

# Mechanical Behavior of Tungsten Carbide Under the High Impact Velocity Application: A Numerical-Based Study

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**Abstract-** This study examines the mechanical response of tungsten carbide under high-velocity impact conditions. Finite element analysis (FEA) simulations were conducted on a rectangular plate, both with and without the incorporation of tungsten carbide. The explicit dynamic simulations were executed using the Ansys LS-DYNA solver. A high-velocity projectile was simulated to impact the rectangular plate, and the resulting deformation behavior and induced stresses for both scenarios were analyzed and compared. The results demonstrate that the plate reinforced with tungsten carbide exhibits significantly higher resistance to deformation under high-velocity impact. Additionally, the stress levels induced in the tungsten carbide-reinforced plate were notably lower compared to the plate without tungsten carbide. These findings highlight the potential of tungsten carbide as a promising material for applications involving high-velocity impacts.

**Keywords -** Tungsten carbide, High-velocity impact, Finite element analysis (FEA), Explicit dynamic simulation, ANSYS LS-DYNA.

## I. INTRODUCTION

Polymer Matrix Composites (PMCs) are composed of a matrix derived from either thermosetting or thermoplastic materials, reinforced with fibers such as carbon, glass, Kevlar, or metals. Thermosetting polymers are often preferred over thermoplastics due to their superior strength and enhanced resistance to elevated temperatures [1]. Personal body armor plays a critical role in protecting individuals from severe or life-threatening injuries. However, these systems must exhibit advanced ballistic performance while remaining lightweight, flexible, and comfortable to ensure user acceptance and operational effectiveness [1, 2]. While polymer-based composites are capable of withstanding low-velocity impacts, their performance under high-velocity impacts is limited. To address this, hybrid materials such as Fiber Metal Laminates (FMLs) have been developed, which combine polymer-based composite layers with metallic alloys in an alternating stack configuration. These hybrid structures demonstrate superior mechanical

performance, particularly under high-velocity impact conditions [3]. The primary function of armor systems, such as bulletproof applications, is to protect against injuries caused by direct hits from weapons or high-speed projectiles.

Thick Kevlar-epoxy plates are commonly employed to study ballistic responses [4]. Extensive research has been conducted on the impact behavior of composite materials and their industrial applications, focusing on their properties, types, and advantages. A comprehensive understanding of energy-absorbing mechanisms in fibers, textiles, polymer laminates, and ceramics has been established [1-5]. Suthan et al. [6] investigated the potential of Kevlar-reinforced epoxy composites as a replacement for aluminum in various applications, utilizing Finite Element Analysis (FEA) to validate experimental results. Marx et al. [7] demonstrated that Composite Metal Foam (CMF) provides effective ballistic protection against projectiles exceeding 800 m/s, absorbing up to 79% of the impact energy. [8] conducted toughness evaluations using Izod and Charpy impact tests on epoxy matrix composites

reinforced with fique fabric, revealing significant differences in performance based on fiber volume fractions. Goyal et al. [9] developed a high-performance composite material that offers lightweight bulletproof protection with minimal surface deformation. Rangaswamy et al. [10] explored the influence of multi-walled carbon nanotubes (MWCNTs) on composite properties, while Shih et al. [11] investigated the impact resistance of aramid fabrics reinforced with shear thickening fluids (STFs). Bao et al. [12] reported that hybrid CFRP/AFRP laminates with 20-30 wt% CFRP content exhibited superior ballistic performance compared to AFRP at projectile velocities ranging from 400 m/s to 800 m/s. Alabay et al. [14] enhanced the impact resistance of aramid fiber-reinforced epoxy composites by incorporating titanium carbide (TiC) and zirconium carbide (ZrC) nanoparticles. Braga et al. [15] improved ballistic performance by modifying the impact geometry of aluminum and multilayered armor systems, with convex-faced ceramics outperforming flat-faced designs. Petrov et al. [16] studied the effects of high-velocity tungsten particle flux on steel surfaces, while Amirian et al. [17] examined the high-velocity impact (HVI) behavior of epoxy-based Kevlar-basalt hybrid composites. Jengin et al. [18] investigated the impact resistance of epoxy laminates reinforced with aluminum oxide nanoparticles under high-velocity bullet impacts. Benzait et al. [19] explored the use of nanomaterials, such as carbon nanotubes and graphene, to enhance the mechanical properties of armor composites. Shen et al. [20] evaluated bonding adhesives under ballistic penetration conditions, observing full penetration at 776 m/s and partial penetration at 791 m/s. Clifton et al. [21] summarized recent advancements in fiber-reinforced hybrid nanocomposites, and Bhat et al. [22] analyzed the ballistic behavior of various armor systems, including fiber-reinforced polymer composites, metallic armor, and multilayer armor systems (MAS).

Carbide materials, which are compounds of carbon with metals or metalloids such as tungsten (WC), titanium (TiC), or tantalum (TaC), exhibit exceptional hardness, wear resistance, and toughness. These properties make them ideal for applications requiring resistance to impact, wear, and high

temperatures. Tungsten carbide, in particular, is renowned for its high melting point and strength, making it highly suitable for high-impact applications such as armor systems. Based on a comprehensive review of existing literature, tungsten carbide has been identified as a highly effective material for high-impact applications. This study aims to investigate the behavior of a tungsten carbide matrix under high-velocity impact conditions using FEA. Explicit dynamic simulations were conducted using Ansys LS-DYNA software. The article is structured as follows: Section 2 discusses material selection, boundary conditions, and simulation parameters. Section 3 presents the results of high-velocity impact simulations for materials with and without tungsten carbide. Finally, Section 4 summarizes the findings of this study.

## II. METHODS

**Modeling:** The geometric modeling of the rectangular plate, with dimensions  $200 \times 300 \times 20$  mm, was performed using the Ansys Design Modeler tool. Additionally, two bullet-shaped objects were constructed for the simulation. The numerical analysis and modeling were carried out using Ansys Workbench 2023 R1. The simulation was conducted in two phases:

**First Phase:** The plate was modeled without any hybrid composite material.

**Second Phase:** The plate was modeled as a hybrid composite material.

Post-processing was performed to evaluate the total deformation and stress distribution in both cases. The simulations were solved using Ansys Explicit Dynamics with AUTODYN, which provided accurate modeling results. Material properties for each component were assigned using the Ansys Engineering Data module. A high-quality mesh was generated, and appropriate boundary conditions and initial states were defined to ensure realistic simulation conditions.

**Bullet Model:**

**The bullet model was divided into two parts:**

Outer Part (Jacket): Represents the Full Metal Jacket (FMJ).

Inner Part (Core): Represents the 9×19mm Parabellum core as shown in Figure 1 and Meshing of bullets as shown in Figure 2. Material properties for the core and jacket were assigned as per Table 1 and Table 2, and Table 3 respectively, forming the FMJ configuration. The material properties were selected from the explicit materials database available in Ansys Engineering Data. For meshing, Ansys Explicit Dynamics was utilized, employing various meshing techniques such as body sizing. The jacket was meshed using hex-tetra elements, while the core was meshed using hex elements, both with default element sizes to ensure computational efficiency and accuracy. This approach ensured a robust and reliable simulation setup for analyzing the high-velocity impact behavior of the plate with and without the hybrid composite material.

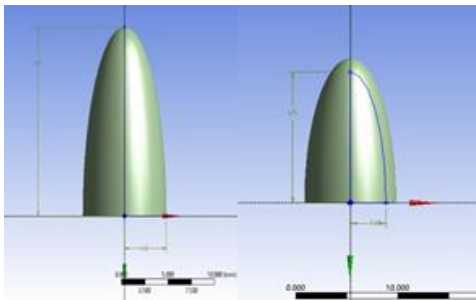


Figure 1: Bullet model in Ansys Design Modler

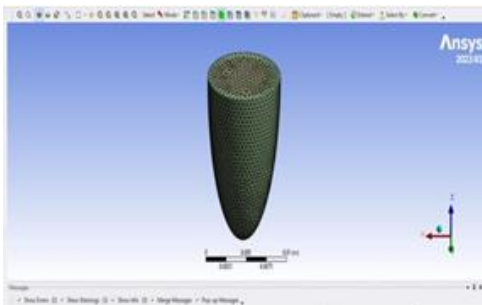


Figure 2: 3D mesh of bullets

**Ballistic Plate:**

The ballistic plate is composed of an epoxy resin matrix reinforced with two materials: Kevlar and tungsten carbide. The plate was fabricated using a hand layup process followed by compression

molding. The thickness of the Kevlar-29 layer is 8 mm, and the tungsten carbide layer is also 8 mm, resulting in a total plate thickness of 16 mm. The total weight of the fabricated plate is 0.87 kg. The material properties for the epoxy resin, Kevlar, and tungsten carbide were obtained from the Ansys Explicit Engineering Data library and modeled using the Ansys Design Modeler. 3D mesh model of Ballistic Plate as shown in Figure 3. The material composition of the ballistic plate is detailed in the accompanying table. For the finite element analysis, the plate was discretized into a mesh with the following specifications:

**Sample 1:**

Total number of elements: 18,270

Total number of nodes: 13,589

**Sample 2 (with Tungsten Carbide):**

Total number of elements: 14,970

Total number of nodes: 8,387

The meshing process ensured an accurate representation of the plate's geometry and material distribution, enabling precise simulation of its ballistic performance under high-velocity impact conditions.

Table 1: material composition of ballistic plate

| Sr. No. | MATERIAL            | COMPOSITION |
|---------|---------------------|-------------|
| 1.      | Epoxy Resin         | 27%         |
| 2.      | Kevlar Fiber        | 23%         |
| 3.      | Tungsten Carbide    | 45%         |
| 4.      | Hardener (HSC 7251) | 5%          |

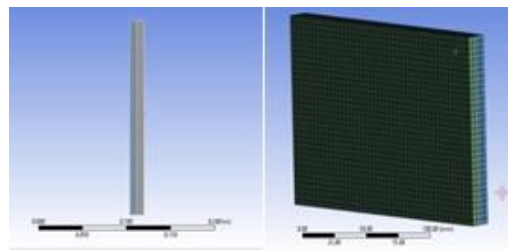


Figure 3: 3D mesh model of Ballistic Plate

Table 2: Material modelling of tungsten carbide lay

|                           |   |   |
|---------------------------|---|---|
| Shock EOS Linear          | Gruneisen Coefficient                     | 1.26  |
|                           | Parameter C1 mm s <sup>-1</sup>           | 4.756e+006                                  |
|                           | Parameter S1                              | 1.38  |
|                           | Parameter Quadratic S2 s mm <sup>-1</sup> | 0   |
| Steinberg Guinan Strength | Initial Yield Stress Y MPa                | 2200  |
|                           | Maximum Yield Stress Ymax MPa             | 4000  |
|                           | Hardening Constant B                      | 7.7   |
|                           | Hardening Exponent n                      | 0.13  |
|                           | Derivative dG/dP G'P                      | 1.501                                       |
|                           | Derivative dG/dT G'T MPa C <sup>-1</sup>  | -22.08                                      |
|                           | Derivative dY/dP Y'P                      | 2.064e-002                                  |
|                           | Melting Temperature Tmelt C               | 4246.9                                      |
|                           | Shear Modulus MPa                         | 1.6e+005                                    |
|                           | Tensile Ultimate Strength MPa             | 400   |
|                           | Density                                   | 1.4356e-005 kg mm <sup>-3</sup>             |
|                           | Specific Heat                             | 2.e+005 mJ kg <sup>-1</sup> C <sup>-1</sup> |

Table 3: Material modelling of Kevlar Constants

|               |   |
|---------------|---|
| Density       | 1.44e-006 kg mm <sup>-3</sup>                 |
| Specific Heat | 1.42e+006 mJ kg <sup>-1</sup> C <sup>-1</sup> |

#### Analysis Settings:

The impact simulation was conducted by assigning initial velocity conditions of 800 m/s, 600 m/s, and 400 m/s in the Z-direction to the projectiles for Sample 1, Sample 2, and Sample 3, respectively. The ballistic plate was subjected to fixed support boundary conditions in the X and Y planes, restricting displacement in these directions. The end time for the analysis was set to  $9 \times 10^{-4}$  s, with a maximum of  $10^7$  computational cycles. The minimum time step was defined as  $1 \times 10^{-10}$  s, and a time step safety factor of 0.5 was employed. A bounded contact interaction was established between the tungsten carbide and Kevlar 29 layers in the ANSYS model simulation settings to ensure accurate interface behavior. To evaluate the ballistic performance, the solver output was configured to analyze both total deformation and Z-directional

deformation of the layered structure as shown in Figure 4. Additionally, the mechanical properties and failure criteria of the materials were defined in the material modeling section.

#### Sample 1 Analysis:

The simulation results indicate deformation in the Z-direction for the ballistic plate, which consists of a tungsten carbide layer, while the additional shielding comprises Kevlar 29. The bullet velocity was maintained at 800 m/s. The model clearly demonstrates that the armor structure was penetrated by the 9 mm FMJ bullet. The influence of incorporating a tungsten carbide layer on Kevlar 29 was observed, as the composite system effectively stopped the high-velocity projectile. Furthermore, von Mises stress distribution was analyzed to assess the residual stress across the entire structure.

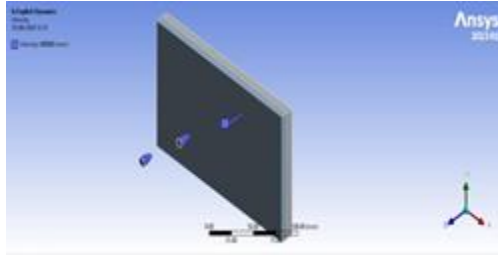


Figure 4: Direction of velocity

As you can see the negative deformation numbers i.e. minimum deformation represent the deformation of Kevlar aka without hybrid is -65.488 mm that's the distance in z direction (direction of thickness of plate) in which the material elongated you can see in the images the yellow and red portion indicates a -65.488 mm hole in plate as shown in Figure 5. Deformation and Stress for hybrid plate for 800, 600 and 400 m/s respectively as shown in Figure 6 to Figure 11.

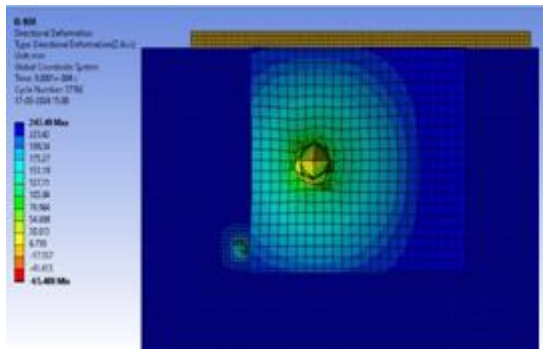


Figure 5: Deformation on Kevlar 29 in Z direction 800m/s

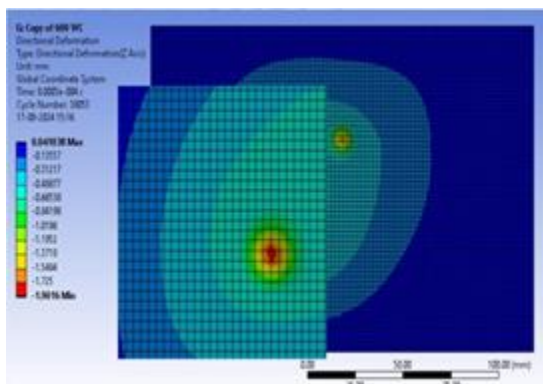


Figure 6: Deformation on hybrid plate in z direction 800 m/s

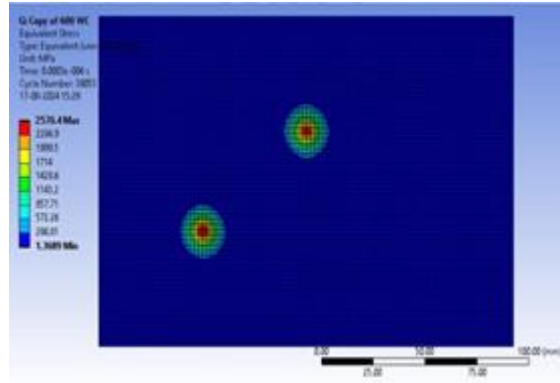


Figure 7: Stress on hybrid plate 800 m/s

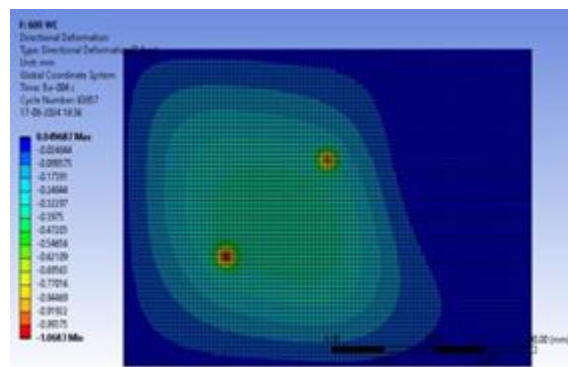


Figure 8: Deformation on hybrid plate in z direction 600 m/s

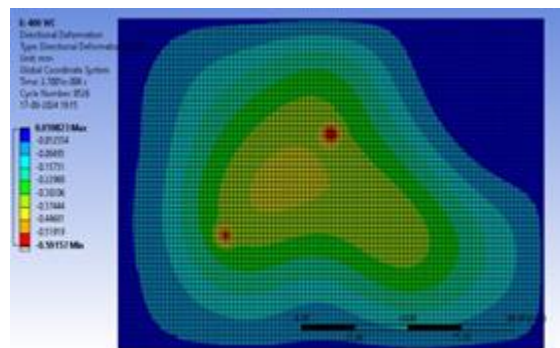


Figure 9: Stress on hybrid plate 600 m/s

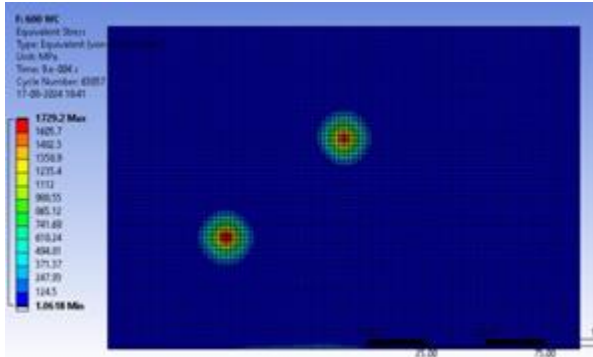


Figure 10: Deformation on hybrid plate in z direction 400 m/s

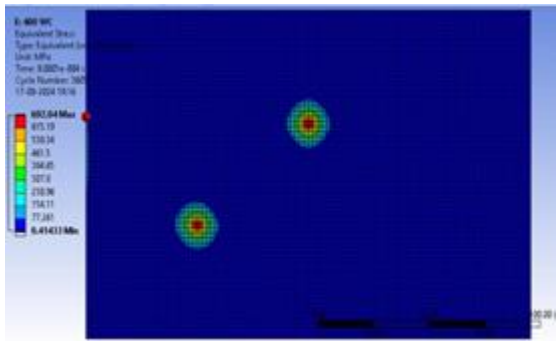


Figure 11: Stress on hybrid plate 400 m/s

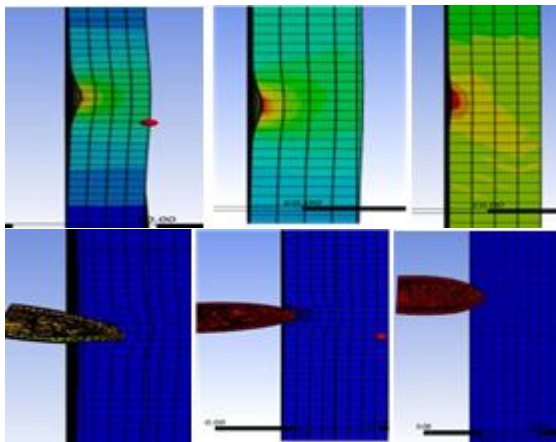


Figure 12: Deformation of Kevlar for 800, 600 and 400 m/s

### Results and Discussion

The analysis considers three samples categorized based on bullet velocity, with six corresponding deformation alternatively, the samples can be classified into two groups: with hybrid composite and without hybrid composite. This section presents and compares the simulation results for impact scenarios with and without hybrid composites.

Deformation of Kevlar for 800, 600 and 400 m/s shown in Figure 12. Directional deformation in Z direction of tungsten layer of sample less as compared to without tungsten layer as shown in Table 5.

Table5: Directional deformation in Z direction of tungsten layer of sample and without tungsten layer during the time of simulation

| Material       | Deformation In Z-Axis (mm) |                |                |
|----------------|----------------------------|----------------|----------------|
|                | Sample 1 (400)             | Sample 2 (600) | Sample 3 (800) |
| Without Hybrid | 7.4733                     | 12.147         | 6.5472         |
| With hybrid    | 0.6713                     | 1.3102         | 1.9142         |

### III. CONCLUSION

This study investigates the impact resistance of hybrid composites through numerical simulations. The analysis considers specimens both with and without a tungsten carbide layer to evaluate their deformation behavior under impact loading.

The results indicate that specimens without tungsten carbide exhibit significant deformation, whereas those incorporating tungsten carbide demonstrate higher resistance to deformation. Additionally, the induced stress in the tungsten carbide-reinforced specimen is observed to be lower compared to the non-reinforced specimen, highlighting its effectiveness in mitigating impact forces.

The numerical analysis confirms that the addition of tungsten carbide enhances the mechanical properties of the composite, making it more suitable for high-impact applications.

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