughness and delamination existence has been the main issue affecting the long-term reliability of thermosetting matrix composites. A number of methods to prevent delamination were developed and evaluated over the years. These include matrix-toughening [1,2], use of braided fabric [3], edge cap reinforcement [4], through-thickness stitching [5,6], and etc. Ductile interleaving seems to be one of recommended methods, in which interleaf layers of toughened materials were inserted into middle plies of the composites. Generally, thermoplastic particles and films have been used as common toughened layers [7,8]. However, difficult preparation of particles due to high toughness of thermoplastic and high thickness of films due to high viscosity of thermoplastic have limited their uses in industry. Recently, nanofibers reinforcing was known as a more useful technique instead of particles or films reinforcing to enhance the mechanical properties of composite because of very small diameter.

Dzenis et al. [9] firstly reported the use of nanofibers to rein-force carbon fiber composite laminate, and they found that entangled nanofibers showed improvement in the interlaminar fracture resistance. Akangah et al. [10] assessed the improvement in impact resistance of composite laminates that have been interleaved by electrospun Nylon-66 nanofabric. Their results showed polymer nanofabric interleaving increased the threshold impact force by about 60%, reduced the rate of impact damage growth rate to one-half with impact height and reduced impact damage growth rate from 0.115 to 0.105 mm²/N with impact force. Li et al. [11] compared the mode I fracture toughness (GIC) of two different toughened carbon/epoxy: 1- toughened by polysulfone (PSF) nanofibers 2- toughened by PSF films. Mode I fracture toughness of the nanofibers toughened composite was 140% and 280% higher than those of PSF films toughened and untoughened composite due to the uniform distribution of polysulfone spheres. So far, most researches has been concentrated on the effect of interleaved nanofibers on mode I and mode II fracture toughness and there is a very limited work regarding the response of these materials under impact loading. In this study, nanofibers produced by polyacrylonitrile (PAN) are inserted between GFRP layers and impact tests are conducted to evaluate the effect of the nanofibrous mats to the laminate impact response in terms of energy absorbing capability, maximum load and rebound velocity.
2. EXPERIMENTAL PROCESS:

2.1. Electrospinning method:
Electrospinning is a process that utilizes electrostatic force to spin fibers from a polymeric solution. PAN powder were dissolved in dimethylformamide (DMF) and the resulting solution transferred to a syringe fitted with a fine needle. The needle was maintained at a positive potential of tens of kilovolts and the collector was grounded. By increasing the electric potential between needle and collector, a critical stage was reached when the surface tension of the solution was overcome by the applied electrostatic field, thereby ejecting tiny jets of the solution from the syringe tip. The discharged jet undergoes a whipping action that further elongates the polymer, and the repulsive electrostatic field splits the jet into fine submicron fibers that were collected on a grounded metal collector or drum. The polymer fiber diameter and its alignment depends on the type and concentration of polymer in the solution, applied voltage, flow rate, needle diameter, distance between needle and collector drum, and the type of collector. A schematic picture of electrospinning process is illustrated in Fig. 1 and the SEM image of electrospun fabric is shown in Fig. 2. The fibers diameter ranged from 200 to 400 nm and lengths of several centimetres. The electrospinning parameters used were: 7.5% w/V PAN concentration, 21 kV applied voltage, 20 cm distance between needle and collector, flow rate 0.02 ml/min per nozzle, and 180 min spinning duration. By conducting this process with these parameters the thickness of obtained mats is 42 ± 8 μm.

![Fig. 1. Electrospinning process (schematic) [10]](image1)

![Fig. 2. SEM of electrospun PAN fibers.](image2)

2.2. Sample preparation:
Glass fiber/epoxy prepreg was kindly supplied by Metal T.I.G. Company. 8 laminates of [0/90/0/90]s stacking sequence was used for fabricating impact test panels. Interleaved panels were made by placing one layer of polymer nanofabric in between two consecutive prepregs except between middle layers where two 90°-layers are on each other. These panels were made in autoclave as per guidance provided by the prepreg supplier. The cured panels were cut into rectangular specimens 150mm in length and 100mm in width and the thickness of the baseline and interleaved laminates are about 45 mm.
2.3. Impact Tests:
Low velocity impact tests were conducted in a drop-weight machine, shown in Fig. 3, equipped with a laser device for determining the position of impactor, a piezoelectric load cell on the tip of the impactor for measuring the contact force during impact. The impactor was a steel spherical ball having a diameter of 12.7 mm. Although, this setup has the potential to cause repeated strikes, but multiple collisions were avoided by means of an electromagnetic braking system. The overall impactor mass was 1.22 kg; two drop heights of 25 and 41 cm were chosen, corresponding to a nominal potential energy of 3 and 5 J, respectively. Two tests were performed at each drop height for every specimen type: 1-interleaved specimen 2- plain specimen. The specimen was placed on a rectangular steel base with a 125 by 75 mm rectangular opening, being correctly positioned thanks to three pins and held by four lever clamps with rubber tip. Images of some damaged specimens are illustrated in Fig.4.

Fig. 3. Drop weight machine

Fig. 4. Images of some damaged specimens for: A) interleaved specimen (H=0.41) B) interleaved specimen (H=0.25) C) Plain specimen (H=0.41) D) Plain specimen (H=0.25).

3. Results and discussion:
In this section the effect PAN nanofiber interleaved between GFRP layers on the impact characteristics, such as peak load ($P_{\text{max}}$), contact duration ($t_0$), maximum deflection ($X_{\text{max}}$), damage area and absorbed energy are examined against the corresponding impact energies (3J and 5J). The maximum load is the maximum contact force between the impactor and the composite in an impact event. The contact duration is the total contact time between the impactor and the composite specimen in a non-perforated case or up to the perforation instant in a perforated case. The maximum deflection is defined as the largest distance between the top surface of the composite specimen that has deflected and its initial position. The absorbed energy is the energy absorbed by the composite specimen in consequence of the formation of damage and the friction between impactor and specimens. These characteristics are important for understanding the impact response of composites. Fig. 5 represent impact force versus time and displacement for plain and
interleaved GFRP test specimens for the two impact energies shown in the figures. As shown the rising part of the curves are not smooth that because of initiation and growth of damage.

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A glance on figures the show that interleaved PAN nanofiber does not affect on the curves. The details of impact response of GFRP laminates for both of 3J and 5J impact energy are presented in Table 1. This information also confirms that Pan nanofiber is not a good choice for toughening glass/epoxy laminates. This result expand researches conducted by Zhang et al. [12]. In this study, PAN nanofibers were employed to toughen carbon/epoxy composites for considering its effect on mode I interlaminar fracture toughness. Their results proved that PAN cannot improve this parameter. Therefore in this study, we decide to investigate PAN nanofiber effect under impact loading.

**Fig. 5.** Impact response of plain and interleaved GFRP laminates (5J-impact energy)

Tab. 1. Impact parameters for plain and interleaved specimens.

<table>
<thead>
<tr>
<th></th>
<th>H  (m)</th>
<th>t  (mm)</th>
<th>Absorbed Energy (J)</th>
<th>P&lt;sub&gt;max&lt;/sub&gt; (kN)</th>
<th>X&lt;sub&gt;max&lt;/sub&gt; (mm)</th>
<th>t&lt;sub&gt;0&lt;/sub&gt; (ms)</th>
<th>Damage Area (mm&lt;sup&gt;2&lt;/sup&gt;)</th>
</tr>
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<tbody>
<tr>
<td>Plain specimen (1)</td>
<td>0.25</td>
<td>2.52</td>
<td>0.6</td>
<td>1.54</td>
<td>3.88</td>
<td>5.49</td>
<td>34.3</td>
</tr>
<tr>
<td>Interleaved specimen (1)</td>
<td>0.25</td>
<td>2.46</td>
<td>0.56</td>
<td>1.53</td>
<td>3.95</td>
<td>5.74</td>
<td>33.7</td>
</tr>
<tr>
<td>Plain specimen (2)</td>
<td>0.41</td>
<td>2.48</td>
<td>1.07</td>
<td>1.955</td>
<td>4.68</td>
<td>5.53</td>
<td>59.9</td>
</tr>
<tr>
<td>Interleaved specimen (2)</td>
<td>0.41</td>
<td>2.51</td>
<td>1.1</td>
<td>1.965</td>
<td>4.79</td>
<td>5.55</td>
<td>59.2</td>
</tr>
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</table>
4. **CONCLUSION:**
Plain and PAN-interleaved GFRP laminates were tested under impact loading for considering the effect of PAN nanofibers on impact response such as damage resistance, maximum force, absorbed energy, and etc. Considerations showed this electrospun nanofiber are not capable for improving weaknesses of composite materials under impact loading.

**LITERATURE:**


