IMPACT ANALYSIS AND COMPARATIVE STUDY FOR DIFFERENT COMPOSITE MATERIAL FOR BULLET PROOF VEST

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***Abstract*—The Response of a material impacted by projectiles especially bullets, or blast fragments, is extremely important in determining the range of impact it can sustain. As explicit finite element codes improve and advances material models become available, the hydro codes find more widespread application in many industries. In this thesis, a study of ballistic response is implemented using simulation of thin metal targets in Explicit Dynamics in Ls-Dyna software. Further in the study an attempt has been made to study the response of composite targets to the projectile impact. For the composite target, a finite element model is implemented.**

In this project, impact analysis of bullet on composite material for bullet proof vest are discussed in order to develop the feasibility of composite ballistic impact loading. This topic is providing a brief overview of bullet impact on composite analysis using Ls-Dyna software. Kevlar-Epoxy is used in an armor applications for bulletproof purposes. This project is providing guidance for engineer's guidance w hile working with Kevlar-Epoxy and S2 glass. In response to the reduce weight of armor, easy for wear.

Index Terms — **Impact analysis, Bullet proof vest, composite.**

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1 LITERATURE SURVEY

Priyawart Lather, "Analysis of composite materials used in bullet proof vests using fem technique", International Journal of Scientific & Engineering Research, May-2013 This shows studying various composite materials used in bullet-proof vests and to analyze their effectiveness by using FEM technique. Hence obtained data would be utilized for designing an optimized bullet-proof vest. When a handgun bullet strikes body armor, it is caught in a "web" of very strong fibers. M. Grujicic, P.S. Glomski, "Material Modeling and Ballistic-Resistance Analysis of Armor-Grade Composites Reinforced with High-Performance Fibers", ASM International, January 2009. The present model is constructed in such a way that it can be readily integrated into commercial finite element programs like ANSYS/Autodyne. To validate the model, a series of transient nonlinear dynamics computational analyses of the transverse impact of armor-grade composite laminates with two types of bullets/projectiles is carried out and the computational results compared with their experimental counterparts.A A Ramadhan , "The Influence of impact on Composite Armor System Kevlar-29/polyester-Al2O3",International Conference on Mechanical Engineering Research, 2011.An experimental investigation of high velocity impact responses of composite laminated plates using a helium gas gun has been presented in this paper. The aim of this study was to develop the novel composite structure that meets the specific requirements of ballistic resistance which used for body protections, vehicles and other applications. Thus the high velocity impact tests were performed on composite Kevlar-29 fiber/polyester resin with alumina powder (Al2O3).

2 INTODUCTION

2.1 COMPOSITE

A broad definition of composite is a two or more chemically distinct materials which when combined have improved properties over the individual materials. Composites are a combination of two materials in which one of the material is called the reinforcing phase, is in the form of fibers, Due to their high strength to weight ratios, laminated composite materials have found extensive applications in the construction of mechanical, aerospace, marine, protective gear and automotive structures [1]. The purpose of the ballistic protective materials is not to just stop the speeding bullets but to protect the individual from fragmenting devices as well, i.e. from grenades, mortars, artillery shells, and improvised explosive devices. We should note that the injury caused to the civilians is mainly due to two factors:

- High velocity bullets from rifles, machine guns which are mainly shot from a long range.
- Low velocity bullets from hand guns which are shot from close range [4].

3 INTRODUCTION TO ARMOR SYSTEMS

Military systems especially supporting the ground forces are being transformed to move faster, more agile and more mobile as to counteract the warfare tactics. Bomb attacks on armored vehicles claimed lives of Defense troops. As a result, an increased demand for improved armor has led to the development of new armor materials. Already in some fields Polymer Matrix

Composites, Ceramics and Metal mobility. Research is still going on in this field to completely replace the armor shield with composite materials which offer good strength to weight ratios [5].

3.1 INTRODUCTION TO BODY ARMOR

Throughout history, lightweight and flexible materials have been sought to reduce the weight of body armor systems to enhance mobility, while providing protection against specified threats. Early materials included leather and even silk, which were used in conjunction with metal plates to provide the needed protection in making vests. These vests provided protection against bomb and grenade fragments, which accounted for the high majority of injuries and deaths among soldiers. Although nylon and E-glass fibers continue to find some use today due to their low cost, high performance fibers are now the standard for most fiber reinforced armor applications. High performance fibers are typically used in the form of woven fabrics for vests and for helmets. Figure 3 shows the Interceptor vest and composite [5].

Fig.1 bulletproof vest

3.2 ARMOR CLASSIFICATIONS FOR BALLISTIC-RESISTANT ARMOR

There are six formal armor classification types, as well as a seventh special type, as follows [4]:

Type I (.22 LR; .380 ACP).

This armor protects against .22 long rifle lead round nose (LR LRN) bullets, with nominal masses of 2.6 g (40 gr), impacting at a minimum velocity of 320 m/s (1050 ft/s) or less, and against .380 ACP full metal jacketed round nose (FMJ RN), with nominal masses of 6.2 g (95 gr), impacting at a minimum velocity of 312 m/s (1025 ft/s) or less. Type I body armor is light. This is the minimum level of protection every officer should have, and the armor should be routinely worn at all times while on duty. Type I body armor was the armor issued during the NIJ demonstration project in the mid-1970s. Most agencies today, however, because of increasing threats, opt for a higher level of protection.

Type II-A (9mm; .40 S&W).

This armor protects against 9mm full metal jacketed round nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr), impacting at a minimum velocity of 332 m/s (1090 ft/s) or less, and .40 S&W caliber full metal jacketed (FMJ) bullets, with nominal masses of 11.7 g (180 gr), impacting at a minimum velocity of 312 m/s (1025 ft/s) or less. It also provides protection against Type I threats. Type II-A body armor is well suited for full-time use by police departments, particularly those seeking protection for their officers from lower velocity 9mm and 40 S&W ammunition.

Type II (9mm; .357 Magnum).

This armor protects against 9mm full metal jacketed round nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr), impacting at a minimum velocity of 358 m/s (1175 ft/s) or less, and .357 Magnum jacketed soft point (JSP) bullets, with nominal masses of 10.2 g (158 gr), impacting at a minimum velocity of 427 m/s (1400 ft/s) or less. It also provides protection against Type I and Type IIA threats. Type II body armor is heavier and more bulky than either Types I or II-A. It is worn full time by officers seeking protection against higher velocity .357 Magnum and 9mm ammunition.

Type III-A (High Velocity 9mm; .44 Magnum).

This armor protects against 9mm full metal jacketed round nose (FJM RN) bullets, with nominal masses of 8.0 g (124 gr), impacting at a minimum velocity of 427 m/s (1400 ft/s) or less, and .44 Magnum jacketed hollow point (JHP) bullets, with nominal masses of 15.6 g (240 gr), impacting at a minimum velocity of 427 m/s (1400 ft/s) or less. It also provides protection against most handgun threats, as well as the Type I, II-A, and II threats. Type III-A body armor provides the highest level of protection currently available from concealable body armor and is generally suitable for routine wear in many situations. However, departments located in hot, humid climates may need to evaluate the use of Type III-A armor carefully.

Type III (Rifles).

This armor protects against 7.62mm full metal jacketed (FMJ) bullets (U.S. military designation M80), with nominal masses of 9.6 g (148 gr), impacting at a minimum velocity of 838 m/s (2750 ft/s) or less. It also provides protection against Type I through III-A threats. Type III body armor is clearly intended only for tactical situations when the The ballistic fabric materials can be arranged to provide effective protection. Each body armor developer has its own method when developing protective systems. The fibers are usually plain woven together, although there are other methods of weaving that are used. Some armors use one single material stacked in multiple layers, others use several types of materials. Each layer of material can be comprised of varying directional fibers. Additional layers of material increase the ballistic resistance and blunt trauma protection, but the weight is also increased. Several stitching methods are employed to hold the layers together. For example, a bias stitch can be applied around threat warrants such protection, such as barricade confrontations involving sporting rifles.

Type IV (Armor Piercing Rifle).

This armor protects against .30 caliber armor piercing (AP) bullets (U.S. military designation M2 AP), with nominal masses of 10.8 g (166 gr), impacting at a minimum velocity of 869 m/s (2850 ft/s) or less. It also provides at least single-hit protection against the Type I through III threats. Type IV body armor provides the highest level of protection currently available. Because this armor is intended to resist "armor piercing" bullets, it often uses ceramic materials. Such materials are brittle in nature and may provide only single-shot protection, since the ceramic tends to break up when struck. As with Type III armor, Type IV armor is clearly intended only for tactical situations when the threat warrants such protection.

Special type.

A purchaser who has a special requirement for a level of protection other than one of the above standard threat levels should specify the exact test rounds and minimum impact velocities to be used and indicate that this standard shall govern in all other respects.

3.3 MANUFACTURING AND TESTING OF BALLISTIC BODY ARMOR

Ballistic resistant body armor is developed for a variety of scenarios and levels of protection. Factors that are considered when developing body armor include weight (i.e. areal density), type of bullet, bullet velocities, and comfort. The idea behind stopping a bullet is to reduce its energy. When the bullet hits the ballistic resistant system, it absorbs and disperses the energy of the bullet by deforming it into a mushroom shape. Typically, military ballistic armor consists of soft and rigid components. The soft armor forms the flexible, protective vest. It contains several layers of ballistic fabric material(s). The rigid armor is used for enhanced protection in specific areas, normally this is over the chest region to protect vital organs. The rigid armor is in the form of a plate that is inserted into a pocket of the vest. The entire body armor system has a carrier, usually made of nylon that has the sole purpose of supporting the ballistic material and securing the armor to the body for correct positioning and comfort the perimeter of the materials. There are several other forms of stitching which include rows of parallel or overlapped vertical, horizontal and diagonal lines. Stitching of ballistic materials has been shown to slightly improve ballistic integrity and enhance protection against blunt trauma [4].

Manufacturing process

Some bulletproof vests are custom-made to meet the customer's protection needs or size. Most, however, meet standard protection regulations, have standard clothing industry sizes (such as 38 long, 32 short), and are sold in quantity Bulletproof vests undergo many of the same tests a regular piece of clothing does. The fiber manufacturer tests the fiber and yarn tensile strength, and the fabric weavers test the tensile strength of the resultant cloth. Nonwoven Spectra is also tested for tensile strength by the manufacturer. Body armor manufacturers test the panel material (whether Kevlar or Dyneema) for strength, and production quality control requires that trained observers inspect the vests after the panels are sewn and the vests completed. Bulletproof vests, unlike regular clothing, must undergo stringent protection testing as required. Not all bulletproof vests are alike. Some protect against lead bullet at low velocity, and some protect against full metal jacketed bullets at high velocity [4].

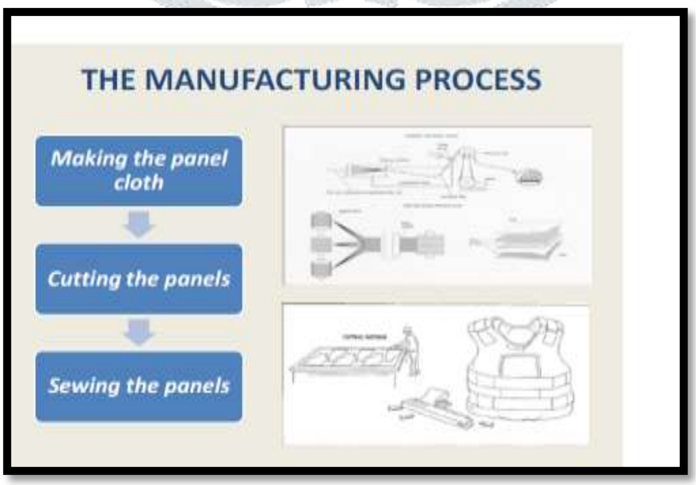


Fig.2. Manufacturing process of bulletproof vest

Quality control

Bulletproof vests undergo many of the same tests a regular piece of clothing does. The fiber manufacturer tests the fiber and yarn tensile strength, and the fabric weavers test the tensile strength of the resultant cloth. Nonwoven Spectra is also tested for tensile strength by the manufacturer. Body armor manufacturers test the panel material (whether Kevlar or Dyneema) for strength, and production quality control requires that trained observers inspect the vests after the panels are sewn and the vests completed. Bulletproof vests, unlike regular clothing, must undergo stringent protection testing as required [4].

Testing

Fig.3. Gas gun tunnel to test the specimens

Bulletproof vests are tested both wet and dry. This is done because the fibers used to make a vest perform differently when wet. Testing (wet or dry) a vest entails wrapping it around a modeling clay dummy. A firearm of the correct type with a bullet of the correct type is then shot at a velocity suitable for the classification of the vest. Each shot should be three inches (7.6 centimeters) away from the edge of the vest and almost two inches from (five centimeters) away from previous shots. Six shots are fired, two at a 30-degree angle of incidence, and four at a O-degree angle of incidence. One shot should fall on a seam. This method of shooting forms a wide triangle of bullet holes. The vest is then turned upside down and shot the same way, this time making a narrow triangle of bullet holes [4].

The instrumented impact test equipment used in this study was a gas gun impact tester M. T. H. Sultan [12] shown in Figure 4. The general features of the testing apparatus are shown in Figure has been designed in order to launch the projectile. The main components of the gas gun are the 2200 Psi pressure tank, the purpose-built "ring section for compressed gas, the 4 m long smooth barrel and (60, 60 and 40 cm) dimensions of box chamber to hold the specimen inside this box which it has (60 x 60 cm) framing window to observe the behavior of target and bullet by photography high speed camera (200,000 fps) for this work [7].

3.4 MATERIAL USED

There are several types of ballistic fabrics that are used today:

Structure & properties

When Kevlar is spun, the resulting fiber has a tensile strength of about 3 620 MPa, and a relative density of 1.44. The polymer owes its high strength to the many inter-chain bonds. These inter-molecular hydrogen bonds form between the carbonyl groups and N*H* centers. Additional strength is derived from aromatic stacking interactions between adjacent strands. These interactions have a greater influence on Kevlar than the van der Waals interactions and chain length that typically influence the properties of other synthetic polymers and fibers such as Dyneema. The presence of salts and certain other impurities, especially calcium, could interfere with the strand interactions and caution is used to avoid inclusion in its production. Kevlar's structure consists of relatively rigid molecules which tend to form mostly planar sheet-like structures rather like silk protein [4].

Thermal properties

Kevlar maintains its strength and resilience down to cryogenic temperatures (-196°C); indeed, it is slightly stronger at low temperatures. At higher temperatures the tensile strength is immediately reduced by about 10-20%, and after some hours the strength progressively reduces further. For example at 160°C about 10% reduction in strength occurs after 500 hours. At 260°C 50% strength reduction occurs after 70 hours [4].

Composites in Ballistic Applications

Composites on the offer very high strength to weight ratios and are hot favorites in aviation and other fields where light weight components that offer high endurance are desired. Composite materials unlike metals lose structural integrity and strength to a great extent upon impact. Composites are combinations of two or more materials embedded in another material called matrix. The reinforcing material can be metal, ceramic or polymer. The combination offers properties superior to individual components. The orthotropic property of composite allows us to design to our requirements still keeping the overall weight minimum. High strength to weight ratio, High creep resistance, High tensile strength, and High toughness are main factors behind the use of composites in many applications [3].

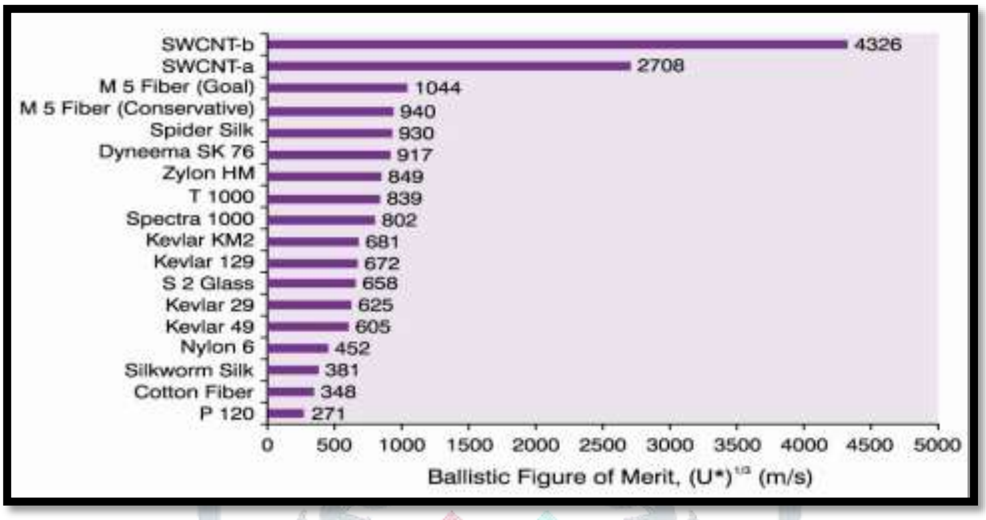


Fig.4. Various material used for Ballistic application.

Elastic properties	Values	Units
Ultimate tensile strength	3000	Mpa
Elongation at break	2.4	%
Tensile modulus	112	GPa
μ	0.36	
ρ	1440	Kg/m^3

Table No.1. Mechanical Properties of KEVLAR Composite Material

Elastic properties	Values	Units
Ultimate tensile strength	4445	MPa
Elongation at break	5.7	%
Tensile modulus	86.9	GPa
μ	0.22	
ρ	2480	Kg/m^3

Table No.2. Mechanical Properties of S2 Glass Composite Material

3.5 RISK OF INJURY

` There are several components of the body where protection should be provided. The spinal column, heart and kidneys are the two major elements that need protection. They perform functions essential for a person to live a normal life. Other areas where protection should be provided are the ribs and scapulae. They are important structures where considerable discomfort could be caused by injuries.

When selecting armor for full-time routine use by an officer, comfort is a major factor. Armor that is set aside or relegated to the trunk of a cruiser is of no benefit. Two fundamental factors were considered fit—from the standpoint of mobility and the weight distribution of the armor—and heat discomfort [4].

Following points should be kept in mind while designing armor,

- The neck opening should not be too high and should be properly shaped.

- The shoulder, neck, and armholes should be feathered to minimize bulk and maximize comfort at these areas, but still not reduce protection.
- The shoulder straps should be wide enough for comfort and to distribute the weight of the armor, but not so wide as to restrict movement
- Seam construction of the armor should allow maximum flexibility and yet maintain protective coverage. The armor should permit size adjustment while retaining protective integrity for the sides of the torso.
- The carrier for the armor material should have a tail that can be tucked into the pants to prevent the armor from riding up.
- The armor should be as light as possible, while still providing protection against the threat that is most prevalent in the geographical area of use.
- The length of the front of the armor should not be too long; otherwise, it will be pushed up into the throat when the officer sits or bends.
- The armor should be wide enough to allow the front panel to overlap the back panel. The armholes of the armor should not be too small.
- The concealed undergarments for officers should conform to the anatomy. The seam construction for such garments that include seams is critical. It is very important that the joined pieces overlap each other a minimum of 1 inch. Particular attention should be paid to the length of the garment, which is a frequent problem. The adjustment straps for the undergarment may be fastened to the back to improve the overall appearance of the uniform. (4)

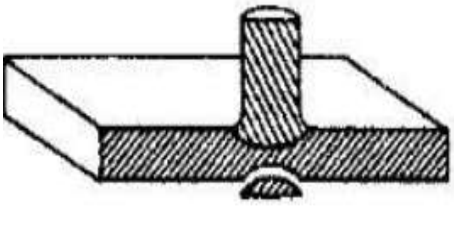
4 MECHANICS OF PENETRATION

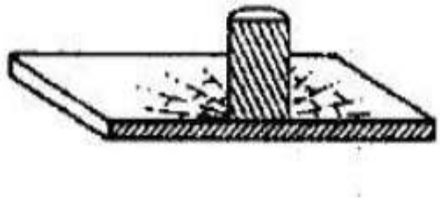
4.1 INTRODUCTION TO PENETRATION OF MECHANICS

The penetration mechanics, also known as the impact and penetration mechanics, is an interdisciplinary subject. A comprehensive discussion of the relevant background would be quite extensive. However, this thesis focuses on the ballistic response during the impact.

Penetration and failure in metal targets

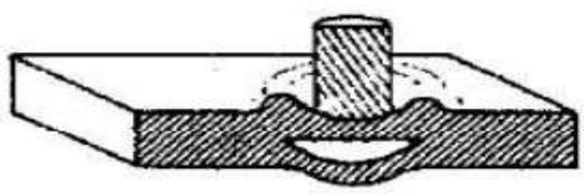
Metals are isotropic materials i.e., having same properties in all directions. Models of penetration and perforations are based on laws of conservation and compatibility. As an Impact occurs, the kinetic energy of the projectile is imparted to the plate. Some of the energy is used to deform the plate. Other energy is given off as light and heat, the remainder of the energy is imparted to the fragments as kinetic energy. Measuring or determining each of these energies is very difficult .For penetration and perforation analysis, the only important aspect is to predict the kinetic energy (i.e. mass and velocity) of the fragments. Once this kinetic energy is determined, conservation of mass and energy, sometimes in terms of momentum, is applied to the projectile/target system. The analysis is still quite complex because the events that occur at the projectile/ target interface are somewhat unknown. Although many studies have been performed, only highly controlled velocities, shapes, sizes and trajectories have been examined. As a result, numerous approximations and assumptions must be made in order to apply to these analyses to fragments. Impact is a much localized phenomenon. Stress and strain effects are usually limited to within 3-6 projectile diameters of the impacted zone. Impacted target materials may fail by a combination of several modes including spalling, plugging, petaling, ductile or brittle fracture, and adiabatic shearing. Figure shows some of these failure modes [6].

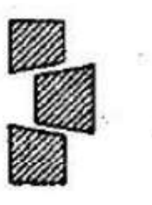




Fracture due to initial stress wave

Radial fracture behind initial wave in a brittle





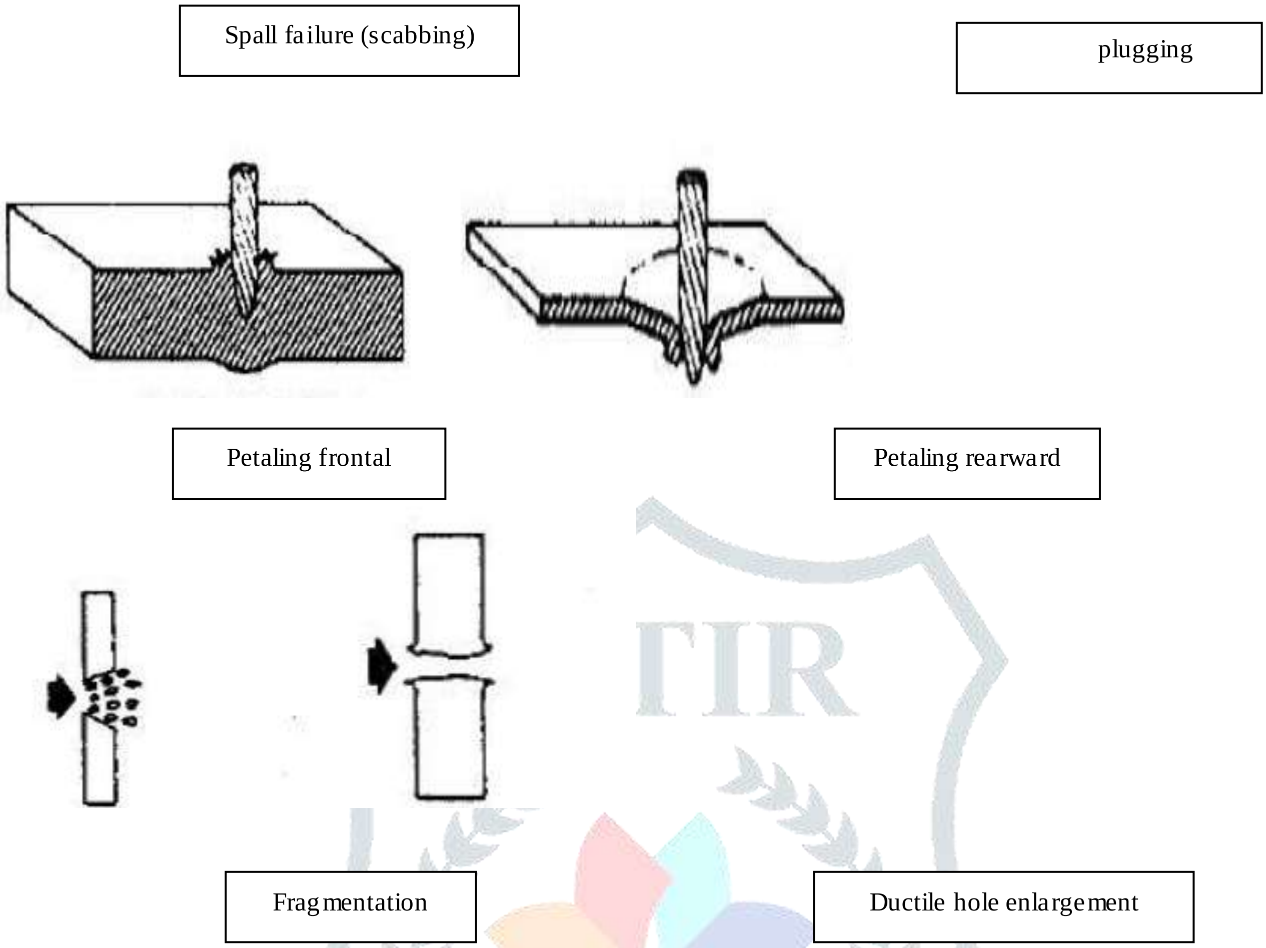


Fig.5 Common failures occurring in projectile impact [6]

A target is considered thick if the distal boundary is influential only after substantial travel of the projectile into the target. For thin targets distal side responds immediately for impact on the frontal side. Spalling is tensile failure of the target material due to the reflection of the initial compressive waves from the far side of the target. Failure by spalling can occur on either the front or back of a target and is characterized by the formation of petals or ejects.

In ductile failure, the impact impulse overcomes the peripheral dynamic shear strength of the target material, pushing it outward and toward the impact surface to form a crater that is much larger than the projectile diameter. At the same time, the projectile pushes into the target, and there is hydrodynamic erosion and inversion of the penetrator material against the preceding face of the target [6].

The penetration process due to high-velocity impact can be represented by four phases: transient, primary penetration, secondary penetration, and recovery. The first, or transient, phase is characterized by a very short pressure spike and occurs when the projectile first contacts the target surface. The primary penetration phase is described as the period during which the projectile acts as a contributing force, imparting its kinetic energy to the target in a hydrodynamic manner. The secondary phase (more than one phase may occur simultaneously), sometimes referred to as cavitations, begins after the projectile is completely deformed and effectively removed from the system as a source of energy. It is marked by target deformation not caused directly by the KE of the projectile material. Instead, the energy density behind the expanding shock wave continues to deform the target material. The fourth, or recovery, phase refers to the period during which the crater recovers or contracts slightly. Material just below the target surface anneals and re-crystallizes [6].

Projectile failure occurs simultaneously with target failure. Thus, penetration models involve both things. The projectiles deform and flatten/spread out as they strike the target, generating high resisting contact forces. For low L/D ratios, either model gave reasonable predictions. Expectedly, this also suggests that a combination of both phenomena actually takes place. Another penetration model is similar to the erosion model, but of a more hydrodynamic nature. The particular treatment here is taken from [24]. In this model, the front end of the projectile and the impacted surface are modeled as flowing liquids. The regions directly behind these surfaces are then modeled as rigid bodies. The projectile is consumed from the impact end as it penetrates the target material and is transformed into a Further it predicts that most of the impacted target material is displaced forward and outward by the projectile during penetration and that a small amount is ejected backwards. Maximum strain criterion is used to show the failure of the material. In present analysis no data is available regarding the deformation of the projectile and mass loss of the projectile, so the projectiles deformation is ignored in the target. In the event of Impact there is an exchange of energy takes place.

$$E_{trans} = IE_{plate} + KE_{plate} + KE^{eroded} + IE^{eroded}$$

Law of Conservation is observed in any physical phenomena. Kinetic energy of the projectile is spent in raising the internal energy and kinetic energy of the plate and some part of the energy is lost in the form of eroded material . This is described by the equation (2.2), where E, IE, KE denote total energy, internal energy, kinetic energy, subscripts trans and plate denote transmitted and related to plate. The superscript eroded denotes eroded mass. Blunt projectiles like cylinders are found to cause plugging because of pure shear failure, while the conical projectiles are found to cause petaling effect. The amount of energy dissipated also differs with the geometry.

4.2 COMPOSITE FAILURE AND DAMAGE

Composites are orthotropic materials i.e., having different properties in perpendicular directions. Parameters which significantly affect the properties of a composite are shape, size, orientation and distribution of the reinforcement and various other features such as matrix, grain size in case of polymer matrix composites. These together with volume fraction constitute what is called the microstructure of the composite. The orientation of the reinforcement within the matrix affects the isotropy of the system. When the reinforcement is in the form of equiaxial particles, the composite behaves essentially as an isotropic material whose elastic properties are independent of direction. Manufacturing process may result in different orientation of the reinforcement and hence the loss of isotropy; thus composite becomes anisotropic in nature. High velocity impact will cause localize compression of the composite and subsequently shearing the fibers and spalling of the resin during impact, the fibers take the shear loading. Once the projectile has slowed, the composite deforms causing fiber stretching, pullout, and delaminating of the composite layers (plies) and thus lower load carrying ability [2].

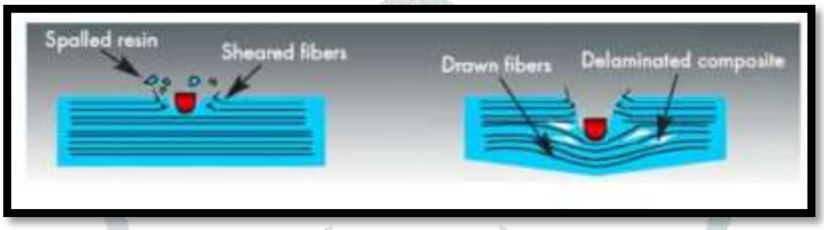


Fig.6 Rigid projectile impacting a composite

Unlike metals, composites lose structural integrity and strength with an impact. A key element in this development effort was in identifying and quantifying the different failure modes as the projectile penetrates the composites. A schematic of these processes is shown in Fig. 2. The initial penetration zone is dominated by punching shear failure, followed by ply tensile failure and then delaminating.

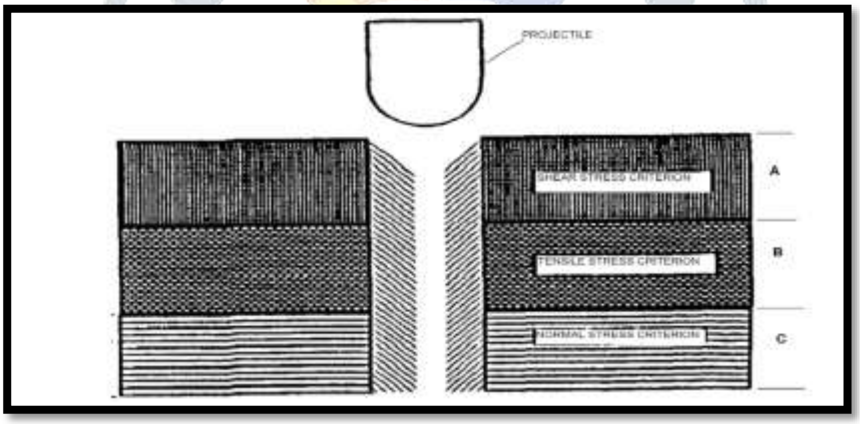


Fig. 7 Schematic of failure modes at different depths of the laminate A, B, C represent the Transverse Shear, Tensile and Delamination regions of the impacted Composite [5]

5 FINITE ELEMENT FORMULATION

5.1 INTRODUCTION TO FE CODES

In current analysis Ls-Dyna is used as main pre-processor Explicit Dynamics which has options for adding the cards for preparation of the code for processing and also for post processing. Finite element analysis involving short-time large deformation dynamics such as crashworthiness evaluation requires the solution of transient dynamic problems over a short time length. Explicit and implicit solution techniques or a combination of both have been used as the basis for FE crash codes. Explicit computational algorithms typically used the central difference method for integration, wherein the internal and external forces are summed at each node point, and a nodal acceleration is computed by dividing by the nodal mass. The solution is advanced by integrating this acceleration in time. The implicit method uses the Newark forward difference method for integration, whereby a global stiffness matrix is computed, inverted, and applied to the nodal out of balance forces to obtain a displacement increment.

The advantage of this method is that time-step size may be selected by the user. The disadvantage is the large numerical effort required to form, store, and factorize the stiffness matrix. The major practical difference between the explicit and the implicit solution technique is the requirement on the time step size, Δt.

Impact Loading: If the time of load application is less than 0.5 times the fundamental period of the mechanical system, the loading is defined as impact. The static methods of stress, strain, and deflection analysis are meaningless under impact conditions. This is due to propagation, reflection, and interference of elastic/plastic waves traveling within the engineering solid. Accurate calculations of stresses and strains most of be based on wave analysis methods, which are exceedingly complex for practical use, and thus must be solved for a limited number of simple cases. Other methods such as contact mechanics, energy methods, and FEA must be used to estimate the effects of impact analysis on mechanical systems that exhibit complexity [2].

Reasons for using the FEA Method in High Speed and Impact Loading conditions are analytical methods are useful in making predictions and understanding the dominant features of impact problems, given the engineering problem can be simplified to a simple geometry. Thus, geometry complexity limits the use of analytical methods. In general, high-speed/impact problems present a complexity of geometry, stiffness, mass distribution, impact angle, contact areas, and multiple impacts. In these cases, the only tool for complex analysis of impact or high-speed is some form of numerical methodology. Two classes of numerical methods exist for the analysis of **impact problems**- the finite difference method and the finite element analysis method. The finite difference method has the advantage of examining hypervelocity (high velocity) impacts involving severe damage or plastic flow and analogous to fluid flow/elastic deformation. FEA is applicable to slower-impact scenarios and as the advantage in addressing irregular geometries and boundary conditions.

5.2 FINITE ELEMENT MODELING OF PROJECTILE IMPACT MODEL

MODELING DETAILS

In this analysis the plate material is KEVLAR EPOXY and S2 glass and projectile (bullet) material is Tool Steel. Actual plate's dimensions are 500mm X 300mm X 4 mm. Finite element model is prepared in Explicit Ls- dyna. In impact event the damaged area is localized so one way biased meshing is used.

Geometry

For the analysis of impact of bullet on bullet proof vest made up of composite material. For the bulletproof vest is made up of Kevlar-Epoxy and S2 glass composite material for the analysis front area of vest is considered as rectangular shape with dimension 500mm X 300mm X 4 mm. and the dimension of bullet as shown in fig. below. According to this dimension front of vest and bullet is modeled on pro-e.

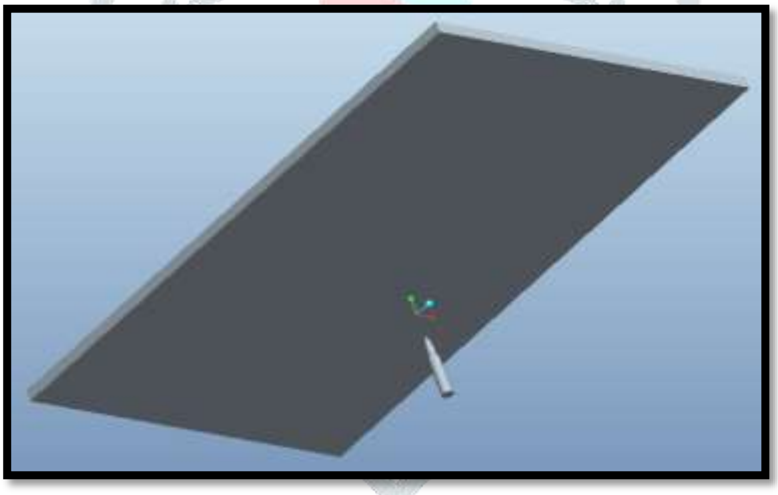


Fig. 4.8 Modeling of bulletproof vest (plate) and bullet

Material properties

In the present model bullet proof vest is of Kevlar-Epoxy and S2glass material and its properties are defined above in table no.1. The bullet is made up of steel material. In the Ls dyna software properties of Kevlar-Epoxy and S2 glass are inbuilt and the properties of steel as well.

Fe modeling:-

Hex meshing prefer for the plate and tetra mesh prefer for bullet. For the composite material we model four layer across the thickness. Average element size for the mesh is 10 mm. At the location of impact for getting good contact behavior we reduced up to 1 mm. For modeling the bullet we prefer Tetra mesh with 1 mm Average size. Hex meshing we prefer element formation 2 and for the tetra meshing we prefer it 10 element formation.

According to input provided from material details we assign the different material to component and check the results. Kevlar Epoxy and S2 glass are two composite material which are very strong for the sustain impact energy .According to cost and application, Strengths we prefer the different class of Kevlar Epoxy and S2 glass.

There is high impact velocity bullet impact on plate so prefer Surface to Surface contact to find out the Resultant force of that component .Automatic means Single surface contact is assigned for taking dynamic action of component where required In that contact we prefer all components. Interior contacts is for solid elements .For different material have different Strength like hard and soft parts comes in dynamic motion then there is chances of node shootout in mesh the run will terminates.so we assign the interior contacts for the solids elements. Mesh model is shown below,

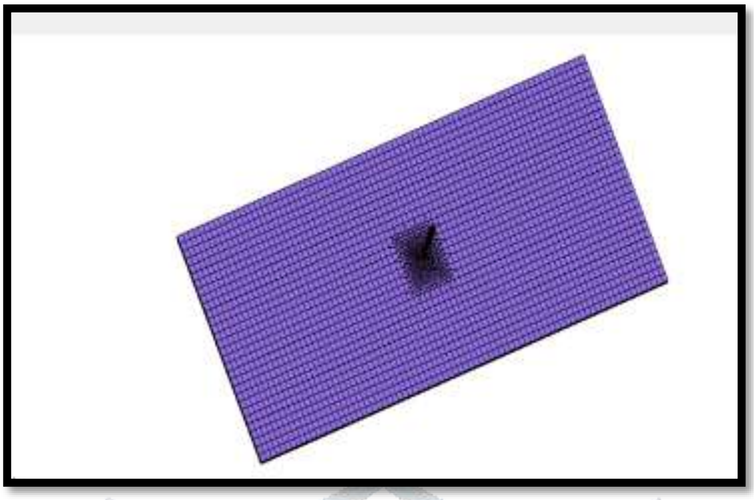


Fig. 8 FE Mesh model of bullet and plate

Loading and boundary condition:-

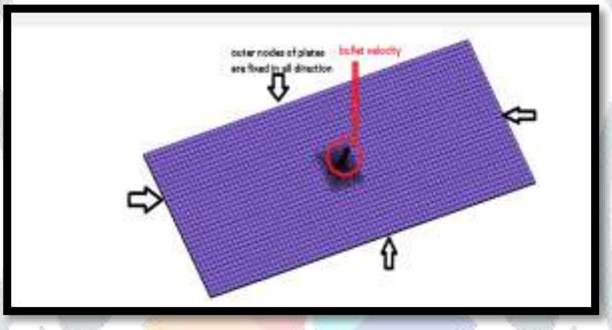


Fig. 9 Loading and boundary condition

Above figure shows Loading and boundary condition apply for the load case .According different load cases there is change initial velocity and material properties. Above figure black arrows shows the fixed the outer nodes of plate in all direction. Bullet velocity impacts shown in the red circle in above figure. Various load cases for which analysis are performed are listed in below table.

Materail / Loadcase	Velocity (m/sec)	Bullet Weight (gm)
Type 1	320	40
Type 2	427	158
Type 2A	332	124
Type 3	838	148
Type4	869	166

Table. 3. Load cases

5.3 RESULTS

Impact Analysis of bullet on composite plate is done by using Ls-Dyana. Result obtained after analysis is the we observed Elastic strain and Von –misses Stresses induced in plate.

Kevlar49 Type 1 :-

Von- Misses stress

The Stress observed in Plate is less than its material yield limit.

The Plate is Safe for this load case .The allowable material yield stress for Kevlar 49 is 3000 Mpa. The results shows 1228.28 Mpa which is less 50 % of the yield so the material is safe for this load case.

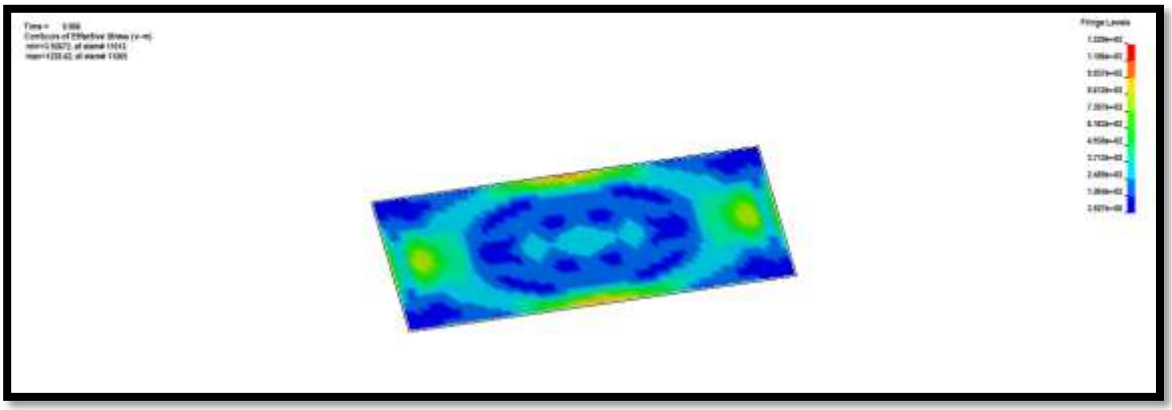


Fig. 10. Von-mises stress plot for Kevlar 49

Plastic Strain

The Plastic strain observed in Plate is less than its material yield limit.

The Plate is Safe for this load case .The allowable material yield strain for Kevlar 49 is 2.4 %.the results shows No strain means which is less than of the yield so the material is safe for this load case. No permanent deformation observed in the plate.

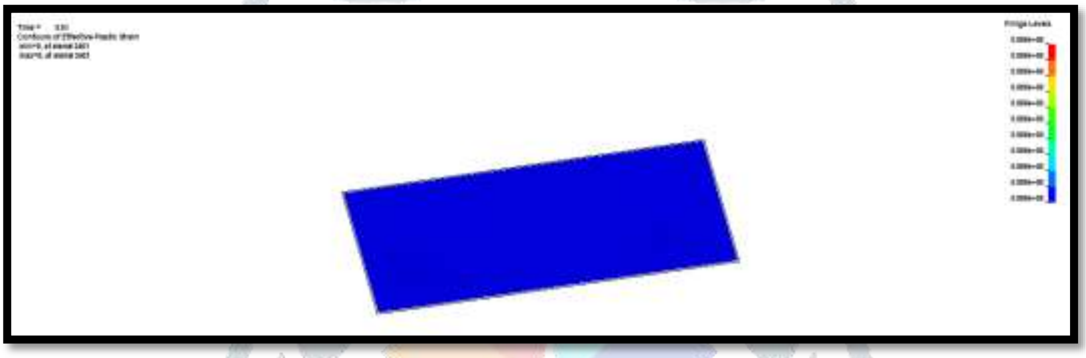


Fig. 11 Plastic Strain plot for Kevlar 49

Effective Strain

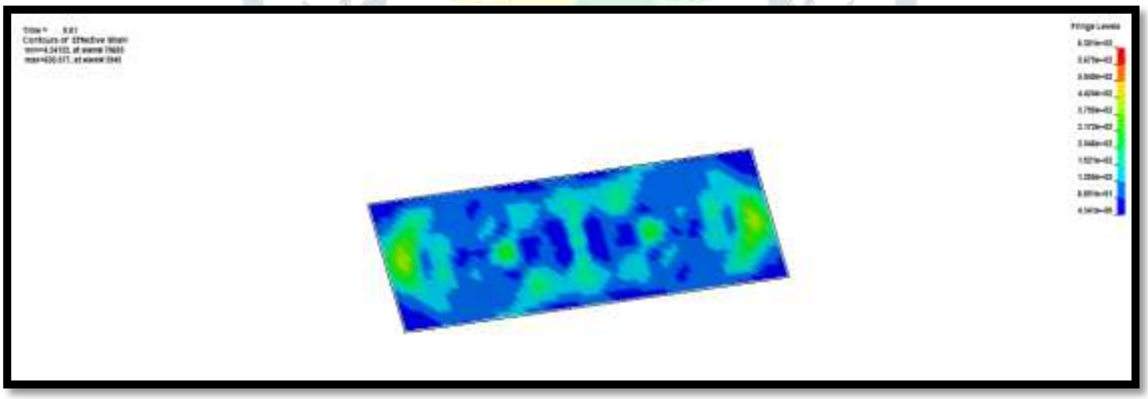


Fig.12 Effective Strain plot for Kevlar 49

The observation shows there is large deformation in the plate but there is no permanent deformation .it is elastic deformation.

Resultant Force

The graph shows high impact of bullet on plate at the initial condition .The resultant force is increases suddenly decreases.

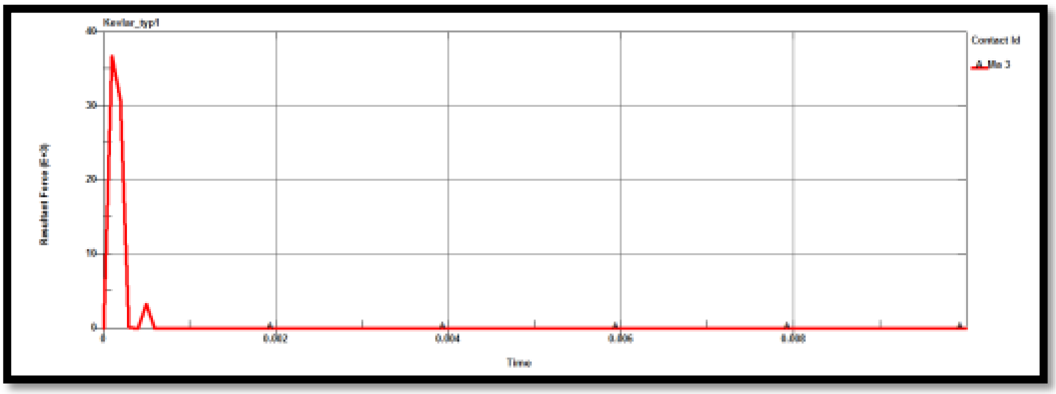


Fig.13 Resultant Force plot for Kevlar 49

Energy Graph

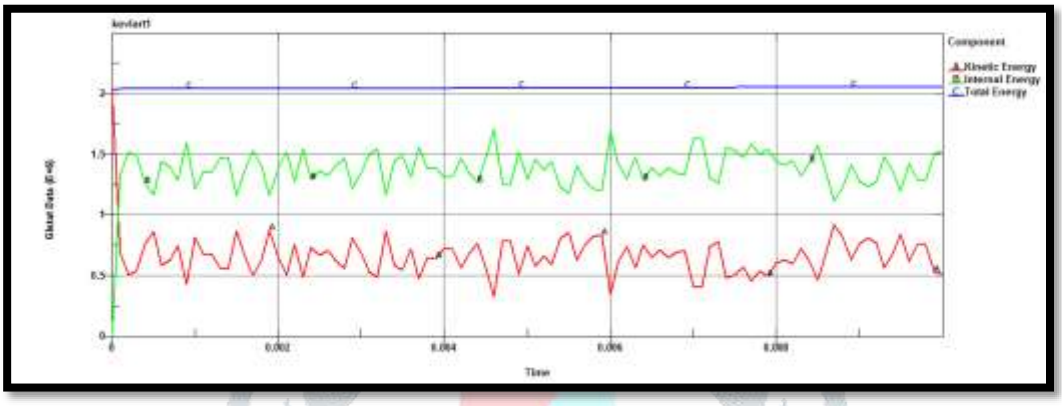


Fig.14 Energy Graph plot for Kevlar 49

The Graph shows the Variation of Kinetic energy, Internal energy and Total energy with respect to time .First kinetic energy decreases as velocity drops there is increases in Internal energy increases with deformation .The total energy remains constant.

Resultant Velocity Graph

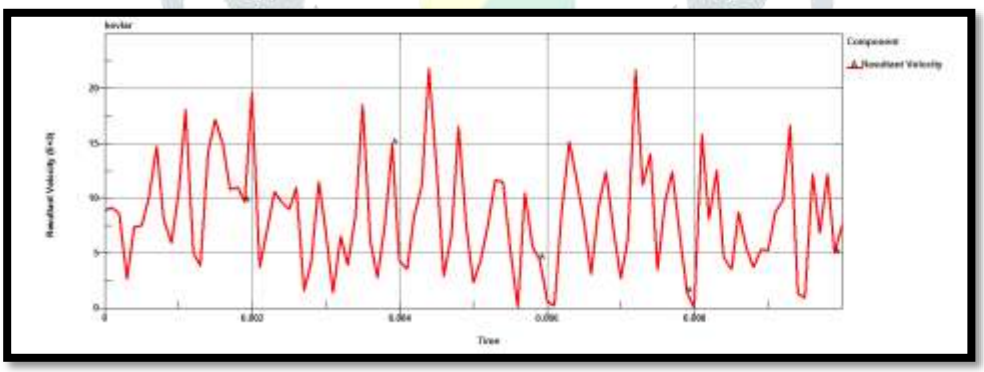


Fig. 15 Resultant Velocity Graph for Kevlar 49

The graph observed the velocity is drops at the initial condition it is drop points of the velocity .At that velocity the stresses increases.

<u>S2 glass Type1:-</u>

Von- Misses stress

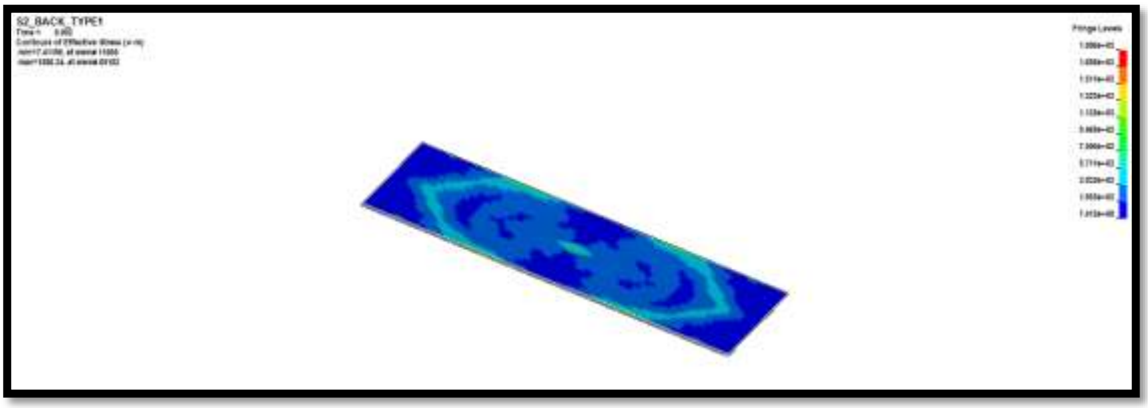


Fig.16 Von- Misses stress plot for S2 Glass

The Stress observed in Plate is less than its material yield limit.

The Plate is Safe for this load case .The allowable material yield stress for S glass is 4445 Mpa. The results shows 1886 Mpa which is less 50 % of the yield so the material is safe for this load case.

Plastic Strain

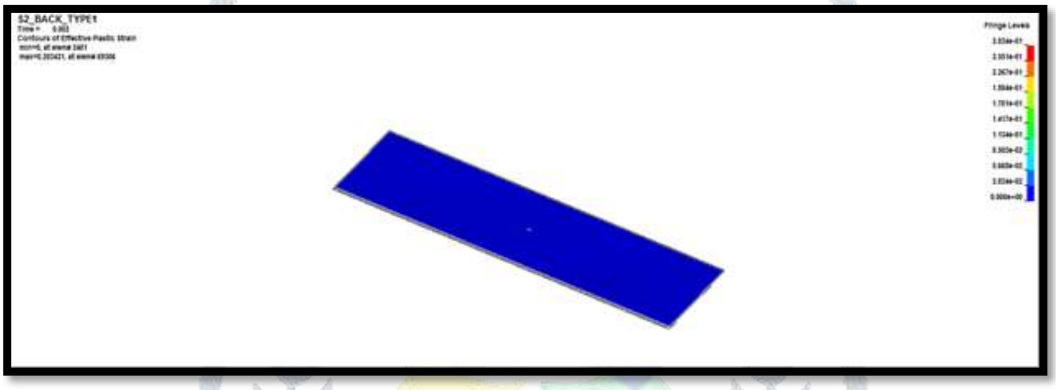


Fig. 17 Plastic Strain plot for S2 Glass

The Plastic strain observed in Plate is higher than its material yield limit.

The Plate is fail for this load case .The allowable material yield strain for S2 glass is 5.7%. The results shows high strain so there chances of high permanent deformation.

Effective Plastic Strain:-

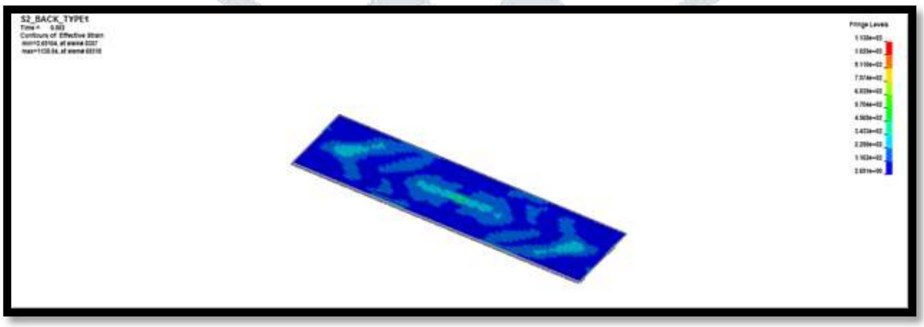


Fig. 18 Effective Plastic Strain plot for S2 Glass

The observation shows there is large deformation in the plate but there is chances of permanent deformation.

Resultant Force

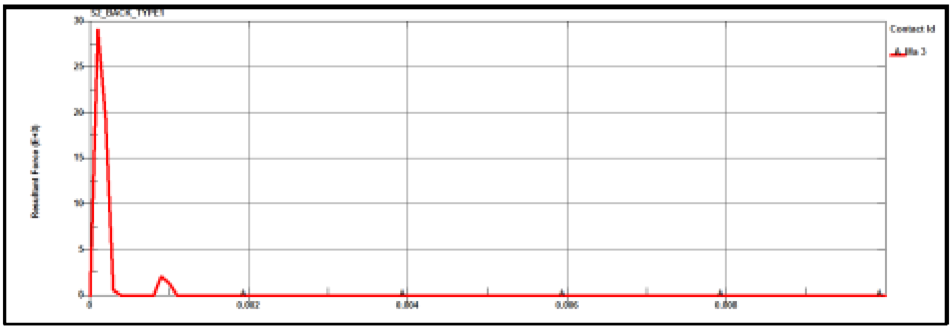


Fig. 19 Resultant Force plot for S2 Glass

The graph shows high impact of bullet on plate at the initial condition .The resultant force is increases suddenly decreases.

Energy Graph

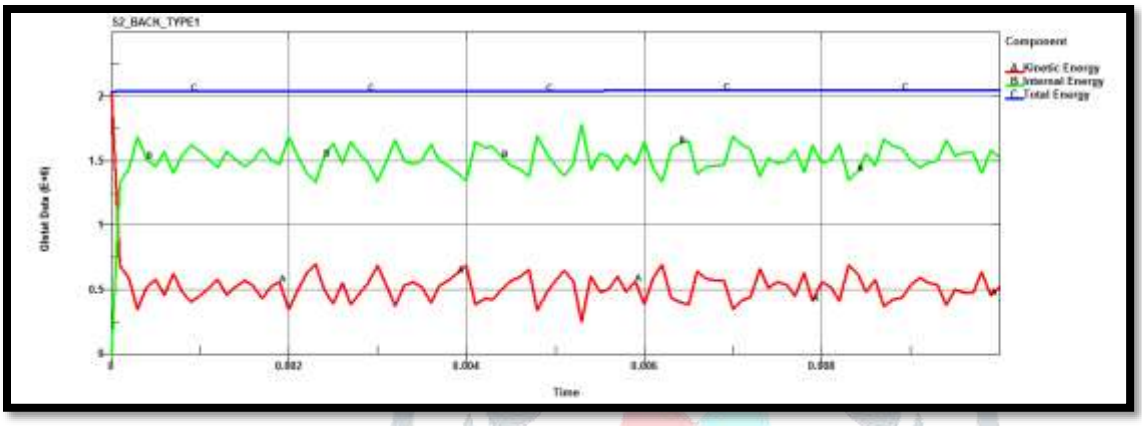


Fig. 20 Energy Graph plot for S2 Glass

The Graph shows the Variation of Kinetic energy, Internal energy and Total energy with respect to time .First kinetic energy decreases as velocity drops there is increases in Internal energy increases with deformation .The total energy remains constant.

Resultant Velocity Graph

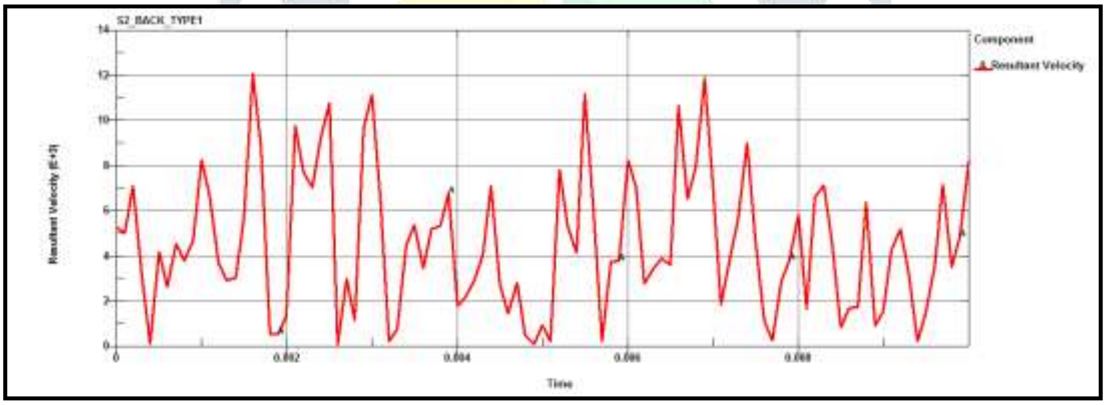


Fig. 21 Resultant Velocity Graph for S2 Glass

The graph observed the velocity is drops at the initial condition it is drop points of the velocity .At that velocity the stresses increases. After solving number of iteration with material Kevlar 49 and S2 glass material with their different material properties We observed following observations for all load cases.

5.4 OBSERVATION TABLE:-

After performing simulation in LS-Dyna for all the load cases for the both material results are viewed in LS-Pre-post. So the results are shown in below

Results	**Kevlar 49 Stress (Mpa)**					**S2 Glass Stress (Mpa)**				
Type	Type 1	Type2	Type2A	Type3	Type4	Type 1	Type2	Type2A	Type3	Type4

Von-Mises Stress	1223	3006	1577	3482	4848	1886	2699	1636	2441	2457
Effective Strain	630	1580	842	2231	3176	1133	2279	2149	1983	2036
Effective Plastic Strain	0	0	0	0	0	0.283	0.581	0.457	0.877	1.024

Material Allowable limit:-

Material	Allowable Stress (Mpa)	Plastic Strain (%)
Kevlar49	**3000**	**2.4**
S2 Glass	**4445**	**5.7**

From the observation table we can easily check strength of material with different material. According to cost, availability in the market we choose the material for the Armor Vest. From the above table.

6 CONCLUSION

- After studying the different parameter for bullet proof vest, while selecting the material for bullet proof vest is to identify the risks and levels of suitability associated with high velocity impacts on the bullet proof composite material.
- After simulate the Ballistic response of thin metallic target using Finite Element software it shows that velocity of bullet major factor for deciding the thickness for bulletproof vest.
- A study was conducted on a composite Kevlar and S2 glass material to study its Ballistic response at different velocities. Parametric studies were conducted on same model by varying mass of projectile, by varying the incident velocity, by changing the dimensions of spherical projectile, by varying the velocity of spherical projectile, by varying the failure strain of the target plate for same cylindrical projectile as in validation case. Thickness of the plate was kept the same only in case of the spherical projectile.
- The Kevlar 49 for Type3 and Type 4 shows high stresses as compare to Type 2Type2A respectively.Kevlar49 for Type1, Type2, and Type2A shows less stress than its allowable limit (3000 Mpa).It is safe for application.
- The Strain observed in Kevlar49 and its Type is less than its material yield limit so it is safe for given loading and boundary condition.
- The S2 glass material and Its Type the Stress observed is less than its allowable limit (4445 Mpa) so it is safe for given loading and boundary condition.
- The high plastic strain observed in the S2 glass material than its allowable limit (5.7 %) So it is chances of permanent deformation in the plate.
- Kevlar 49 material having less weight as compare to S2 glass material so its weight. S2 glass material having weight for same dimension is 1.723 times greater than Kevlar 49.
- From above point Kevlar 49 material is best suitable as compare to S2 glass for high velocity impact having less weight composite material.

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