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# A SURVEY OF THE OPTIMIZATION TECHNIQUES FOR THE DESIGN AND MANUFACTURING OF BALLISTIC PROTECTION

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**Abstract**

In this research, a brief survey of the techniques used for the optimization of ballistic protection are discussed. Moreover, this paper focuses on the modelling techniques of the blast/explosions from an IED or a suicide bombing. The study focuses only one single aim i.e design of a highly efficient ballistic protection. Ballistic Protection is a major concern when there exist high level threats of terrorism targeting security personnel and military patrol vehicles. Land Mines do pose a significant threat to military operations. Two types of impacts that are the major cause of lethality of Improvised Explosive Devices and other Suicide Bombings are the shockwaves and the shrapnel. Similarly, law enforcing agencies often do tackle situations where law-breakers often use arms against them. In all these situations there is a high urge to briefly elaborate and discuss the effect of explosions and blast and how to develop a protection that can mitigate the effect of the bomb partially or completely. In this regard, the contribution of composite structures for the design and manufacturing of ballistic protection is surveyed. Evaluation of materials with different behaviors used in the development of ballistic protection was discussed. The technique and approach for solving the problems associated with explosion/ blast modelling in LS-Dyna was briefly elaborated in one of the publications surveyed.

**Keywords**: ballistic protection, Improvised Explosive Devices (IED), Kevlar, Dynamic Explosions, Blast Simulation, NIJ-National Institute of Justice

## 1. INTRODUCTION

In late 1960s new fibers were discovered and research was started to find light weight body armor. DuPont's Kevlar ballistic fabric was one of the most significant discoveries in body armor research, the intended purpose of the fiber was to replace the steel belting in vehicle tires. The bullet proof vest had also become a part of metropolitan police department. The anti-ballistic proof jackets were used in world war-II which is also known as Flak jacket. The designed jacket did not prove effective for the pistols and the rifle threats. The heavy weight of the jacket was a main reason behind the low demand of the jacket in the armor market.

Meanwhile, the creation of Kevlar armor protection by National Institute of Justice was based on four phases that spanned several years. The very initial phase determined if Kevlar fabric could stop a bullet. The next phase covered estimation of the numeral of sheets of material sufficient enough to stop the bullet from penetration at various speeds with different calibers, as well as constructing a prototype vest to defend officers from the most common threats: 38 Special and 22 Long Rifle rounds.

The movement's third phase included thorough medical examination and inspection to assess the amount of body armor performance required to preserve police officers' lives. For the very final case, armor's method used to measure the effectiveness were monitored. The vest was found to be comfortable, prevented any undue generation of stress or pressure on the shoulders, and allowed typical body movement required for police duties in a preliminary test in three cities with ease. Adaptability in variations of temperature, comfort level during a complete working day, and durability over long years of use were all the necessary considerations for the design. Designers worked out to make a body armor which could bear the 38-caliber bullet which had the velocity of 800 ft/s. The design proved very effective as it demonstrated extremely low penetrations from bullets. The novel protective material proved as an effective solution in delivering a bullet protective jacket that was lighter in weight and comfortable for long shift/time duties, according to a report finalized in 1976.

For many years, the main goal of body armor development was to provide increased levels of protection. This process appears to have reached a nadir, as modern body armor offers less protection than that of the 1970s, owing to the belief that increased mobility comes after a compromise on the level of offered protection.

## 2. LITERATURE REVIEW AND ANALYSIS

### 2.1 Study of methods of development for improvement in ballistic protection of vehicles using the concept of composites and sandwicthed panels.

Stiavnicky with Adamec [1] proposed a comparative study of composite materials for safety required by military patrol vehicles in terms of ballistic protection. They designed three different composite armors and analyzed it via LS dyna software package and their individual performances were evaluated against a sub-caliber round. Stiavnicky and Adamec further concluded that the that from the comparison of a homogenous ballistic protection plate from SSAB (Swedish Steel Group Company), a Silicon Carbide plate inserted between two armox 500T plates, a several layer woven Kevlar fibers sandwiched between two Armox 500T plates and the same Kevlar layer combined with two Toolox 44 material, the Toolox and Kevlar combination was clearly the most effective as it absorbed the most impact energy.

### 2.2 Evaluation of explosion resistance of ballistic polymeric materials

Skalicky, Komenda, Vitek, Jedlicka and Vlhova [2] published the results of an experimental comparative study of different materials subjected to a highly explosive blast for ballistic testing. They used fabric from two different manufacturers, three laminated and three woven and therefore conducted six sample tests. Their experiment was primarily based on the exposure of the specimen to the effects of blast from a reference charge. The testing conditions were maintained the same for each of the six fabrics. Test samples with similar constraints were extracted from the set of fabrics chosen. Their experiment proved different explosion resistances and proved the claim of the manufacturers about their impact absorption values.

### 2.3 The Damage Analysis from Ballistic Threats on Transparent Armor

Chaichuenchob and his team [3] had carried their research in transparent armors comprising of transparent. They laminated various soda lime panes of glass using polyvinyl butyral as reinforcements. The testing of the designed armor was done using a 7.62 mm FMJ armor fired at different speeds. They realized that the total of cracks generated on the 12 mm strike plate was greater when compared with a 19 mm strike plate tested under the same conditions. They calculated the surface areas for these two plates and further deciphered that the same amount of energy (kinetic) was absorbed during the impact. The bifurcation of the cracks was observed when the velocity surpassed $838\ ms^{-1}$. Ultimately, they concluded their research with the recommendation that their study can be used for the optimization and improvement in the field of transparent armor.

### 2.4 Evaluation of various Textiles for high performance as ballistic protection

Agrawal [4] proposed a detailed analysis on high performance textiles essentially significant in ballistic protection. They explored the use of several textiles such as Nylon, Carbon fibers, Ceramic fibers, Aramids and Glass Fibers, Ultra High Modulus Polyethylene (UHMPE), Thermoplastic Liquid Crystal Polymer (TLCP), p-Phenylene -2,6-Bezobisoxazole (PBO). He further proposed an approach for the construction of ballistic protection such as woven textiles, non-woven, Composites and laminates, moreover he proposed the recent development in the field of ballistic safety particularly in bullet proof pocket square and Soldier exoskeleton.

### 2.5 Prefabricated Steel Stud Wall as Bulletproof protection

Ngamjarungjit, and others [5] investigated the behavior of a bullet proof steel stud wall. They had initially described their purpose of research that was to design a rapidly installable wall. They used cold-formed 10-cm thickness steel that served as the cladding for the external surface. This insulation was extracted from concrete mixed with foam that made the design lighter in weight and weather resistant. Results of the 0.5 mm thick sandwiched steel stud wall showed the level of protection provided by the wall system. The firing took place on a firing range with a standard range between the rifle and the test subject of 15 meters. 5.56x45mm ammo and an M16Al rifle were used for the tests. They, concluded their research after claiming that their product satisfied and met the requirements essential for the level III protection.

**Table 1:** Results of experiments performed [2]

| No. | Style | Areal density ($kg.m^{-2}$) | Number of layers (ks) | Thickness of one layer (mm) | Sample thickness (mm) | Total areal density ($kg.m^{-2}$) | Number of punched layers (mm) | Areal density of punched layers ($kg.m^{-2}$) | Relative punched thickness (%) | Relative number of punched layers (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UD-42 | 0.246 | 20 | 0.23 | 4.6 | 4.92 | 0.92 | 0.98 | 20 | 20 |
| 2 | Microflex | 0.216 | 23 | 0.26 | 6 | 4.96 | 1.3 | 1.08 | 21.74 | 22 |
| 3 | CT 714/2 | 0.203 | 25 | 0.22 | 5.4 | 5.07 | 1.08 | 1.02 | 20 | 20 |
| 4 | Sp Sa-3118 | 0.173 | 29 | 0.17 | 5 | 5.01 | 1.21 | 1.21 | 24.14 | 24 |
| 5 | CT 709/2 | 0.122 | 41 | 0.12 | 5 | 5 | 0.73 | 0.73 | 14.63 | 15 |

### 2.6 Simulations of the aftermath of Suicide-Bombing via Blast-sim

Zeeshan, Usmani and others [6] proposed their research in Blast-Sim. Blast-Sim refers to the physics associated with stationary multi-agent computational model of blast-waves. The effect of the blast on human body was also an integral part covered in their research. The agents were constrained by mechanics of the blast wave and its physical characteristics. The simulations were designed to capture the effect of human group formation and patterns on the scale of wounds and number of fatalities in case of a bomb attack particularly a suicide attack.

### 2.7 Emergency 101 – Suicide Bombers, Crowd Formations and Blast Waves

Zeeshan and Kirk [7] again investigated the impact of suicide bombing in another paper they published. They declared Suicide bombing as the most effective method for terrorist organizations worldwide. They showed the significance of the impact crowd density on the effectiveness of the suicide bomb. They developed a virtual simulation tool which had the capacity of analyzing the effect of human formation and crowd layouts on the magnitude of wound and number of expiries during the madness.

### 2.8 Study of the testing method of aerial blast point based on shock wave overpressure.

Sheng, Hao and Xue-Lin [8] showed their interest in the analyses of the examination technique of aerial blast points primarily reliant on blast wave over pressurization. They began their research by initially describing the problem associated with low positioning accuracy that poses a great threat to the workers in traditional method of the aerial blast point, a built a model to locate the point. They investigated the peak over pressure information for incident shock wave along with newtons method that are capable of solving the problem described initially. Finally, they verified positioning accuracy of the model through experiments.


### 2.9 The Simulation Analysis on the Numerical Destructiveness of different wall materials Under the Explosion Overpressure Shock Wave

Jiang and others [9] presented the idea of analysis via simulations of the numerical destructiveness of various wall materials when exposed to an explosion overpressure shock wave. The paper they published includes the modeling and analysis of the dynamic response of the common wall, blast wall and shear wall under blast loading. The models were simulated using ANSYS\LS-DYNA as software for simulations and analysis. By the analysis of the stress changes and overpressure peaks of wall under the blast loading, they were able to achieve properties of the wall material against over pressurization.

### 2.10 Research of Dynamic Response Numerical Simulation Technology about Underground Chamber with Blasting Load in Deep Environment

Dynamic Response of Numerical Simulation Technology (NST) in Relation to Underground Chamber with Blasting Load in Deep Environment was addressed by Hu and Yang [10]. They used the general (FEA) finite element analysis program ANSYS/LS-DYNA for their investigation. They used a conversion function and combined static and dynamic response in the methodology they adopted. They introduced nodal displacements as IC's (Initial Conditions. An extensive dynamic analysis was done to simulate the terrible effects that the blasting load would have on the next chamber. They offered the enthusiastic readers to further investigate the respective field.

### 2.11 Investigation and Application of Parallel Method for Blast Wave Interaction and Detonation

Application of Parallel Methods Essential for Blast Wave Contact and Discharge was explored by DENG and colleagues [11]. They proposed a similar strategy for the investigations through simulations of flow fields with moving and deforming pieces or chemical non-equilibrium explosion. The idea was built on an environment with multiple concurrently operating jobs. They provided two examples to demonstrate the speed increment of the parallel computation. Finally, they concluded that the results indicated the parallel algorithm, they implemented is effective and effectual and encouraged to further explore the relative field.

### 2.12 Computational Simulation of Shock Tube and the Effect of Shock Thickness on Strain-Rates

Laksari, Assari and Darvish [12] discussed about the computational Simulation of Shock Tube. They further brought along the impact of Shock Thickness on Strain-Rate into consideration. They looked into the high rates of loading involved in the development of explosive devices as well as the blast-induced neuro damage, which is a significant worry. On the basis of current investigations, they asserted that brain tissue experiences brief and rapid displacements under blast loading circumstances after studying recent publications. When modeling the reaction of tissues in shock tube situations, Laksari and colleagues investigated the effects and significance of shock front thickness. They showed in their research that the precautions they had made might significantly imply damage and causation hazards in computer models.

### 2.13 Damage modeling of ballistic impact in woven fabrics:

In this case study, S.D. Rajan and B. Mobasher [13] had made the structural system structural by dry woven and it was subjected to ballistic impact. The finite element analysis was main key which was used in modeling. They used fabric woven as it was having high strength to weight ratio in addition to it had the capability to fight from high-velocity piece impact. A continuum model was made at macro scale level instead of tale geometry at musicale level for analysis of ballistic influence. Friction and tension test were used for this experiment. Friction test was used to determine the static and dynamic coefficient. In order to calculate the distortion, damage and catastrophe reply of polymer matrix. It used the influence condition and it required the accurate material model. The changes could come in this model as well to make it more efficient and worthful.

### 2.14 Ballistic impact response of Kevlar reinforced thermoplastic composite armors:

In this Aswani Kumar Bandaru, Vikrant V Chavan, Suhail Ahmad R Alagirusamy, and Naresh Bhatnagar [14] used thermoplastic composite made by Kevlar of propylene composite armors. The performance of ballistic impact was observed by using this material. Kevlar fabrics of many architectures which are named as, 2D plain woven, 3D orthogonal and 3D angle interlock fabrics, were generated which made the panel of composite armor. The main technology which was used was compression molding. They used the coupling agent called maleic anhydride in order to make the interfacial property between Kevlar and propylene more efficient.

### 2.15 Ballistic Impact Behavior of thermoplastic Kevlar composites: Parametric studies:

In this research paper, Aswani, Kumar, Bandaru and Suhail Ahmad [15] observed the ballistic impact behavior by using Kevlar and propylene through Ansys software by doing hydrocode simulations. The investigational and mathematical results were investigated of ballistic impact reply against the Kevlar. The mathematical model was validated by scoring the presentation of Kevlar's ballistic impact under the simulated impact of a SATANG-2920 fragment. The shear plugging was main failure mechanism in thermoplastic composites. A body armor was made which was a good object in protective piece of clothing. The shear plugging was seen near the impact zone in terms of energy absorption method. The impact velocity was directly proportional to residual velocity. The increased residual velocity showed steep ballistic limit.

### 2.16 A ballistic material model for continuous-fiber reinforced composites:

To facilitate computational studies of advanced damage/failure in plain-weave composite coverings under high velocity ballistic impact circumstances, Chian-Fong Yen [16] created a ply-level material constitutive model for plain-weave composite laminates. In order to account for failures brought on by tensile, compressive, punch shear, and crush loads, they employed failure starting criteria and harm development regulations in their model. These fiber and matrix failure mechanisms were caused by the ballistic event. The Ansys software's and LS Dyna dimension was used to predict the plain weave composite layers' progressive failure performance. In the impact of ballistic in composite panels, the damage development and progression occur could be seen through this composite material.

### 2.17 Modelling of composite materials behavior for blast and ballistic impact:

C.F.Yen [17] developed the robust computational constitutive model. The failure behavior of composite laminates was investigated under explosion and ballistic circumstances. The LS-dyna program, which is a component of the Ansys software, was used to simulate the blast and ballistic impact on composite panels. In blast loading of light weight composite material, the damaged development and progression happened which could be seen through this composite models. The prophesied panel damage was related with tested panel. The current ballistic assessment approach yielded results for the value of V50 and projectile residual velocities for composite laminated panel with a precision of 13%, according to a comparison of repeated results with investigational data for composite panels

### 2.18 A computational analysis of the ballistic performance of light weight hybrid composite armors:

Basically, M. Grujicic and his team [18] determined strength of hybrid light weight fiber strengthened polymer matrix composite laminate armor so as to know that how much it could bear with impact of fragment simulating projectiles. It was supervised by using the non-linear dynamic transient computational analysis. They used carbon fiber reinforced epoxy which had high strength and high toughness. It was used in different combinations and stacking sequences. The ballistic performance of the armor was greatly hit because of using the assembling sequence and number of the laminates. The ballistic performance of the hybrid armor was increased by using the Kevlar fiber reinforced epoxy laminates which was the outer face of the armor.

### 2.19 Ballistic impact simulation of an armor-piercing projectile on hybrid ceramic/fiber reinforced composite armors:

In this Daniel Bürger and his team [19] made the composite of the model were alumina plates and ultra-high molecular weight polyethylene composites. The explicit finite element code was used for the three different constitutive models which were made for testing. The investigational and mathematical results were compared so as to cater the damage shape. Then the composite and ceramic materials were used to make it more efficient and useful. It enhanced the performance of the armor materials. The commonly used fiber for the armors is aramid and ultra-high molecular weight poly-ethylene. The alumina, silicon carbide and boron carbide were the commonly used ceramics. It was important to develop more efficient tolls to make the price low.

### 2.20 Fragment ballistic performance of homogenous and hybrid thermoplastic composites:

S.B. Sapozhnikov, O.A. Kudryavtsev and M.V. Zhikharev [20] had done many extensive ballistics tests on various protective composite structures. The speed had been reached up to 900 m/s. they used 6.35mm steel ball. The V50 threshold as well as the post V50 limit were used to evaluate the ballistic performance. It was seen that the effect of temperature was negligible. In high velocity impact condition, the absorbed energy and indicators of $V_{50}$ of UHMWPE fibers were good than by using other fibers. However, as the projectile's velocity reached the ballistic limit, their energy absorption capability dropped significantly. The ballistic limit, which establishes the incident impact velocity at which there is a 50% likelihood of damage, was one of the important variables.

### 2.21 Measurement of ballistic impact properties of woven kenaf-aramid hybrid composites:

In this case study, R. Yahaya, S.M. Sapuan, M. Jawaid, Z. Leman and E.S. Zainudin [21] made the two arrangements of woven kenaf Kevlar composite materials by varying the volume fraction of the composite material. The different impact and residual velocities were performed by using fragments simulating projectiles since the ballistic measurement test of hybrid composites was done. The failure modes were investigated by invigilating the damaged sample of hybrid composites. In comparison to other fiber composites, the 14 layers of Kevlar and the 2 layers of kenaf exhibited better characteristics and demonstrated higher ballistic performance. The hybrid composite had good thickness a areal density due to which the ballistic properties are increased.

### 2.22 Ballistic impact of a KEVLAR helmet: Experiment and simulation:

C.Y. Thama, V.B.C. Tanb and H.P. Lee [22] experimented and simulated the ballistic impact of Kevlar helmet. The experiment that was done was a light gas gun fired the spherical projectile which was hit the Kevlar helmet at the speed of 205 m/s and at the mean time when projectile was hit the helmet, it was detected through high-speed photography. The investigational and replicated results were compared. The simulation was compatible with the response that the helmet had bear. By getting the experimental and simulation results, it was seen that projectile could not penetrate through helmet.

### 2.23 An experimental investigation on the impact behavior of hybrid composite plates:

In this, Metin Sayer, Numan Bektas and Onur Sayman [23] had performed the behavior of hybrid composite plates that how they act. The two hybrid composite pates were used. The plates were tested by increasing the impact energy. They kept on increasing the impact energy until it caused the hole into the specimens. As to get the relationship between absorbed energy and impact energy, they used the energy profile method. When load deflection curve was added then they got about three things which were penetrations, rebounding and holes. The hybrid composite had good fatigue life and corrosion resistance. When impact load was applied on the composites material s it had more importance in engineering field.

### 2.24 Composite materials with the polymeric matrix applied to ballistic shields

In this paper, M. Rojek, M. Szymiczek, J. Stabik , A. Mężyk , K. Jamroziak E. Krzystała and J. Kurowski [24] made an alternative armor plate by using the composites paper. It was capable to resist against caliber bullets of 7.62 and 5.56. in this epoxy matrix composite was used which was strengthened with the glass fiber and the glass fiber was in the state of steel mesh, fabric or mat. The three sheets were attached with the ceramic panel. This composite fiber was used for the light weight armed vehicles in the ballistic protection. The steel mesh was connected with glass mats in order to strength it and by doing this, it would reduce the destruction of the composite material. The defragmentation was also reduced decreased by strengthening the ceramic panel with inter layer of steel mesh.

### 2.25 An Experimental and Numerical Study of Fracture Toughness of Kevlar- Glass Epoxy Hybrid Composite.

J. Maheswaran and his colleagues [25] used experimental methods and finite element analysis to study the behavior of a Kevlar and Glass Epoxy Hybrid Composite during fracture. The tension test was used with fixtures in accordance with ASTM guidelines. The Fracture Toughness for both across the direction of the fiber and along the direction of the fiber of the test material was obtained experimentally. It was observed from the results that the cracked sample was tougher along the direction of the fiber as relative to across the direction of the fiber. The elastic modulus for both cases had a difference of 417 MPa, more for along the fiber case, same behavior was observed for critical stress intensity factor.

## 3. BEST THREE METHODOLOGIES

### 3.1 Ballistic Analysis of 14.5 AP Bullet on Armor Material

In the very first significant methodology, a 14.5 mm AP bullet was tested to analyze the impact on armor. Furthermore, ballistic resistance numerical simulation was performed. In order to properly define and monitor the strength of metallic material Johnson-Cook strength model was used. The conditions under which the material was tested involved large and high strains, strain rates and temperatures.

$$Y = [A + B\varepsilon^{n}{}_{p}]\ [I + C \log e^{*}{}_{p}]\ [I - T^{m}{}_{H}\}] \quad (1)$$

Here the term $\varepsilon_p$ can be defined as the effective plastic strain with $e^*_p$ as the rate of the normalized effective plastic strain and the term $T_H$ is the homologous temperature.

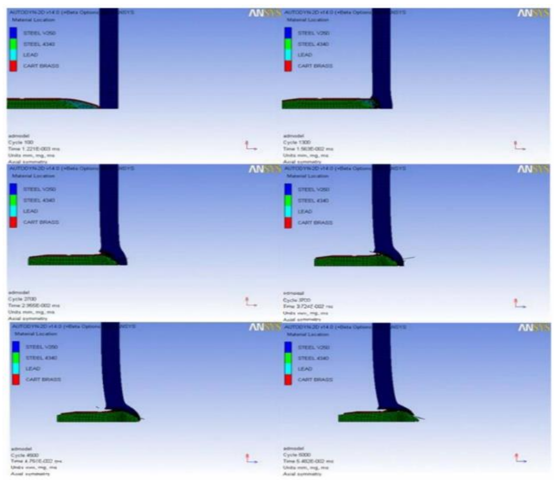


***Figure 2: V250 steel (Simulation result,thickness 11.0 mm, steel core) [26].***

On ANSYS commercial software, the research progressed with explicit dynamic code on AUTODYN. The study found that a 14.5 mm AP bullet could not be stopped by a single layer of

10mm V250 steel, the simulation was done using explicit dynamic method with non-liner finite element. The simulation consisted of two parts a bullet and the target, the bullet was made of three components, a steel core made with AISI 4340 hardened steel, Lead and brass were used for jacket and cartridge. A circular shape of steel V250 was used for the target. The bullet made impact on the center of the target. Because of restricted computational resources the analysis was done with plain strain condition in 2-D manner, the components were set up into frictionless pullies.

The study was carried out in two cases in case 1 the armor was made of V250 only and in case 2 a layer of alumina was also added. The following results were obtained from simulations of case 1.

The maximum plastic deformation was observed at 0.55 millisecond but at that time the bullet had perforated the target and still had a velocity of 650 $ms^{-1}$, adding a second layer of alumina ceramic increased the resistance of V250 steel to ballistic impact. The bullet hit the target with an impact velocity of 911 $ms^{-1}$.

The simulations done for case 2 got the following results.

$2.2x10^8$ and $5.5x10^8$ mj were plastic work of V250 steel and alumina respectively, at 0.055 ms. In case of double layer, the plastic work of V 250 steel was significantly less than that for the single layer.

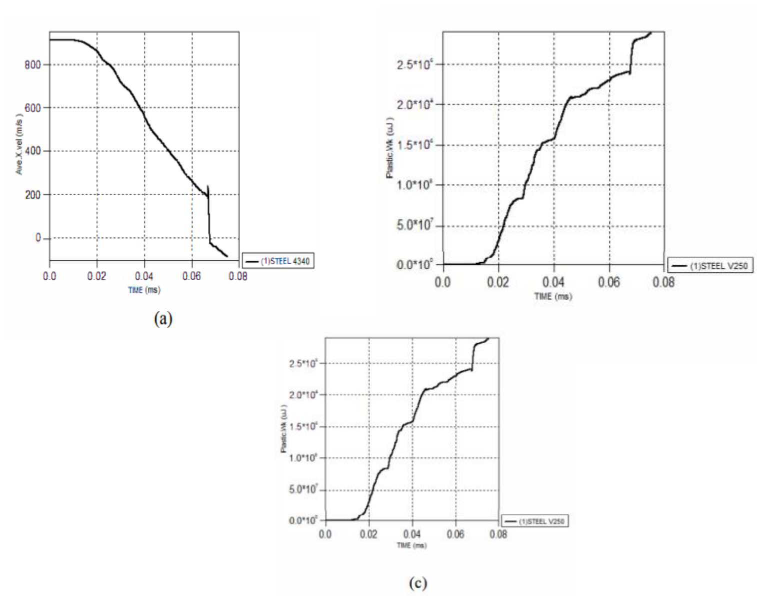
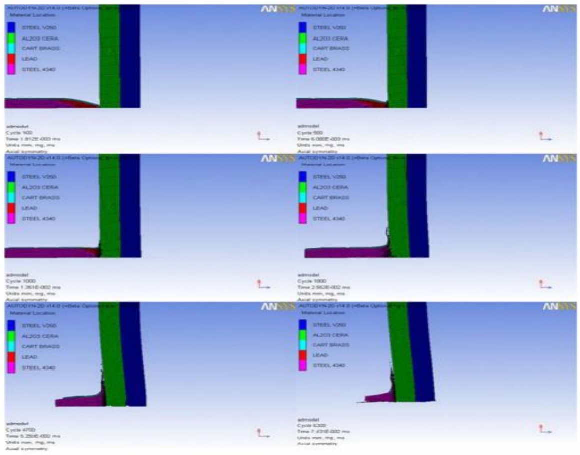


***Figure 3: Result of simulation of 10 mm V250 steel (a) Plastic work of the sheet vs. time (b) Velocity of the projectile vs. time [26].***

The ceramic layer increased the ballistic response as the V 250 could not stop the bullet but adding alumina proved helpful. The mathematical model of the material used for simulation assumed that the strain rate of a material is independent of the temperature sensitivity, which is contrary to what happens in real life. Due to lack of computational resources only 2D analysis was done.

### 3.2 Modeling and Simulation of a Shock Absorbing Shell for Ballistic Vests and Helmets to Achieve Optimal Protection

By using modeling and simulation-based study of shock-absorbing shells, Suciu, Fukui, and Kimura's research was published with the intention of enhancing the design of helmets and vests for ballistic protection [27]. When a colloidal pad was positioned on the exterior of the shell, up against the bullet, it was discovered that the back-face signature was reduced by 10%. However, when the colloidal pad was positioned on the inside of the shell, up against the striking bullet, the back-face signal was diminished by 25%.



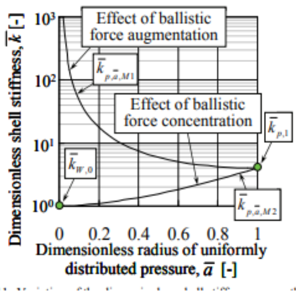



***Figure 4: V250 steel (Simulation result, thickness 10.0 mm additional alumina) [26].***

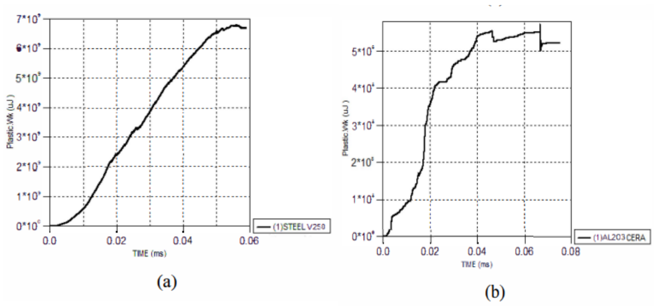


***Figure 5: The result of the simulation of l0 mm alumina added with V250 steel (a) Velocity of steel core vs. time (b) Plastic work of alumina vs. time and (c) Plastic work of V250 steel vs. time [26].***

The following equation can be used to calculate a membrane's transverse out-of-plane displacement, w:

$$\nabla^2 D \nabla^2 w = p \tag{2}$$

Or for constant flexural rigidity throughout the plate

$$\nabla^4 w = \frac{p}{D} \tag{3}$$

Where the bending or flexural stiffness of the plate is D, defined as: where Pressure, acting in the same direction as z and w, is represented by p, $\nabla^4$ is known as the bi-harmonic differential operator, and $\nabla^2$ is Laplace's differential operator.

$$D = Et^3/12(1-v^2) \quad (4)$$

Here, E stands for the Young's modulus of elasticity, v for the Poisson's ratio of the material used to make the plate, and t for the plate's thickness.

$\nabla^2$ is the Laplace's differential operator and can be written as

$$\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial\theta^2} + \frac{\partial^2}{\partial z^2} \quad (5)$$

For a pressure that was evenly distributed across the surface of a shell with a clamped edge, the equation shown below was found. With the origin at (r = 0) and the clamped edge at (r = R) and the following boundary conditions:

$$w_{p,1}\,(r{=}R) = \frac{dwp{,}1}{dr}(r{=}R) = \frac{dwp{,}1}{dr}(r{=}0) \quad (6)$$

The shell displacement $w_{p,1}$

$$w_{p,1}(\overline{r}) = \frac{3(1-v^2)}{16\pi}\frac{WR^2}{Et^3}\left(1-\overline{r}^2\right)^2 \quad (7)$$

Where the W is the force and $\overline{r}$ is the dimensionless radius, both can be expressed as.

$$\overline{r} = \frac{r}{R} \quad , \quad W = \pi R^2 p \quad (8)$$

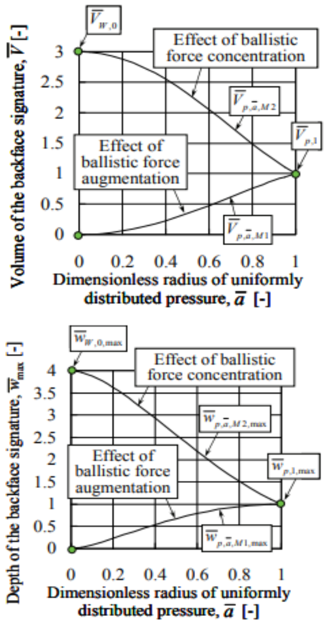
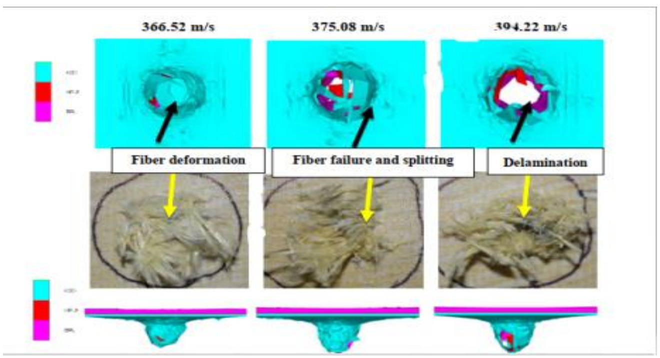



***Figure 6: Fig graphical representation of the entire results [27].***

At the center of the shell the back face signatures depth is

$$w_{p,1max} = w_{p,1}\,(\overline{r} = 0) = \frac{3(1-v^2)}{16\pi}\frac{WR^2}{Et^3} \quad (9)$$




*ms) [28]*

The volume of the back face can be calculated from the equation

$$V_{p,1} = 2\pi R^2 \int_0^1 \overline{r}\; w_{p,1}\,\overline{r}\,.\, d\overline{r} = \frac{(1-v^2)}{16}\frac{WR^4}{Et^3} \quad (10)$$

The shell's stiffness

$$_{p,1} = \frac{W}{wp{,}1max} = \frac{16\pi}{3(1-v^2)}\frac{Et^3}{R^2} \quad (11)$$

For the modeling of a circular ballistic shell with a clamped edge that has been evenly loaded throughout.

$$Q_r = -\frac{W}{2\pi r} \quad (12)$$

The shell displacement;

$$W_{W,0}(\overline{r}) = \frac{3(1-v^2)}{16\pi}\frac{WR^2}{Et^3}\left(1-\overline{r}^2 + 2\overline{r}^2\, ln\overline{r}\right) \quad (13)$$

The volume of the back face signature;

$$V_{W,0} = 2\pi R^2 \int_0^1 \overline{r}\; w_{W,o}\,\overline{r}\,.\, d\overline{r} = \frac{3(1-v^2)}{16}\frac{WR^4}{Et^3} = 3V_{p,1} \quad (14)$$

The shell stiffness;

$$k_{W,0} = \frac{W}{w\; w{,}o\; max} = \frac{4\pi}{3(1-v^2)}\frac{Et^3}{R^2} = \frac{kp{,}1}{4} \quad (15)$$

For the modeling of a circular shell with clamped edge, loaded by eccentric focused force, the dimensionless depth of the back-face signature is given by:

$$\overline{w}_{w,\overline{b},max} = \overline{w}_{w,\overline{b}}(\overline{b} = \overline{r}\,,\, \Theta = 0) = 4(1-\overline{b}^2)^2 \quad (16)$$

They investigated the impact of the force eccentricity in more detail and came to the conclusion that ballistic vests and helmets could not provide the highest level of protection. This was so that they could make the biggest back face autographs the majority of the time. They discovered that when the bullet impacted the unit cell at a specific eccentricity and caused the impact force to spread over a larger area, it was able to boost the protection of the helmets and vests. They conducted an experiment to see the armor strengthening and added silica colloidal pads to either the exterior or inner face of the shell unit.

### *3.3 Ballistic impact performance of hybrid thermoplastic composite armors reinforced with 2D/3D Kevlar and basalt fabrics*

The composite thermoplastic material is used in which it includes the Kevlar with basalt fabrics of 2D plain woven as well as 3D interlock angle was also viewed through simulations and experiment to check the ballistic protection performance. Random stacking sequence (H-1) was used as well as symmetric stacking sequence (H-2) as hybrid armors types. The 9mm full jacket impact was targeted on H-1 as well as H-2 armor. H-2 resisted perfectly but H-1 armor was

Perforated for velocity between 365 $ms^{-1}$ to 395 $ms^{-1}$. The material and method they used to test the armor was similar to our working process for the Kevlar based ballistic protection for military armor vehicle. The aim of the working of this paper is to develop polypropylene-based Kevlar/basalt composite armors to check the performance of ballistic protection. The hybrid 3D fabric is implemented for the composite armors.

The Defense Metallurgical Research Laboratory is used to the ballistic protection. The software which was used for the ballistic protection performance of hybrid composite material is ANSYS-AUTODYN -3D. The equivalent pressure is given as:

$$P = -\frac{1}{3}(\sigma_{11} + \sigma_{22} + \sigma_{33}) \quad (17)$$

Whereas the effective bulk modulus is given as:

$$K = \frac{(C_{11}+C_{22}+C_{33}+2(C_{12}+C_{23}+C_{31}))}{9} \quad (18)$$

It was seen that there is linear relation in pressure and volumetric strain.
The following equation enables the connection of an orthotropic

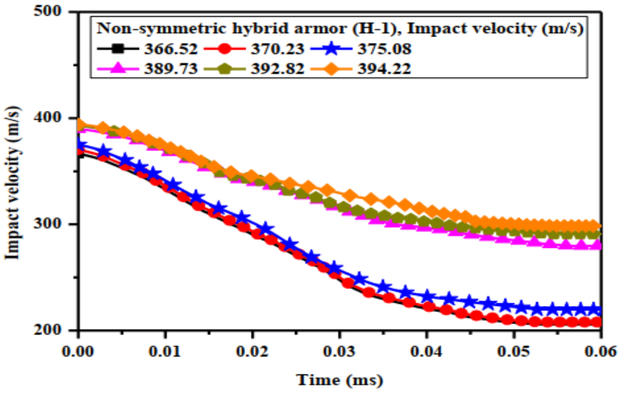



*Figure 8: Full Perforation (Velocity time history for H-1 armor) [28]*

material toughness with a nonlinear equation of state.

$$C_0 = \sqrt{\frac{k}{\rho}} \quad (19)$$

where k denotes the effective bulk modulus, $C_0$ is the bulk acoustic speed of sound, and $\rho$ is the material density.
The following graph depicts that the ballistic limit velocity is less than these velocities. In order to predict he ballistic impact velocity further simulations were made at lower velocity

## 4. Conclusion

- Through the implemented material models, researchers were able to foresee thermoplastic hybrid armors can effectively withstand a variety of failure modes, such as matrix cracking, fiber failure, shear plugging, and delamination.
- The symmetric stacking sequences was able to meet the requirement of the experimental performance as it showed good resistant against the 9 mm full metal jacket.
- The non-symmetric stacking sequences have absorbed very small amount of energy of projectile, it shows that the implemented model was capable.
- The stacking sequence has a strong impact on back face damage pattern instead of the front face damage pattern.
- Materials reinforced with strong materials had a lower rate of failure compared to those that were not reinforced.
- Coating of Impact Resistant Materials with different binding and tough agents also contribute positively in the determination of level of protection offered by an armor.
    - Bullet impact is an intense phenomenon. The process needs to be analyzed with modern tools and specialized equipment.
- Crowd formations and the human pattern/layouts are a deciding factor in terms of lethality of IEDs.
- Textiles including Nylon, Carbon fibers, Ceramic fibers, Aramids and Glass Fibers, UHMPE, TLCP, and PBO are quite effective in the ballistic protection design.
- The orientation/ angle of approach and the distribution of pressure are some but not all the key factors responsible for damage during a ballistic impact.
- The impact of the bullet at a certain eccentricity on the unit cell causes even force distribution and minimizes the effect of bullet shots on a helmet or other protective equipment.
- Lamination of soda lime panes of glass using polyvinyl butyral as reinforcements increases the level of protection from 7.62 mm FMJ armor shots.
- **Recommendation**
- Designers associated with ballistic sciences should collect data to understand the impact of different factors as the composite ballistic performance solely dependent on the nature of fabric.
- The research on applied technology of polymerization is not enough for advancement at a faster pace so the research on sintering technology should be considered.
- Use of latest materials in the development of ballistic protections is an essential and crucial phase, further investigation needs can reveal interesting behaviors of these materials.
- Lamination of protective materials with strong materials to reinforce their strengths should be explored.
- Kevlar based strong protective materials are the most stable in terms of bullet impact. Therefore, further research needs to be pursued in Kevlar fabrics.
- Human bodies are very sensitive to shrapnel. A safe and secure protection needs to be developed to lower the threat level for soldiers.
- Back face signature of protection plates is the most crucial field to study in terms of ballistic impacts.

## Nomenclature

- ACH = Advanced Combat Helmet
- AISI= American Iron and steel institute
- ASTM= American society of testing and material.
- BP = Ballistic Protection
- CNF = Carbon nano fibers
- E = Modulus of elasticity
- ECH = Enhanced Combat Helmet
- FDM = Fused Deposition Modelling
- FEA= finite Element Analysis
- IC = Initial conditions
- IED = Improvised explosive device
- MS = Mild Steels
- NRL = Natural Rubber Latex
- PASGT = Personnel Armor System Ground Troops
- PBO = p-Phenylene -2,6-Bezobisoxazole
- PTFE = hybrid poly tetra fluorethylene fabric
- RP = Rapid Prototyping
- TLCP = Thermoplastic Liquid Crystal Polymer
- TPO = Thermoplastic Polyolefin
- TS = Tensile Strength

- UDF = Uni Directional Fabric
- UHMPE = Ultra High Modulus Polyethylene

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