SIMULATION OF BALLISTIC IMPACT ON DIFFERENT COMPOSITE SAMPLES OF BULLET PROOF VEST

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Abstract. This paper presents the simulation results of ballistic impact tests on sample of composite material. The materials used are Kevlar 29, Carbon Fiber, E-Glass Fiber and Steel 1006. In simulation test, we used 9mm parabellum bullet having velocity of 400 m/s. The cad and analysis were done in Ansys Workbench Explicit Dynamics. The result was compared within different combinations of composite material and the most efficient and cost-effective composite material was chosen.

Keywords. Ballistic, Kevlar 29, Carbon Fiber, E-Glass Fiber, parabellum bullet, Explicit Dynamics, composite

1. Introduction

The main use of bullet proof vests is preventing entry of bullets into the protected area. The bullet proof vest to be utilized ought to be sturdy and simple to create, use and repair. The use of thick steel plates is the traditional method of armouring. Later, multilayer bullet proof vest was created which improved the penetration resistance/weight ratio relative to steel.

In multi-layered armours, the outer ceramic layer deflects the bullets and the fibres hold the bullet particles and the metal part stops the bullet. These kinds of bullet proof vests generally weigh less than single layer steel armours providing same protection.

So, to enhance the ballistic resistance of the bullet proof vest, different combination of composite materials together was used. Composite multi layered bullet proof vest is generally light weight and durable. The composite materials used are- carbon fiber, Kevlar, E-glass and ballistic steel 1006. The composite materials used here are not that expensive and are easily available. Software’s like Solidworks, Catia, Ansys workbench were used for modelling and analysing.

In this study, multi layered bullet proof vest was designed with different combinations of composites where composites were stacked up uni-directionally and multi-directionally and simulations on software were performed and the results are presented.

2. Design of Armour

The armour design is usually done in two phases specially for those that may have multiple stacks for maximum efficiency. First phase of armor design is the selection of optimum combination of materials to be used and the second phase includes simulation and testing of the structure for the ballistic resistance of the material being used in the designing of the bullet proof vest and to check the total efficiency of the armor. The bullet proof Armor or vest was designed using several reinforced prepeg fibers like carbon fiber, Kevlar, E-glass and ballistic steel 1006. Different combinations of these composite materials were designed in two ways- unidirectional and other is multidirectional. The first combination of composite material for the armor is Kevlar-Ballistic Steel composite. In this combination, 2 steel plates of 0.5 mm thickness and 8 kevlar29 fiber of 0.25mm thickness is used for the design. The second combination used for the design is Carbon Fiber Ballistic Steel Composite. In
this combination, 2 steel plates of 0.5 mm thickness and 8 carbon fiber of 0.25mm thickness is used for the design. The third combination used for the design is carbon fibre-glass fiber-steel composite. In this combination, 2 steel plates of 0.5 mm thickness and 4 carbon fibers and 4 glass fibers of 0.25mm thickness is used for the design. The fourth combination used for the design is Kevlar-carbon steel composite. In this combination, 2 steel plates of 0.5 mm thickness and 4 carbon fibers and 4 Kevlar fibers of 0.25mm thickness is used for the design. The fifth combination used for the design is Kevlar/glass steel composite. In this combination, 2 steel plates of 0.5 mm thickness and 4 glass fibers and 4 Kevlar fibers of 0.25mm thickness is used for the design. All these combinations were stacked up in uni-directional layup and then in multi directional layup and the simulation was done on the samples to find the minimum deformation in the sample, hence to provide maximum protection.

3. Modelling and impact simulation

3.1 Modelling methodology

The bullet-proof vest has been modelled with Ansys Workbench 19. First, the geometry of both the bullet and the vest has been modelled with Ansys Design Modeler, and then simulation of the projectile against each sample stacked up in unidirectional layup has been done. Which is followed by simulation of the projectile against samples stacked up in multi-directional layup is done.

Ansys Explicit Dynamics has been used to solve the model and generate modelling results. The materials of each part have been modelled into Ansys engineering data, and then the model properties like mesh and contact conditions between parts have been setup. Finally, the solver properties like initial conditions, system statics, and dynamic properties, and desired output have been defined.

3.2. Projectile

The bullet is made according to the dimensions of 9mm parabellum bullet. The model is made in Ansys software and finite meshing is done. A material lead alloy is assigned to bullet model and is ready for the analysis part. The bullet which has to hit the plate is made of lead alloy having a speed of 400 m/s.

3.3. Ballistic Armor

The Armor is made with several combinations of materials like carbon fiber, Kevlar, E-glass and ballistic steel 1006. Each material had to be modelled separately into Ansys material engineering data. Five samples of vest are made using different combinations of materials. All these materials are stacked up first in unidirectional layup and then multidirectional layup.

Since a small part of material also exhibits the same properties as original, we took a 10*10 cm sample plate of the selected material for simulation instead of whole bullet proof vest. And that 10*10 cm sample is made by composites of different material mentioned above.

Each sample is made by taking different materials combining together by layup. Each sample is of 3 mm thickness.
3.4. Kevlar-29 200gsm
Kevlar has a unique combination of high strength, high modulus, toughness and thermal stability. It was developed for demanding industrial and advanced-technology applications. Currently, many types of Kevlar are produced to meet a broad range of end uses. Kevlar mainly use for two reasons, and both are about performance: It’s lightweight and easy to integrate. A thin blanket can serve as structural reinforcement or ballistic protection, everywhere from seismic shear walls to bank counters. Sprinkle the fibers into carbon composites to cut weight and boost strength. The grades Kevlar 49 and 149 are the lightest and most robust; Kevlar 29 is comparable impotency to glass fibre, but weighs less. Kevlar 29 mechanical properties are as shown as below-

3.5. Carbon fiber UD prepreg 230 gsm
Carbon fibers or carbon fibres are fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive. When compared with similar fibers, such as glass fibers or plastic fibers.

3.6. Glass Fiber
The glass fiber composites strength/weight ratios are higher than those of most other materials and their impact resistance is phenomenal. Further they possess good electrical properties, resistance to moisture and outdoor weathering and resistance to heat and chemicals. These properties are coupled with ease of fabrication. Properties: controlled flexibility, high mechanical strength, lightness of weight, easy formability, durability, molded in colors excellent surface and resistant to corrosion and wear.

3.7. Steel1006
In the simulation steel was modelled as an explicit material with grade code SAE 1006 from Ansys Explicit material data sources. This grade of steel is mostly used for ballistic impacts because of its properties.

3.8 Simulation
The entire layup is done using Acp analysis in Ansys software. The model has been solved in Ansys Explicit dynamics in Ansys workbench 19. The analysis is given necessary boundary conditions like cycle time of 7e-03 sec , speed of bullet of 400m/s, fixed support to plate on all edges. The initial condition of the test has been simulated by assigning an initial component velocity to the bullet parts equals to 400 m/s in the Z direction and fixed support boundary condition at X and Y faces of the stack. The simulation is first done for unidirectional layup and then for multi directional layup and difference between the layup is found using the result.

And the simulation is performed
Each time different sample is analyzed and different deformations are observed. Out of all we considered the best when compared to quality and cost and we selected five samples of certain layup pattern.

Result and Discussion
After performing the simulation for each sample which are stacked in unidirectional way the results are shown below. In addition, the simulation model could predict the total and directional deformations.
Sample 1:
Every sample layup is symmetrical (such that i and n-i materials are same)
First sample layup consists of two different types of materials one is Kevlar and the other is ballistic steel. These are arranged in a pattern in a stackup such that the top most two layers are Kevlar prepeg
fibers followed by steel followed by two layers of Kevlar. Two layers of this stackup is used to make the sample of bullet proof vest. Here we used Kevlar and steel as materials. Kevlar sample pattern after the impact has max deformation of 6.8077 mm. Since the sample is hit by a bullet at 400 m/s we can see the deformation in the figure below. The region with red colour has maximum deformation and light blue region has min deformation.

Figure 2. Sample 2

Sample two layup consists of three different types of materials one is Kevlar, one is carbon fiber and the other is ballistic steel. These are arranged in a pattern in a stackup such that the top most two layers are Kevlar prepeg fibers followed by one layer of steel followed by two layers of carbon fiber. Two layers of this stackup arranged in opposite orientations such that outer surface exposed to environment is Kevlar and is used to make the sample of bullet proof vest. Here we used Kevlar, carbon fiber and steel as layup materials. And the reason why we used Kevlar fiber exposed to bullet is it has good piercing resistance when compared to carbon fiber. Kevlar Carbon sample after the impact has max deformation of 5.3268 mm. Since the sample is hit by a bullet at 400 m/s we can see the deformation in the figure below. The region with red colour has maximum deformation and light blue region has min deformation. We have done the analysis for carbon fiber as top layer it showed more deformation than this Kevlar carbon sample in which Kevlar fibers are as top most layers.

Figure 3. Sample 3
Sample Three consists of three different types of materials one is Kevlar, one is Glass fiber and the other is Ballistic steel. These are arranged in a pattern in a stackup such that the top most two layers are Kevlar prepeg fibers followed by one layer of steel followed by two layers of Glass fiber. Two layers of this stackup arranged in opposite orientations such that outer surface exposed to environment is Kevlar and is used to make the sample of bullet proof vest. Here we used Kevlar, Glass fiber and Steel as layup materials. And the reason why we used Kevlar fiber exposed to bullet is it has very good properties when compared to Glass fiber.

Kevlar Glass sample after the impact has max deformation of 5.8439 mm. Since the sample is hit by a bullet at 400 m/s we can see a the deformation in the figure below. The region with red colour has maximum deformation and light blue region has min deformation.

Sample Three consists of three different types of materials one is Carbon fiber, one is Glass fiber and the other is Ballistic steel. These are arranged in a pattern in a stackup such that the top most two layers are Glass prepeg fibers followed by one layer of steel followed by two layers of Carbon fiber. Two layers of this stackup arranged in opposite orientations such that outer surface exposed to environment is Glass and is used to make the sample of bullet proof vest. Here we used Carbon fiber, Glass fiber and Steel as layup materials.

Glass Carbon sample after the impact has max deformation of 14.836 mm. Since the sample is hit by a bullet at 400 m/s we can see a the deformation in the figure below. The region with red colour has maximum deformation and light blue region has min deformation. The reason why this sample experienced such deformation is glass fiber is used as top layer which does not has that good impact resistance and even Carbon fiber has less impact strength than Kevlar.
Fifth sample consists of two different types of materials one is Carbon fiber and the other is Ballistic steel. These are arranged in a pattern in a stackup such that the topmost two layers are Carbon prepeg fibers followed by Steel followed by two layers of Carbon fibers. Two layers of this stackup is used to make the sample of bullet proof vest. Here we used Carbon fiber and steel as materials.

Carbon sample pattern after the impact has max deformation of 14.067 mm. Since the sample is hit by a bullet at 400 m/s we can see a the deformation in the figure below. The region with red colour has maximum deformation and light blue region has min deformation. Since the carbon fiber has less piercing resistance than Kevlar it showed much deformation than carbon sample.

The strength can be further improved by increasing the thickness. Based on the above simulations we observed that kevlar carbon fiber is most effective.

The explicit analysis is done again by following multi directional layup. Since multi directional layup has some effect on it, we used it in the analysis.

The deformations after analysis are:

Sample 1:

Kevlar sample pattern after the impact has max deformation of 6.8077 mm. It has no effect for only one type of material fiber (Kevlar) used in the layup process.
Kevlar carbon sample deformation is 4.9383 mm. This sample had shown less deformation than the one done in unidirectional layup process. Since the thickness is very less the deformation is only slightly reduced. By increasing the thickness we can reduce the deformation further.

Sample 3:
Kevlar glass sample deformation is 5.486 mm. Even for this sample the multidirectional layup has shown some effect.
Sample 4:
Carbon glass sample deformation is 14.583 mm. It is same for this sample too. The deformation is reduced for multi directional layup.

Sample 5:
Carbon sample has a deformation of 14.107 mm. As it is discussed above same material fibers sample has shown no effect on the deformation. This sample deformation is same as the unidirectional sample.
As we can see there is not much deformation for same material (kevlar sample and carbon sample) multi directional layup. The deformation slightly decreased for other type of composite samples since its thickness is less there is not much change. From this we know that multi directional layup can be helpful for larger thickness and useless for same material composites.

Conclusion

Different materials and geometry designs were developed using composite materials for ballistic structural armors. In this research, a 100 cm² sample of a laminate plate consists of different materials. Composite laminate structures with like carbon fiber, Kevlar, E-glass and steel layers were modeled with Ansys simulation program to check the technical feasibility of the armor design. The strength can be further improved by increasing the thickness of the plates. Based on the above simulations we observed that Kevlar carbon fiber is most effective.

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