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Research Article

Enhancing puncture resistance and mechanical properties of hybrid polymer composites reinforced with silica nanoparticles for aerospace applications

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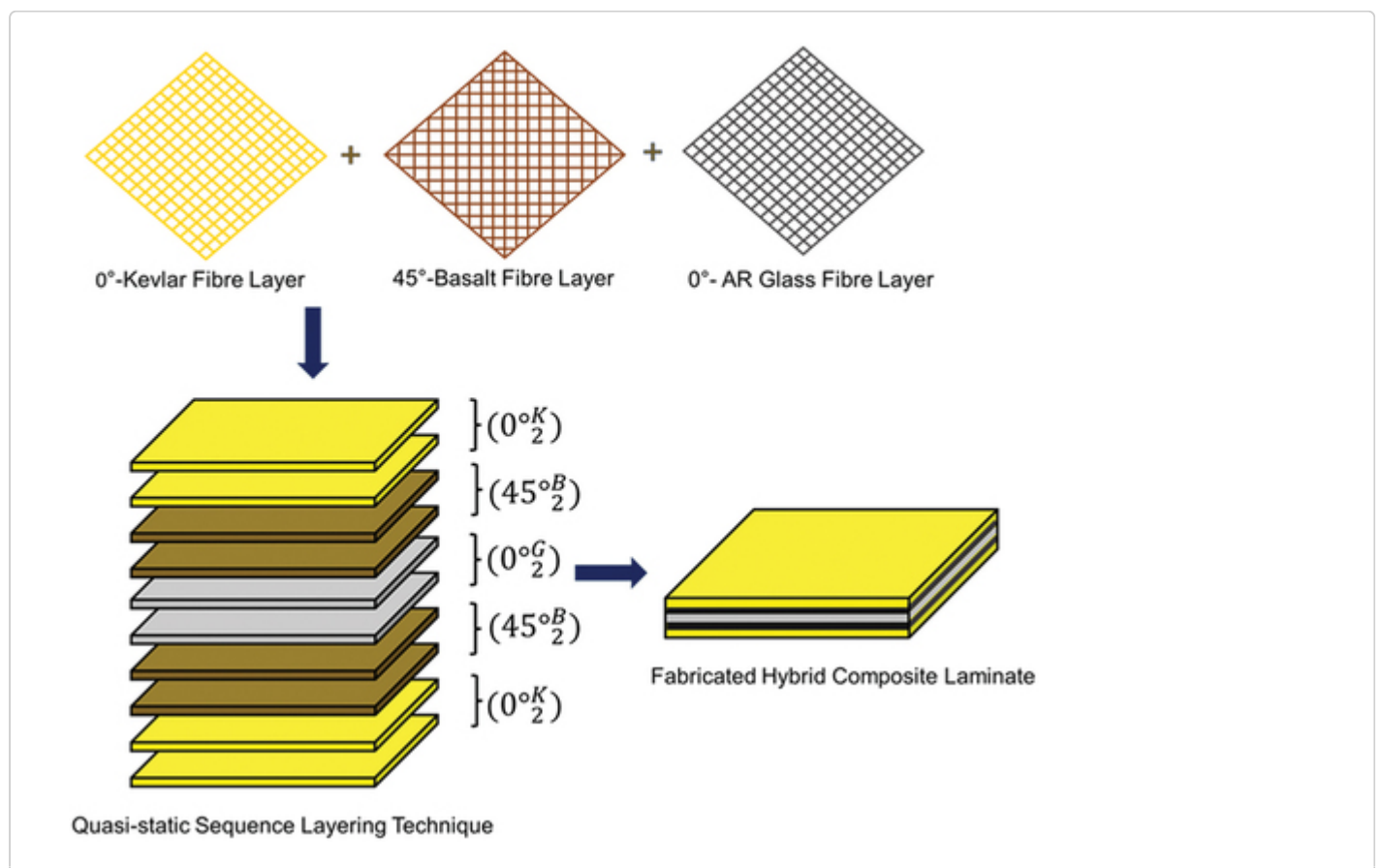
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ABSTRACT

This research focuses on developing lightweight and rigid defense structures using hybrid polymer composites reinforced with silica nanoparticles (SiNPs). The primary objective is to enhance the puncture resistance, mechanical properties, structural efficiency, and cost-effectiveness of these composites for defense, military, and marine applications. To achieve these goals, advanced materials and reinforcement techniques, such as optimized fibre orientation and nanoparticle inclusion, were

employed. The composite laminates were fabricated using bidirectional interply 0-degree Kevlar, AR glass, and 45-degree basalt fibre woven matrices combined with an epoxy resin matrix. Silica nanoparticles were incorporated at weight percentages (wt.%) of 0, 1.5, 3, 4.5, and 6. A quasi-static sequence method ($0_2^{\circ} K / 45_2^{\circ} B / 0_2^{\circ} G / 45_2^{\circ} B / 0_2^{\circ} K$) was utilized to further enhance the mechanical and structural properties of the hybrid composites. Mechanical performance was characterized through various tests, including puncture resistance, tensile, flexural, interlaminar shear, Izod impact, and Charpy impact tests. Among the composites tested, the hybrid laminate reinforced with 4.5 wt.% silica nanoparticles exhibited superior mechanical properties, achieving puncture strength, tensile strength, flexural strength, interlaminar shear strength, Izod impact energy, and Charpy impact energy of 112.09 MPa, 167.93 MPa, 109.93 MPa, 17.03 MPa, 1598.1 J/m, and 834.9 J/m, respectively. These findings highlight the effectiveness of silica nanoparticle reinforcement and precise fibre orientation techniques in enhancing the mechanical performance of hybrid polymer composites. This study provides a strong foundation for developing high-performance, lightweight structures for advanced engineering applications.

GRAPHICAL ABSTRACT



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[Hybrid polymer composite](#) [puncture resistance](#) [mechanical characterization](#) [silica nanoparticles](#)
[structural effectiveness](#)

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Made available on request.

Highlights

- Development of lightweight, high-strength hybrid polymer composite laminates.
 - Nanoparticles enhance puncture resistance, mechanical strength, and structural integrity.
 - Improved strength-to-weight ratio for defense applications.
 - Enhanced performance and efficiency in defense, military, and marine structures.
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