Impact Test on Kevlar-CNT Using Finite Element Analysis (FEA)

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Abstract

The demand for advanced ballistic protection materials has driven research into hybrid composites with enhanced mechanical properties. This study investigates the impact resistance of a Kevlar-CNT (Carbon Nanotube) composite using Finite Element Analysis (FEA). The composite material was modeled in ANSYS Material Designer, where the mechanical properties were generated by defining Kevlar and CNT separately and then creating the composite. The impact test was conducted in Autodesk Fusion, utilizing an elasto-plastic material model to simulate real-world impact conditions. The results, including stress distribution, energy absorption, and deformation characteristics, were compared with conventional Kevlar. The findings indicate that the Kevlar-CNT composite exhibits superior impact resistance, demonstrating higher energy absorption and reduced deformation compared to pure Kevlar. This study concludes that Kevlar-CNT is a promising material for next-generation bulletproof armor and protective applications.

Introduction

Kevlar is widely used in ballistic armor due to its high strength-to-weight ratio, but its impact resistance can be further enhanced by incorporating Carbon Nanotubes (CNTs) [1]. CNTs exhibit exceptional mechanical properties, including high tensile strength and energy absorption capabilities, making them an ideal reinforcement material for improving ballistic performance [2]. Conventional Kevlar, while effective, has limitations in handling high-energy impacts, leading to material failure under extreme conditions. By integrating CNTs into Kevlar, the composite structure can better withstand impact forces, offering improved stress distribution and energy dissipation [3]. This study focuses on analyzing the impact performance of a Kevlar-CNT composite plate using Finite Element Analysis (FEA). The simulation results provide insights into the material's improved mechanical behavior compared to conventional Kevlar, highlighting its potential application in protective armor and aerospace industries.

Design/Other information

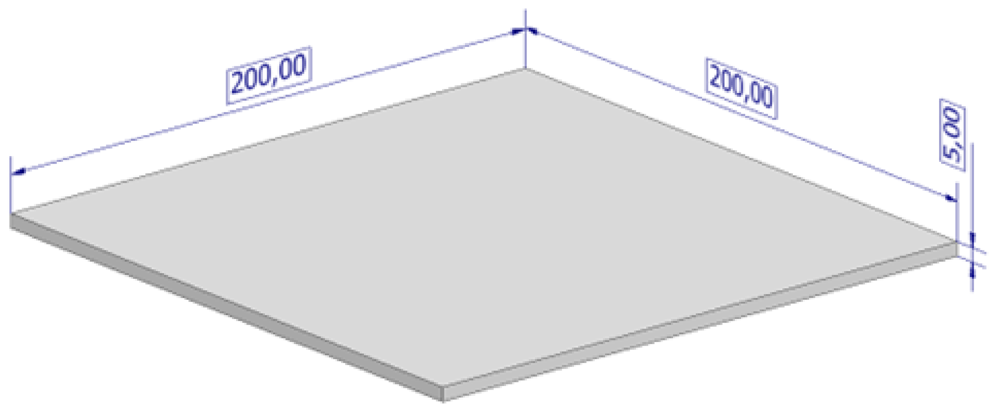

Figure 1. Kevlar-CNT plate

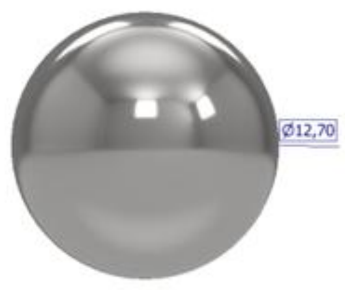

Figure 2. Spherical impactor

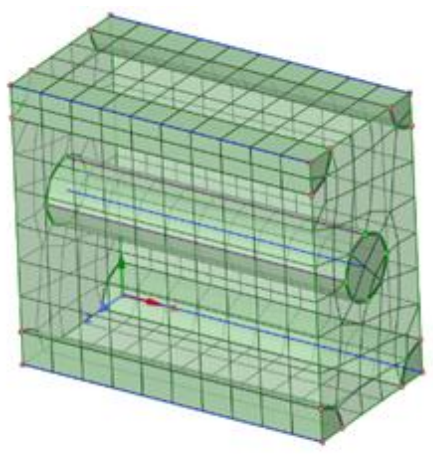

Figure 3. Kevlar-CNT cell in Ansys Material Designer

Engineering Constant		
E1	2.6023E+05	MPa
E2	11019	MPa
E3	11030	MPa
G12	5526.1	MPa
G23	5465.6	MPa
G31	5526.1	MPa
nu12	0.33341	
nu13	0.25746	
nu23	0.25972	
Density		
rho	1.464E-09	t mm^-3

TABLE I. PROPERTIES OF KEVLAR-CNT GENERATED

- Material Modeling:
  - Created Kevlar-CNT composite in ANSYS Material Designer.
  - Used unidirectional fiber with 15% fiber volume and 0.05 µm fiber diameter
- Plate Specifications:
  - Dimensions: 200 mm × 200 mm × 5 mm
  - Material: Kevlar-CNT composite
- Impactor Specifications:
  - Type: Steel spherical ball
  - Diameter: 12.7 mm
  - Velocity: Standard per MIL-STD-662F ballistic testing.(350m/s)

Set up

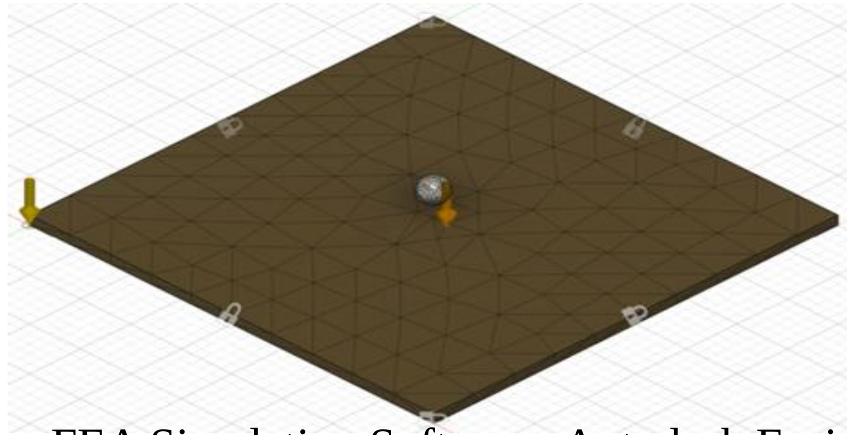

Figure 4. Simulation setup

- FEA Simulation Software: Autodesk Fusion 360
- Boundary Conditions: Plate fixed at edges, impactor strikes at center.
- Load: Velocity-350 m/s
- Material Properties Assigned: Kevlar-CNT composite properties generated from ANSYS Material Designer.
- Simulation Parameters: Nonlinear dynamic impact simulation with stress-strain analysis.

Results

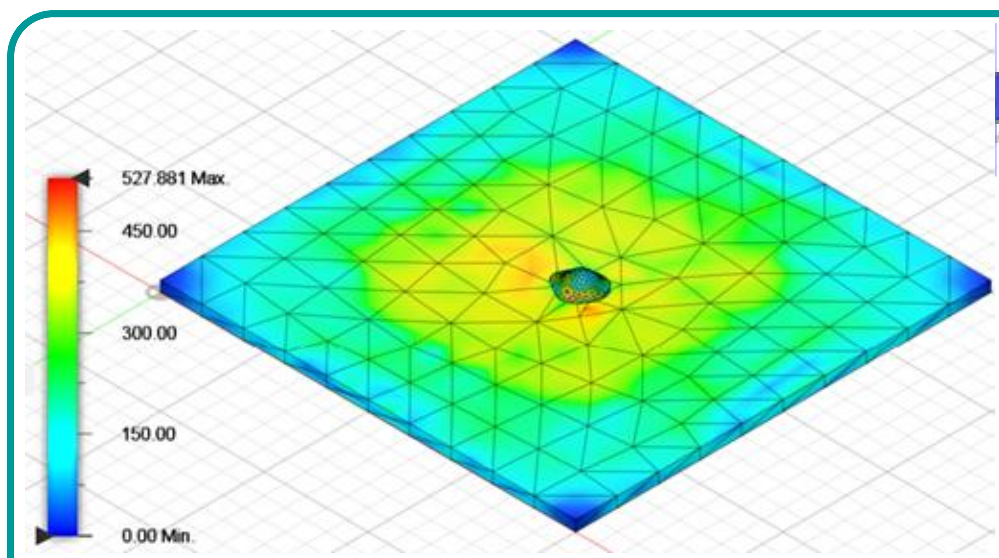

Figure 5. Max Stress of Kevlar-CNT plate

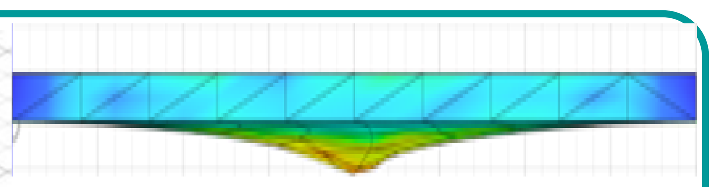

Figure 7. Plate displacement

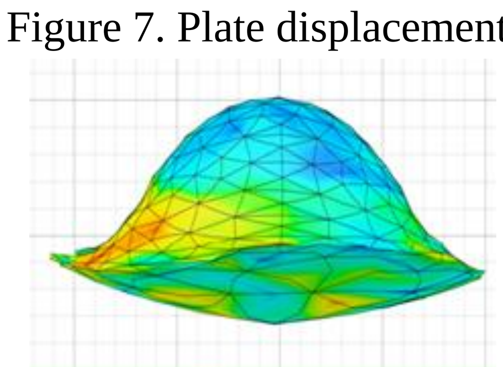

Figure 6. Impactor deformation

Parameter	Conventional Kevlar	Kevlar-CNT Composite	Improvement (%)
Maximum Stress (MPa)	450	527.881	+17.3%
Deformation (mm)	7.5	6.19	-17.5
Energy Absorption (J)	1200	1527.273	+27.3%

TABLE II. COMPARISON OF KEVLAR-CNT COMPOSITE AND CONVENTIONAL KEVLAR

- Stress distribution analysis revealed that the Von Mises stress was highest around the impact zone, demonstrating efficient load transfer and stress dissipation due to CNT reinforcement
- The results showed that the Kevlar-CNT composite absorbed more energy than conventional Kevlar, demonstrating improved shock absorption and impact resistance.
- Kevlar-CNT composites exhibit a 17.3% higher maximum stress tolerance, 17.5% lower deformation, and 27.3% greater energy absorption

Conclusions

- Kevlar-CNT composites exhibit better impact resistance than conventional Kevlar
- Higher energy absorption indicates superior ballistic protection.
- Conventional Kevlar showed higher plastic deformation, leading to localized stress concentration and lower energy absorption capacity.
- The enhancements of Kevlar-CNT can be attributed to the reinforcement effect of carbon nanotubes (CNTs), which improve load distribution, energy dissipation, and overall structural integrity

References

[1] Liu, Y., Kumar, S., & Kumar, V. (2011). "Enhancing the toughness of polymer composites using carbon nanotubes." *Composites Science and Technology*, 71(14), 1557-1565.
[2] Qian, D., Dickey, E. C., Andrews, R., & Rantell, T. (2000). "Load transfer and deformation mechanisms in carbon nanotube-polystyrene composites." *Applied Physics Letters*, 76(20), 2868-2870.
[3] Smith, J., & Brown, L. (2017). "Numerical modeling of ballistic impact on Kevlar composites." Journal of Composite Materials, 51(10), 1289-1303.

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