STUDY OF BULLET IMPACT ON BULLETPROOF VEST USING EXPLICIT DYNAMICS TOOL IN ANSYS

A Project report submitted

in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

M.MANIKANTA	:	**315126520132**
K. HARSHITH KIRAN	:	**315126520080**
K. VIJAY BABU	:	**315126520112**
M.VINEETH RAGHAVA	:	**315126520133**
M.SITA RAMA RAJU	:	**315126520144**

Under the esteemed guidance of

BASA NAGARAJU

ASSISTANT PROFESSOR

DEPARTMENT OF MECHANICAL ENGINEERING

PRAGNANAM BRAHMA

ANITS

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

Autonomous status accorded by UGC and Andhra University
(Approved by AICTE, Permanently Affiliated to Andhra University, Accredited and reaccredited by NBA, accredited by NAAC- 'A' Grade)

Sangivalasa, Bheemunipatnam Mandal
Visakhapatnam (District) – 531162

(2015-2019)

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

Autonomous status accorded by UGC and Andhra University
(Approved by AICTE, Permanently Affiliated to Andhra University, Accredited and reaccredited by NBA, accredited by NAAC- 'A' Grade)

Sangivalasa, Bheemunipatnam Mandal
Visakhapatnam (District) – 531162

PRAGNANAM BRAHMA
ANITS

CERTIFICATE

This is to certify that the Project Report entitled "**STUDY OF BULLET IMPACT ON BULLET PROOF VEST USING EXPLICIT DYNAMICS TOOL IN ANSYS**" being submitted by **M.MANIKANTA (315126520132), K. HARSHITH KIRAN (315126520080), K. VIJAY BABU (315126520112), M.VINEETH RAGHAVA (315126520133), M.SITA RAMA RAJU (315126520144)** in partial fulfilments for the award of Degree of BACHELOR OF TECHNOLOGY in MECHANICAL ENGINEERING. It is the work of bonafide, carried out under the guidance and supervision of BASA NAGARAJU, ASSISTANT PROFESSOR of Department of Mechanical Engineering, during the academic year of 2015-2019.

PROJECT GUIDE	HEAD OF THE DEPARTMENT
B.N.Raju	13.4.19
(BASA NAGARAJU)	**(Prof. B.NagaRaju)**
ASSISTANT PROFESSOR	Head of the Department
Mechanical Department	Mechanical Department
ANITS, Visakhapatnam.	ANITS, Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa 531 162, VISAKHAPATNAM Dist. A.P.

THIS PROJECT WORK IS APPROVED BY THE FOLLOWING BOARD OF EXAMINERS

1. INTERNAL EXAMINER: 13/4/19

2. EXTERNAL EXAMINER: 13/4/19

ACKNOWLEDGEMENTS

We sincerely thank to our project guide **BASA NAGARAJU**, Assistant professor, Anil Neerukonda Institute of technology and Sciences for his whole hearted co-operation, unfailing inspiration and valuable guidance. Throughout the project work, his useful suggestions, constant encouragement has gone a long way in his valuable time for his patience and understanding he showed.

We are very thankful to **Prof. T. Subramanyam,** Principal, and **Prof. T.V. Hanumantha Rao,** Dean-Academics, Anil Neerukonda Institute of Technology & Sciences for their valuable suggestions.

We express our sincere thanks to the staff members of Mechanical Engineering for their kind co-operation and support to carry on work.

We also thank all those who contributed directly or indirectly in successfully carrying out this work.

M.MANIKANTA

K. HARSHITH KIRAN

K. VIJAY BABU

M.VINEETH RAGHAVA

M.SITA RAMA RAJU

ABSTRACT

Protection of soldiers had been under focus since ancient times. With the modernization of arms, demand for rise in protection levels against potential threats has also been increasing. For designing of armour vest, various parameters should be considered such as threat level, durability, weight and cost etc. Ceramic armours are preferred over metals mainly for their low weight and increased durability. But they lag in performance and reliability. To design armour, hit and trial procedure is not viable for being costly, time taking and labour intensive. So, impact studies of bullet on armours using ANSYS software is better alternative to reduce cost and labour.

This project focuses at presenting the simulation results of ballistic impact tests on laminated armour samples that consist of three layers of different materials: fibre-cement, Kevlar fabric, and steel. A 9 mm FMJ bullet was launched towards a sample of the armour from the fibre-cement side. ANSYS Workbench Explicit Dynamics was used to model and simulate the ballistic impact. Simulation results were compared with a reference paper to analyse the behaviour of armour designs, and a good agreement was observed and further the analysis was carried out to study the impact using materials, spectra and carbon fiber in place of Kevlar to suggest an alternative material to Kevlar.

Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER - 1

1. INTRODUCTION

1.1 History and development of vest

Throughout history, people have protected themselves from injury with different types of materials. In the earliest days, people used animal skins as barriers to injury and attacks. As weaponry advanced, they added wooden and metal shields to their defensive arsenals.

In the 1500s, Italian and Roman royalty experimented with the idea of bullet proof vests. They built body armour with layers of metal that were meant to deflect bullets. The outer layer was designed to absorb the bullet's impact, while the inner layer was added to stop further penetration. However, metal body armour was largely ineffective against firearms.

In the 1800s, softer body armour was developed by the Japanese, who made the armour from silk. These silk garments proved to be quite effective but also expensive. After President William McKinley was assassinated in 1901, the US military explored the use of soft body armour as well. The silk-derived garments were shown to be effective against low-velocity bullets, but not the new generation of handgun ammunition. The US military decided against silk armour because of this, combined with the high price of silk.

The flak jacket was invented during World War II. It was made from ballistic nylon and provided protection from ammunition fragments. Flak jackets were bulky and ineffective against most rifle and pistol fire, but they were widely used, as they provided some modicum of protection and allowed soldiers to feel secure.

In the 1960s, new fibres were discovered that made truly bullet resistant vests possible. In the early 1970s, DuPont's Kevlar ballistic fabric was invented. The fabric was originally intended to replace steel belting in tires, and it was extremely strong. Waterproofing and additional layers of fabric were added to the Kevlar to make the vests more durable and wearable. The National Institute of Justice tested versions of Kevlar vests for several years, and found that the vests could stop the most common lead bullets: 38 Specials and 22 Long Rifle Bullets.

A final phase of testing monitored Kevlar armour effectiveness. Kevlar armour was found to ensure a 95% probability of survival after being hit with a .38 calibre bullet at a velocity of 800 ft/second. The probability of requiring surgery after being hit by a projectile was found to be 10% or less.

In 1976, scientists came to the conclusion that Kevlar was bullet-resistant, wearable and light enough for police officers to wear full-time. The funny thing was that bulletproof vests had already become commercially available, even before the National Institute of Justice published these claims.

Since that time bulletproof vests have improved. Currently, a level IIIA bulletproof vest weighs approximately 5.5 pounds and can protect the wearer from almost all handgun rounds. According to the International Association of Chiefs of Police, bulletproof vests have saved over 3,000 officers' lives since 1987.

1.2 History about bullets:

A bullet is a projectile, often a pointed metal cylinder that is shot from a firearm. The bullet is usually part of an ammunition cartridge, the object that contains the bullet and that is inserted into the firearm. projectiles fired from small or personal firearms such as pistols, rifles, and shotguns were discussed below.

Though there were cast lead bullets used with slings thousands of years ago, the history of the modern bullet starts with the history of firearms. Sometime after A.D.1249, it was realized that gunpowder could be used to fire projectiles out of the open end of a tube. The earliest firearms were large cannons, but personal firearms appeared in the mid-fourteenth century. Early projectiles were stone or metal objects that could fit down the barrel of the firearm, though lead and lead alloys (mixtures of metals) were the preferred materials by 1550. As manufacturing techniques improved, firearms and lead bullets became more uniform in size and were produced in distinct calibres (the diameter of the bullet).

The industrial revolution produced further improvements. Firearms with rifled barrels (spiral grooves inside of the firearm barrel that impart stabilizing spinning motion to the bullet) led to the familiar conical bullet. More powerful smokeless powders replaced gunpowder (now called black powder) in the late nineteenth century, but they also required harsher firearm and bullet materials. Lead bullets left lead residue in the barrel, jacketed bullets (a harder metal layer surrounds the softer lead core) were developed to stop this. The familiar metal ammunition cartridge (containing a bullet, a case, a primer, and a volume of propellant) was common by World War I.

1.3 Materials used in bullets:

Bullets are made of a variety of materials. Lead or a lead alloy (typically containing antimony) is the traditional bullet core material. Traditional bullet jackets are made of copper or gilding metal, an alloy of copper and zinc. There are many other materials that are used in bullets today, including aluminium, bismuth, bronze, copper, plastics, rubber, steel, tin, and tungsten.

Bullet lubricants include waxes (traditionally carnauba wax made from the carnauba palm), oils, and molybdenum disulphide (moly). Modern wax and oil formulas are generally not made public. Moly is a recent innovation, this naturally occurring mineral sticks to metal on contact. The bullet making process can also use grease and oils to lubricate the bullet during machining and pressing steps. This lubrication prevents damage to the bullet or the machinery by allowing the bullet and machinery to move against each other without sticking. Solvents are used to remove grease and oil from the bullet afterward.

1.4 Types of bullets:

1.4.1 9mm bullet:

After World War I, acceptance of the 9×19mm Parabellum cartridge increased, and 9×19mm Parabellum pistols and submachine guns were adopted by military and police users in many countries. The 9×19mm Parabellum has become the most popular calibre for U.S. law enforcement agencies, primarily due to the availability of compact pistols with large magazine capacities that use the cartridge.

Fig. 1.1: 9mm Brass Bullet

Worldwide, the 9×19mm Parabellum is one of the most popular pistol cartridges where it is legal (some countries ban civilian use of weapons that chamber current or former military service cartridges), and cartridges in this calibre are generally available anywhere pistol ammunition is sold.

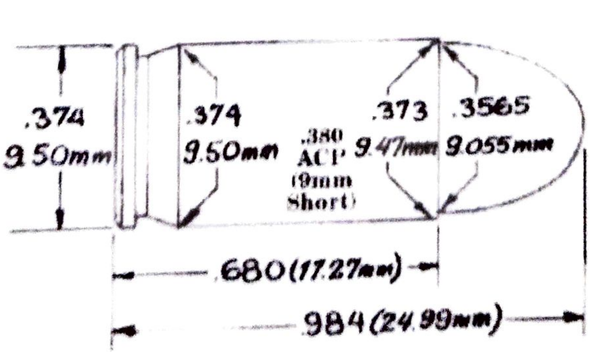

Fig.1.2: Dimensions of 9mm bullet

1.4.2 .45 ACP (Automatic Colt Pistol):

Fig.1.3: .45ACP Bullet

The **.45 ACP (Automatic Colt Pistol)**, or **.45 Auto** (11.43×23mm) is a handgun cartridge designed by John Browning in 1905, for use in his prototype Colt semi-automatic pistol. After successful military trials, it was adopted as the standard chambering for Colt's M1911 pistol being named .45 ACP.

The .45 ACP is an effective combat pistol cartridge that combines accuracy and stopping power for use against human targets. It has relatively low muzzle blast and flash, and it produces moderate recoil in handguns, made worse in compact models. The standard issue military .45 ACP round has a 230-grain bullet that travels at approximately 830 feet per second when fired from the government issue M1911A1 pistol and approximately 950 feet per second from the M1A1 Thompson submachine gun. The cartridge also comes in various specialty rounds of varying weights and performance levels.

Drawbacks for military use include the cartridge's large size, weight, increased material costs in comparison to the smaller, flatter shooting NATO standard 9×19mm Parabellum cartridge, which uses less powder, brass, and lead per round. Standard 9mm NATO ammunition has limited armour penetration capability – a deficiency with .45 ACP whose large, slow bullet does not penetrate armour to any great extent. The low muzzle velocity also makes the bullet drop over long ranges, making hits more difficult; however, it is important to note that the vast majority of self-defence situations involving handguns typically occur at close ranges.

1.4.3 .38 special:

Fig.1.4: .38 special bullets

The .38 Special was the standard service cartridge of most police departments in the United States from the 1920s to the 1990s, and was also a common sidearm cartridge used by soldiers in World War I. It is Known for its accuracy and manageable recoil, the .38 Special remains one of the most popular revolver cartridges in the world more than a century after its introduction. It is used for target shooting, formal target competition, personal defence, and for hunting.

1.4.4 FMJ (Full Metallic Jack):

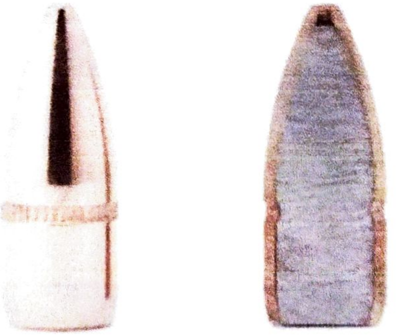

Fig. 1.5 : FMJ bullet

A **full metal jacket** (**FMJ**) **bullet** is a small-arms projectile consisting of a soft core (often lead) encased in a shell of harder metal, such as gilding metal, cupronickel, or, less commonly, a steel alloy The bullet was invented in 1882 by Swiss Colonel Eduard Rubin while he was working for the Swiss Federal Ammunition Factory and Research Center which developed ammunition for the Swiss military

1.4.5 .50 BMG(Browing Machine Gun):

During World War II the .50 BMG was primarily used in the M2 Browning machine gun, in both its "light barrel" aircraft mount version and the "heavy barrel" (HB) version on ground vehicles, for anti-aircraft purposes. An upgraded variant of the M2 Browning HB machine gun used during World War II is still in use today. Since the mid-1950s, some armoured personnel carriers and utility vehicles have been made to withstand 12.7 mm machine gun fire, restricting the destructive capability of the M2.

Fig. 1.6: .50 BMG

It still has more penetrating power than lighter weapons such as general-purpose machine guns, though it is significantly heavier and more cumbersome to transport. Its range and accuracy, however, are superior to light machine guns when fixed on tripods, and it has not been replaced as the standard calibre for Western vehicle-mounted machine guns

1.4.6 Hollow tip:

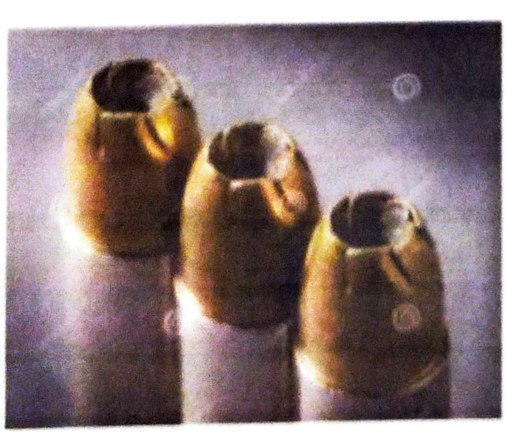

Fig. 1.7: hollow tip bullet

When a hollow-point hunting bullet strikes a soft target, the pressure created in the pit forces the material (usually lead) around the inside edge to expand outwards, increasing the axial diameter of the projectile as it passes through. This process is commonly referred to as *mushrooming*, because the resulting shape, a widened, rounded nose on top of a cylindrical base, typically resembles a mushroom.

The greater frontal surface area of the expanded bullet limits its depth of penetration into the target, and causes more extensive tissue damage along the wound path. Many hollow-point bullets, especially those intended for use at high velocity in centre fire rifles, are *jacketed*, i.e. a portion of the lead-cored bullet is wrapped in a thin layer of harder metal, such as copper, brass, or mild steel. This jacket provides additional strength to the bullet, increases penetration, and can help prevent it from leaving deposits of lead inside the bore. In *controlled expansion* bullets, the jacket and other internal design characteristics help to prevent the bullet from breaking apart; a fragmented bullet will not penetrate as far.

1.4.7 Open tip:

Fig. 1.8: open tip bullet

The open tip match bullet will either be jacketed in a copper-alloy or another harder-than-lead material to prevent deformation when firing and to help with accuracy at long range. The open tip match core is poured in through the hole at the nose of the bullet. This creates a very uniform bullet that is weighted the same with each bullet you fire, and is one of the methods that makes this bullet type so accurate.

These bullets are designed for one basic purpose, and that's accuracy at range. You have a very high ballistic coefficient, and any OTM bullet will be highly regarded for its ability to consistently hit a target with great grouping. The only reason these bullets have an open tip is because of the way they are made. There's some politics behind whether or not they are hollow points, and depending on who you ask, the answer you get will be very different. Technically, these are not hollow points in the traditional sense that they were not made to expand on impact.

1.4.8 Ballistic tip:

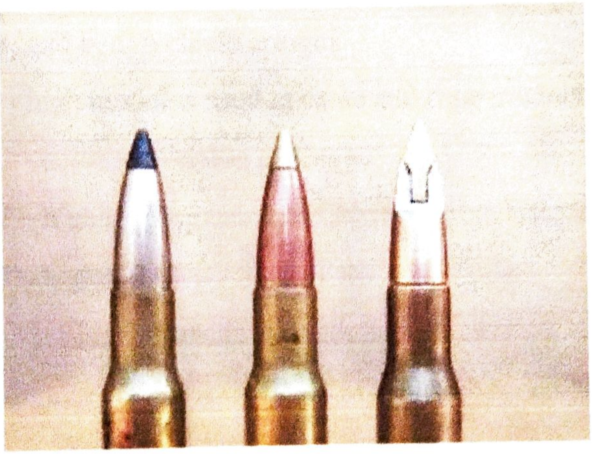

Fig. 1.9: ballistic tip bullet

The polymer tip is colour coded by calibre, and acts as an aerodynamic "plug" at the nose of the hollow-pointed bullet. This tip helps prevent clogging of the hollow point that would effectively make it a full metal jacket. The hollow point and polymer tip cause the bullet to expand rapidly and uniformly when penetrating a target.

Any hunter familiar with this line of ammo will tell you that these bullets are extremely predictable. And when hunting thin-skinned game like whitetails or pronghorns, they will go down almost every single time. The expansion of these bullets when they strike a vital area is top of the line, and the accuracy is near perfect in the hands of a seasoned hunter familiar with this ammo type.

1.5 Different materials and their properties:

1.5.1 Kevlar:

Kevlar is a heat-resistant and strong synthetic fiber, developed by Stephanie Kwolek at DuPont in 1965, this high-strength material was first commercially used in the early 1970s as a replacement for steel in racing tires.

Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests, because of its high tensile strength-to-weight ratio. By this measure it is five times stronger than steel. It is also used to make modern marching drumheads that withstand high impact.

Several grades of Kevlar are listed below:

Kevlar K-29 – in industrial applications, such as cables, asbestos replacement, brake linings, and body/vehicle armour.

Kevlar K49 – high modulus used in cable and rope products.

Kevlar K100 – coloured version of Kevlar

Kevlar K119 – higher-elongation, flexible and more fatigue resistant

Kevlar K129 – higher tenacity for ballistic applications

Kevlar AP – 15% higher tensile strength than K-29

Kevlar XP – lighter weight resin and KM2 plus fiber combination

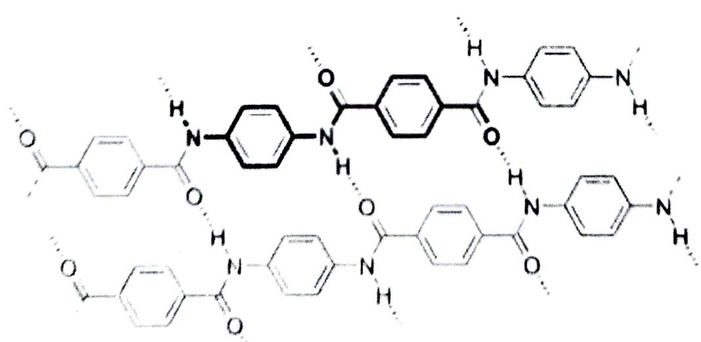

Fig.1.10: Molecular structure of Kevlar (poly paraphenylene terephthalamide)

1.5.2: Kevlar properties:

Table 1.1: Mechanical properties of Kevlar 29 [1]

Orthotropic elasticity									
Temperature (°C)	Youngs modulus X direction (Pa)	Young's modulus Y direction (Pa)	Young's modulus Z direction (Pa)	Poisson's ratio XY	Poisson's ratio YZ	Poisson's ratio XZ	Shear modulus XY (Pa)	Shear modulus YZ (Pa)	Shear modulus XZ (Pa)
25	1.85e + 010	1.85e + 010	6e + 009	0.25	0.33	0.33	7.7e + 008	5.43e + 009	5.43e + 009

Constant and response	
Density (kg·m^{-3})	Specific heat constant pressure J·kg^{-1}·C^{-1}
1440	1420

Yield strengths	
Compressive yield strength (Pa)	Tensile yield strength (Pa)
1.85e + 008	1.85e + 009

1.5.3: Fibre cement:

Fibre cement is a composite building and construction material, used mainly in roofing and facade products because of its strength and durability. One common use is in fibre cement siding on buildings.

In fibre cement there is a fibre reinforcement, which contributes to making the fibre-cement material even stronger. Together with a carefully planned production process, fibre cement makes it possible to develop strong and long lasting construction materials. Today fibre cement is considered as a material physically suited for construction products such as cladding and roofing. It is primarily due to its function, performance and commercial value.

1.5.4: Fibre cement properties:

Table 1.2: Mechanical properties of fibre cement

Isotropic elasticity				
Temperature (°C)	Youngs modulus (Pa)	Poisson's ratio	Bulk modulus (Pa)	Shear modulus (Pa)
25	7.62e + 009	0.1	3.175e + 009	3.4630e + 009

Constants	Failure response
Density (kg·m^{-3})	Tensile ultimate strength (Pa)
1390	2.9e + 009

Bilinear isotropic hardening	
Yield strength (Pa)	Tangent modulus (Pa)
6e + 006	1.2e + 007

1.5.5: Steel 1006:

AISI 1006 steels are dead mild steel comparably called drawing quality steel because of extremely low carbon content and other alloying materials. The qualities of AISI 1006 low carbon steel are chiefly low hardness and plasticity. 1006 mild steels have excellent Weldability and formability.

Mechanical Properties of 1006 Soft Mild Steel:

- Hardness in HRB as specified in technical sources is near about 55.
- Tensile strength is around 330 MPa in some technical sources.
- Yield strength is around 285 MPa in some technical sources.
- Elongation is 20% in 50 mm in the standard.
- Young's Modulus is 190-210 GPa

1.5.6 Steel 1006 properties:

Table 1.3: Mechanical and ballistic properties of steel

Constant and response	
Density ($kg \cdot m^{-3}$)	Specific heat constant pressure ($J \cdot kg^{-1} \cdot C^{-1}$)
7896	452

Shock EOS linear			
Gruneisen coefficient	Parameter C1 ($m \cdot s^{-1}$)	Parameter S1	Parameter quadratic S2 ($s \cdot m^{-1}$)
2.17	4569	1.49	0

Initial yield stress Pa	Hardening constant Pa	Hardening exponent	Strain rate constant	Thermal softening exponent	Melting temperature C	Reference strain rate (sec)
$3.5e+008$	$2.75e+008$	0.36	$2.2e-002$	1	1537.8	1

Shear modulus (Pa)
$8.18e+010$

1.5.7 Brass:

Brass is an alloy of copper and zinc, in proportions which can be varied to achieve varying mechanical and electrical properties. It is a substitutional alloy atoms of the two constituents may replace each other within the same crystal structure. In contrast, bronze is an alloy of copper and tin.

1.5.8 Brass properties:

Brass has higher malleability than bronze or zinc. The relatively low melting point of brass (900 to 940 °C, 1,650 to 1,720 °F, depending on composition) and its flow characteristics make it a relatively easy material to cast. By varying the proportions of copper and zinc, the properties of the brass can be changed, allowing hard and soft brasses. The density of brass is 8.4 to 8.73 grams per cubic centimetre (0.303 to 0.315 lb/cu in).

Today, almost 90% of all brass alloys arc recycled. Because brass is not ferromagnetic, it can be separated from ferrous scrap by passing the scrap near a powerful magnet. Brass scrap is collected and transported to the foundry where it is melted and recast into billets. Billets are heated and extruded into the desired form and size. The general softness of brass means that it can often be machined without the use of cutting fluid, though there are exceptions to this.

Aluminium makes brass stronger and more corrosion-resistant. Aluminium also causes a highly beneficial hard layer of aluminium oxide (Al_2O_3) to be formed on the surface that is thin, transparent and self-healing. Tin has a similar effect and finds its use especially in seawater applications (naval brasses). Combinations of iron, aluminium, silicon and manganese make brass wear and tear resistant.

1.5.9 Lead:

Lead is a heavy metal that is denser than most common materials. Lead is soft and malleable, and also has a relatively low melting point. When freshly cut, lead is silvery with a hint of blue; it tarnishes to a dull gray color when exposed to air. Lead has the highest atomic number of any stable element and three of its isotopes each include a major decay chain of heavier elements.

Lead is easily extracted from its ores; prehistoric people in Western Asia knew of it. Galena, a principal ore of lead, often bears silver, interest in which helped initiate widespread extraction and use of lead in ancient Rome. Lead production declined after the fall of Rome and did not reach comparable levels until the Industrial Revolution. In 2014, the annual global production of lead was about ten million tonnes, over half of which was from recycling. Lead's high density, low melting point, ductility and relative inertness to oxidation make it useful. These properties, combined with its relative abundance and low cost, resulted in its extensive use in construction, plumbing, batteries, bullets and shot, weights, solders, pewters, fusible alloys, white paints, leaded gasoline, and radiation shielding.

CHAPTER - 2

2. LITERATURE REVIEW

Before going to start our project, a brief study on papers related to model and analysis of bullet impact on bullet proof vest were studied. Some of the literature review that was under taken was presented here forth.

Ali Murat Soydan et.al. [1] has done the experiments and simulations in ANSYS of ballistic impact tests on laminated armour samples that consist of three layers of different materials: fibre-cement, Kevlar fabric, and steel. In experimental tests, a 9 mm FMJ bullet was launched towards a 100 cm^2 sample of the armour from the fibre-cement side. Ansys Workbench Explicit Dynamics and Ansys AUTODYN 3D were used to model and simulate the ballistic impact. Experimental testing and simulation results were compared to analyse the behaviour of composite armour designs.

M. A. G. Silva, C. Cismaşiu, and C. G. Chiorean [2], carried out the experimental and numerical simulation of ballistic impact problems on thin composite laminated plates reinforced with Kevlar 29. Ballistic impact was imparted with simulated fragments designed in accordance with STANAG-2920 on plates of different thickness. Numerical modelling was developed and used to obtain an estimate for the limit perforation velocity and simulate failure modes and damage. Computations were carried out using a commercial code based on finite differences and values obtained are compared with the experimental data to evaluate the performance of the simulation. Good correlation between computational simulation and experimental results was achieved, both in terms of deformation and damage of the laminates.

A. Banerjee, S. Dhar, S. Acharyya, D. Datta, and N. Nayak [3], has done research on Ballistic impact of typical armour steel plate of medium thickness by ogive-nosed projectiles travelling with ordnance velocities has been investigated through numerical simulations. Johnson-Cook material and failure models have been used to simulate the behaviour and failure of the material under impact conditions. Simulation has been done in Altair-Hyper Works FE package. The stages of penetration have been predicted. The residual velocities, ballistic limit velocity and perforation times have been determined from the simulation results and found to match with experimental data.

L.M. Bresciani, A. Manes a, A. Ruggiero b, G. Iannitti c, M. Giglio [4] had done a research on Kevlar29. The work developed in this paper has analysed several aspects of ballistic impacts on composite Kevlar 29 tiles, made of 2D plain weave fabrics layers with an epoxy matrix. The experimental tests provide arrange of data, most of them close to the ballistic limit, of two different configurations of composite tiles (5 and 10 mm thick). All the tiles have been impacted by tungsten blunt shaped projectiles. Experimental tests have been reproduced by numerical models exploiting and refining several approaches from the literature.

C.Y.Tham,V.B.C.Tan,H.P Lee [5] have done research on Ballistic impact on Kevlar helmet. In this research the 21st century military helmets are subjected to a series of ballistic 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 ballistic helmets. Hydro code simulations can alleviate the expense incurred during the development of these new helmets. Through hydro code simulations, helmet designers can cost-effectively explore and assess the ballistic resistance of prototype helmets which are designed using cheaper, lighter and stronger fiber materials.

Shashi kanth and S.L.Verma [6] have investigated that the modular jackets are meant to provide "graded level of protection" depending on the mission to be undertaken. The jacket would weigh less than 4 kg with a trauma pad with all around soft armour plate including front, side, back, collar and neck for low risk/threat missions. For many years, modern bullet resistant vests were made from woven Kevlar but newer materials have since been developed that are lighter, thinner and more resistant, although much more expensive.

A.A. Ramadhan, A.R. Abu Talib, A.S. Mohd Rafie, R. Zahari [7] Kevlar 29/ epoxy and 6061-T6 alluminium laminated panels were tested for high velocity impact response. The energy absorption of the composites were increased as the initial velocity increases. This model considers three different thickness of the laminated plates. They used a lagrange model of autodyn v.12.1 to optimise the stacking sequence of composite laminates when subjected to a high velocity impact

Aswani kumar bandaru, suhail ahmad [8] by performing hydro code simulations in ANSYS Autodyn -2D/3D, ballistic impact behavior of Kevlar composite is studied.

These results are validated by impacting the specimen with STANAG-2920 fragment simulating projectile (FSP) numerical simulations are further extended to study the influence of mass of the projectile. It is observed that shear plugging is the dominant failure mechanism in thermo plastic composites.

N. K. Naik, B. C. K. Reddy [9] analytical method based on wave theory was adopted to investigate the ballistic impact behavior of 2D woven fabric composites. Different damages and energy absorbing mechanisms during ballistic impact were identified as cone formation on the back face of the target, tension in primary yarns, deformation of secondary yarns, delamination, matrix cracking, shear plugging and friction during penetration

CHAPTER - 3

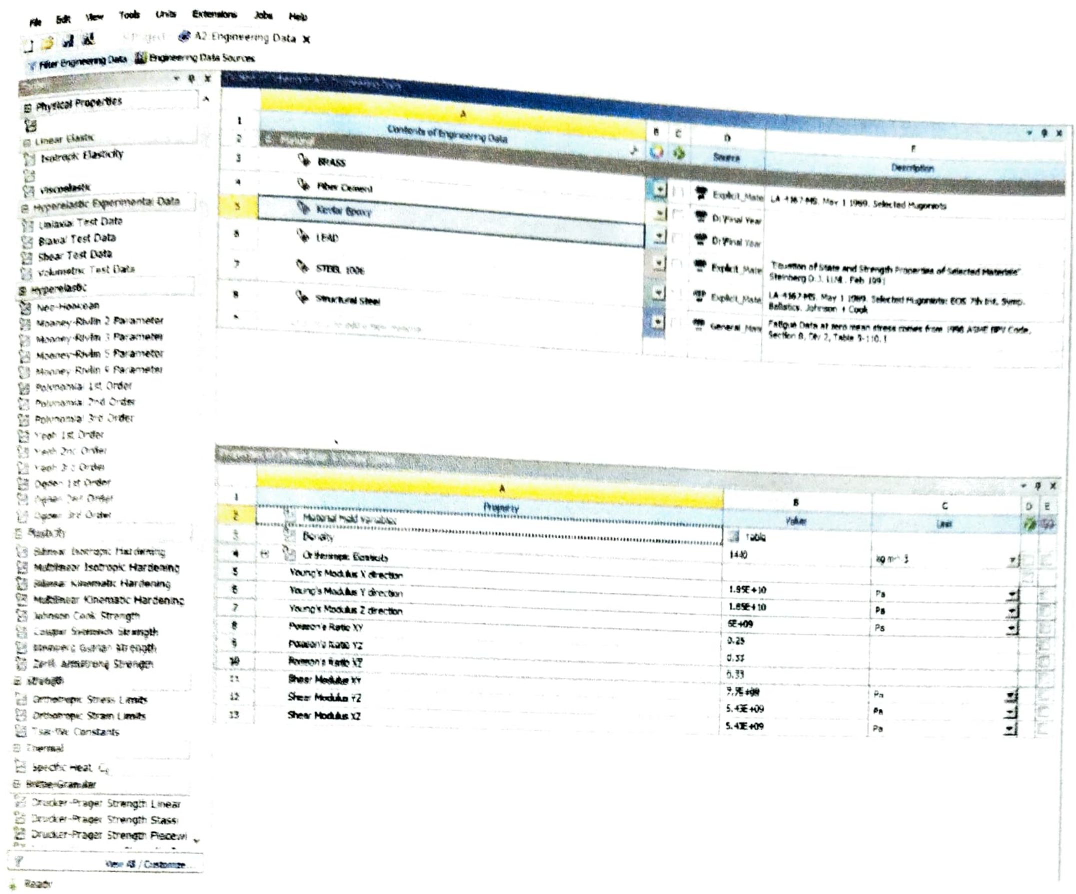

Fig. 3.2: Kevlar properties

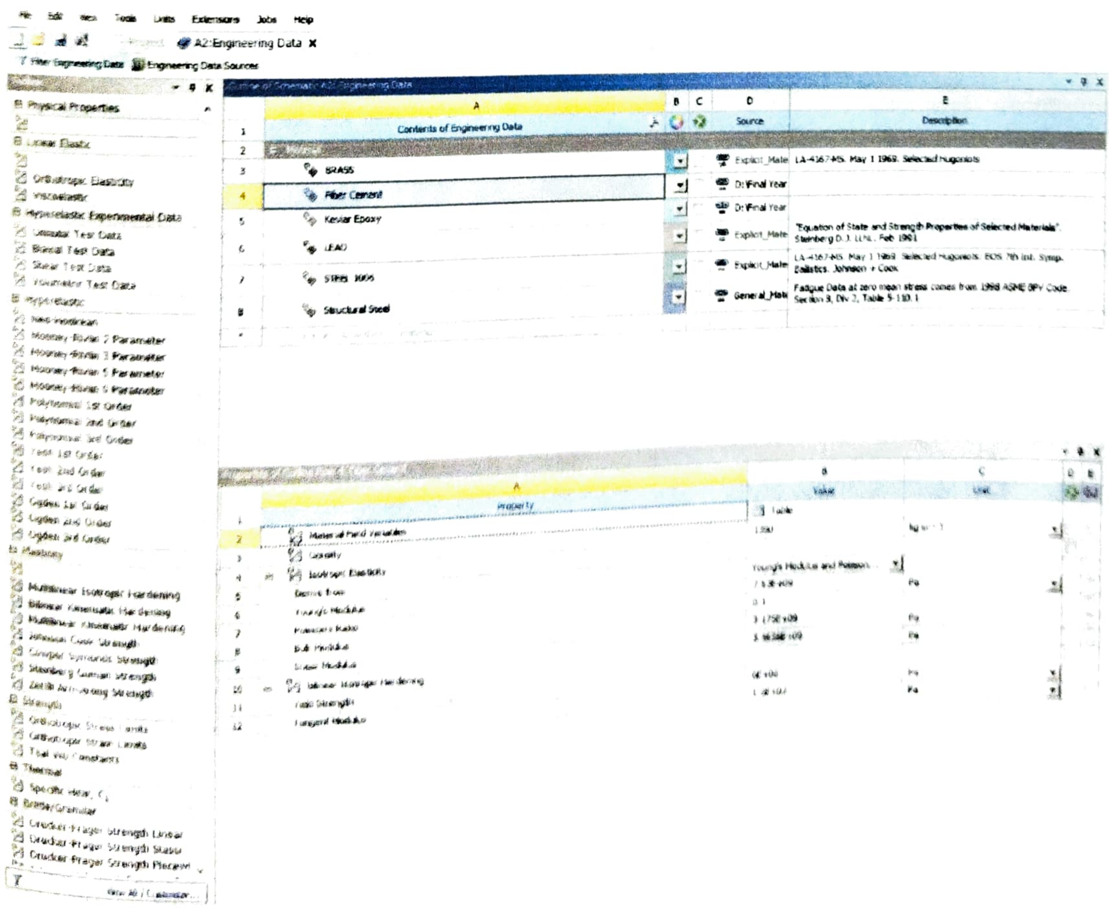

Fig.3.3: Fiber cement properties

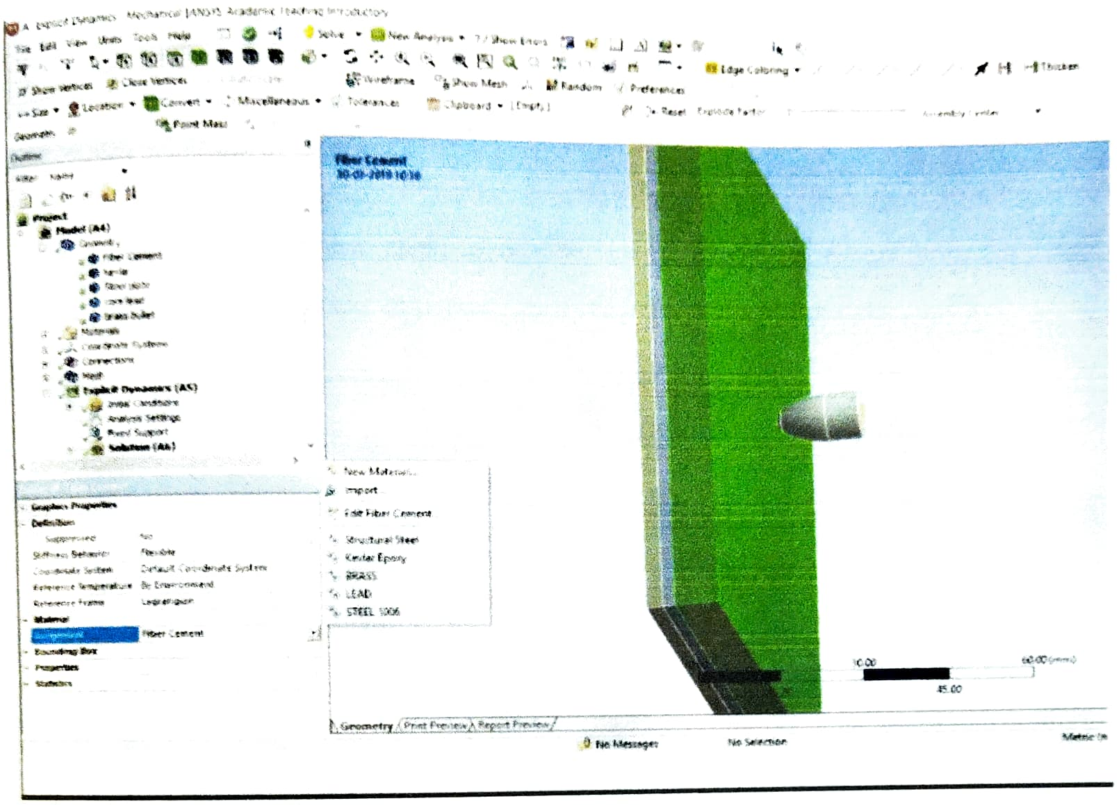

Fig.3.4: Assigning of materials to each element

3.3 Meshing:

- Edge sizing of 30 elements in length and width of the plate with automatic meshing method was adopted.
- Cartesian method was selected with mesh size of 1 mm for meshing of bullet.

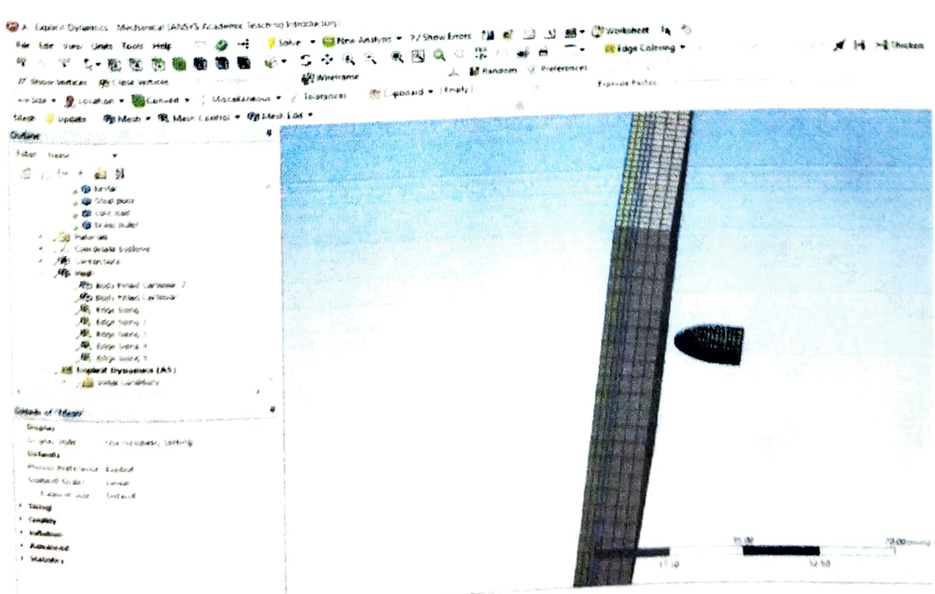

Fig 3.5: Meshing of all the components

- Generate mesh was clicked to generate mesh for the plates and bullet assembly.

3.4 Boundary conditions:

- Four sides of the plate assembly were given as fixed boundary by right clicking on explicit dynamics and inserting fixed supports.

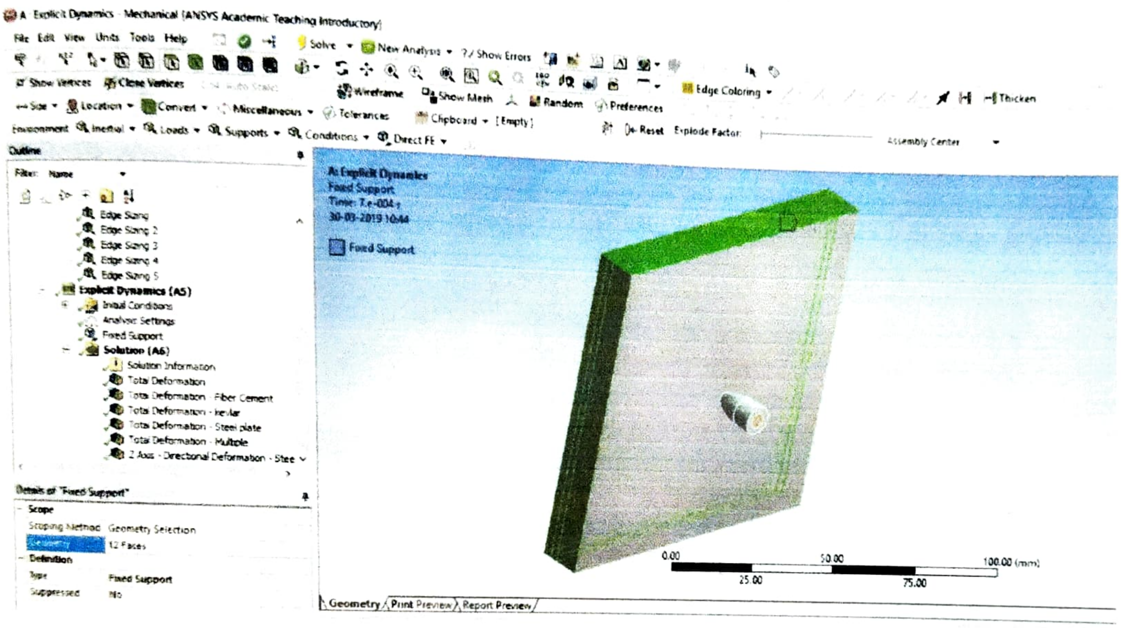

Fig.3.6: Fixed support on all four sides

3.5 Initial conditions:

- Velocity was inserted by right clicking on initial conditions.
- Geometry was selected for which velocity has to be given by clicking on velocity in initial conditions.
    - Velocity for the selected body (bullet) can be given either by vector or by components method as shown in figure 3.9,3.10

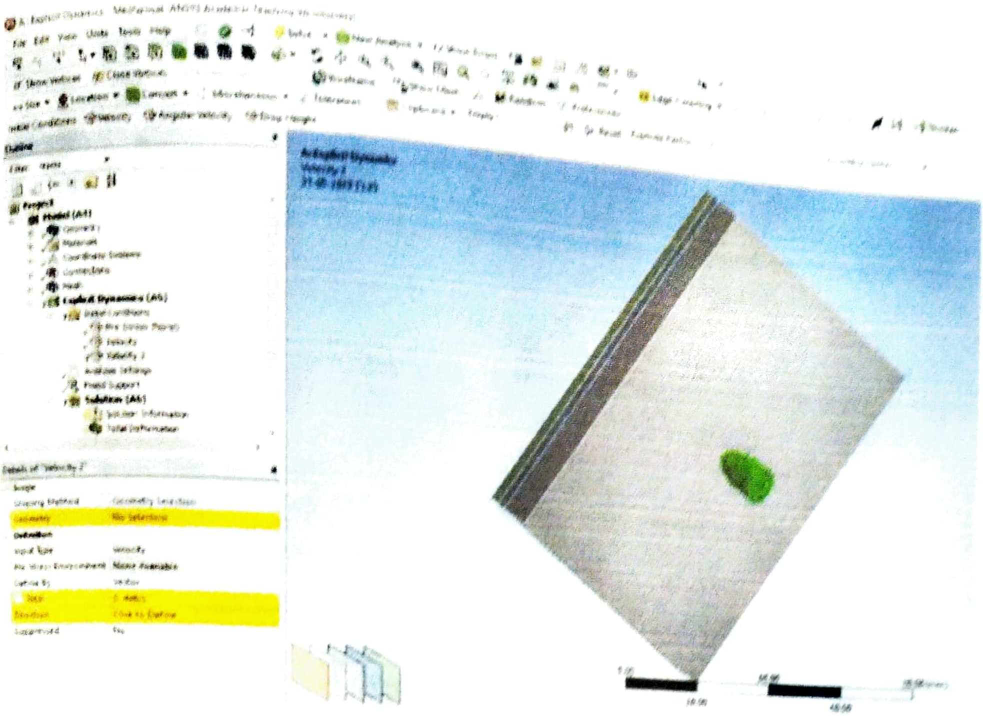

Fig.3.7: defining geometry of bullet

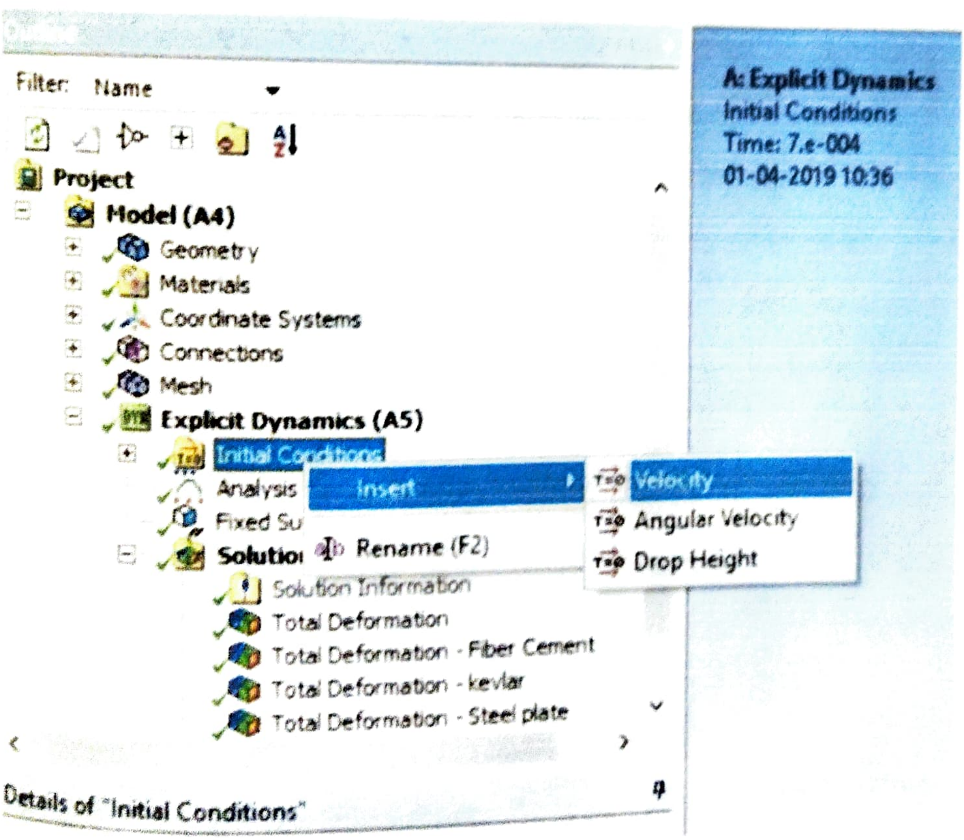

Fig.3.8: Velocity selection

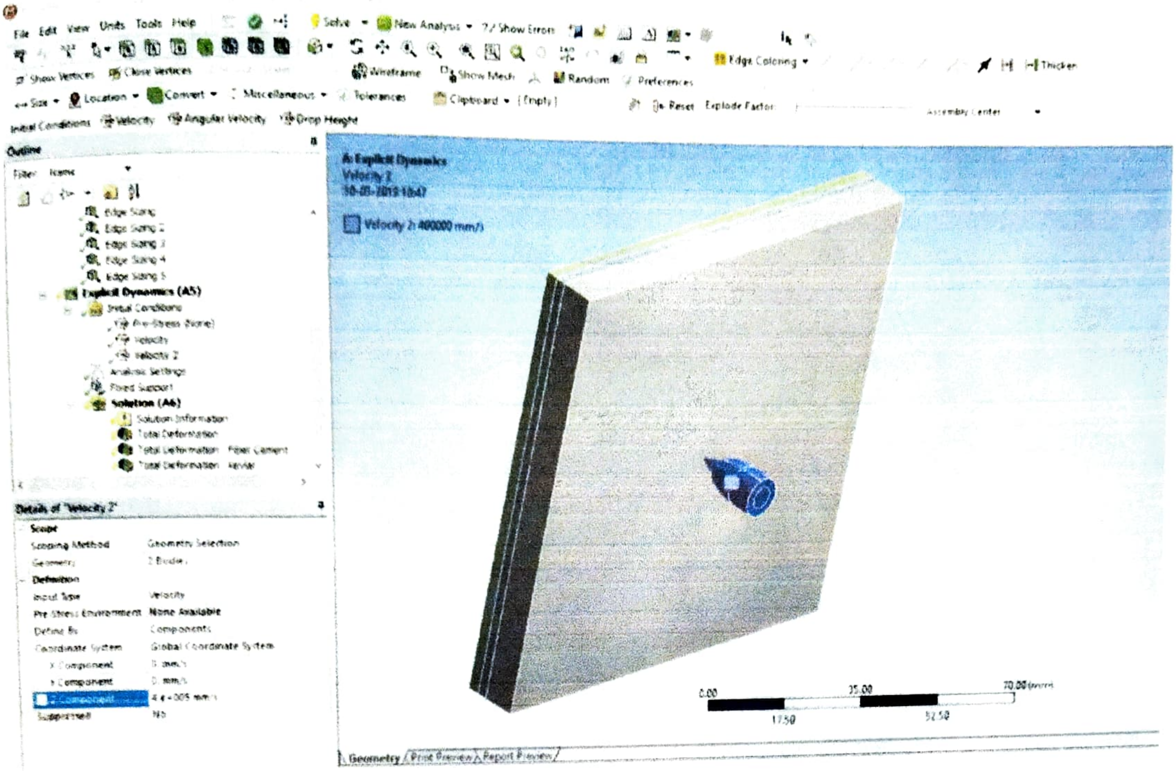

Fig.3.9: Component method

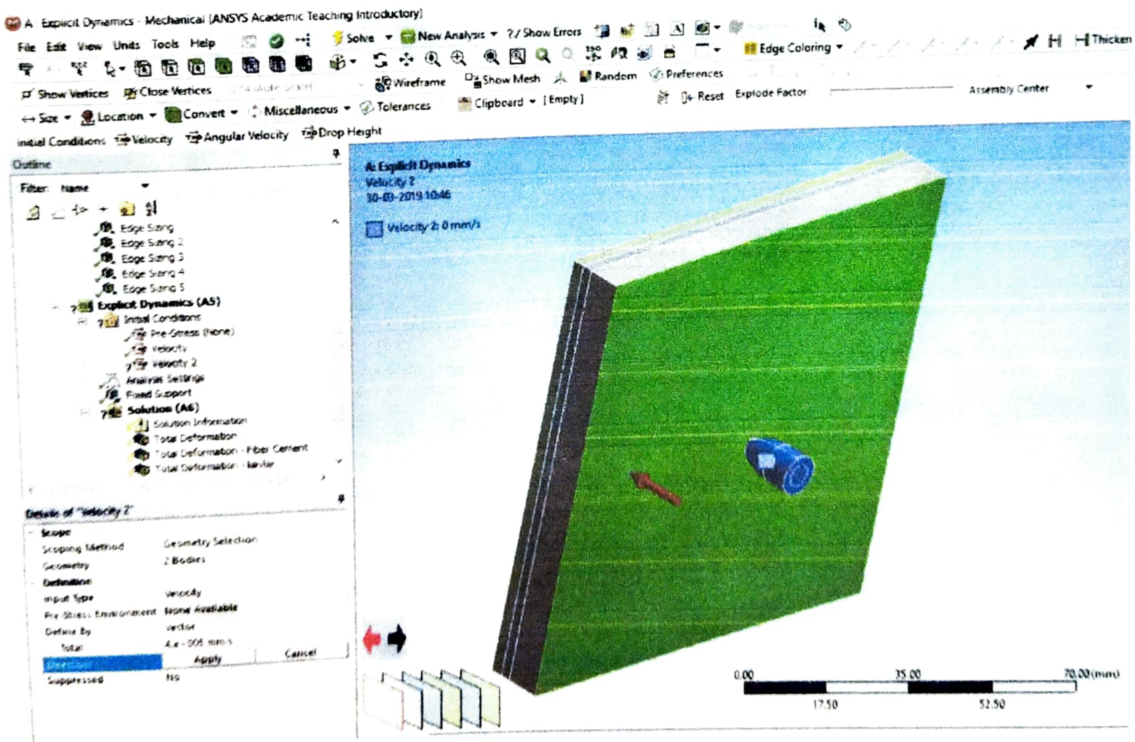

Fig.3.10: Vector method

3.6 Analysis settings:

- End time was set as 7e-4 s and maximum number of cycles were set as 1e7 as shown in figure 3.11
- Solution was started by clicking on solve.

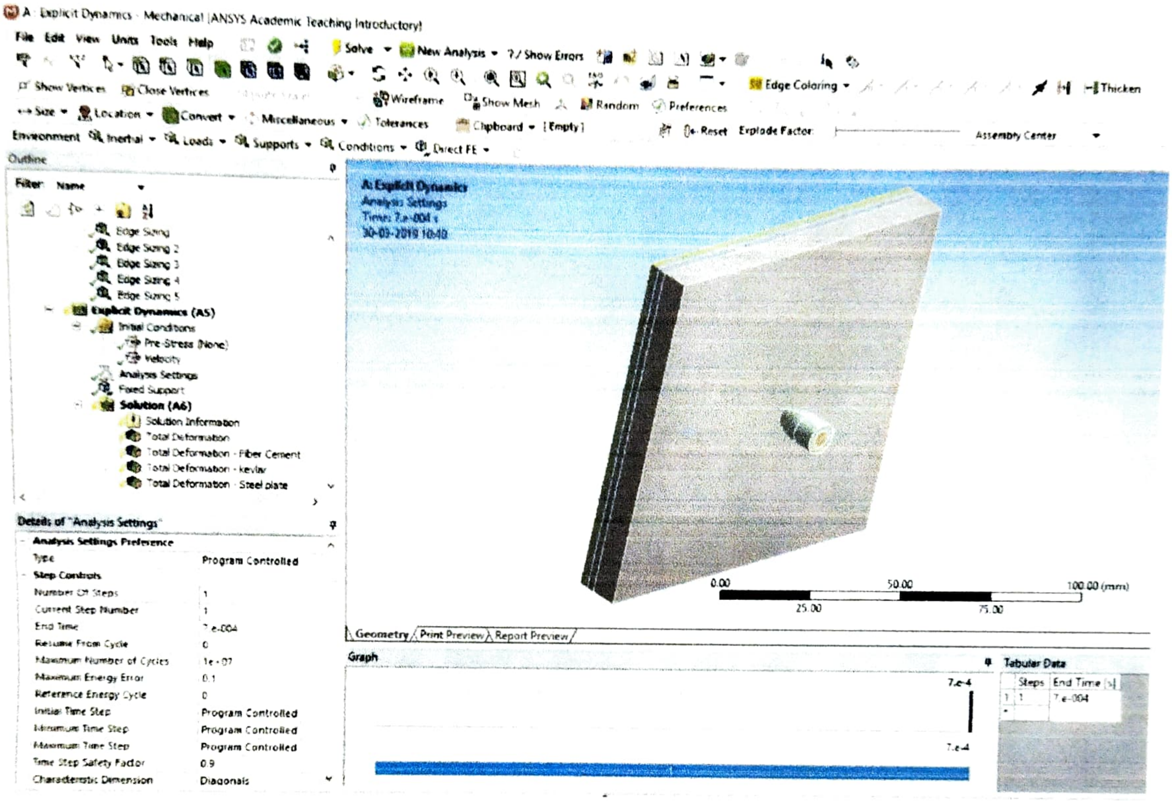

Fig.3.11: Specifying end time and number of cycles

3.7 Results:

- The required results can be inserted by right clicking on solution as shown in figure

CHAPTER - 4

4. RESULTS AND DISCUSSION

4.1 Validation:

Before starting the analysis of bullet impact on bullet proof vest, the simulation procedure that was explained in chapter 3 was validated with the results published by Ali Murat Soydan et.al [1]. The reference paper was simulated with three different plate thickness combinations. The three samples considered were of same thickness for fibre cement as 8 mm and thickness of Kevlar as 2.4 mm. The steel plate thickness considered for Sample 1 as 3 mm, sample 2 as 1.5 mm and sample 3 as 1 mm. The results comparison is discussed here.

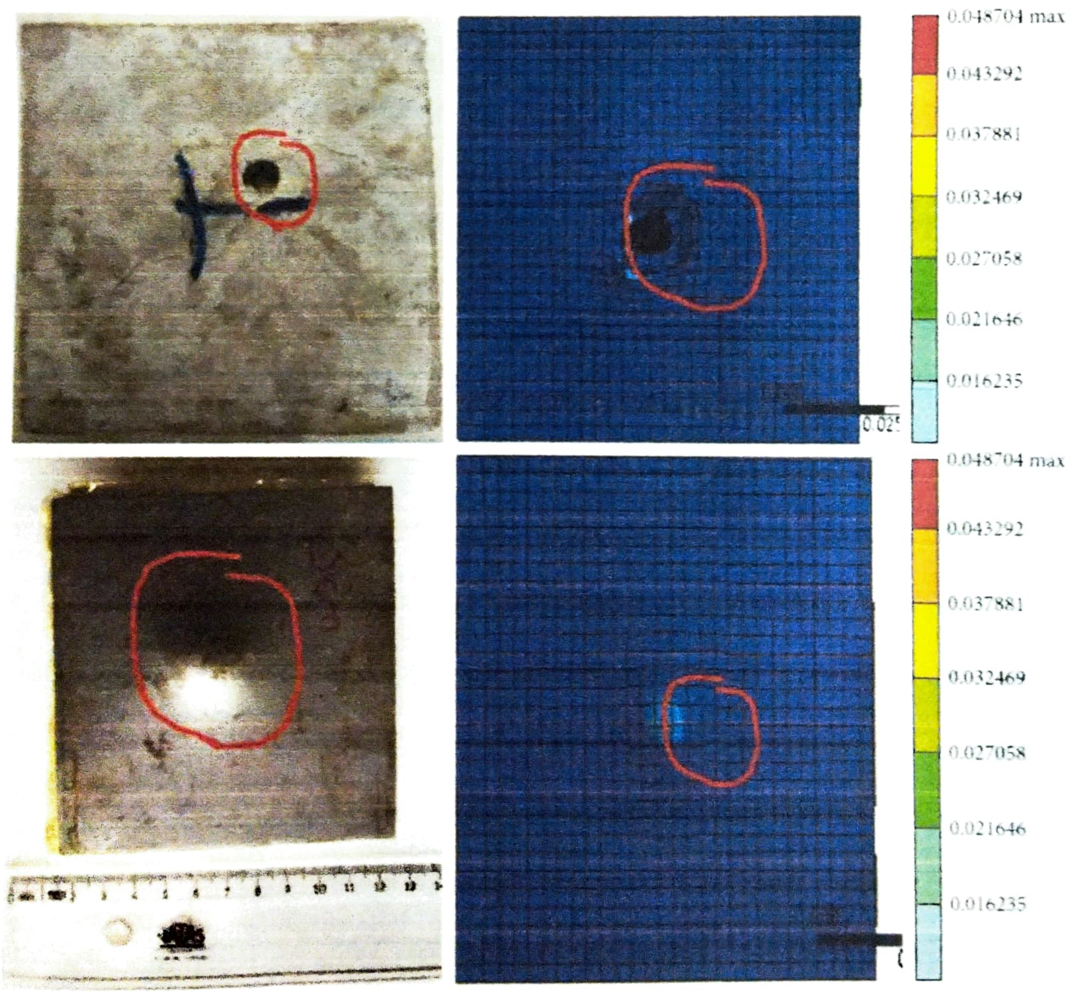

Fig.4.1: Total deformation of sample 1 as in reference paper [1]

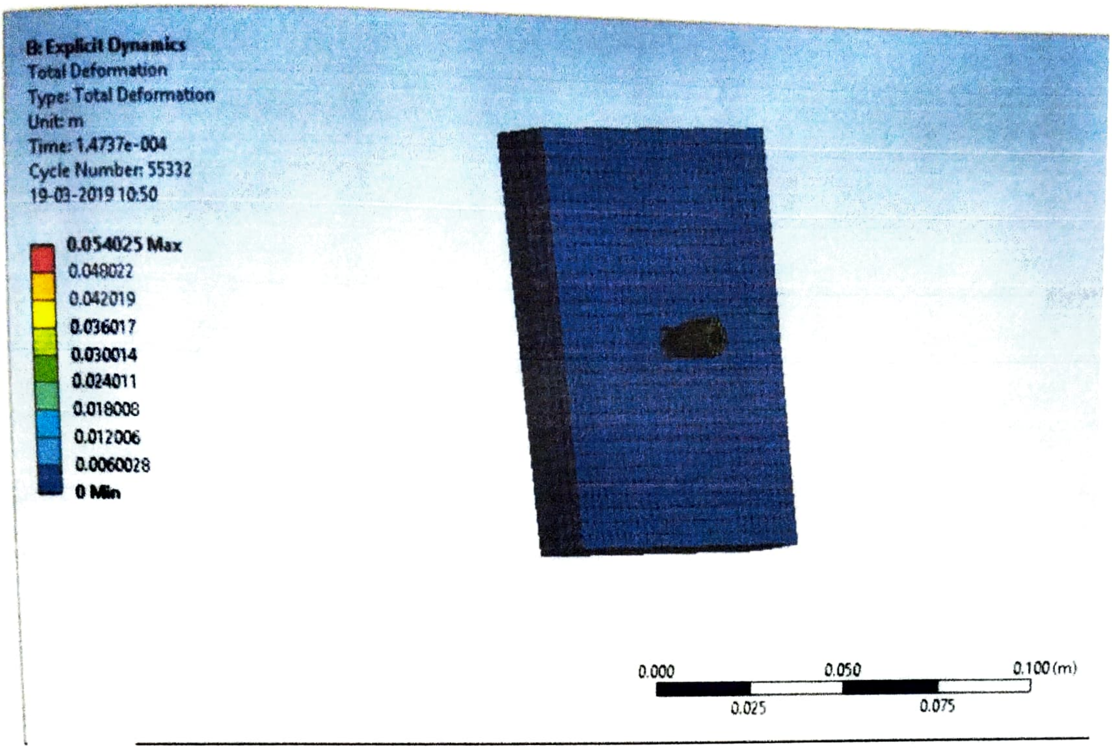

Fig.4.2: Deformation of sample 1 by present study

Total maximum deformation of sample 1 by our simulation was 0.054205 m as shown in fig. 4.2 against 0.048704 m as shown in fig. 4.1. The percentage error is 11%. The error was small and acceptable. The error can be minimised further by proper meshing of bullet as it is not a regular geometry.

Table 4.1: Z axis directional deformation of steel in sample 1 from reference paper [1]

Time (s)	Minimum (m)	Maximum (m)	Average (m)
1.1755e-038	0	0	0
3.5025e-005	-1.0591e-005	2.2814e-003	5.7685e-005
7.0025e-005	-6.6276e-005	6.554e-003	2.5768e-004
1.0506e-004	-7.5644e-005	7.6125e-003	5.2781e-004
1.4002e-004	-7.6373e-005	8.1679e-003	8.2409e-004
1.7503e-004	-1.2504e-004	8.5275e-003	1.1284e-003
2.1003e-004	-2.0057e-004	8.7608e-003	1.4199e-003
2.4503e-004	-1.1072e-004	8.8981e-003	1.6691e-003
2.8003e-004		8.9576e-003	1.8495e-003
3.1502e-004		8.954e-003	1.9437e-003
3.5e-004		8.8967e-003	1.9528e-003
3.8505e-004		8.7837e-003	1.8952e-003
4.2003e-004	0	8.6263e-003	1.7947e-003
4.5502e-004		8.446e-003	1.67e-003
4.9001e-004		8.2587e-003	1.5314e-003
5.2506e-004		8.0735e-003	1.3848e-003
5.6005e-004		7.8903e-003	1.234e-003
5.9505e-004		7.7064e-003	1.0826e-003
6.3005e-004		7.5225e-003	9.3409e-004
6.6505e-004	-1.4061e-005	7.3395e-003	7.8644e-004
7.0005e-004	-1.6921e-004	7.1569e-003	6.418e-004
	-2.722e-004		

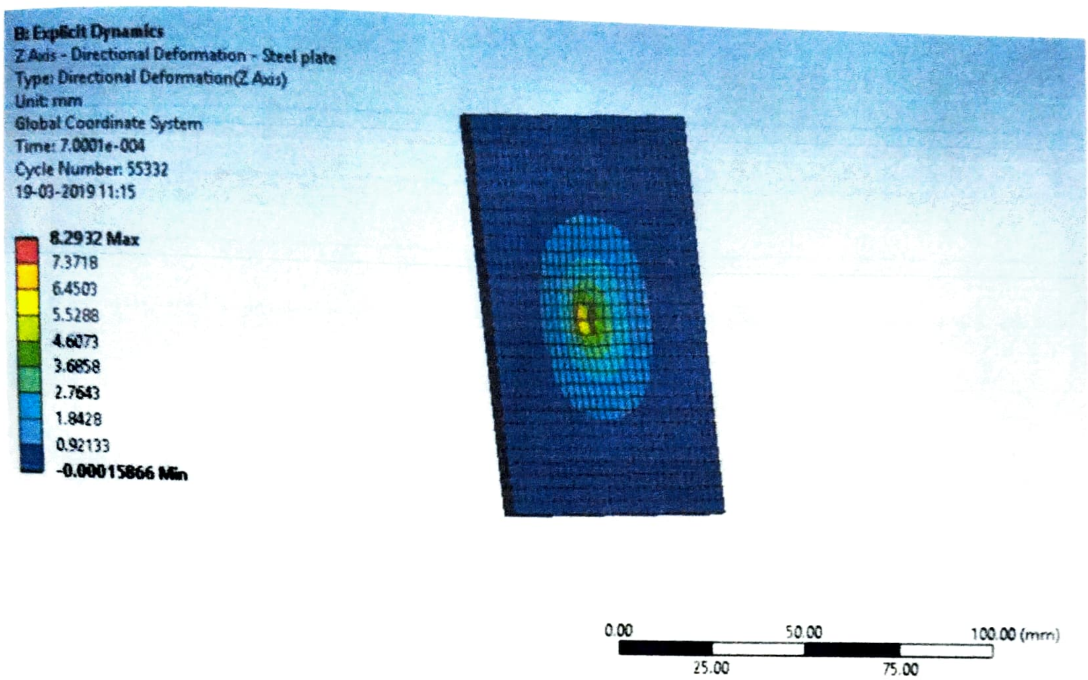

Fig. 4.3: Z axis directional deformation of steel trail 1

The maximum Z directional deformation of steel plate of sample 1 by our simulation is 8.2932 mm as shown in fig. 4.3 against 8.9576 mm as in table 4.1. The error was 7.4% which is small and acceptable.

4.2 Results:

At present Kevlar is most commonly used material in bullet proof vests. Present research in the industry of bullet proof vests, is focussed on the replacement of Kevlar with some other materials which are most suitable. Simulations were carried out to suggest an alternative material for Kevlar by using spectra and carbon fibre. The results of total deformation and equivalent stress are shown in figures 4.4 t0 4.11 and tabulated in table 4.3.

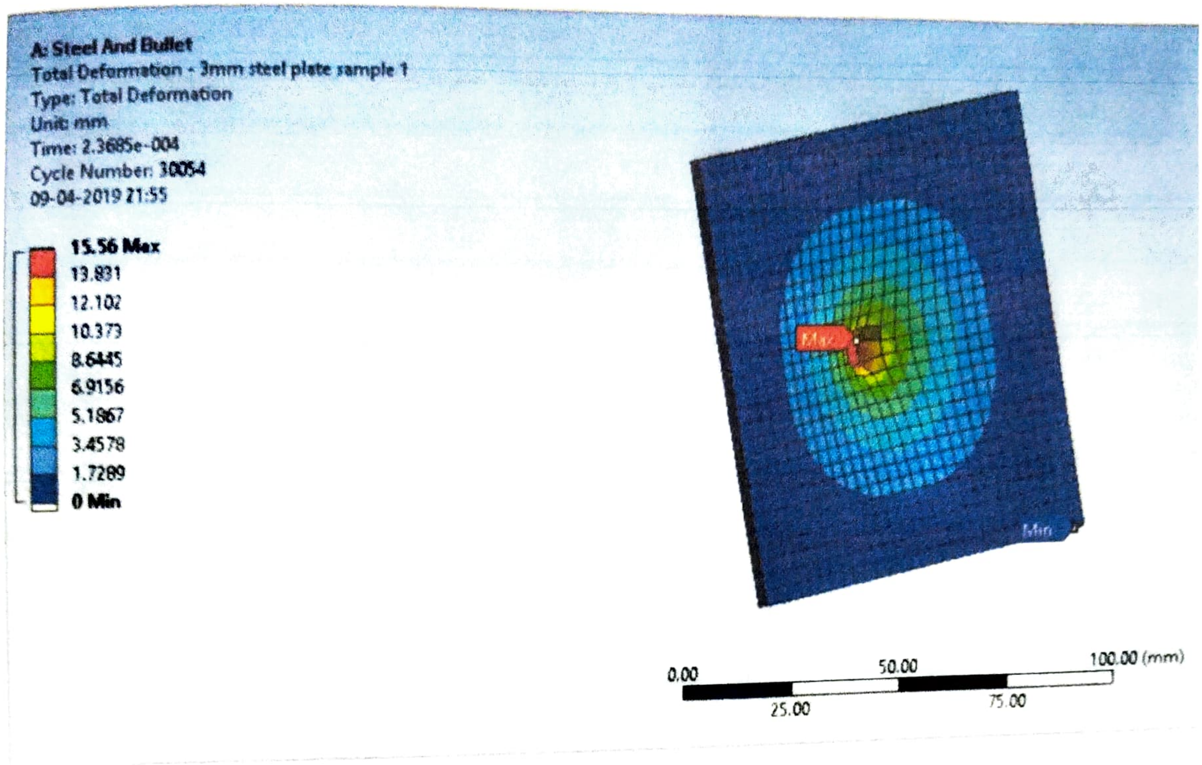

Fig. 4.4: Total deformation of steel plate alone.

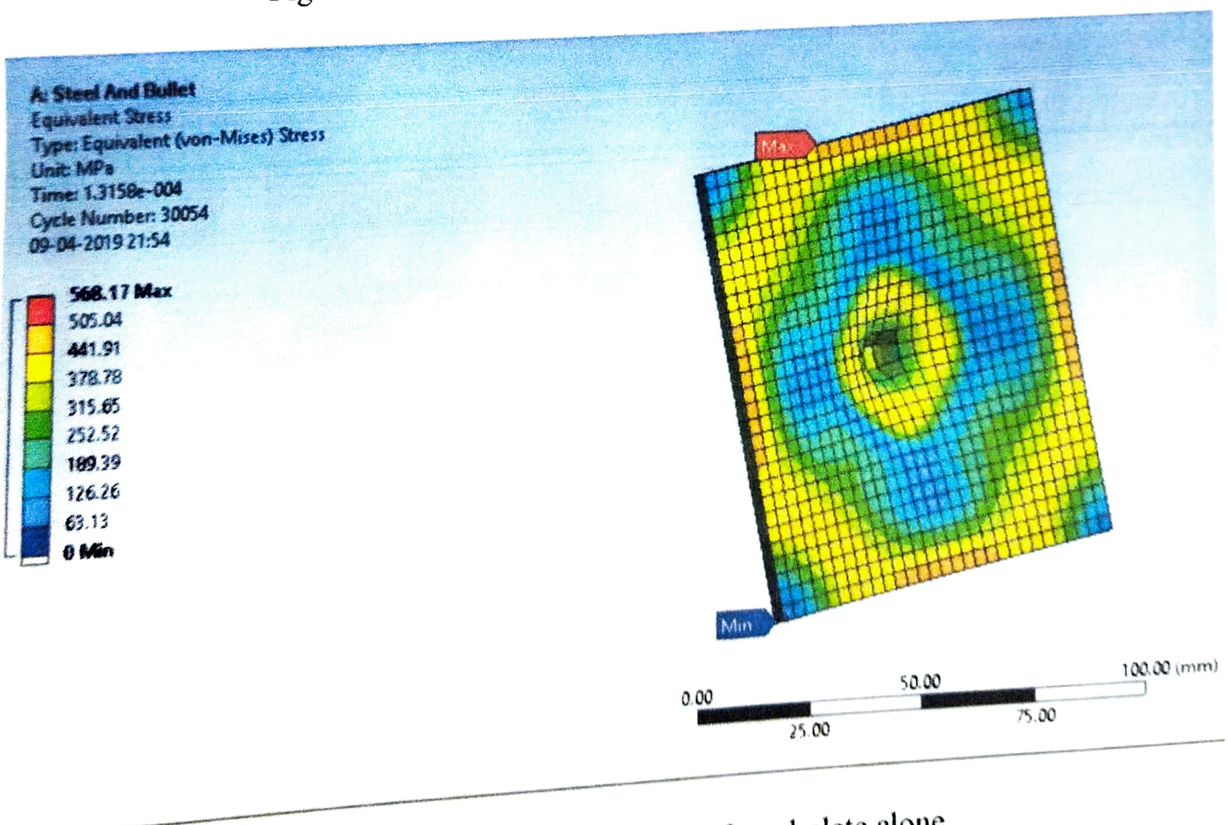

Fig. 4.5: Equivalent stress distribution of steel plate alone.

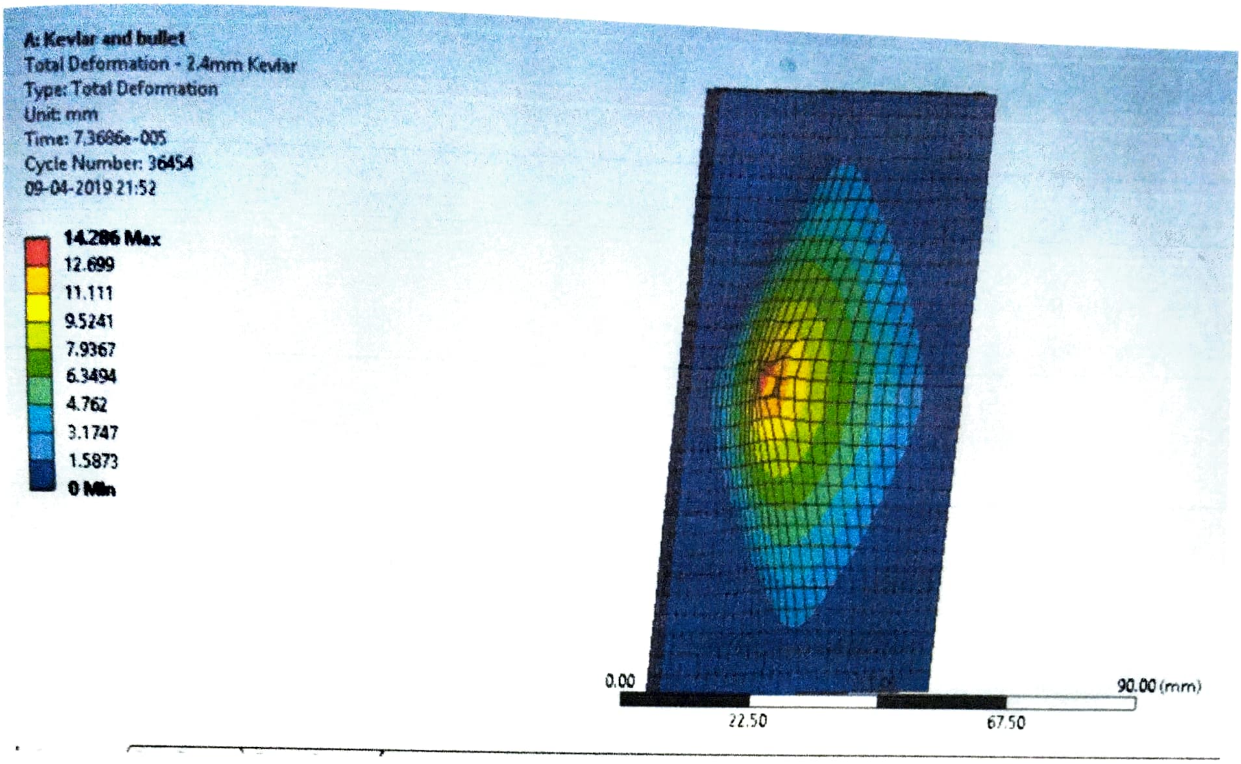

Fig. 4.6: Total deformation of Kevlar alone.

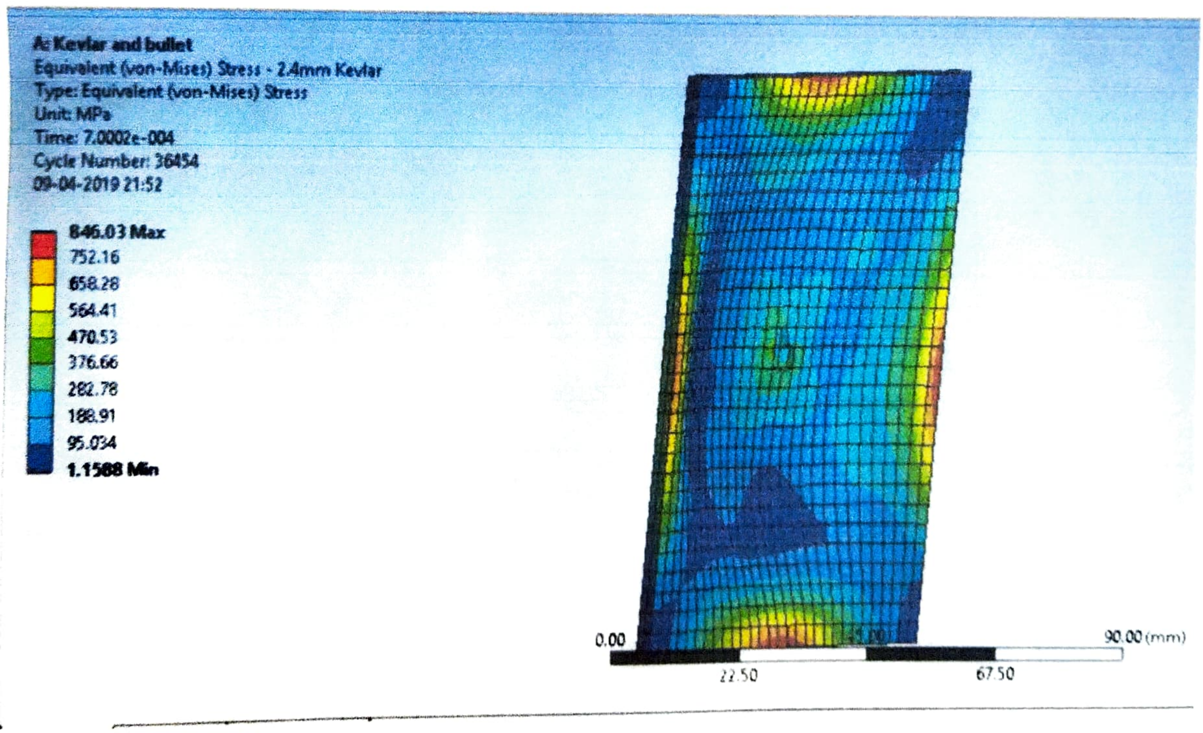

Fig. 4.7: Equivalent stress distribution of Kevlar alone.

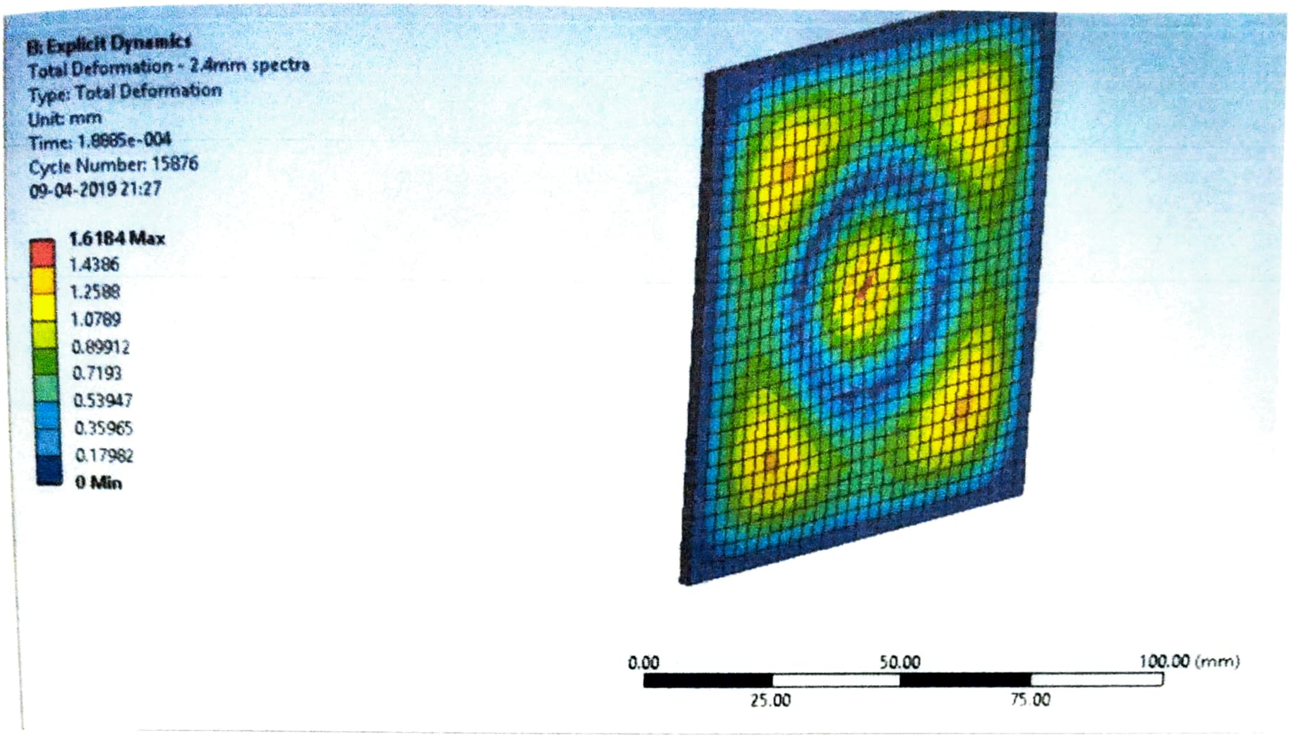

Fig. 4.8: Total deformation of Spectra alone.

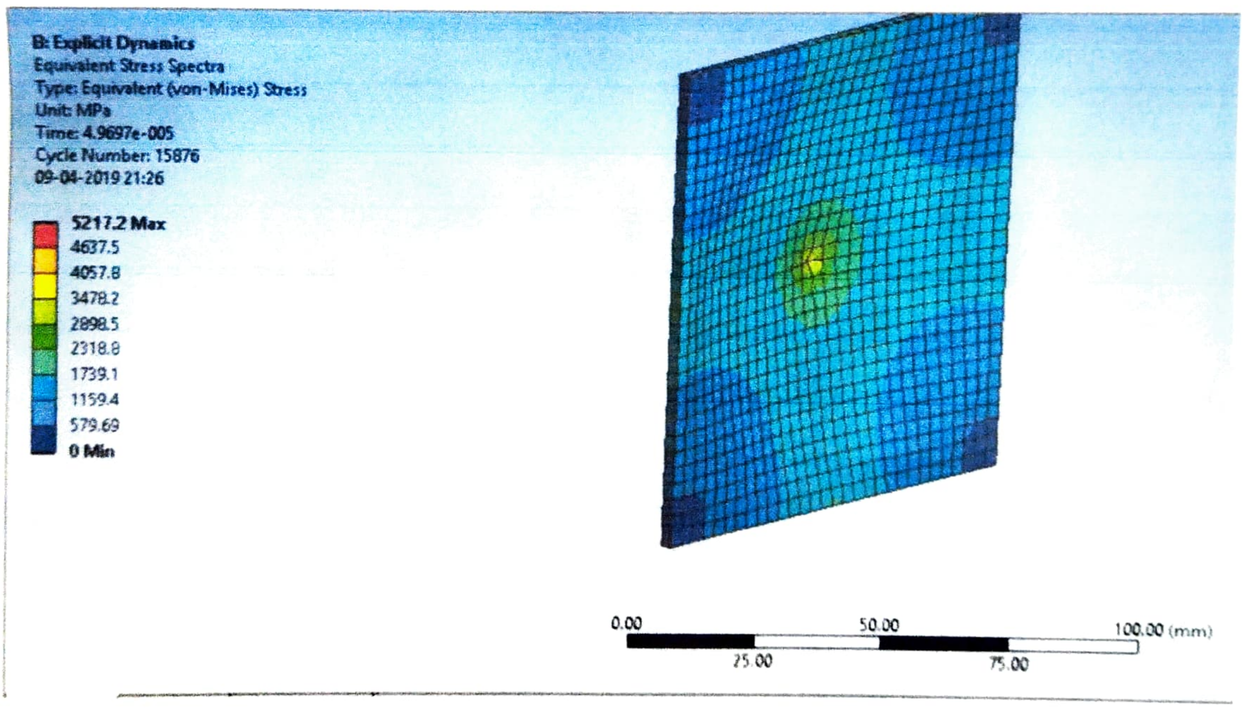

Fig. 4.9: Equivalent stress distribution of Spectra alone.

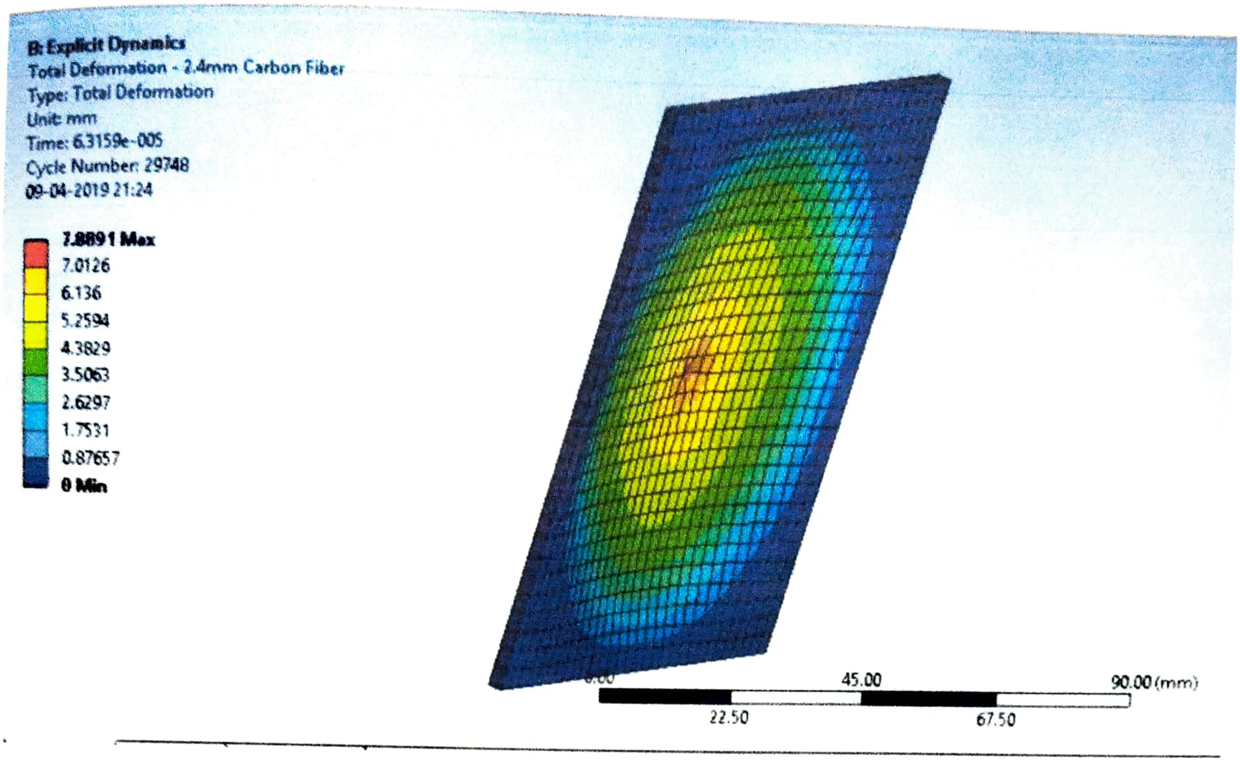

Fig. 4.10: Total deformation of Carbon fibre alone.

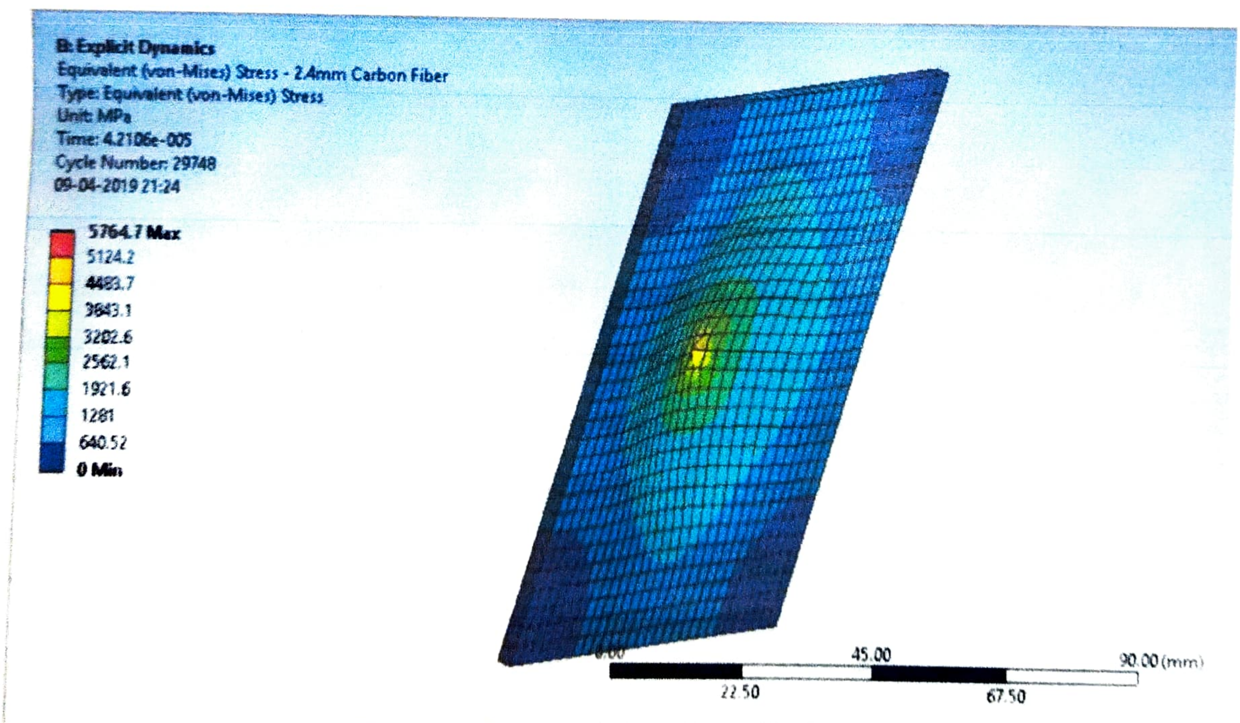

Fig. 4.11: Equivalent stress distribution of Carbon fibre alone.

Table 4.2: total deformation and equivalent stress distribution on individual plates alone

Description	Total deformation (mm)	Equivalent stress (MPa)
Steel	15.56	568.17
Kevlar	14.286	846.03
Carbon fibre	7.8891	5764.7
Spectra	1.6184	5217.2

Total deformation is lowest for spectra and highest for steel plate. Equivalent stress is lowest for steel and highest for carbon fibre as low deformation induces more stress. So, from the above results, spectra has better properties to withstand deformation and can be suggested to use in vests. But, the cost of spectra is quite high when compared to Kevlar and carbon fibre. Carbon fibre is found good alternative to Kevlar both in resisting the bullet penetration and cost wise.

Bullet proof vests are generally designed in 3 layers. The function of the first layer, from bullet side is to reduce the velocity. The function of the second layer is to reduce the impact and penetration. The function of third layer which is touching the body of soldier is to protect him from hitting and minimising stress.

The first layer is selected as fibre cement of thickness 8 mm and third layer is selected as steel of thickness 3 mm and the middle layer which is of main focus is checked with three different materials Kevlar, spectra and carbon fibre of thickness 2.4 mm. The results of the assembly of three layers is shown in fig 4.12 to 4.17 and tabulated in table 4.3.

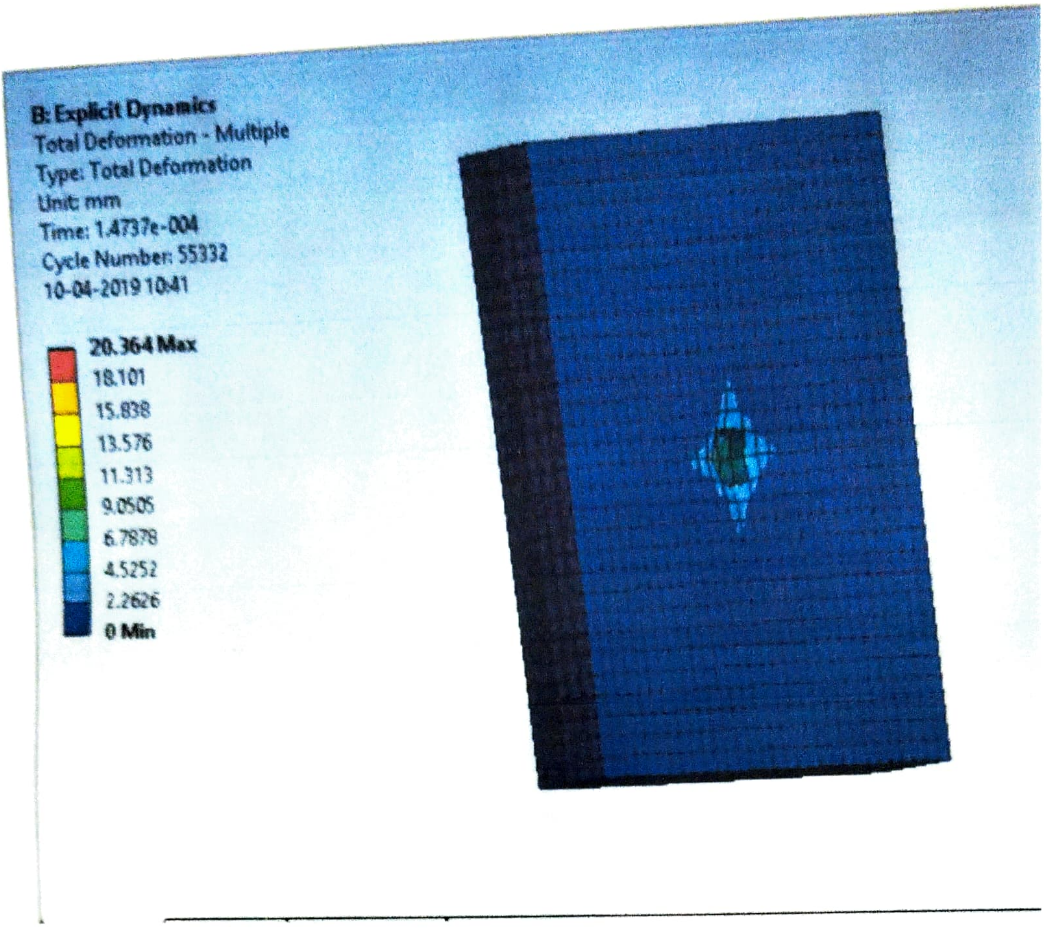

Fig. 4.12: Total deformation of sample using steel, Kevlar and fibre cement.

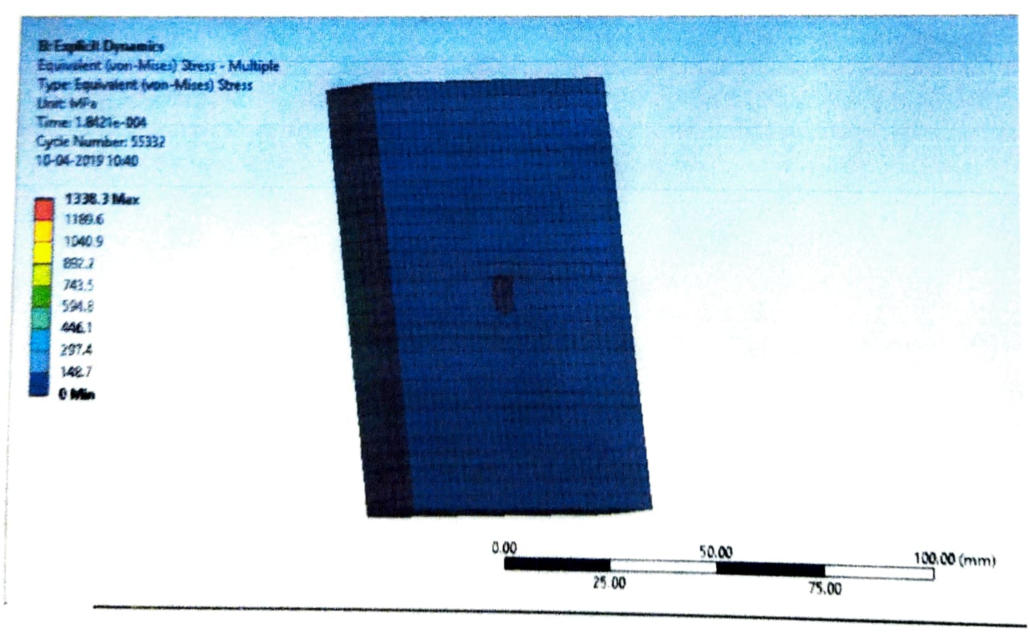

Fig. 4.13: Equivalent stress of sample using steel, Kevlar and fibre cement.

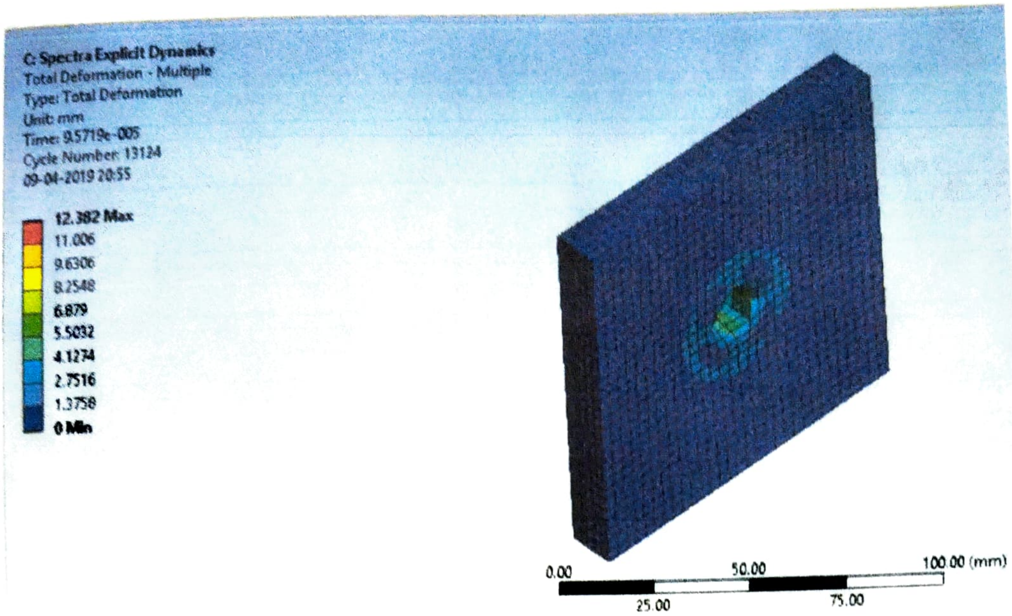

Fig. 4.14: Total deformation of sample using steel, Spectra and fibre cement.

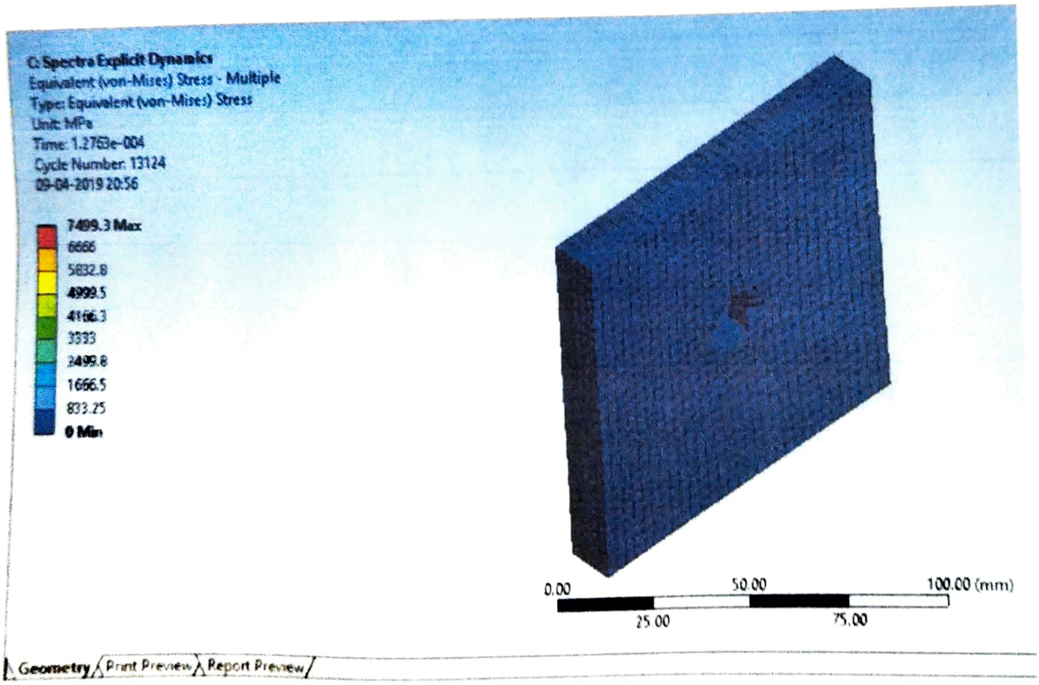

Fig. 4.15: Equivalent stress of sample using steel, Spectra and fibre cement.

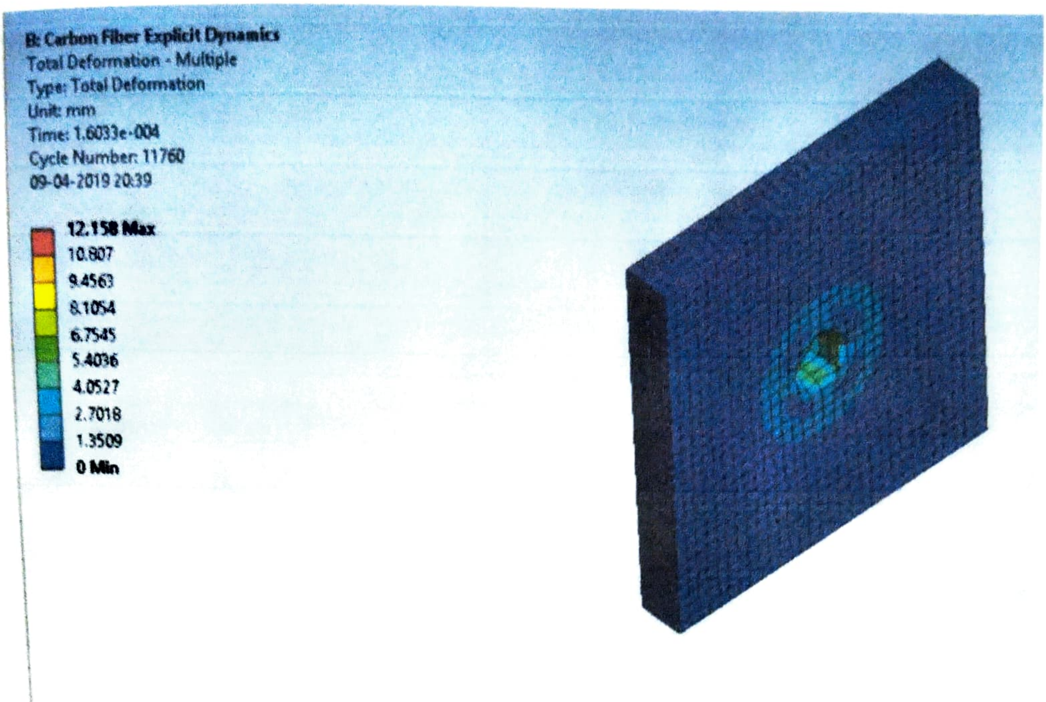

Fig. 4.16: Total deformation of sample using steel, carbon fibre and fibre cement.

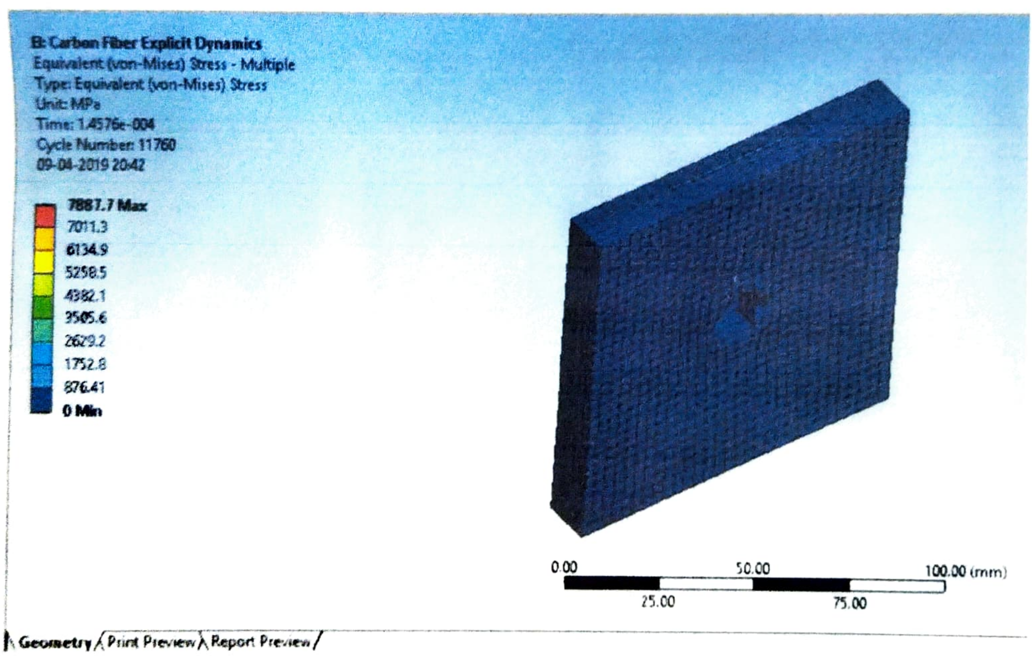

Fig. 4.17: Equivalent stress of sample using steel, carbon fibre and fibre cement.

Table 4.3: total deformation and equivalent stress distribution on individual plates

Description	Total deformation (mm)	Equivalent stress (MPa)
Steel + Kevlar + Fibre cement	20.364	1338.3
Steel + spectra + Fibre cement	12.382	7499.3
Steel + carbon fibre + Fibre cement	12.158	7887.7

From the figures 4.12 to 4.17 and table 4.3, it is observed that the deformation and equivalent stress is almost same for the assembly using spectra and carbon fibre. The deformation is less for the assembly using spectra or carbon fibre compared to Kevlar. So, both spectra and carbon fibre are the better alternatives to the Kevlar. Carbon fibre is better alternative compared to spectra as it has lesser deformation and cost.

CHAPTER - 5

5. CONCLUSION

Protection of soldiers from bullets is one of the important criteria of the defence sector. Bullet proof vests are used for this purpose. Generally, bullet proof vests are made of assembly of steel, Kevlar and fibre cement. Intense research is focused to use better alternative to Kevlar.

Spectra and carbon fibre were selected as alternative materials to Kevlar and the simulations are carried out to. It is observed that, spectra is having less deformation when compared to Kevlar and carbon fibre. But the cost of spectra is very high and is about $45-82. Whereas the cost of Kevlar and carbon fibre is approximately equal and its cost ranges from $5-25. Therefore, carbon fibre is suggested as the better alternative to Kevlar.

REFERENCES

[1] Ali Murat soydan et al, "Simulation and Experimental Tests of Ballistic Impact on Composite Laminate Armor" Advances in Materials Science and Engineering Volume 2018,

[2] M. A. G. Silva et al, "Numerical simulation of ballistic impact on composite laminates," International Journal of Impact Engineering, vol. 31, no. 3, pp. 289–306, 2005.

[3] A. Banerjee et al,"Numerical simulation of ballistic impact of armour steel plate by typical armour piercing projectile," Procedia Engineering, vol. 173, pp. 347–354, 2017.

[4] L. M. Bresciani et al "Experimental tests and numerical modelling of ballistic impacts against Kevlar 29 plain-woven fabrics with an epoxy matrix: macro-homogeneous and meso-heterogeneous approaches," Composites Part B: Engineering, vol. 88, pp. 114–130, 2016.

[5] C. Y. Tham, et al, Lee, "Ballistic impact of a KEVLAR helmet: experiment and simulations," International Journal of Impact Engineering, vol. 35, no. 5, pp. 304–318, 2008.

[6] S. L. V. Shashi Kant, "A review on analysis and design of bullet resistant jacket-ballistic analysis," International Advanced Research Journal in Science, Engineering and Technology, vol. 4, pp. 1–10, 2017.

[7] A. A. Ramadhan, et al "High velocity impact response of Kevlar-29/epoxy and 6061-T6 aluminum laminated panels," Materials and Design, vol. 43, pp. 307–321, 2013.

[8] Aswani Kumar Bandaru et al,"Ballistic Impact Behaviour of Thermoplastic Kevlar Composite : parametric studies" volume 173,Procedia Engineering 2017

[9] Naik, N.K. et al . Ballistic impact behavior of thick composites: analytical formulation, AIAA Journal, 43:1525-1536. 2005