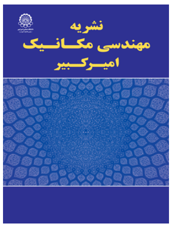

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The Effect of Graphene Nanoparticles on the Strength of the Sandwich Panel Structure Inspired by the Dragonfly Wing Vein Microstructure under Quasi-Static Loading

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ABSTRACT: Dragonfly wings are a fascinating composite microstructure and highly specialized flight organs well adapted for dragonfly flight behavior. This paper aims to investigate the effect of graphene nanoparticles on the strength of a sandwich structure inspired by the microstructure configuration of a dragonfly wing under quasi-static loading. Sandwich vein structures are made of glass/epoxy layers with different percentages of graphene nanoparticles. Polyurethane foam was used in the central core of the vein. After the quasi-static test, the crashworthiness characteristics of these structures were discussed. On the other hand, the effect of polyurethane foam on the amount of damage to the sandwich structure due to quasi-static force was investigated. Pictures of the damaged surface and the cut view of the damage were taken to check the damage in the manufactured samples, and the results were reported. Finally, Field Emission Scanning Electron Microscopes analysis was used to evaluate the distribution of graphene nanoparticles in the samples. The results showed that the presence of graphene nanoparticles in the resin of this type of sandwich structure with a foam core if it is less than one value, will not have much effect on the strength of the structure. On the other hand, if the graphene nanoparticles exceed a certain amount, it shows relatively good resistance.

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Polyurethane foam core.

1- Introduction

Among the different types of insects, dragonflies have an excellent wing structure with high stability. They have attracted the attention of physicists and biology experts for a long-time regarding flight movement and mechanical performance. The dragonfly wing has a complex microstructure, mainly composed of a thin skin-like membrane and longitudinal veins [1]. The wing longitudinal vein has a sandwich structural model with two chitin shells and an intermediate protein layer, which was first reported by Wang et al. [2]. This issue can significantly help us design new structural materials with a high strength-to-weight ratio. Sandwich panels with a foam core are a group of solid composite materials with a low-density core, which are widely used in marine, military, aerospace, etc. they take. Composite and nano-composite sandwich structures with a foam core, under quasi-static loading, can show several damage modes, including fiber breakage, matrix cracking, matrix crushing, and delamination. Graphene Nanoparticles (GNs) have remarkable mechanical and physical properties and are potentially ideal materials for reinforcing polymers.

In the present study, the effect of graphene nanoparticles on the strength of a new composite sandwich panel structure as a design inspired by the dragonfly wing microstructure, which consists of a polyurethane foam core, is investigated under quasi-static loading. The suggested structure with a wingtip comprises of E-glass/epoxy laminated unidirectional composite shells attached to a polyurethane foam core and filled with 0.1, 0.3, and 0.5% graphene nanoparticles mixed in epoxy resin, respectively. As a result of quasi-static loading, each sample's force-displacement and total energy absorption diagrams were reported, and the comparison between the results in the force-displacement response and their crashworthiness characteristics, including crushing force efficiency and energy absorption ability, was also investigated.

2- Experimental Work

Composite layers were made of 300 g/cm3 unidirectional glass fibers, epoxy resin (EPR1080), and hardener (EPH 1080). GP7 graphene nanoparticles with different weight percentages were added to the desired epoxy resin. To inject polyurethane foam by combining two substances, polyol, and isocyanate, with a specific weight percentage, polyurethane foam with a density of 50 kg/m3 was obtained. Single-direction glass continuous raw fibers were placed inside the mold with an angular arrangement [0/90/0/90], and fiber compression was done using the Vacuum Injection Method (VIP). The built composite model is shown in Fig. 1.

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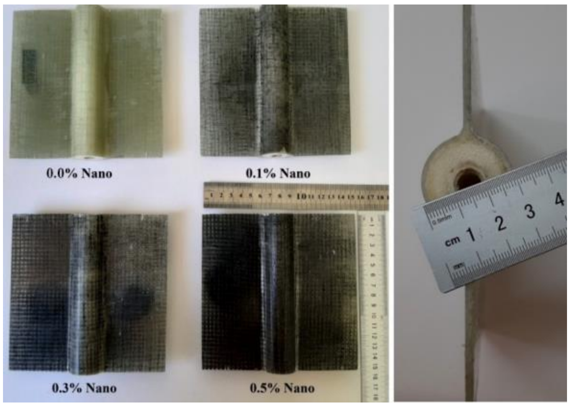


Fig. 1. Made samples of sandwich panels.

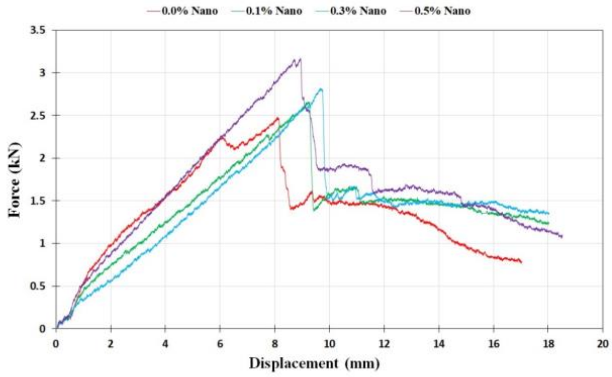


Fig. 2. Comparison of force-displacement graphs of sandwich structures with different percentages of nanoparticles.

3- Quasi-Static Test

The sandwich panel sample was placed between two fixture plates and fixed with eight screws to create completely clamped boundary conditions in the sample. The loading speed was fixed at 2 mm/min for the quasi-static test in all four samples. The indenter geometric model used in this experiment is a hemispherical impactor penetrating the sandwich veins.

Eq. (1) is used to calculate crashworthiness characteristics [3, 4].

$$EA = \int_{S_i}^{S_f} F(x)dx \tag{1}$$

EA is the total energy absorption (area under the force–displacement between break distance curve). S_i and S_f are the compression's initial and final displacement values, respectively. Specific Energy Absorption (SEA) is one of the most important parameters for evaluating energy absorption capacity and is shown in the following formula.

$$SEA = \frac{EA}{W_m} \tag{2}$$

4- Results and Discussion

4- 1- . Force-displacement response

Fig. 2 shows the comparison of overall force-displacement diagrams for sandwich strands with different percentages of graphene nanoparticles. Force-displacement diagram of the composite target with 0.0% of nanoparticles, due to the lack of use of graphene nanoparticles in its resin, it has less resistance and elastic yield than composite targets with different percentages of nanoparticles. On the other hand, the sandwich vein structure with 0.5% of graphene nanoparticles has the highest resistance. In the last part of the penetration process, the power loss has increased due to the non-use of graphene nanoparticles in the composite tube made for the first-mentioned purpose (0.0% nano vein structure).

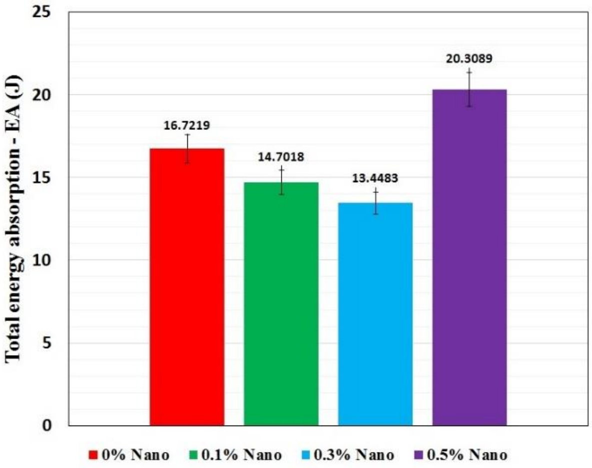
4- 2- Energy absorption capability

The total absorbed energy is the area under the force-displacement curve shown in Fig. 3a. The highest energy absorption capacity is related to the vein structure with a ratio of 0.5% of graphene nanoparticles. In addition, all the sandwich structures had a higher specific energy absorption than the streak structure with 0.3% nano. The results of specific energy absorption are shown in Fig. 3b, which provides better information for understanding energy absorption. Sandwich panels with zero percent, 0.1, 0.3, and 0.5% of graphene nanoparticles have specific energy absorption values of 0.136, 0.117, 0.114, and 0.170 J, respectively. The streak structure with 0.5% graphene nanoparticles has the highest specific energy absorption, and the streak structure with 0.3% graphene nanoparticles has the lowest specific energy absorption.

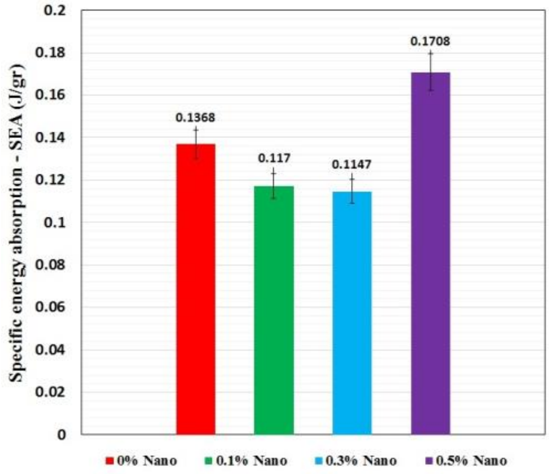
5- Conclusions

The important results of this research are summarized as follows:

- The existence of a sandwich vein structure with polyurethane foam core due to quasi-static forces can limit the spread of damage and leave the rest of the structure intact.
- When the amount of graphene nanoparticles increased beyond a specific limit, this structure showed remarkable resistance.
- For the sandwich vein structure with 0.5% nanoparticles due to its good resistance, the value of the initial peak force increased, and the sandwich structure with 0% nanoparticles had the lowest value of the initial peak force.



(a)



(b)

Fig. 3. (a) total absorption energy, (b) absorption specific energy.

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