Numerical Simulation of Bullet Proof Vest Using Finite Element Method under Impact Loading

[1]A. Saravanapandi Solairajan, [2]S. Alexraj, [3]P.Vijaya Rajan
[1, 2, 3]Assistant Professor,
[1, 2, 3] Department of Mechanical Engineering,
[1, 2, 3] Infant Jesus College of Engineering and Technology, Tuticorin, India

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***Abstract* - with the increasing concern on occupational safety, people pay more and more attention to mechanical protection. At present, the focus of relevant researches is on the mechanical protection performance of high performance and high strength. The influences that mechanical properties have on the mechanical protective performance of material are discussed in this paper. Using material is made on the grapheme, SWNT and al layers. This model is created in the PRO E software. When the material is used for the defense purpose and for the safety purpose at the time of the war enclosure the problem facing here is when the impact is applied at a point the material deformation occurs and a particular point and the deflection will be very high so that the human who is wearing the material as the body proof experience a heavy pain in that, concluded is we are introducing the new composite material for the design(i.e. Attach aluminum layer at the front and back) which will convert a point in to a uniformly distributed load across the material hence by reducing the point deformation. In this paper validation of experimental and a numerical result of impact tests of composite laminate (al layers, graphene, SWNT) has been carried out using ANSYS. The mechanical response and energy absorption characteristics of material under high speed projectile impact are dependent up on intrinsic constitutive relations, construction parameters such as material type and construction, area, density, projectile shape, and impact conditions such as impact velocity and boundary conditions.**

***Index Terms* - Ballistic Impact, Energy Absorption, Finite Element Modeling, Simulation, Material Used as Al Layers, Graphene, Single Walled Carbon Nanotubes**

I. INTRODUCTION

Graphene has been used in a new composite material that can produce the toughest fibers to date, even tougher than spider silk and Kevlar. The latest discovery in the nano world of carbon, Graphene has proven to be an amazing building block for advanced materials. The new graphene composite can then be wet-spun into fibers with potential applications in bullet-proof vests and reinforcements for advanced composite materials. As published today in Nature communications, Researchers at the University of Wollongong base of the ARC Centre of Excellence for electro materials Science (ACES) have shown that graphene can work just as well as the more common toughening agent, carbon nanotubes, in polymer composites. Graphene is also a much cheaper material and can be produced easily in large quantities. ACES Senior Researcher and paper co-author Professor Geoff Spinks from ACES said that the ratio of graphene to carbon nanotubes was a key factor in development of the composite. “Quite surprisingly, we found that a “magic mixture” of equal parts carbon nanotubes and graphene added to the polymer gave exceptionally high toughness,” Aluminum is a chemical element in the boron group with the symbol **AL** Aluminium is the third most abundant element Aluminium is remarkable for the metal`s low density and for its ability to resist corrosion. This model is created in the PRO E software. When the material is used for the defense purpose and for the safety purpose at the time of the war enclosure the problem facing here is when the impact is applied at a point the material deformation occurs and a particular point and the deflection will be very high so that the human who is wearing the material as the body proof experience a heavy pain in that, concluded is we are introducing the new composite material for the design(i.e. Attach aluminum layer at the front and back) which will convert a point in to a uniformly distributed load across the material hence by reducing the point deformation. In this paper validation of experimental and a numerical result of impact tests of composite laminate (al layers, graphene, SWNT) has been carried out using ANSYS. The mechanical response and energy absorption characteristics of material under high speed projectile impact are dependent up on intrinsic constitutive relations, construction parameters such as material type and construction, area, density, projectile shape, and impact conditions such as impact velocity and boundary conditions.

II. BULLET PROOF VESTS

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 becomes involved in preventing the bullet from penetrating. This also helps in dissipating the forces which can cause no penetrating 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.

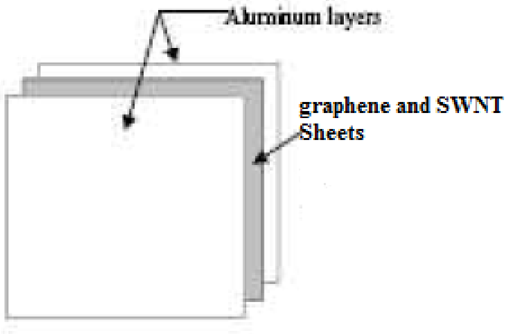

Fig 1 Composite laminate

III. MATERIAL PROPERTIES

The material investigated in this paper is made from high-strength namely graphene, single walled carbon nano tubes and Al layers. The highly oriented material endows it with many excellent physical and chemical characteristics.

Table 1 Properties of Materials

S.No	**Material properties**	**Tensile strength**	**Young's modulus**	**Density**
1	Graphene	250-1200 MPa	1.5 Tpa	.77mg/m^2
2	SWNT	13-15 Gpa	1-5 Tpa	1.3-1.4g/m^2
3	Aluminum	70-700 Mpa	70,000 Mpa	2.70 g/cm^2

IV. IMPACT LOADING

The low velocity impact tests were performed by During test impact machine was equipped with a hemispherical with varying impact force(i.e. transient analysis) in kN indentor with diameter of 25 mm. Specimens with dimensions of (100 × 100) mm ±5 mm were fixed. Impact velocity was set to 319 m/s to provide resultant impact energy of 313 J.

V. THE MODELING OF PROJECTILE

The 9 mm FMJ is assigned as a projectile in the simulation. The finite-element modeling proposed and meshed with ANSYS is shown in Figure 3. The projectile is modeled as a rigid body using solid elements. The projectile is modeled in full so as to be able to simulate the stress waves propagating in the fabric from the point of impact towards the free and clamped edges. This is used to predict how the material responds under different impacts at different times.

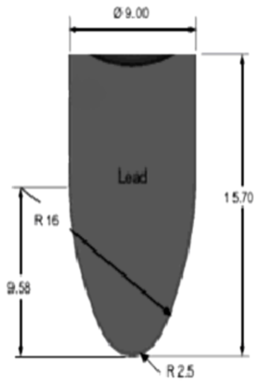

Fig 2 The geometry of the 9mm FMJ.

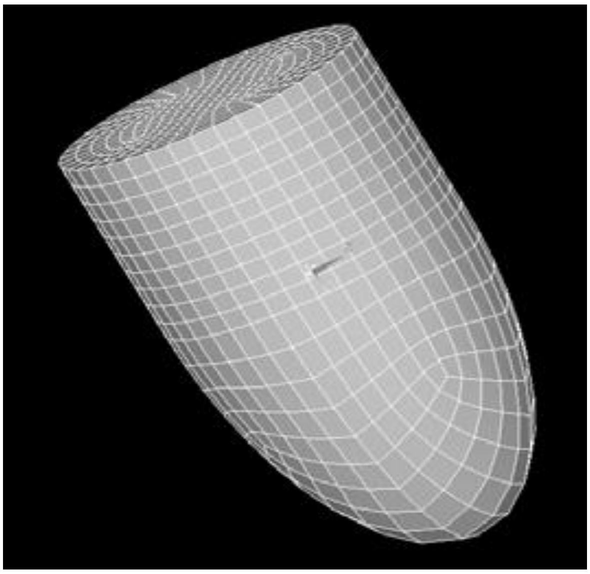

Fig 3 The modeling of projectile

VI. THE MODELING OF FABRIC

The length of the yarn is 100mm as shown in Figure 6 and the fabric with dimensions of 200mm200mm as shown in Figure 7 are also modelled using elements in this paper. In the analysis, the length and width of the specimen are considerably larger than its thickness (0.57mm). Hence, a two-dimensional plane stress condition can be assumed which corresponds to shell formulation.

Fig 4 The Modeling of Bullet And Bullet Proof Vest (Side View)

A semi-empirical approach is adopted to formulate a material constitutive relationship for fabric. A system of Hooke an spring and Newtonian dashpot are used to model the viscoelastic behavior of fabric.

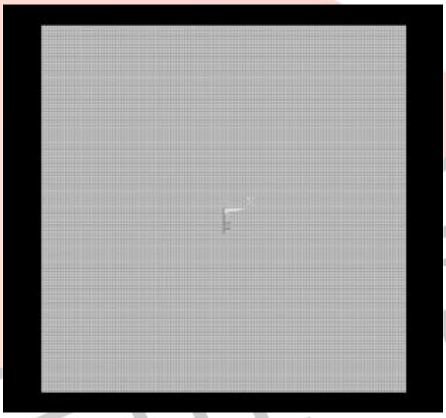

Fig 5 The Modeling Of Bullet Proof Vest (Front View)

VII. CONSTITUTIVE RELATIONS

A three-element system of two Hooke an springs and a Newtonian dashpot is shown in Figure 8. Values of the constants describing the springs and dashpot of this viscoelastic model can be derived semi-empirically. Generally, the constitutive equation of any linear viscoelastic model can be derived mathematically and parameters describing the components of the model can be assigned values so that the derived equation reflects actual constitutive properties of the material of interest. The viscoelasticity of fabric can be described by

$$\left(1+\frac{K_2}{K_1}\right)\sigma+\frac{\mu}{K_2}\dot{\sigma}=K_2\varepsilon+\mu\dot{\varepsilon}$$

WhereK_1, K_2 are the two spring constants.

μ is the damping constant,

ε is the Stress,

$\dot{\varepsilon}=\frac{d\varepsilon}{dt}, \dot{\varepsilon}\ is\ a\ constant$

To solve the impact problems of fabric, the modeling of projectile and fabric are put in the same plane. Hence, the loading conditions of projectile are settled with velocity on the loading point of fabric.

VIII. RESULTS

I. Constitutive Relations

Energy absorption is an important index commonly used to assess the ability of the mechanical protective performance of fabric under impact. The fabric energy absorption includes the strain energy dissipated in stretching of the yarns and the energy loss from transverse deflection of the whole fabric and the inward movements of yarns towards the loading point. Moreover, a portion of the projectile kinetic energy is dissipated due to frictional forces. But in this work, the friction forces are not considered among the complicated impact conditions.

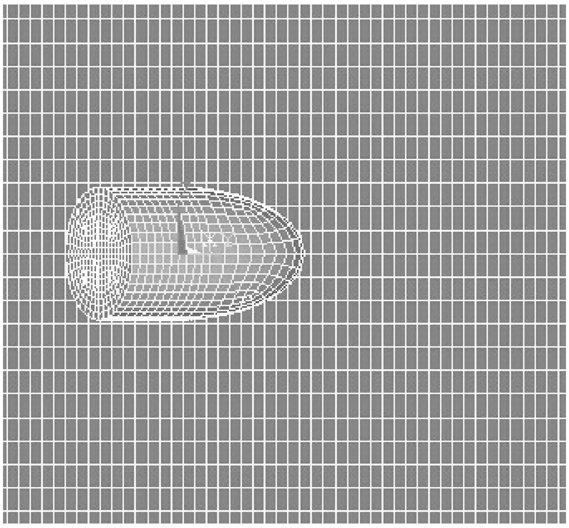

Fig 6 The Projectile Loading On The Material

To calculate the energy absorption, the reduction of energy due to projectile deformation is assumed to be negligible. With the increasing impact velocity, the relation of absorbed energy and kinetic energy is changing. Generally, variation of energy absorbed with impact can be divided into three regions.

(1) **The low region**: the impact velocities are lower than the limit velocity. In this region, the projectile has not penetrated into the fabric. Hence, the energy absorbed by fabric is practically equal to the total kinetic energy possessed by the projectile.

(2) **The middle region**: the impact velocities are higher than the limited velocity, but lower than critical velocity. In this region, the projectile penetrates into the fabric, and then moves on with a residual velocity. The initial increase in stress is insufficient to reach the failure stress of fabric. Hence, the transverse deflection has time to propagate to the edges. Absorption energy increases with kinetic energy up to the critical velocity.

(3) **The high region**: the impact velocity is higher than the critical velocity. In this region, the projectile penetrates into the fabric rapidly. Hence, the stress wave has no time to propagate to the edges of fabric. The energy absorbed is very small and becomes approximately constant.

According to the energy conservation equation, the energy absorbed by fabric can be described by

$$E_A = \frac{1}{2} m_P v^2 - \frac{1}{2} m_P {v_r}^2$$

In this paper the low impact velocities in region one are analyzed by ANSYS. The projectiles have not penetrated into the fabric. Hence, the energy absorbed by fabric is practically equal to the total kinetic energy possessed by the projectile.

II. Deformation and Stress Distribution

When a projectile impacts on a fabric, stress waves that originate from the impact point move along the yarns to the edges of the fabric where they get reflected. When the projectile touches the fabric with the initial velocity, the loading point is stressed along the direction of initial velocity.

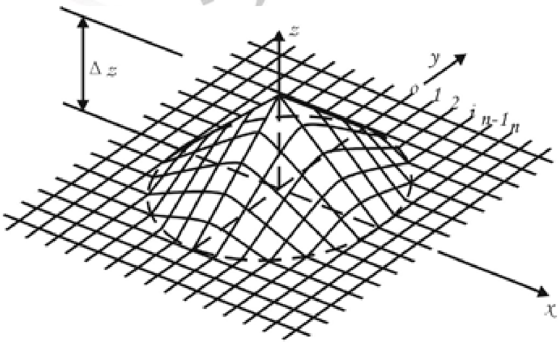

Fig 7 The Diagram Illustrating of Projectile on Material

After the initial penetration, the projectile pushes away the rest of the material. In each yarn crossover point serves to partly transmit and partly reflect the stress wave. When a material is impacted by a projectile transversely, longitudinal strain waves propagate to the edges of the fabric along the yarns. The strain wave, called the elastic wave propagates at a velocity described as follows.

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$$c = \sqrt{\frac{E}{\rho}}$$

Where, C is the velocity of strain wave;
E is the elasticity modulus of the material;
ρ is the density of material.

Such observation can easily be verified by penetrating a pen into the fabric. The theoretical deformation of fabric during the impact is shown. Moreover, during the impact process, the level of strain and rate of strain changes considerably with time. Hence, the material properties which are functions of strain rate vary throughout the process. The behavior of material under transverse impact therefore involves a complex relationship involving many factors. The change in deformation of the fabric obtained after the impact for a specific time, using the proposed model is shown in Figure 8.

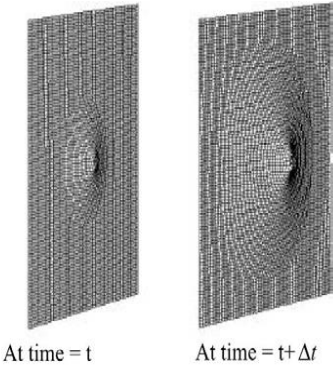

Fig 8 The Material Affected T Seconds after Impact

IX. CONCLUSION

The mechanical protective clothing has to be designed with high-strength fiber materials, and yet is expected to provide increased mechanical protective performance from mechanical damage. To ensure that these improved products with high-strength fabrics are able to provide adequate protection, they are subjected to a series of mechanical tests based on the requirements specified in test standards from government agencies. This process can be expensive when exploring design variations during the development of the next generation of protective products. Finite-element simulations can alleviate the expense incurred during the development of these new protective products. Through finite-element simulations, protective clothing designers can cost-effectively explore and assess the mechanical resistance of protective clothing which are designed using cheaper, lighter and stronger materials.

The model proposed in this study provides a conceptual framework for better understanding on the finite-element simulation of material behavior under projectile impact loading. This investigation also explored the suitability of employing load curves to represent the viscoelastic nature of material. Idealized dynamic characteristics were obtained through mathematical manipulation of the equation describing the three-element spring-dashpot model and by using the available experimental data. The energy absorption and the deformation of material under impact are also obtained to describe the performance of fabric. The finite-element modeling of mechanical protective clothing is much closer to the real impact condition.

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