FLEXURAL PROPERTIES OF WOVEN E-GLASS/POLYESTER NANO SILICA COMPOSITES

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ABSTRACT

The aim of this study was to understand the flexural properties of the multistitched/nano composites. The addition of nano silica to the stitched structures improved their damage resistance slightly. The failure of multistitched/nano woven E-glass/polyester composite structures was matrix breakages, and partial and complete filaments and yarn (tow) breakages in their surfaces. They had a local delamination in their cross-sections and the delamination did not propagate to the large areas due to multiple stitching. This was considered that the damage tolerance performance of the multistitched structures was enhanced due to four directional stitching.

Key Words: Multistitched woven preform, stitched composite structure, flexural strength, flexural failure, nano composite.

1. INTRODUCTION

Textile structural composites have been used in various industrial, ballistic and medical areas due to their high stiffness to weight ratio, delamination free and damage tolerance properties. The uniform distribution of stitching yarns in the woven composite resulted the decreasing the resin rich region and fiber damage and they eventually increased in-plane tensile and impact strengths [1]. Contrarily, it was reported that the three-point flexural strength of two directional stitched E-glass/vinyl ester composite structure was reduced by stitching and stitched induced stress concentration sites [2]. The 2D woven nano clay composite showed not only to better stiffness but also to an increase of impact resistance and fracture toughness [3]. The amine functionalized single wall carbon nano tubes (a-SWCNTs) incorporated at the fiber/fabric–matrix interfaces of a 2D woven carbon/epoxy composite showed improvement in the tensile strength and stiffness and resistance to tensile–tensile fatigue damage [4]. It was claimed that the pre-dispersed over coating nanotubes and the processing modification led to enhancement of the interface properties of 2D woven E-glass/vinyl ester composites partly due to Z directional reinforcements [5]. The objective of this study was to develop two dimensional multistitched/nano E-glass/polyester structures and to experimentally understand the flexural properties of those structures.

2. EXPERIMENTAL

2.1. 2D Unstitched and Multistitched Multilayer Woven E-Glass/Polyester Preform and Composite

E-glass woven fabric (Cam Elyaf A.S., Turkey) was used to make unstitched and multistitched multilayer woven structures. The E-glass yarn linear density was 2400 tex and the warp and weft directional fabric densities were 16 and 18 per 10 cm, respectively. The fabric unit areal weight was 800 g/m² and its thickness was 1.01 mm. Some of the important properties of nano materials were that silica (SiO₂) (nano sphere, Sigma-Aldrich, Germany)
density was 2.2-2.6 g/cm³ and its measured particle size was 30.80±8.6 nm. Carbon (C) (nano sphere, Sigma-Aldrich, Germany) density was 2.1-2.3 g/cm³ and its measured particle size was 40.71±7.4 nm. Five types of E-glass preform structures were mainly developed: unstitched (FBAL, DI45 and DO45), unstitched/nano (FNSL, FNSM, FNSH and FNCM) and stitched/nano (FMNS). The developed unstitched performs included a layered fabric [(0°/90°)]₄ (FBAL) and oriented layered fabrics as [0/90/±45/±45/0/90] (DI45), and [±45/0/90/0/90/±45] (DO45). The stitched/nano structure was a layered fabric [(0°/90°)]₄ four-directionally stitched in the warp (0°), weft (90°) and ±bias directions (FMNS). The stitching yarn used was Kevlar® 129. Vacuum assisted resin transfer molding (VARTM) was used to make composite which is an easy and cost effective technique to consolidate performs. Dicyclopentadiene based unsaturated polyester resin (Crystic 703PA, Scott Bader, UK) was used. Methyl ethyl ketone peroxide (MEKP) was used as hardener, 2% by weight of resin to produce neat E-glass/polyester composites. The polyester resin and hardener were mixed homogenously and applied to the preforms. However, catalyst (Cobalt Naftalat-CoNAP) was also used to produce nano composite structures. Amounts of MEKP and CoNAP by weight of resin and mixing conditions are given in Table 1. Nano materials were mixed first by a mechanical stirrer (IKA-T25 Digital Ultra Turrax, IKA® Werke GmbH & Co. KG) in which mixing was gradually carried out starting from 3000 rpm to 20000 rpm, stay 2 min, then from 20000 rpm to 3000 rpm. Later on, mixing was continued in ultrasonic bath, 5 min at 25°C, to get homogeneous distribution of nano particles in polyester resin. After that, matrix was vacuumed to get rid of the air bubble, and finally hardener and catalyst were added. This matrix was applied to the preforms under vacuum at 20°C. The density of the 2D unstitched and multistitched multilayer woven E-glass/polyester composite was determined by ASTM D792-91. The composite volume fraction and void content were also determined by ASTM D3171-99 and ASTM D2734-91, respectively.

**Table 1.** Mixing conditions of nano materials in polyester resin for VARTM.

<table>
<thead>
<tr>
<th>Nano materials</th>
<th>Amount of nano materials (% wt.)</th>
<th>Hardener (MEKP) (%)</th>
<th>Catalyzer (CoNAP) (%)</th>
<th>Mixing conditions</th>
<th>Gelling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica (SiO₂) (nano sphere)</td>
<td>%2.5</td>
<td>%5</td>
<td>%0.3</td>
<td>2 min. 20,000 rpm</td>
<td>40 min.</td>
</tr>
<tr>
<td></td>
<td>%7.5</td>
<td></td>
<td></td>
<td>5 min. 25°C</td>
<td>60 min.</td>
</tr>
<tr>
<td>Carbon (C) (nano sphere)</td>
<td>%5</td>
<td>%4</td>
<td>%0.3</td>
<td>2 min. 20,000 rpm</td>
<td>40 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 min. 25°C</td>
<td>90 min.</td>
</tr>
</tbody>
</table>

2.2. Flexural Test

The three point bending test of the composite structures was performed on a Shimadzu AG-XD 50 (Japan) tester equipped with Trapezium® software based on ASTM D790-90.

3. RESULTS AND DISCUSSIONS

3.1. Density and Fiber Volume Fraction Results

The density and fiber volume fraction results of 2D unstitched, unstitched/nano and multistitched/nano multilayer woven E-glass/polyester composites varied from 1.806-2.017
g/cm³ and from 79.829%(62.668%) - 74.162%(56.232%). The density and total fiber volume fraction results indicated that partly stitching and partly VARTM process caused a local misalignment and uneven fiber-matrix-nano placement in the structure. The stitching caused a local misalignment and uneven fiber placement during needle piercing to the preform structure.

### 3.2. Flexural Results

Figures 1-3 show the flexural strength, modulus and strain of 2D woven E-glass/polyester unstitched, unstitched/nano and multistitched/nano composite structures, respectively. It was found that the specific flexural strengths of all unstitched, unstitched/nano and multistitched/nano structures were proportional to their warp and weft directional flexural strengths. The warp and weft directional specific flexural strengths of unstitched structures (FBAL, DI45, DO45) were higher than those of the multistitched/nano structures (FMNS) due to stitching caused filament breakages. When the nano silica material in the unstitched E-glass/polyester composite structure increased from 2.5 wt. % to 7.5 wt. %, the warp and weft directional specific flexural strengths of the unstitched structures increased. In addition, the warp and weft directional specific flexural strengths of unstitched/nano (FNSL, FNSM, FNSH, FNCM) composite structures were higher than those of the unstitched structures. Generally, the warp directional specific flexural strength of the composite structures was higher than that of the weft.

![Figure 1. Flexural strength and specific flexural strength of composite structures.](image)

The warp and weft directional specific flexural modulus of unstitched structures were higher than those of the multistitched/nano structures due to stitching caused filament breakages. When the nano silica material in the unstitched E-glass/polyester composite structure increased from 2.5 wt. % to 7.5 wt. %, the warp and weft directional specific flexural modulus of the unstitched structures increased. In addition, the warp and weft directional specific flexural modulus of unstitched/nano composite structures were higher than those of the unstitched structures. Generally, the warp directional specific flexural modulus of the composite structures was higher than that of the weft.
The warp and weft directional specific flexural strains of unstitched structures were higher than those of the multistitched/nano structures, except weft directional strain of FBAL, due to stitching. When the nano silica material in the unstitched E-glass/polyester composite structure increased from 2.5 wt. % to 7.5 wt. %, the warp and weft directional specific flexural strains of the unstitched structures slightly decreased. In addition, the warp directional specific flexural strains of unstitched/nano composite structures were lower than those of the unstitched structures.

3.3. Failure Results after Flexural Test

Figure 4 shows the damaged areas and the specific damaged areas of 2D woven E-glass/polyester unstitched, unstitched/nano and multistitched/nano composite structures after warp and weft directional flexural load was applied. Figure 5 shows the front face and the cross sectional views of unstitched and unstitched/nano 2D E-glass/polyester woven composites after warp directional flexural load was applied.
It was found that the warp and weft directional specific damaged areas of unstitched structures were lower than those of the unstitched/nano structures but, higher than those of the stitched/nano structures. The warp and weft directional specific damaged areas of FNCM structure were very low compared to the FNSH due to nano carbon material.

As seen in Figure 5, the failure of warp directional 2D unstitched and unstitched/nano woven E-glass/polyester composite structures was observed as a form of matrix breakages, and partial or total fiber breakages in their front and back surfaces. In addition, the unstitched and unstitched/nano structure composites had delamination in their cross-sections. The failure of warp directional 2D unstitched/nano woven E-glass/polyester composite structures showed more brittle behavior compared to the unstitched structures. When the nano silica material in the unstitched E-glass/polyester composite structure increased, the damaged areas of the unstitched/nano structures were also increased. The failure of stitched/nano (FMNS) woven E-glass/polyester composite structure was observed as a form of matrix breakages, and partial and complete filaments and yarn (tow) breakages in their surfaces. In addition, the FMNS structure had a local delamination in their cross-sections and the delamination did not propagate to the large areas due to multiple stitching. The warp or weft directional flexural load was confined at a narrow area in which the catastrophic failure lead to the damage as a form of matrix breakages, fiber-matrix pull-out and local multiple fiber breakages.
addition, the damaged area of the stitched/nano structures was lower than those of unstitched and unstitched/nano structures due to multiple stitching. On the other hand, it was observed that the failure of 2D machine stitched/nano woven E-glass/polyester composite structures showed more brittle behavior. It could be considered that the multistitched/nano structures showed a damage tolerance behavior under the static flexural load.

4. CONCLUSIONS

The warp and weft directional specific flexural strengths and modulus of unstitched/nano composite structures were higher than those of the unstitched structures. When the nano silica material in the unstitched E-glass/polyester composite structure increased, the warp and weft directional specific flexural strength and the modulus of the unstitched/nano structures increased. In addition, the warp and weft directional specific flexural strengths and modulus of unstitched structures were higher than those of the multistitched/nano structures due to stitching caused minor filament breakages. The warp and weft directional specific damaged areas of unstitched structures were lower than those of the unstitched/nano structures but, higher than that of the stitched/nano structure. It could be concluded that the addition of nano silica in the stitched structures improved their damage resistance slightly. This was considered that the damage tolerance performances of the multistitched/nano structures were enhanced due to stitching.

5. REFERENCES