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On the Behavior of Carbon and Kevlar Fibers in Cylindrical Composites Subjected to Low-velocity Impact: Experimental Observation and Numerical Analysis

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ABSTRACT: High ratio of strength to weight in fiber reinforced polymer composites causes to their applications in many of the structures and components. In this study, an experimental and numerical investigation on four composite cylinders' response to low-velocity impact is carried out. The studied cylinders were considered to be carbon-only, kevlar-only, kevlar-outside/carbon-inside, and carbon-outside/kevlar-inside. The experimental impact test was applied to the samples using a drop-weight impact apparatus without initial velocity with a spherical steel impactor. In the numerical part, a finite element modeling technique has been used in ABAQUS software to investigate the impact behavior. In this paper, various types of modeling methods, meshing process and types of elements such as conventional shell, continuum shell, and solid elements were discussed in the software. The impactor was modeled as an analytical rigid part and the composite cylinders were modeled as conventional shell composite lay-ups. The issues of concern were the contact force, contact duration, and deflection of the specimens. It was found that kevlar fiber has more ability to absorb energy compared to carbon fiber and that the carbon-only specimen has the greatest contact force and the lowest deflection compared with the other samples. To validate the experimental data, they were compared with the results obtained from the finite element analysis and a strong concurrence was found between them.

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1. Introduction

In recent decades, polymer composite and fiber-reinforced composites due to properties such as low density, high strength to weight ratio, inherent chemical stability at ambient temperature and high mechanical properties have been widely used in aerospace structures and sports equipment, pressure vessels, marine equipment, and automotive parts. In many applications, these composite structures are likely to encounter impact load. This has led many researchers to investigate the low-velocity impact behavior of laminated composite structures.

In addition, Khalili et al. [1] used the ABAQUS/Explicit and ABAQUS/Implicit software to study the impact response of curved composite panels. Kumar et al. [2] explored the impact response and impact-induced damages of graphite/epoxy laminated cylindrical shells. The focus of the present paper is to study the response of four cylindrical composite structures made of either carbon or kevlar fibers or a combination thereof to low-velocity impact.

2. Experimental Method

2.1. Material properties and geometry

Four cylindrical composite specimens (Fig. 1) were used in the present study: (a) carbon-only, (b) kevlar-only, (c) kevlar-outside/carbon-inside, and (d) carbon-outside/kevlar-inside. Specimens (a) and (b) were made of nine woven layers of carbon fiber and kevlar fiber, respectively; Sample (c) had five outer layers of kevlar fiber and four inner layers of carbon fiber; and sample (d) was composed of five outer layers of carbon fiber and four inner layers of kevlar fiber. Internal diameter, thickness, and length of each cylinder were 48.5 mm, 3.25 mm, and 250 mm, respectively.

The tests were based on the ASTM D3039 standard, which is used to determine the mechanical properties of polymer matrix composites. The properties (i.e., density, Young's modulus, shear modulus, and Poisson's ratio) are listed in Table 1.

2.2. Impact test

Impact tests were performed in the Composite Materials Research Laboratory in the Amirkabir University of Technology in Tehran, Iran. A drop-weight impact apparatus

(a) (b) (c) (d)

Fig. 1: The specimens used in the study: (a) carbon-only (b) kevlar-only (c) kevlar-outside/carbon-inside (d)carbon-outside/kevlar-inside

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Table 1: The properties of the carbon and kevlar fiber laminates

Dimensions/ Properties	Symbol	Carbon	Kevlar
Sample thickness (mm)	T	1.19	1.34
Sample width (mm)	W	25.4	26.08
Density (kg/m^2)	P	1380	1380
Young's modulus (GPa)	E_x	120	60
	E_y	120	60
Shear modulus (GPa)	G_{xy}	15	7.5
	G_{xz}	15	7.5
	G_{yz}	9	5
Poisson's ratio	υ_{xy}	0.24	0.12

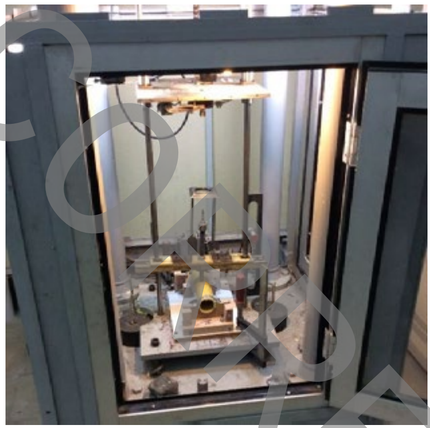

Fig. 2: The drop-weight impact apparatus used in the study

Table 2: The properties of the impactor

Dimensions/ Properties	Steel
Density (kg/m^3)	7800
Young's modulus (GPa)	200
Poisson's ratio	0.3
Diameter (mm)	16
Total mass (kg)	3.2

with a free-falling mass (Fig. 4) was used to apply impact on the four specimens. The test setup consisted of the specimen holder and a spherical steel impactor released from a height of 300 mm. The mechanical and geometrical properties of the impactor are given in Table 2.

3. Finite Element Model

The Finite Element Model (FE) modeling of the impact behavior of the cylindrical composites under investigation was carried out using the ABAQUS software version 6.10-1. In order to model composite cylindrical laminates, there exist three options: conventional shell, continuum shell, and solid elements [3]. In the present study, the conventional shell composite lay-up was used. Modeling of the impactor and composite cylinders are shown in Fig. 3.

4. Results and Discussion

This section first gives the experimental results of the study and then presents the results of FE analysis performed

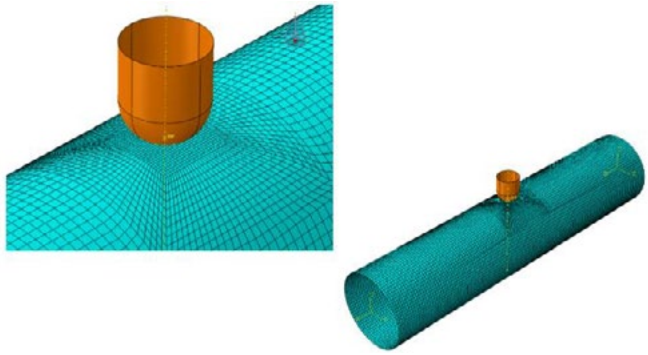

Fig. 3: Modeling the impactor using analytical rigid shell and modeling composite cylinders using the S4R element

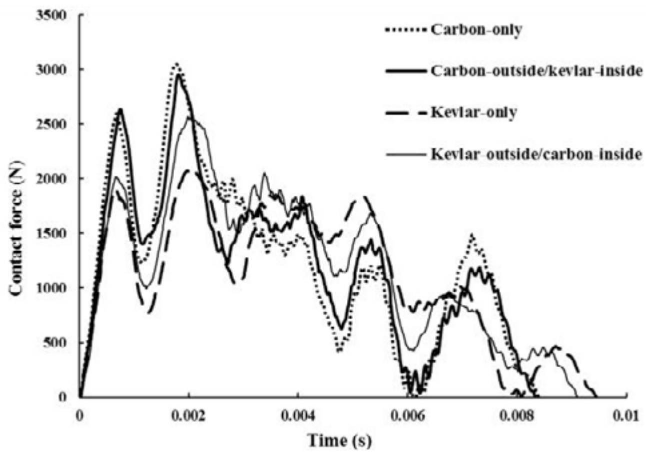

Fig. 4: Experimental results for the contact force history of the specimens under study

with the purpose of numerically verifying the experimental findings.

4.1. Experimental results

To calculate the contact force, 2,043 quantity data were recorded. Fig. 4 gives the experimental results for the contact force history of the specimens of the study when subjected to the low-velocity impact. As can be seen, the carbon-only, carbon-outside/kevlar-inside, kevlar-outside/carbon-inside, and kevlar-only specimens had the greatest maximum contact force history, respectively. It is also clear from this figure that the order is almost reverse for contact duration. In other words, as carbon fiber increased in the outer part of the cylinder composites, the maximum contact force and duration time increased and decreased, respectively.

The difference between carbon-only and carbon-outside/kevlar-inside in terms of contact force is much smaller than the difference between kevlar-only and kevlar-outside/carbon-inside. This is because the indentation occurred in the upper layer. In other words, the velocity and energy were not enough to get to and damage the inner layers and achieve the plastic phase.

4.2. Numerical verification

The experimental results of the study were compared with FE results. The reason behind this numerical verification was

Table 3: Experimental and numerical results for maximum contact force (N)

maximum contact force (N)				
	Carbon-outside/ kevlar-inside	Kevlar-outside/ carbon-inside	Kevlar-only	Carbon-only
Experimental data	2952	2576	2097	3042
Numerical data	2911	2653	2075	2997
Percentage of discrepancy	1.4	2.9	1	1.5

that FE simulations can accurately predict the impact events. Table 3 compares experimental and numerical data for maximum contact force. The data presented in these tables reveal that there were minimal discrepancies between the two data sets.

5. Conclusion

This research studied the response of four composite cylinders to low-velocity impact with an emphasis on contact force, contact duration, and deflection. Furthermore, the experimental data were verified using FE analysis. It was also found that, of all the cylindrical composites, the carbon-only sample has the greatest contact force and the lowest deflection. Moreover, the kevlar-only specimen had the minimum contact force and the maximum deflection.

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