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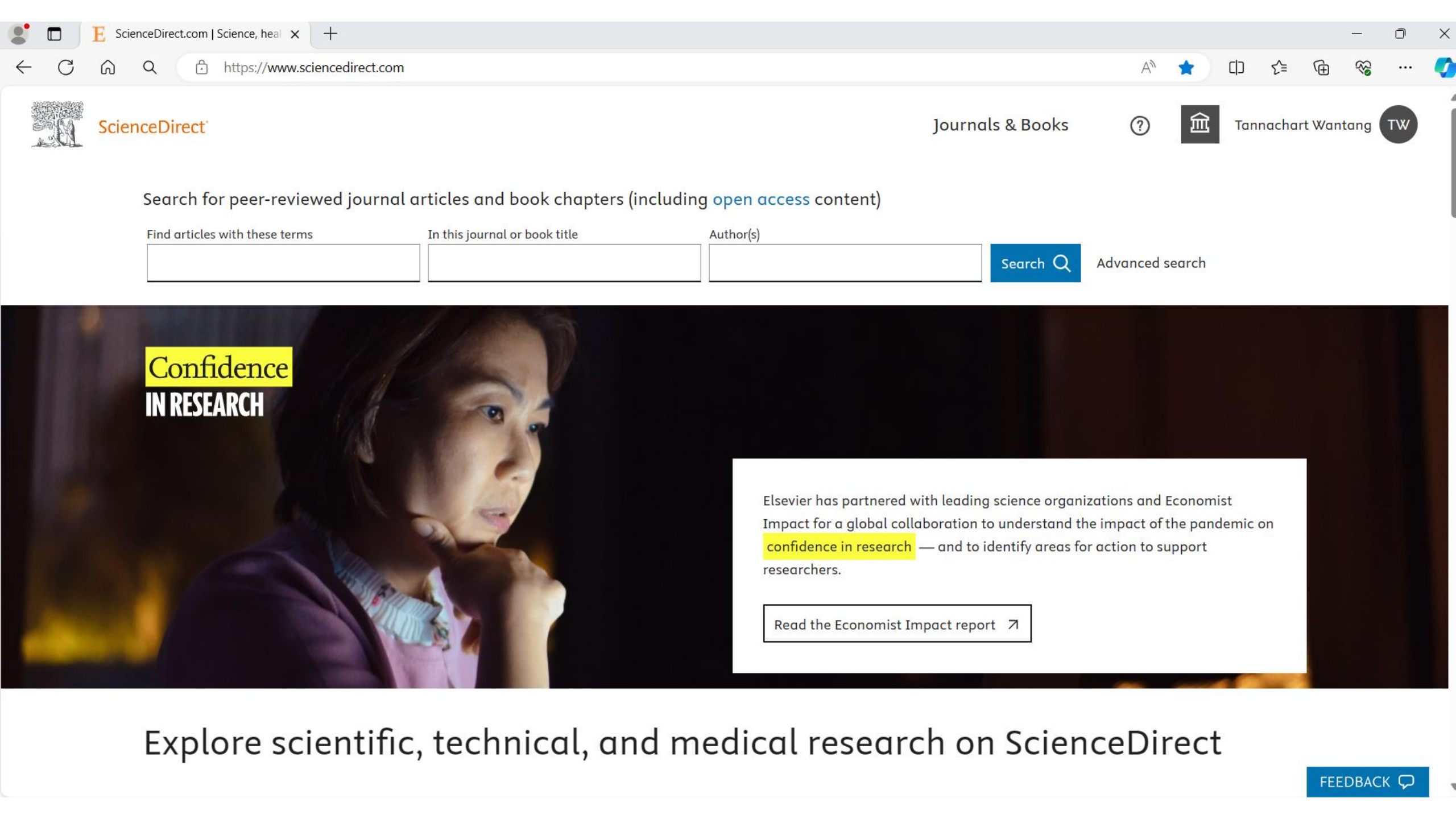
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## Optimizing Carbon-Kevlar Composites for Enhanced Bullet-proof Vest Design Against 9 mm Parabellum Projectiles

Tannachart Wantang<sup>1</sup>, Manop Pipathattaku<sup>2</sup>, Fasai Wiwatwongwana<sup>1\*</sup>

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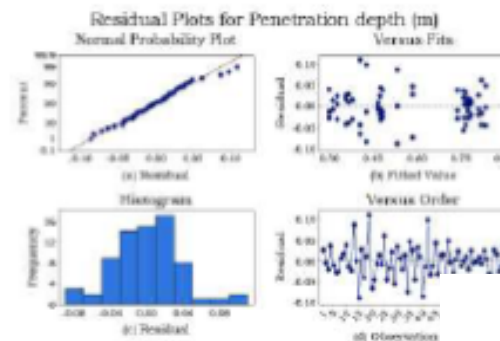
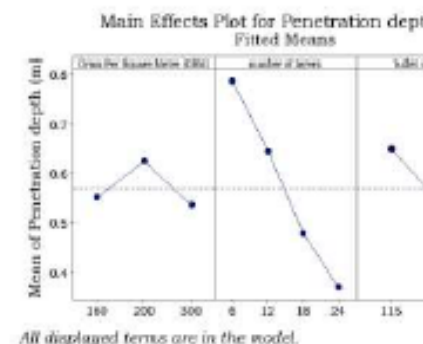


Fig.4 Residual plots for penetration depth



All displayed terms are in the model.

Fig.5 Main effects plot for penetration depth.

The Main Effects Plot in Fig. 5 provided a comprehensive analysis of interactions on penetration depth. The findings unequivocally demonstrated that in determining penetration depth. Notably, the main effects plot reveals a non-linear association between higher GSM and penetration depth in the ballistic analysis revealed that both low and high GSM values resulted in decreased penetration depth. When GSM was at a moderate level, the depth of penetration increased linearly and significantly linear correlation among these factors. Specifically, the interaction between variations in layers and bullet size, directly influencing the observed penetration depth. Moreover, the analysis revealed a consistent reduction in penetration depth as the number of layers and the employment of larger bullet sizes independently contributed to a decrease in penetration depth. The insights into the intricate nature of penetration depth and furnished guidance parameters to ensure the effective protection of bulletproof vests.

### Abstract

The study aimed to investigate the bulletproof capabilities of carbon-Kevlar composites, particularly for the design of bulletproof vests against pistol bullets. Carbon-Kevlar is known for its high strength, lightweight nature, and affordability, making it a popular choice in car tuning equipment. The objective was to determine the optimal number of layers and weight of carbon-Kevlar for the design of effective and safe bulletproof vests. Experimental tests were conducted using carbon-Kevlar materials to evaluate their performance against FMJ 9 mm parabellum. The tests focused on measuring the penetration depth of the bullets in a ballistic gelatin block, providing insights into the required number of layers and gram per square meter (GSM) weight necessary for effective bulletproofing. Statistical analysis revealed that all factors, including the number of layers and weight, significantly influenced the penetration depth. Comparing the performance of different weights of carbon-Kevlar in stopping 9 mm parabellum projectiles, it was observed that there was no linear correlation between weight and anti-penetration performance. However, a minimum of 36 layers with a weight of 300 GSM of carbon-Kevlar was estimated to effectively stop the projectiles. These findings provided valuable guidance for the design of bulletproof vests, ensuring they could effectively withstand 9 mm parabellum projectiles.

**Keywords:** Carbon-Kevlar; Ballistic gelatin; 9 mm Parabellum; Bulletproof; Handgun

### 1. Introduction

This research focused on optimizing carbon-Kevlar bulletproof vests to provide enhanced protection against 9mm Parabellum ammunition. Carbon-Kevlar is an intriguing material known for its high-impact resistance, strength, lightweight properties, and affordability [1-6], making it ideal for bulletproof vests [7]. The study utilized a 3<sup>2</sup> factorial design [8] to investigate the influence of different weights of carbon-Kevlar, the number of layers, and bullet size (115 grains and 124 grains) on the vest's performance [9,10]. The research identified the key factors affecting the vest's effectiveness by evaluating the penetrating distance of 9 mm Parabellum FMJ bullets in ballistic gelatin [11-14]. Notably, the findings highlighted the significant impact of bullet size and the number of layers and weight of carbon-Kevlar. By estimating the minimum number of layers required, the study provided valuable insights for designing bulletproof vests that could reliably and safely stop 9 mm Parabellum projectiles. Ultimately, this research contributed to advancing personal safety equipment and improving protection against firearm threats [15].

Riaan and Sarp researched to ascertain the minimal quantity of Kevlar layers indispensable for constructing a reliable bulletproof vest. They pursued this objective by subjecting combinations of ballistic gel and Kevlar layers, varying in weight, to rigorous ballistic testing. Their investigations revealed that no fewer than 21 layers of 200 GSM Kevlar are requisite to effectively halt a 9 mm Parabellum projectile. Furthermore, they astutely noted the efficacy of different quantities of GSM Kevlar material, uncovering the lack of a linear correlation between distinct Kevlar types featuring disparate weights [9]. Zhi-yong et al. examined the consequences of ballistic penetrations inflicted upon hybrid plain-woven laminates composed of carbon, Kevlar, and ultrahigh molecular weight polyethylene (UHMWPE) arranged in various stacking sequences. Their insightful findings illuminated the significant influence that fiber combinations and laminate stacking sequences exerted on the ballistic performance of said laminates. Particularly noteworthy was the UHMWPE/Kevlar hybrid laminated with Kevlar layers as the front face and the carbon/Kevlar hybrid laminated with carbon layers as the front face, which exhibited superlative energy absorption capacities. The observed damage modes encompassed fiber breakages, matrix cracks, and interlayer delamination. In summary, these collective investigations furnished a substantial contribution towards enhancing our comprehension of bulletproof vest design, specifically about the indispensable number of Kevlar layers, the

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## Sustainable innovation in bulletproof vest design: Exploration of polyurethane-coated hemp fabrics and sandwich composites against 9 mm and .40 S&W bullets

### Abstract

This research aimed to evaluate the bulletproof capabilities of hemp fabrics and optimize the design factors for effective bulletproof vests. Three main aspects were investigated: enhancing toughness with polyurethane-coated hemp fabrics, determining optimal placement of fabric-reinforced hemp epoxy composites in various configurations, and identifying the optimal number of fabric layers for performance against 9 mm and .40 S&W bullets. Penetration depth was measured in ballistic gelatin to analyze the results. The study showed strong statistical correlations between factor variables and penetration depth shifts. The most effective strategies included polyurethane-coated hemp on all layers and increased layering. The ammunition of 9 mm bullets exhibited the least penetration depth when tested against the sandwich-reinforced configuration. In contrast, the larger .40 S&W bullets demonstrated that the frontal arrangement yielded the minimum penetration depth. Notably, 9 mm bullets penetrated 1.24 times deeper than .40 S&W bullets. These findings emphasize hemp fabric's potential for reliable bulletproof vests. Utilizing polyurethane-coated hemp with a sandwich reinforcement of at least 241 layers is recommended to stop 9 mm bullets effectively. The research contributes valuable insights to sustainable bulletproof vest development, utilizing natural materials with exceptional bullet protection capabilities.

**Keywords:** Bulletproof vests; Hemp fabrics; Sandwich reinforcement; Ballistic gelatin

### 1. Introduction

This research is centered around the optimization of hemp fabric bulletproof vests, with a specific emphasis on elevating their protective capabilities against 9mm and .40 S&W ammunition. Hemp fabric is recognized for its exceptional tensile strength [1], lightweight properties, and cost-effectiveness, rendering it a highly suitable material for fashioning bulletproof vests [2-4]. This study employs experimental methodologies to examine the intricate interplay of diverse parameters. These encompass the application of polyurethane-coated hemp fabrics, the strategic arrangement of hemp fabric reinforcements, the

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Author 2 Manop Pipathattakul <sup>2</sup>	Data curation	Software	Visualization, Investigation		
Author 3 Fasai Wiwatwongwana <sup>1*</sup>	Conceptualization	Validation	Supervision.	Writing- Original draft preparation	Reviewing and Editing

#### Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Fasai Wiwatwongwana reports statistical analysis and writing assistance were provided by Pathumwan Institute of Technology. Tannachart Wantang has patent Carbon fiber bulletproof armor plates. pending to 9250.

#### Cover letter

July 17, 2023

Editorial of Results in Materials

Colorado State University,

Department of Mechanical Engineering,

Fort Collins, Colorado, United States of America

Dear Editor of Results in Materials.

I am submitting a manuscript for consideration for publication in Results in Materials. The manuscript is entitled “Experimental Investigation of Bullet-Proof Capabilities in Carbon-Kevlar Composites: Weight and Layer Variations with 9 mm Projectiles”.

It has not been published elsewhere and it has not been submitted simultaneously for publication elsewhere.

Carbon-Kevlar presents an intriguing material choice for the fabrication of bulletproof vests, particularly against pistol bullets. Its exceptional strength, lightweight nature, and cost-effectiveness have made it a preferred option in the realm of car tuning equipment. The objective of this study was to conduct a comprehensive examination of various factors, including the number of layers and weights of Carbon-Kevlar, in order to determine the optimal configuration for designing a secure and reliable bulletproof vest. Through rigorous testing, which involved evaluating the penetration depth of FMJ 9mm parabellum in ballistic gelatin blocks, it was established that a minimum of 36 layers, with a weight of 300 GSM, of Carbon-

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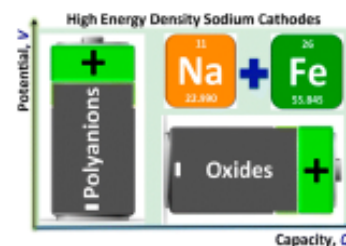
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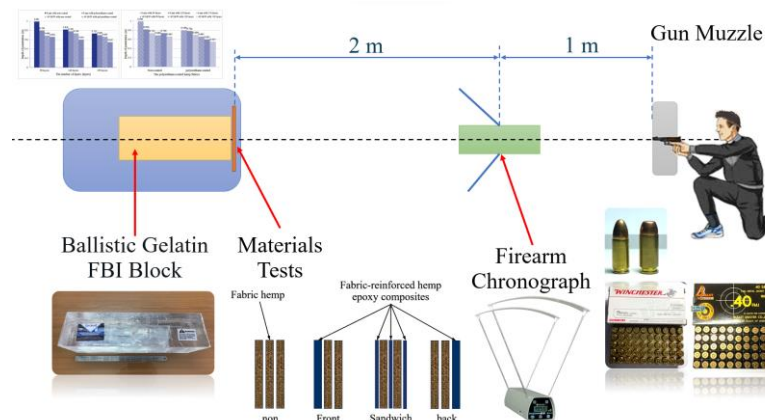
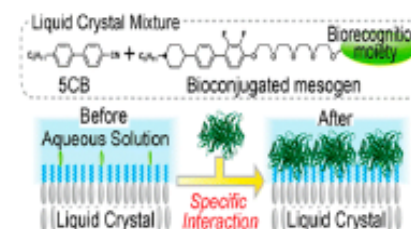
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Editor: Please note while some reviewers may have suggested a list of references to be added to the manuscript, the authors have the right to decide what references to use in their work. Authors can choose different references to be added as long as they address the comments from the reviewers.

Reviewer 1: 1. Normally it is expected the manuscript is written in third person language (I, we must be avoided). The sentences can be reframed.  
2. Figure 2(b) can be improved by marking distance.  
3. Figure 4, 5 and 6 are dull and may be improved.  
4. Some real images of penetration, fracture of layers, test sample after penetration may enhance results.  
5. Following reference may be added:  
DOI: 10.1007/s10443-023-10112-0  
DOI: 10.1007/978-981-16-9523-0\_13

Reviewer 2: The manuscript can be considered for publication in this journal after addressing the following major issues:

- 1- In the Title, the statistical analysis should be placed due to its great role in the study.
- 2- The literature review of the manuscript should be enhanced. Please refer to the more related references to improve the level of the manuscript. Following papers are useful for this aim:  
- DOI: 10.1080/00405000.2021.1914408  
- DOI: 10.1177/0954406219897935  
- DOI: 10.1016/j.mtcomm.2018.08.016
- 3- In page 4 (5 of pdf) and in section 2.2, please explain more about how the layers are placed together.
- 4- In section 2.2, it is necessary to mention the number of chosen test layers and the reason for this choice.
- 5- In page 5 (6 of pdf) and in section 2.4, specify the material type of projectile.
- 6- The quality of figures 3-11 is low.
- 7- Page 3- Delete paragraph 3 (The article was ... for future investigations.)
- 8- Do not use the word "we" in the manuscript.
- 9- The abbreviations should be mentioned in manuscript completely after the full names (For example: complete the full name of the abbreviation of UHMWPE).
- 10- Throughout the text, Carbon should be written in lowercase letter in sentences.
- 11- Figures 7-11, the title of the axes of these figures must be added correctly.
- 12- The absorption kinetic and the residual velocity of individual bullets after the impact could be reported.
- 13- For better interpretation of results and helping the discussion, there is a need to investigate every

## Major Revision

## Minor Revision

## Journal Pre-proof

Experimental investigation of Ballistic capabilities in Carbon-Kevlar composites: Effects of weight and layer variations against 9 mm projectiles

Tannachart Wantang, Manop Pipathattakul, Fasai Wiwatwongwana

PII: S2590-048X(23)00102-4  
DOI: <https://doi.org/10.1016/j.rinma.2023.100464>  
Reference: RINMA 100464

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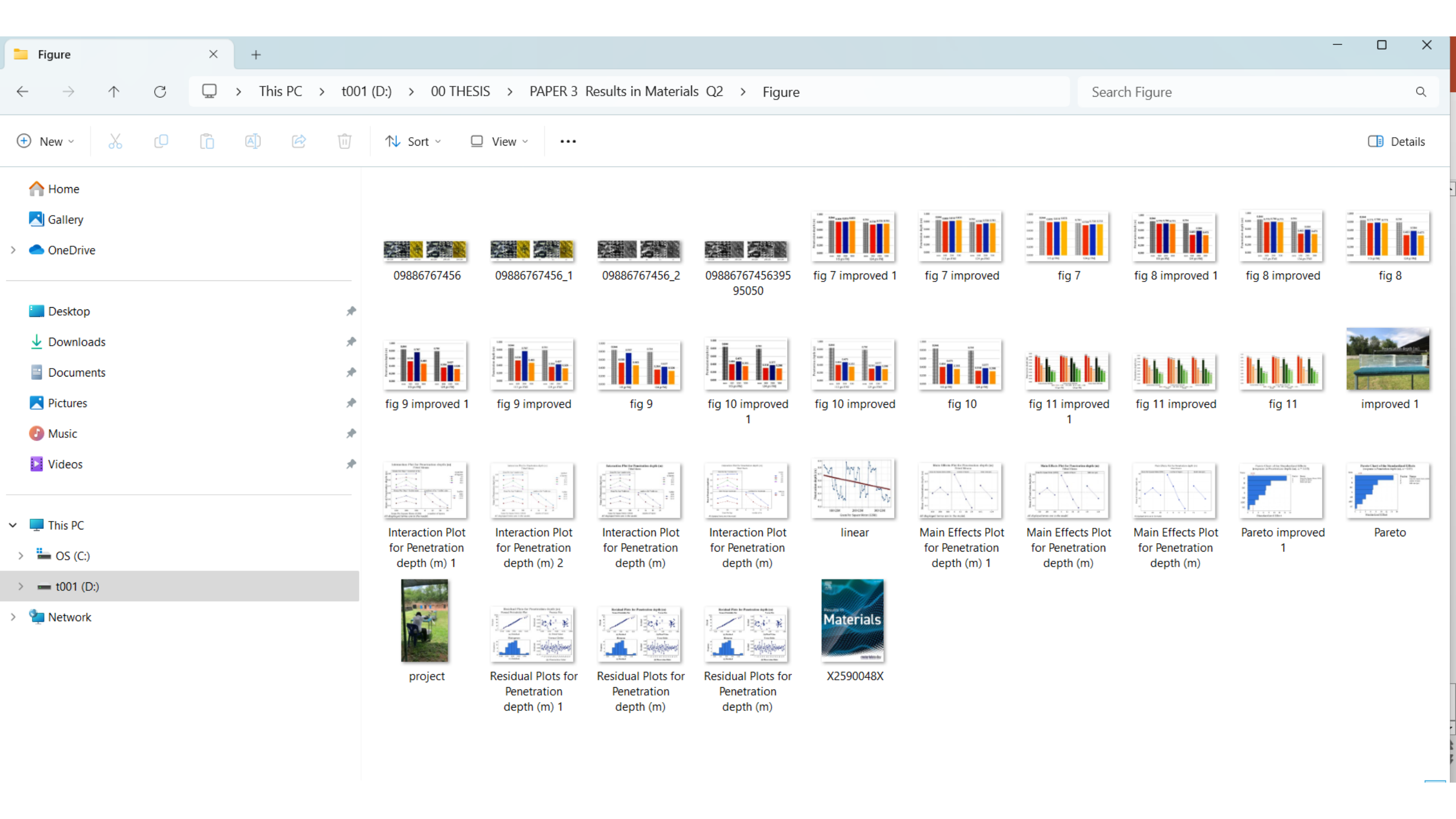
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3D-numerical-simulations-of-ductile-targets-subj_2010_International-Journal-	5/9/2563 2:42	Adobe Acrobat D...
A-comparison-of-the-ballistic-behaviour-of-conventionally-si_2020_Defence-Te	5/9/2563 2:39	Adobe Acrobat D...
Aerodynamics-of-ducted-re-entry-vehicles_2020_Chinese-Journal-of-Aeronautics	5/9/2563 2:39	Adobe Acrobat D...
An experimental investigation on ballistic efficiency of silica-based	11/1/2564 14:40	Adobe Acrobat D...
A-numerical-study-on-the-deformation-and-fracture_2014_International-Journal	5/9/2563 2:42	Adobe Acrobat D...
Ballistic impact analysis of graphene nanosheets reinforced kevlar-29	11/1/2564 14:38	Adobe Acrobat D...
Ballistic trauma patients have decreased early narcotic demand	11/1/2564 14:41	Adobe Acrobat D...
Ballistic-behavior-of-epoxy-matrix-composites-rein_2020_Journal-of-Materials	5/9/2563 2:39	Adobe Acrobat D...
Ballistic-comparison-between-epoxy-ramie-and-epox_2018_Journal-of-Materials-	5/9/2563 2:48	Adobe Acrobat D...
Ballistic-Energy-Conversion-with-78--Efficiency-an_2020_Cell-Reports-Physica	5/9/2563 2:40	Adobe Acrobat D...
Ballistic-impact-properties-of-woven-bamboo--woven-E-glass--_2019_Defence-Te	5/9/2563 2:48	Adobe Acrobat Dacume
Ballistic-performance-and-failure-modes-of-woven-and-unidir_2021_Composite-S	11/1/2564 7:29	Adobe Acrobat D...
Ballistic-thermal-transport-in-asymmetric-Y-branch-three-_2020_Results-in-Ph	5/9/2563 2:39	Adobe Acrobat D...
Damage-and-self-healing-characteristics-of-monolayer-grap_2021_Mechanics-of-	11/1/2564 7:29	Adobe Acrobat D...
Damage-mechanics-and-energy-absorption-capabilities-of-natural-_2020_Defence	5/9/2563 2:39	Adobe Acrobat D...
Damage-modeling-of-ballistic-penetration-and-impact-behavior_2020_Defence-Te	5/9/2563 2:39	Adobe Acrobat D...
Delamination-process-in-cross-ply-UHMWPE-laminates-under-_2020_Defence-Techn	5/9/2563 2:39	Adobe Acrobat D...
Design-strategy-for-optimising-weight-and-ballistic-perfo_2020_Composites-Pa	11/1/2564 7:29	Adobe Acrobat D...

