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Modeling and Simulation of Bullet Resistant Composite Body Armor

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Abstract: *Composite Ballistic body armor materials has become a better body armor protection as compared to traditional steel body armor in terms of its reduction in weight and an improvement in ballistic resistance[1,2]. However, the complex response of composite materials coupled with high costs and limited amount of data from ballistic testing has lead to modeling and simulation of ballistic body armor with different grade of material becomes the best option to optimize and design the composite body armor with less weight and affordable cost. The long term goal of this research is to develop domestic knowledge, model and simulate capability of composite armors with less cost and weight. As a research methodology there was modeling and simulation by Solid work 2012 and Abaqus 6.10software were used to model and simulate the composite bullet resistant body armor respectively.The material used for modeling of composite body armor was Kevlar-29 fiber and polyester resin. The simulation result for20layers (10mm thick) of woven Kevlar-29 fiber with polyester resin as a matrix shows that there is no penetration through the modeled composite body armor panel by a projectile of 7.62x39mm bullet impact load at 10 and 50meters and the weight of modeled composite body armor was 1.5kg. These results were validated against published data and good correlation was observed. There is also an attempt to localize the product from local material through technology transfer as affordable cost.By considering the current thickness and weight of modeled and simulated bullet resistant composite body armor there is a recommendation thrown to any researcher to reduce the weight in terms of thickness in any available technique.*

Keyword: *Armor Material, Aramid Fiber, composite Body Armor, FEM.*

1. Introduction

Fiber-reinforced composite materials have become important engineering materials used such as marine bodies, aircraft structures and light-weight armor for ballistic protection in military applications. This is due to their outstanding mechanical properties, flexibility in design capabilities, ease of fabrication and good corrosion, wear and impact resistant. Composite Body armor is an item or piece of clothing that is designed to protect the wearer against a variety of attacks. They can be made to stop different types of threats, such as bullets, knives and needles, or a combination of different attacks.There are two types of body armor – soft body armor, which is used in regular bullet and stab proof vests, and hard armor, which is rigid, reinforced body armor, and is used in high risk situations by police tactical units and combat soldiers[1].

Figure 1. *Hard and flexible Bullet resistant body armor* [3]

The first protective clothing and shields were made from animal skins. As civilizations became more advanced, wooden shields and then metal shields came into use. Eventually, metal was also used as body armor, what we now refer to as the suit of armor associated with the knights of the Middle Ages. However, with the invention of firearms around 1500, metal body armor became ineffective [4]. Then only real protection available against firearms was stone walls or natural barriers such as rocks, trees, and ditches. It would not be until the late 1960s that new fibers were discovered that made today's modern generation of cancelable body armor possible. When a handgun bullet strikes body armor, it is caught in a "web" of very strong fibers. These fibers absorb and disperse the impact energy that is transmitted to the vest from the bullet, causing the bullet to deform or "mushroom." Additional energy is absorbed by each successive layer of material in the vest, until such time as the bullet has been stopped. Because the fibers work together both in the individual layer and with other layers of material in the vest, a large area of the garment with composite technology becomes involved in preventing the bullet from penetrating. This also helps in dissipating the forces which can cause nonpenetrating injuries (what is commonly referred to as "blunt trauma") to internal organs. Unfortunately, at this time no material exists that would allow a vest to be constructed from a single ply of material [5]. People have always attempted to protect themselves against their enemies and the weapons being used, but this has always been balanced by their need to be mobile. The earliest form of armor was not intended to protect any form of transportation but to protect the person. From the middle Ages, the foot soldier was protected with some kind of body vest, a helmet and a shield. When the scale of attack was dramatically increased with the advent of fire arms, any form of protection was easily overmatched and it was soon abandoned in favor of the greater mobility given to the individual. When the need for fighting vehicles was arisen, the importance of achieving lightweight protection has also been recognized [6].

Cristescu et alcarried out a detailed computational analysis of the ballistic performance of composite and hybrid armor panels hard-faced with Al_2O_3 ceramic tiles by using AUTODYN software. The initial simulations were performed to validate the composite material model. In these simulations, there was an agreement between the V_{50} values obtained from the numerical simulations and those from the experimental results. Next, the simulations were done by considering the whole armor system, i.e. composite panels hard-faced with alumina ceramic tiles [7]. Again the overall agreement between the experimental and computational results is quite good.Fabric based body armors function well against deformable threats by distributing the kinetic energy through the high strength fibers with dissipation modes including fiber shear or fracture, fiber tensile failure or straining and associated delamination or pullout. To provide isotropic properties when laminated, $0^{o}/45°$ and $0^{o}/90°$ cross ply arrangements are used [10].High shear stresses cause the delamination between the neighboring layers which is the failure mode of composite material. In addition to delamination, fiber breakage, which is another failure modern fiber composite material under impact loading, occurs in the composite plate. The degree of delamination decreases as the thickness of the backing plate is increased. Energy absorbed during delamination depends on the interlaminar shear fracture energy, the length of delamination and the number of delamination. Progressive delamination causes a ductile material behavior in the composite and significant amount of impact energy is absorbed. For composite failure evaluation method Tsai-Wu’s and Hashin failure modes are the most popular methods [8].

Figure2. *Damage mechanisms occurred in composite materials under ballistic impact***[9]**

2. Material and Methodology

The modeled composite body armor in this research was consisted of 20layer of plain-woven Hexcel Aramid fiber (polyparaphenylene terephthalamide),impact high performance fabric Style 706 (Kevlar KM-2, 600 denier) with an areal density of 180 g/m2 and a polyester resin as matrix. The designed methodology was computer modeling and simulation, literature review and analytical method was used to validate the obtained result.

3. Composite body armor Modeling and Impact Simulation

In Finite element modeling and simulation there is three stages i.e. pre-processing, solution, post processing stage were well known stage.

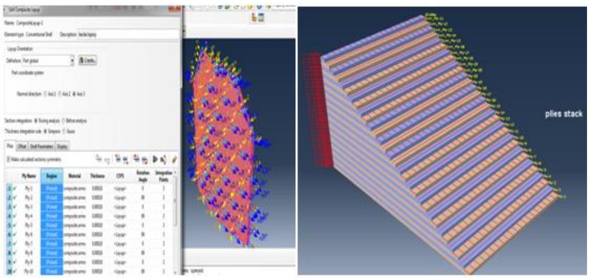

Figure 3. *Defining composite lamina sections and plies stack*

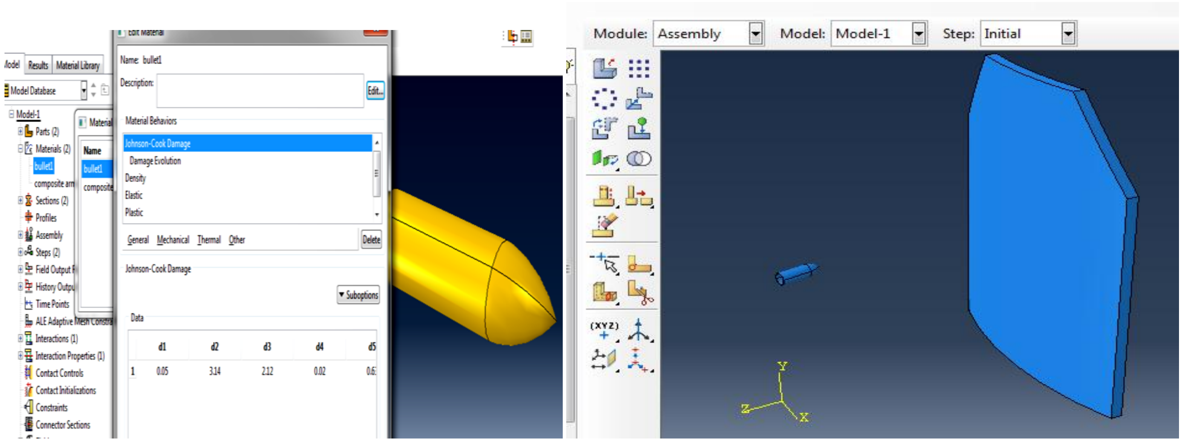

Figure 4. *Elastic and Plastic Modeling of Bullet and dynamicassemblingof Bulletwith Armor Disk*

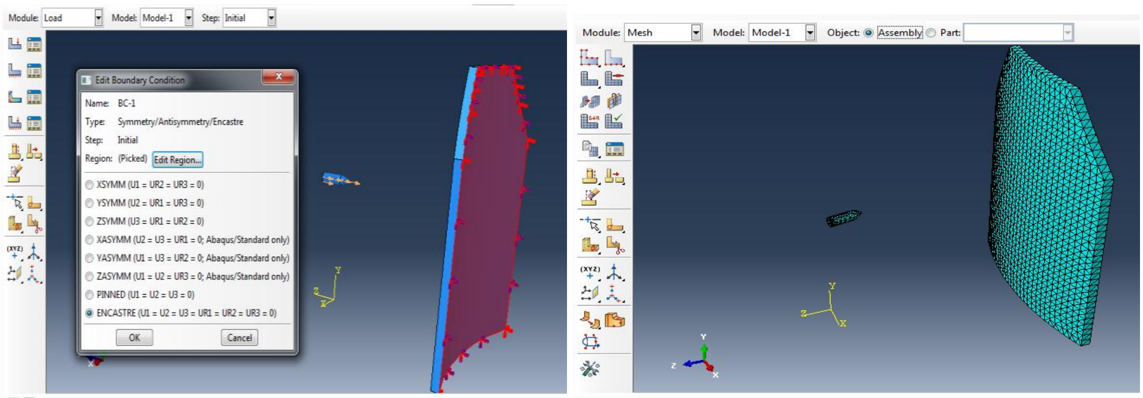

Figure 5. *Boundary condition, load assignment and meshed body armor*

Table 1. *FEM formulated procedure information*

No	Parameter	Value and types
1	Mesh type	Solid Mesh
2	Mesher Used:	Standard mesh
3	Jacobian points	4 Points
4	Element Size	7.51878 mm
5	Tolerance	0.375939 mm
6	Mesh Quality	High
7	Total Nodes	15616
8	Total Elements	7738
9	Maximum Aspect Ratio	14.353

4. Result and Discussion

As seen in the fig below the Von Mises stresses induced in the composite body armor at projectile speed of 720m/s and at a shooting distance of 50meters, that is, the muzzle velocity can't damage the harder armor.As fig. 6 shows that the dynamical interaction of bullet and composite armor starts to deform at the first instance with the projectile, the bullet where fired at distance of 50meter from target.

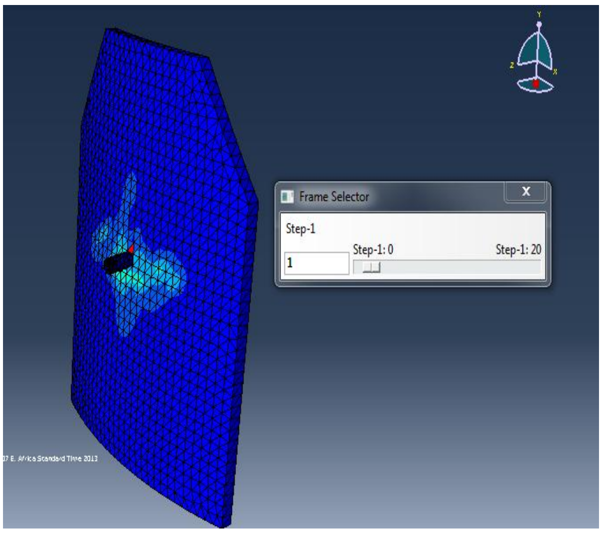

Figure 6. *First instance of bullet strike with disk panel of integral armor*

As fig. 7 shows that the dynamical interaction of bullet and Kevlar-29 composite armor at the last instance moment where the projectile ends to strike the panel and resulted there is more energy distribution over the body armor, there is no penetration over the sample. The bullet where fired to the target at distance of 50meter.

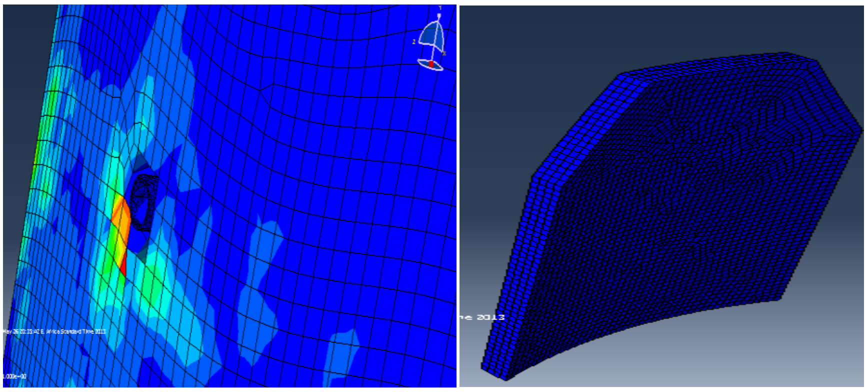

Figure7. *Front face of armor composite disk of bullet impact area***andback side with zero penetration**

4.1 Result by Graphical Interpretation

As fig. 8: shows, the bullet strikes the integral composite body armor and there is slow drop of kinetic energy absorption which indicates us there is more deformation of the specimen rather than the bullet and this will cause severe trauma.The bullet where fired to the target at distance of 50meter.

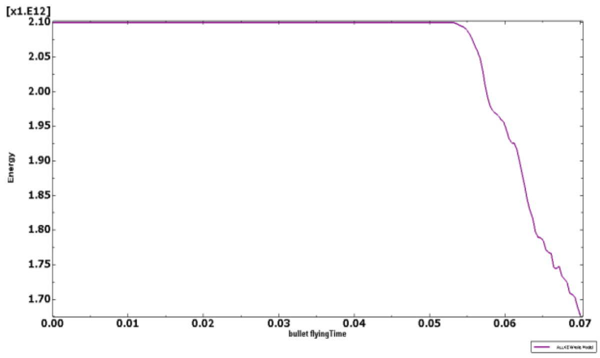

Figure 8. *Kinetic energy absorbedcomposite body armor (by kevla-29)*

As figure-9: shows, *t*he simulation that made over Kevlar-29 with polyester and the result obtained indicates that there was more deformation of the modeled armor which indicates that there is less energy absorption by the modeled sample and can cause severe trauma over wearers body. The bullet where fired to the target at distance of 50meter.

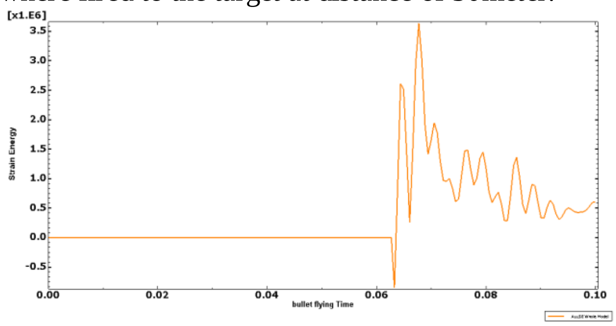

Figure 9. *Strain energy vs time graph of body armor*

As fig 10: shows, the sample that made from Kevlar-29 were exposed to take 0.07second to absorb and stop the bullet energy which indicates that there is more energy absorption by the armor and this will cause severe trauma over wearer body. Kevlar-29 armor sample were thick about 10mm and the bullet where fired to the target at distance of 50meter.

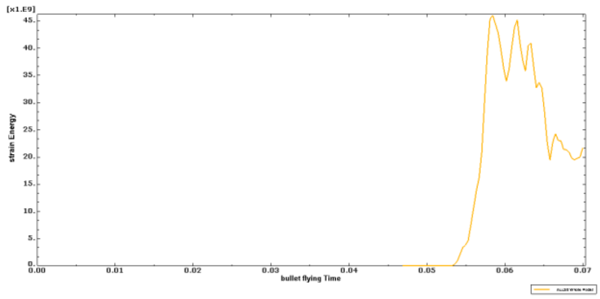

Fig. 10. *Strain energy vs time graph of body armor made by Kevlar-29*

5. Conclusion and Recommendations

In this study, the modeling and simulation of composite body armor that modeled from Kevlar-29 and polyester resin were studied and the following conclusion has been made.

- ✓ It was found that 20layers of a Kevlar-29fiber with a polyester resin can stand impact energy of 7.62x39mm bullet type that firedat a distance of 10meterwith a muzzle velocity of 720m/s.
- ✓ The authors' used the commercial finite element software, ABAQUS/CAE; to analyze and simulate the dynamic deformations of laminated composite body

armor caused by the impact of a 7.62x39mm copper coated bullet.

- ✓ From the simulation of composite body armor under dynamic explicitly condition, there wasan observation that, of bullet that strike the body armor at kinetic energy of about 1.9e9joule have been absorbed by the composite body armor which have been shown byFig8.
- ✓ The researched bullet resistant composite body armor cost about 6500birr and have a weight of about 1.5Kg, if back and front were to used at combat field it weighs up to 3Kg.
- ✓ The cost comparative study shows that for localization of body armor there is 63.8% cost reduction.
- ✓ As per the Standerd for the united states of state of America under UL-752,the researched bullet resistant body armor wasclassified under level 5.

Recommendation

There is a recommendation that the Ethiopian national ministry of defence have to be agreeing to open their door to any both external and internal researcher that will upgrade the capacity of military organization in terms of technology to form a modern army with modern military gear.

- ✓ The authors' highly recommend that any interested researcher to deal with ballastic property of kevlar-29 fiber with epoxy or other thermoset resin as a body armor.
- ✓ For the design and manufacturing of body armor there should be a consideration of mobility, safety and cost to the customer.
- ✓ As Ethiopian standard there should rule and eligibility concern to use and not to use body armor
- ✓ Lastly the authors of this paper that entitle modeling and simulation ofbullet resistant composite body armorforward an idea to any researcher to deal with the optimization for weight and thickness of body armor.

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