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Presentation Title

Mechanical and Energy Absorption Behaviors of 3D Printed Continuous Carbon/Kevlar Hybrid Thread reinforced PLA Composites

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01 Introduction

Abstract
Research Background

02 Experimental Methodology

2.1. Materials and processing
2.2. Characterization

03 Results and Discussion

3.1. Mechanical performance and energy absorption
3.1.1. Tensile behaviors
3.1.2. Three-point bending & impact performance.

04 Conclusions

05 Progress & Future work

Achievements', Future Plans.

INTRODUCTION

Aims

This study aimed to 3D print hybrid threads by merging several types of continuous Kevlar and Carbon fibers.

Tests'

Tension tests, three point bending tests, and drop hammer impact tests were performed.

Technology

Via material extrusion 3D printing to accomplish cooperative ductility and brittleness augmentation.

Impact test

For hybrid composites was enhanced by over 91% compared to carbon fiber non-hybrid composites.

Analysis

To analyze the mechanical performance and reveal the failure and deformation mechanisms.

SEM

Hybrid specimens provided an insight of the failure mechanisms, resulting in stable hybrid composites.

INTRODUCTION

01

In recent years, three-dimensional printing (3DP) of continuous fiber reinforced plastic (CFRP) composites have been rapidly developed by material extrusion(ME) which is also known as fused deposition modelling (FDM) technology.

02

So far, several problems faced by 3D printing of CFRP composites and mechanical performance of 3D printed composite parts have been discussed by different researchers mostly on layer by layer hybrids.

03

Continuous fibers such as glass fibers (GFs), carbon fibers(CFs) and Kevlar fibers(KFs) were used to improve the mechanical behavior of thermoplastic composites.

04

A quasi-static indentation (QSI) test based study was published on short, continuous carbon fiber and Kevlar fiber reinforced PA composites on alternate layers by using a 3D printer containing two modules to print each layer independently. (central South University, china).

05

3D printing method for hybrid threads (HT) reinforced PLA composites were proposed in this research to achieve cooperative enhancement of ductility and brittleness, by combining different kinds of continuous (Kevlar 130D&200D and 1 k carbon) fibers.

*Mechanical and energy absorptions responses of the composites were studied with the help of drop hammer impact test, three-point bending and tensile test.

experimental

Materials and Processing

01 Exp. Study

Polylatic acid (PLA) from eSUN Filament with 1.75 mm diameter is used as an effective matrix, 1 k continuous commercial virgin carbon fiber (Tory Corp., Japan), Kevlar fibers (130D and 200D) purchased from DuPont were as reinforcement.

02

PLA was stored in dry environment to minimize the humidity before its use. Hybrid and non-hybrid 3D printed composites with continuous carbon and Kevlar fibers were prepared by using FiberTech 3D printer.

03

A total five types of hybrid and non-hybrid specimens were created for one sort of test. And each type contained three samples, allowing us to take the average of the results.

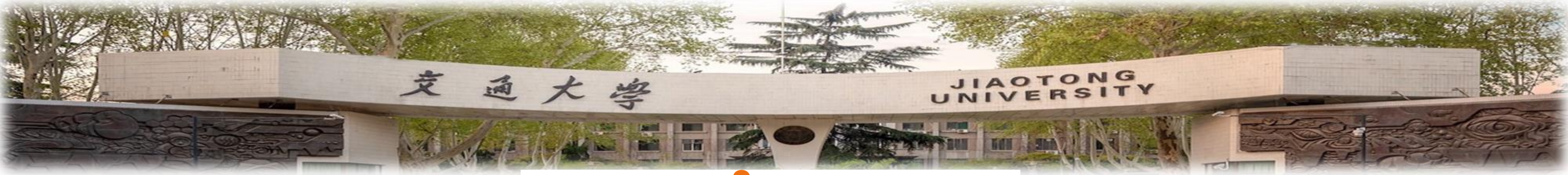
experimental

2.1. Materials and Processing

- ✓ Nozzle 1.0mm, Printing temperature 210 degrees.
- ✓ Printing speed 300mm/min, 0º/90º printing orientation.
- ✓ $200 \times 25 \times 2.1 \pm 0.2$ for Tensile test according to ISO 527-4 Standard.
- ✓ $200 \times 25 \times 3.2 \pm 0.1$ Bending test according to ISO14125 test standard .
- ✓ $200 \times 100 \times 4 \pm 0.1$ Impact test according to ISO 6603 test standard.
- ✓ Universal machine MTS(GMT4304-5kN, SANS Group., China) For Bending and Tension tests and test speed 2mm/min.
- ✓ Instron CEAST 9350HV drop weight impact test machine, Italy. impact velocity 3.12m/s, impact mass 20.5kg and falling height 496.316mm.

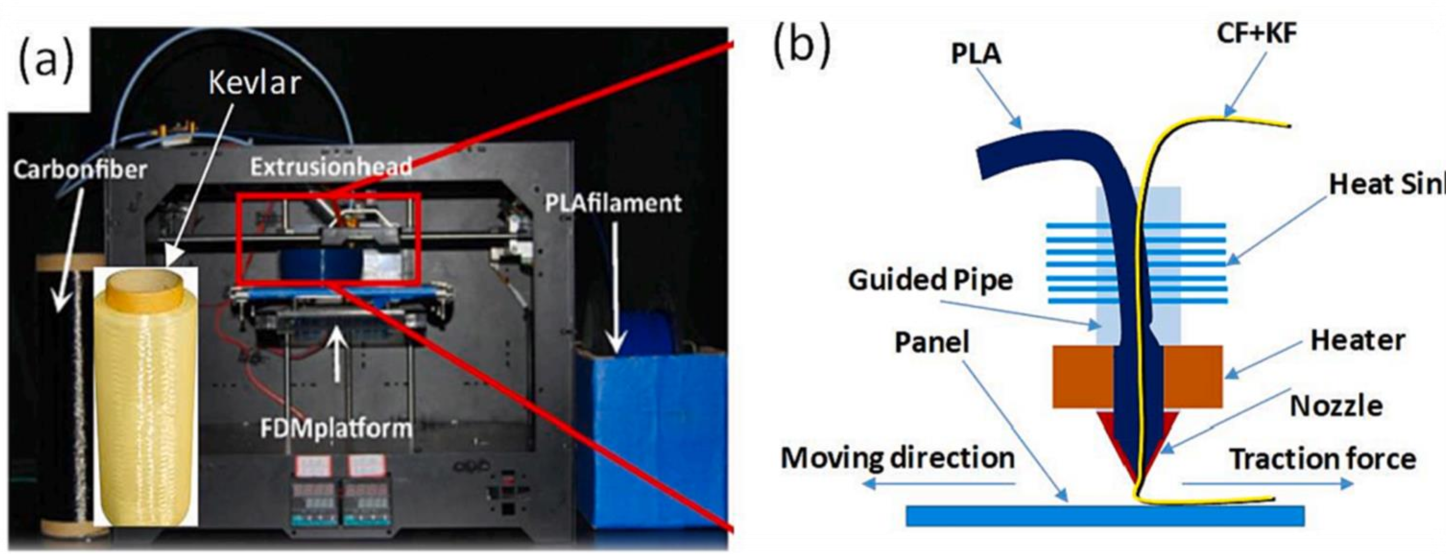
$$V_f = \frac{S_f}{T.H}$$

Where, ***Vf*** is volume fraction, ***Sf*** cross section of fibers, ***T*** is layer thickness and ***H*** is hatch spacing.



experimental

Representation of (a) FDM machine, (b) Schematic working process of FDM.



(a). Is representing the FDM printer and its main working parts.

(b). Is the schematic working process of the FDM machine in which continuous carbon fibers and Kevlar fibers are entering through the same inlet and PLA from the other inlet.

Results

3.1. Overall Performance

3.1. Mechanical performance and energy absorption

- 3.1.1. Tensile Behaviors
- 3.1.2. Three-point bending performance
- 3.1.3. Drop Hammer impact performance

3.2. Discussion

- 3.2.1. Fracture behaviors
- Schematic presentation of damage mechanisms of hybrid composites during impact test
- 3.2.2. Hybrid effect

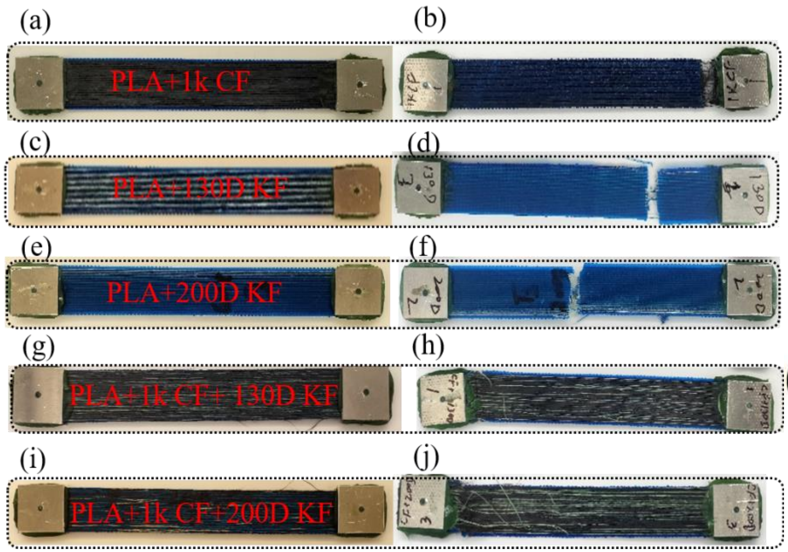
- The flexural behaviors and energy absorption
- Energy absorption with respect to displacement.

SEM
Hybrid, Non-Hybrid

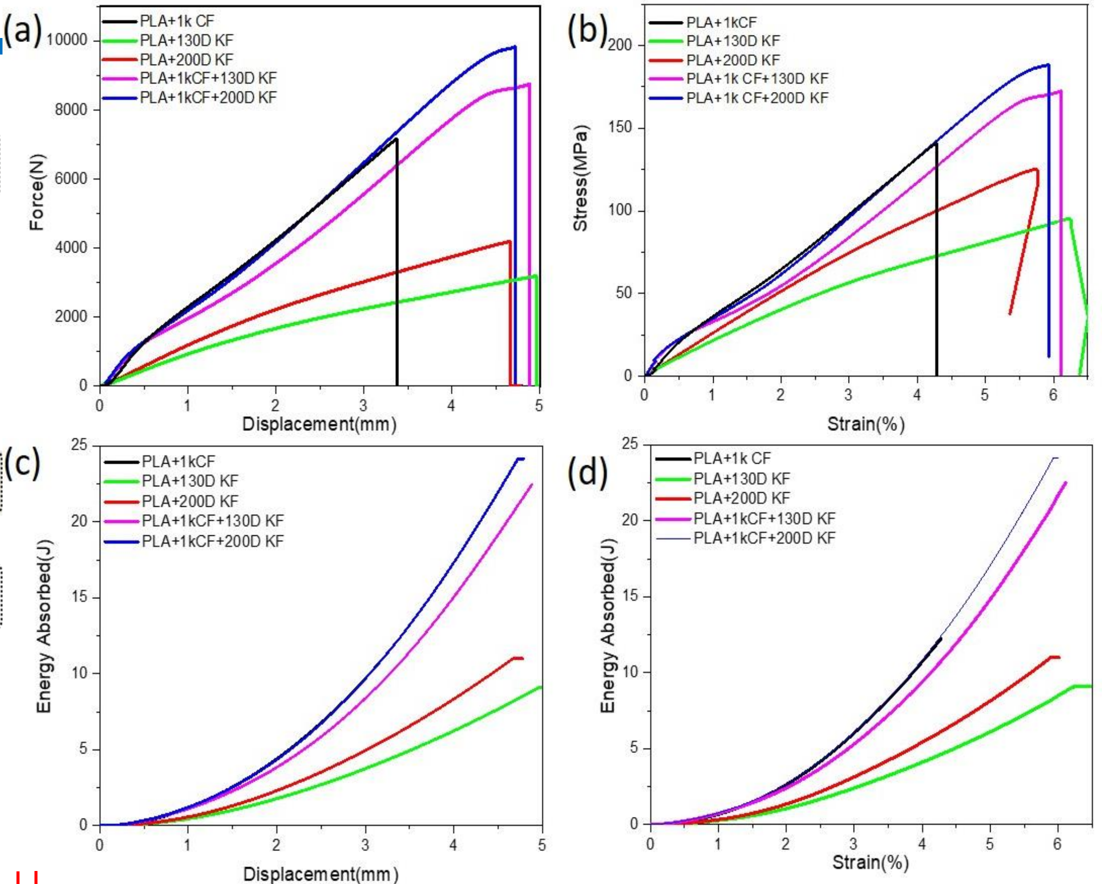
- Drop hammer impact test of hybrid and non-hybrid composites
- a Force-displacement curves, breaking phenomenon
- SEM images of hybrid and non-hybrid composites, tensile test, three- point bending test drop hammer impact test.

4. Mechanical & energy absorption behaviors of hybrid & non hybrid composites

4.1. Tensile behavior



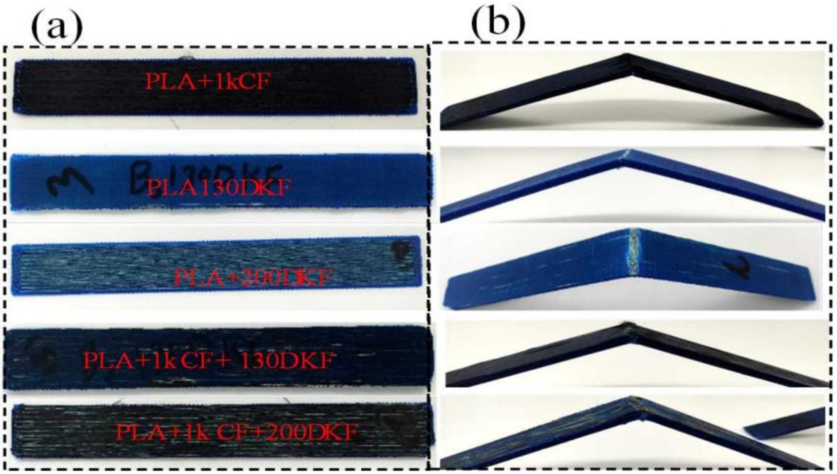
Hybrid and non-hybrid specimens before and after tensile test. (a,b) PLA+1K CF,(c,d) PLA+130D KF, (e,f) PLA+200D KF, (g,h) PLA+1K CF+130D KF,(i,j) PLA+1K CF+200D KF.



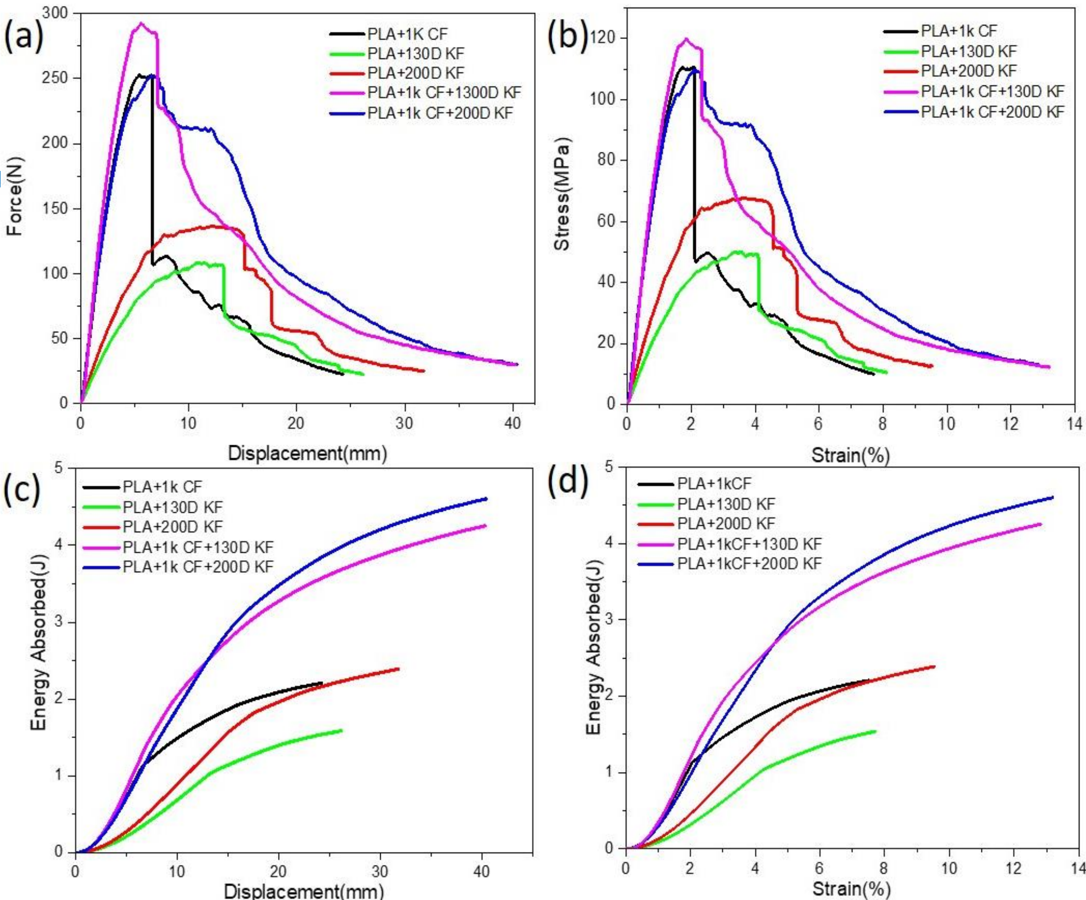
a. Force and displacement curves, b. Stress and strain curves, c. Energy absorbed with respect to displacement, d. Energy absorbed with respect to strain.

- PLA+1k CF+130D KF and PLA+1k CF+200D KF) were able to stand against higher tensile force (8761.53N and 9833.16N), tensile strength (172.47MPa and 188.43MPa) and higher energy absorption (83.61% and 97.23% compared with PLA+1k CF).

4.2. Three point bending performance



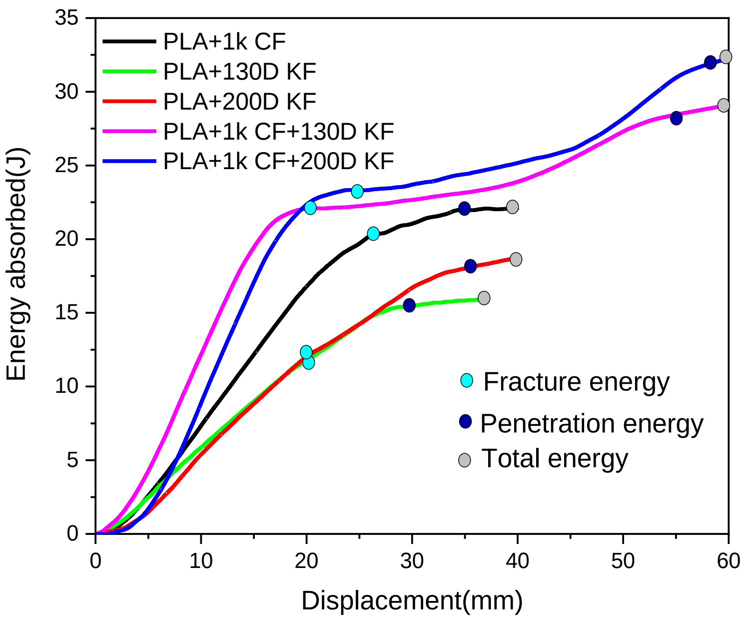
Fracture behavior due to bending test, (a) before the test of printed hybrid and non-hybrid composites of PLA+1K CF, PLA+130D KF, PLA+200D KF, PLA+1K CF+130D KF and PLA+1K CF+200D KF, (b) specimens after the test.



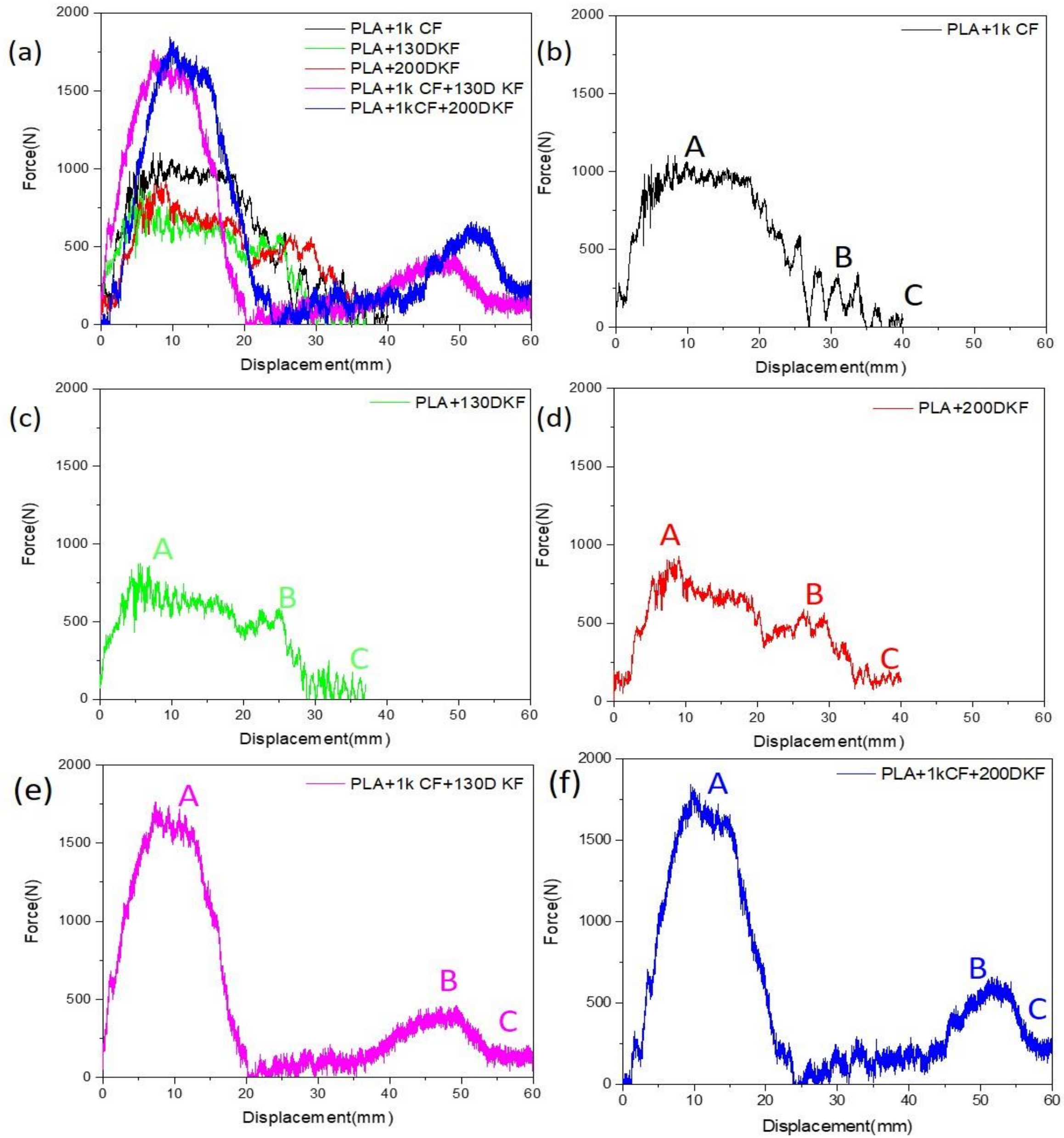
(a) Force and displacement curves, (b) stress strain curves, (c) energy absorbed and displacement curves, (d) energy absorbed and strain curves, of PLA+1K CF, PLA+130D KF, PLA+200D KF, PLA+1K CF+130D KF and PLA+1K CF+200D KF

- Both hybrid (PLA+1K CF+130D KF, and PLA+1K CF+200D KF) composites were showing higher flexural modulus (9516.67 MPa and 10095.08 MPa), higher bending force and higher energy absorption (93.18% and 109.09% more than PLA+1K CF).

4.3. Drop hammer impact performance



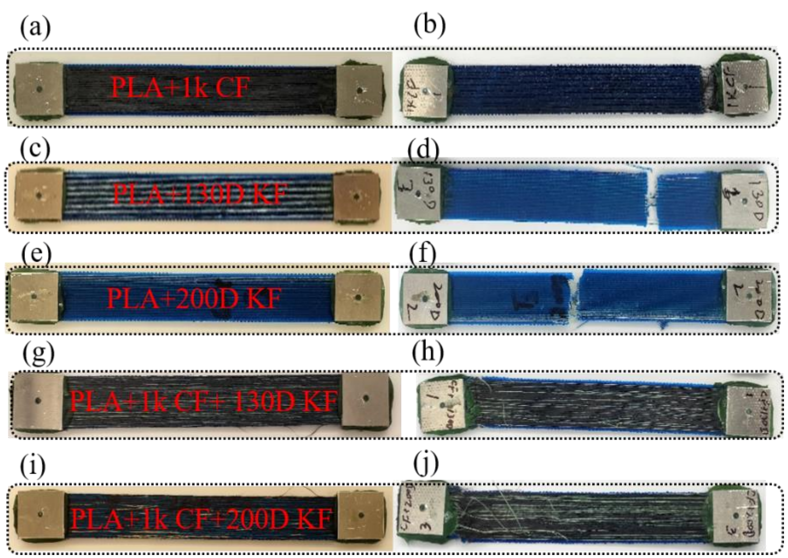
Energy absorption with respect to displacement.

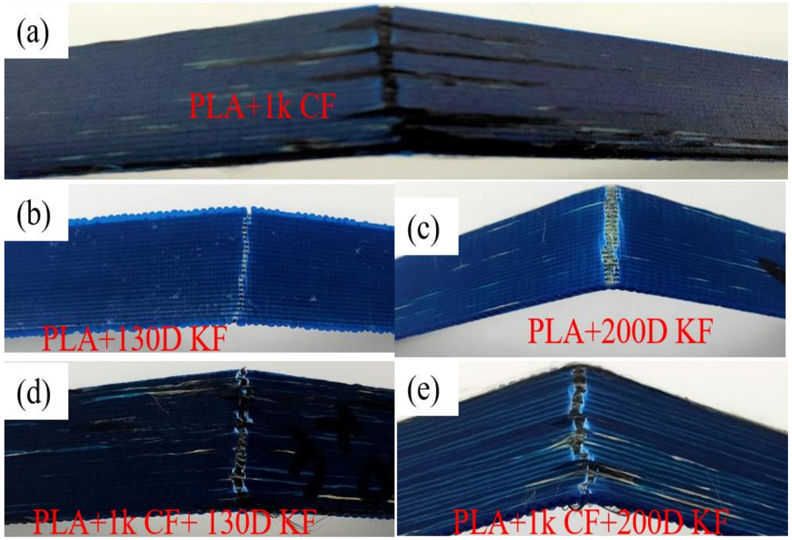


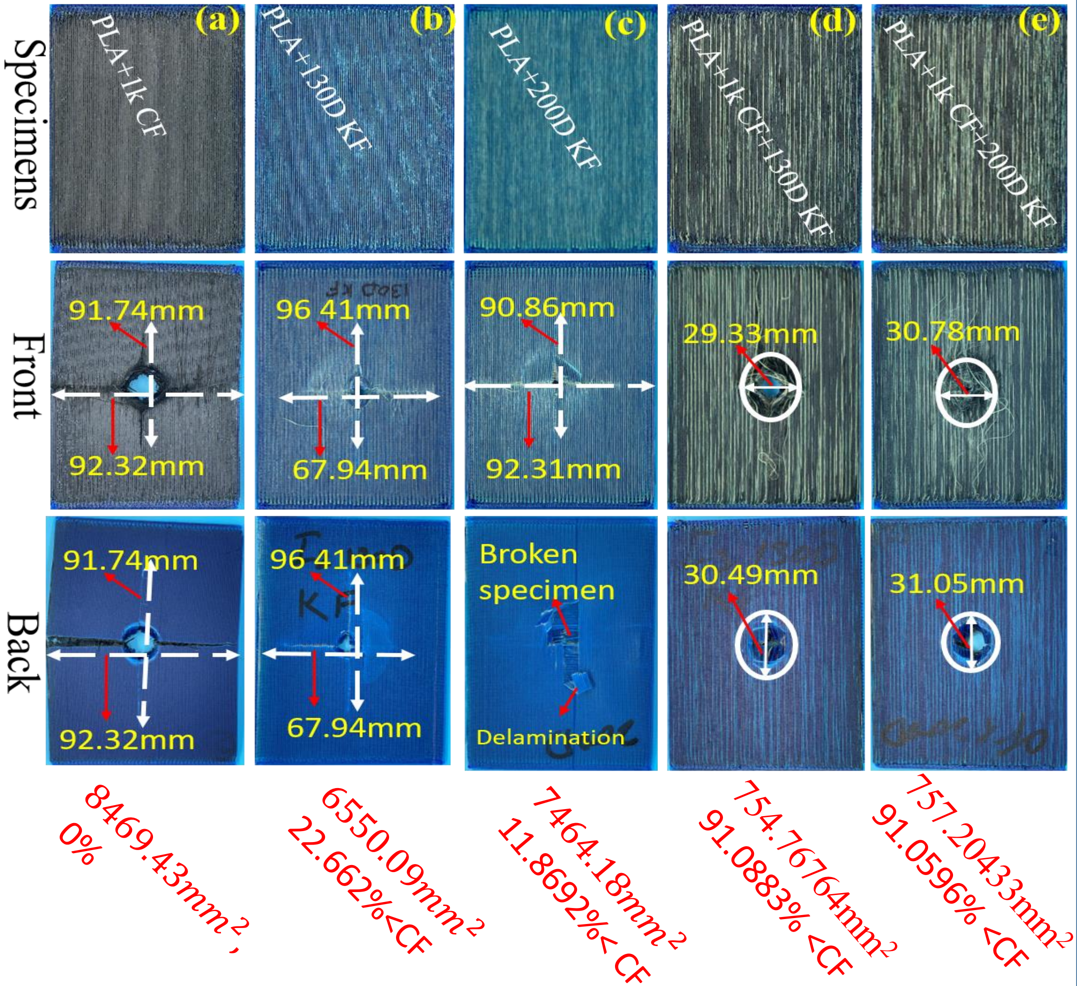
- PLA+1k CF+130D KF and PLA+1k CF+200D KF almost same with each other with slight variations. specimens were punctured at 1741.86N and 1806.10.

Drop hammer impact test of hybrid and non-hybrid composites (a Force-displacement curves, (b-f) breaking phenomenon (A first peak, B second peak, C final point of the event).

4.4. Fracture behaviors

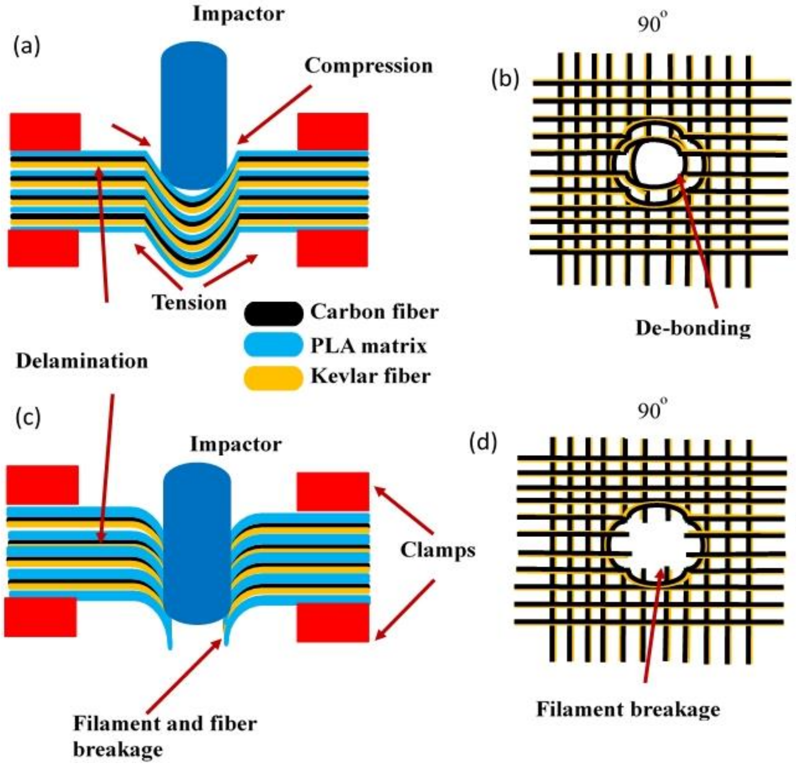




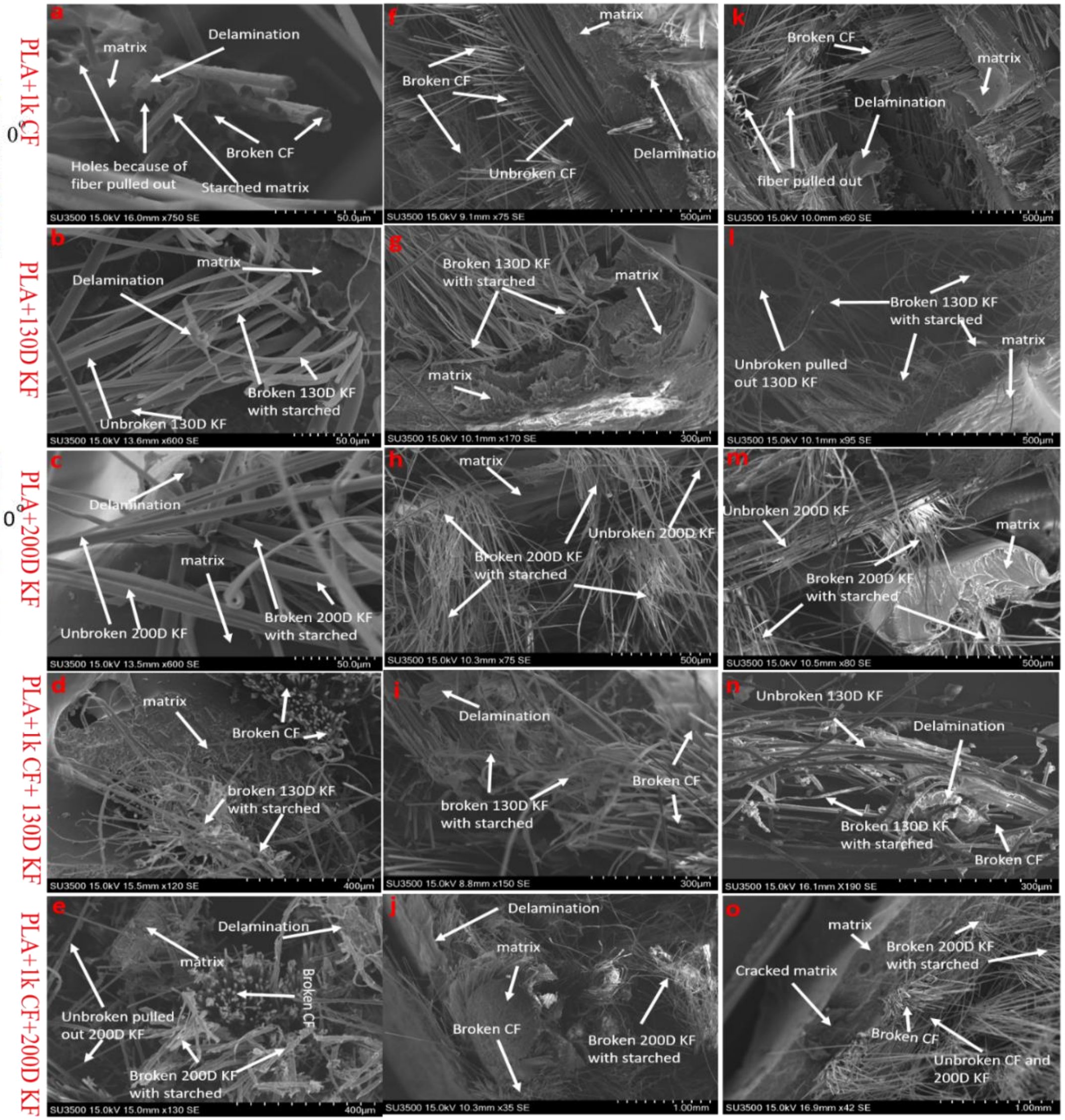


- The fractures in PLA+1k CF+130D KF and PLA+1k CF+200D KF were less and different then other non hybrid specimens

4.4. Fracture behaviors



Schematic presentation of damage mechanisms of hybrid composites during impact test.



- CF broken mostly KFs broken with stretch.

4.5. Hybrid effects

- Hybridization is one of the most ideal approach to increase the penetration resistance and energy absorption ability of composites. Herein, hybrid effects of tensile test and drop hammer impact test specimens are calculated as followed;

$$hybrid\ effect = \frac{\acute{\varepsilon}_c - \varepsilon_c}{\varepsilon_c}$$

$h_e>0$, Positive hybrid effect
$h_e < 0$, Negative hybrid effect

- 0.43 for PLA+1K CF+130D KF and 0.38 for PLA+1K CF+200D KF positive hybrid effect obtained. Suggesting that it has good energy absorption capabilities.

$$E_{ROM} = \frac{1}{3}\left(E_{(PLA+1k\ CF)} + E_{(PLA+130D\ KF)} + E_{(PLA+200D\ KF)}\right)$$

$$h_e = \frac{E_h}{E_{ROM}} - 1$$

- For PLA+1k CF+130D KF and PLA+1k CF+20D KF, the hybrid effect (h_e) of printed composites was 0.53 and 0.70 respectively. The positive hybrid effect suggests a strong capacity for energy absorption. PLA+1kCF+200D KF, in particular, has a greater energy absorption capacity than PLA+1kCF+130D.

Conclusion

01

Hybrids were stronger than non hybrids in every aspect

02

Greater penetration resistance without any further fracture propagation

03

SEM , Positive hybrid effects were providing the capabilities of high energy absorption

04

High speed camera, different orientations

05

In future, hybrid threads composites will have potential to apply in aerospace and automobile industries.

Thank you

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