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Finite Element Analysis Of Ballistic Impact On A Composite Lamina

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Abstract. On the field of battle, the protective gear plays a significant role for safety of personals. It is desirable that the gear protection level should be high and light weight, so that they can be carried easily. The aim of this study is to analyze, through simulation, the actual behavior of the impact of 0.303 caliber bullet on the Kevlar 149 composite sheet for single and double layers using the finite element approach. The lamina of composite material K149 and steel has been utilized for the bullet impact test using ANSYS software in order to determine the stress and strain in the lamina. The final analysis gives the maximum stress, strain, total velocity, total acceleration, total deformation and the directional deformation for the singleand double-layer composite lamina.

Keywords: Pre ACP; Bulletproof; Impact analysis; Finite element method; Ballistic.

INTRODUCTION

On the field of battle, the protection gear plays a significant role for a safety of personals So, the gear protection level should be high and light so, they can easily carry. Personal protecting armour is a very important protection system that safeguards humans from impact and shock masses. Since the dawn of humanity, people have sought to protect their bodies from a variety of threats, including projectile weapons and sharp objects. To protect themselves from a variety of threats, people carried clothing made from various types of primitive and advanced materials, such as animal products (leather), wood, stones, copper, and steel. In addition to being used for clothing, a variety of textiles and laminates made of traditional fibres like linen, cotton, silk, and nylon are also used in ballistic applications and as protective materials against a variety of threats. Nylon with ballistic properties was the standard for quality fabric utilised for bulletproof or antiballistic vests until the 1970s. In 1965, a chemist at Du Pont, Stephanie Kwolek, invented Kevlar, which we know as a trademark for poly-para-phenylene terephthalamide. This polymer is a liquid polymer compound that may be rotated into aramid fiber and knitted into the fabric [1]. Formerly, Kevlar was established to be used in tires, and far along for such various merchandise as gaskets, sealing materials, ropes, and varied components for boats and planes. In 1971, Lester Shubin of the National Institute of Law Enforcement and Criminal Justice advocated its application to substitute large and heavy ballistic nylon in bulletproof vests. Ever since then the Kevlar has been the standard for quality ballistic material. The Allied Signal Company, in 1989 established a contending for Kevlar and named it as Spectra. Formerly applied for material as sail cloth, the synthetic resin polyethylene fibres are currently liable to create stronger, nonetheless lighter, non-knitted material to be used along-side the traditional Kevlar in bulletproof vests [2]. For occurrence, Infantry assurance clothing was made by utilizing creature skin on Balkan nation or Grecian shields, different layers of silk in antiquated Japan, and defensive layer suits with chain defensive layer all through the Center Ages was utilized in other ways for guard and assurance [3]. In any case, advanced and stylish military operations, technology-driven war strategies, on-street weapons and ammo require the advancement of progressed damage-resistant, adaptable, lightweight, and decent endothermic ballistic security protective layer frameworks. These days, the ballistic materials of different styles of materials are utilized in a few specialized applications, in conjunction with ballistic assurances, since they are lightweight, have tall defensive execution, and are moo in cost. Moreover, progressions in high-strength yarns composed of filaments with tall modulus, tall quality, and exponential anti-degradation properties play an critical part within the improvement of predominant high-performance ballistic materials for next-generation ballistic ensuring body Armor and armouring vehicles [4,5,6]. Since of their lightweight, affect resistance, and high-energy retention capacity, such materials' auxiliary reactions are broadly utilized in building applications.

MATERIALS PROPERTIES AND MODELLING

Material Properties

In this study, the composite material of Kevlar-149 with steel has been utilized, in which three layers of Kevlar-149 and two layers of steel at different orientations are used for the analysis. The mechanical properties for the Kevlar-149, steel, and lead antimony alloy are taken from [8,9], which are mentioned in Table 1

TABLE 1 Material properties

Component	Material	Density (g/cm3)	Young's Modulus (GPa)	Tensile Strength (GPa)	Poisson' sRatio
Bulletproof sheet	Kevlar-149	1.47	186	3.40	0.30
	Steel	7.850	200	0.046	0.30
	Epoxy Resin	1.21	3.8	-	0.29-0.34
Bullet	Lead-Antimony alloy	11.3	13-15	0.032	0.435

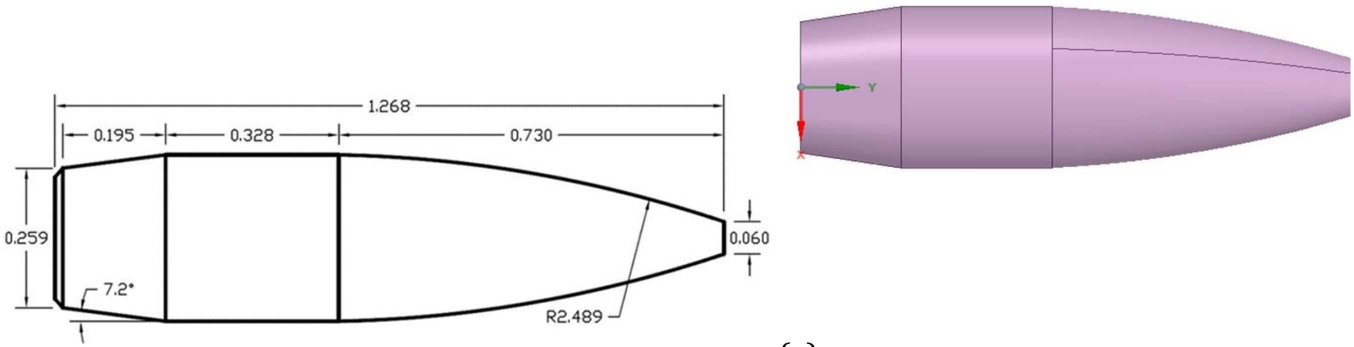
Kevlar is widely used for many applications in defense such as bulletproof vests, tankers, armors, anti-ballistic missiles, etc. Kevlar-49 [10,11] is wide as associate degree anti-ballistic part, but Kevlar-149 has high tensile modulus and high impact strength. It is not utilized in all around purposes since it is yet to be studied and is at an undiscovered state of science. Even though K-149 is more durable, it has an enormous shortcoming over K-49 i.e., it is denser than K-49 thereby machining method is troublesome. The properties of K-149 can be summarized as follows [12,13]: Ultra-high modulus, high strength, low density, highly crystalline fibers, highly stiff, high strength to weight quantitative relation, impact resistance, abrasion resistance, does not expand on heating, difficult to chop and drill, resistant to the majority varieties of chemicals, negative constant of thermal growth, withstands temperatures -196 oC to +450 oC. Kevlar-149 has the highest perseverance for ballistic, armor, and part applications

CAD Modelling

The CAD model of a square lamina of length 300 mm and width 300 mm has been developed for the analysis, as shown in Fig. 1.

For the modeling of bullet, Lead-antimony alloy is considered. The CAD model of the bullet with dimensions is shown in Fig. 2

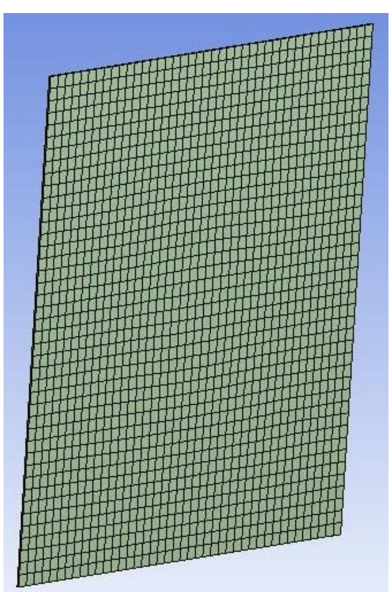
FIGURE 1 CAD model of the composite lamina of Kevlar-149 Kevlar



(a)

(b)

FIGURE 2 (a)Draft model of Bullet, (b) CAD Model of Bullet on CATIA V5



FINITE ELEMENT ANALYSIS

The sheet and bullet CAD models were discretized using the Finite element method. The quadratic type meshing is used for the model in this study, which provides an accurate result, with the meshed model containing 2747 elements and 5754 nodes, as shown in Fig. 3.

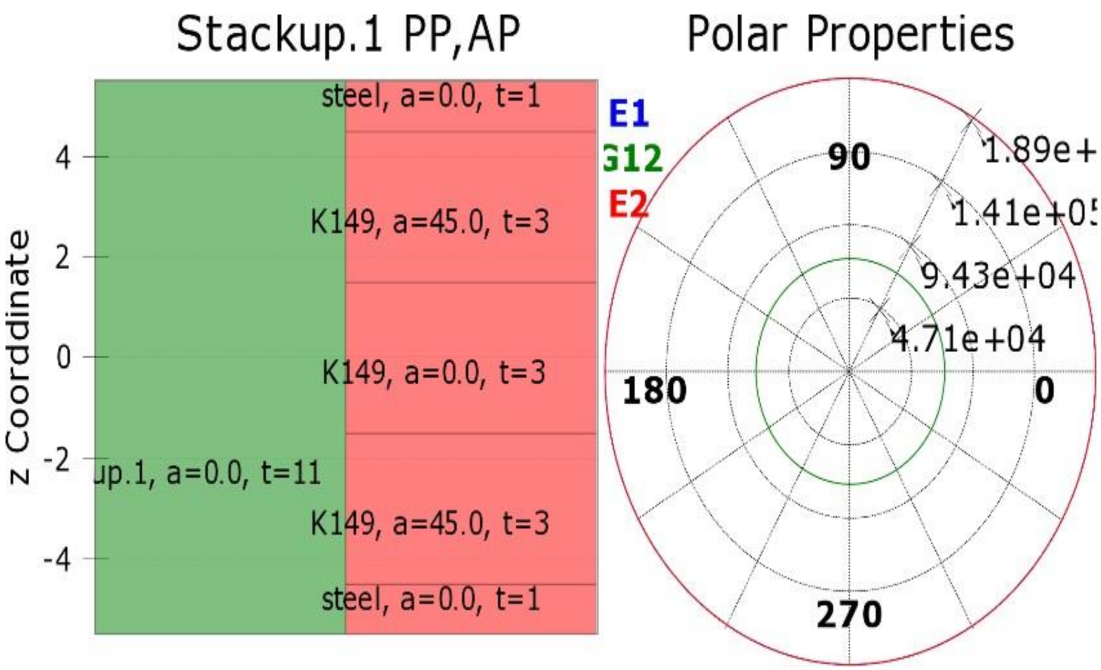


FIGURE 3 Meshed model of the composite lamina of Kevlar-149

METHODOLOGY

As shown in Fig. 3, a sandwich plate made of Kevlar-149 and steel has stack up layers at two different angles (0/45/0). They are created with ANSYS ACP Pre. The upper and last layers are made of steel, and the material used between them is K-149. Each layer has a different orientation angle. [14,15].

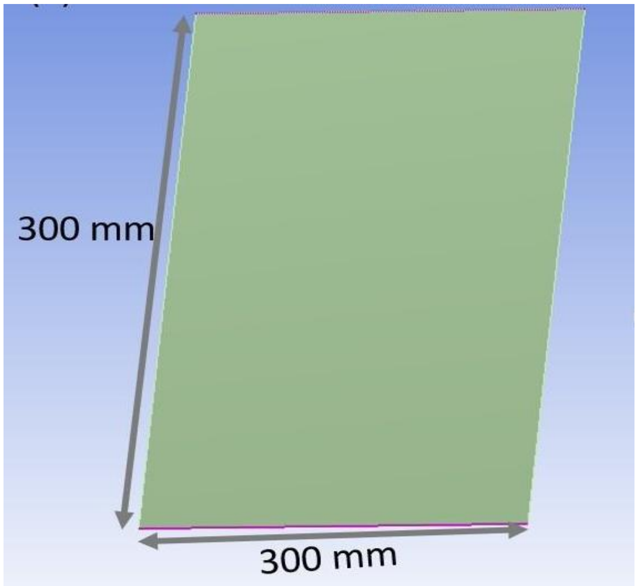


FIGURE 4 Stack up of K-149 and steel

In between the stack up of K-149 and steel there is a sub laminate layer of epoxy resin was used to join these two material stack up layer properly The material properties for the single layer composite lamina were shown in table 2.

TABLE 2 Mechanical Properties for Single plate lamina

Properties	Value
Shear Stiffness (Flexural Laminate)	31661.2684471
Shear Stiffness (Laminate)	26501.0229412
Stiffness (Flexural Laminate E1)	17867.8572969
Stiffness (Laminate E1)	22792.0722
Stiffness (Flexural Laminate E2)	18296.2511421
Stiffness (Laminate E2)	38949.7573747
Out of Plane Shear G23	2633.30783864
Shear Correction Factor of k44 (G23)	0.622237201948

Out of Plane Shear G31	2276.04414133
Shear Correction Factor of k55 (G31)	0.591487562717

After the model has been discretized, the loading and boundary conditions must be assigned. The model's boundary condition is that the sheet's edges are fixed supported, and the bullet is moving at a velocity of 844 m/s.

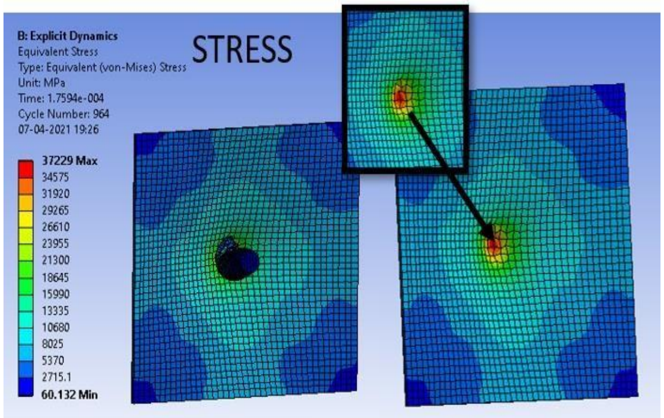
RESULTS AND DISCUSSION

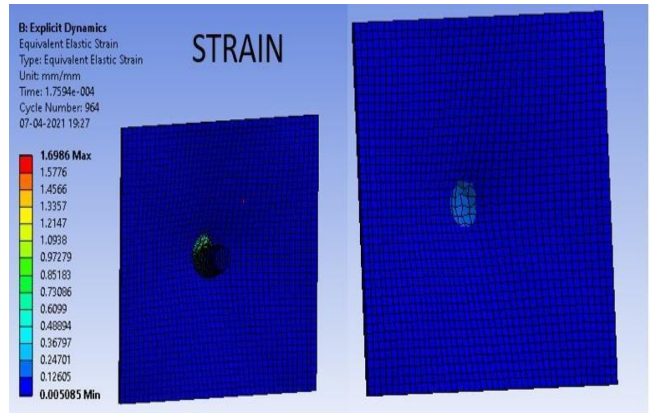
The analysis has been performed to determine the impact of 0.303 caliber rifle bullet (with velocity of 844 m/s) on Kevlar-149 lamina through simulation. This simulation study is performed considering single layer and double layers of K-149 sheet.

It is important to mention that the analysis combines the results of bulletproof sheet and the bullet; hence, the maximum or minimum value of a parameter can be for the sheet or for the bullet. Here, we are interested to analyze the sheet only, after the bullet impact. Therefore, theresults for the bulletproof sheet are estimated by the help of color-coded bars in ANSYS. The values for the impact analysis are shown in the minimum-maximum color-coded bars, in which the red color indicates the maximum value for that parameter and the blue color indicates the minimum value for that parameter.

In Fig. 4, the result of the single layer of Kevlar-149 is shown, where two figures are shown for each parameter, first figure is showing the combined bullet and sheet, while the second one shows the impacted sheet only. The color-coded bars show the values for the combined bullet and sheet.

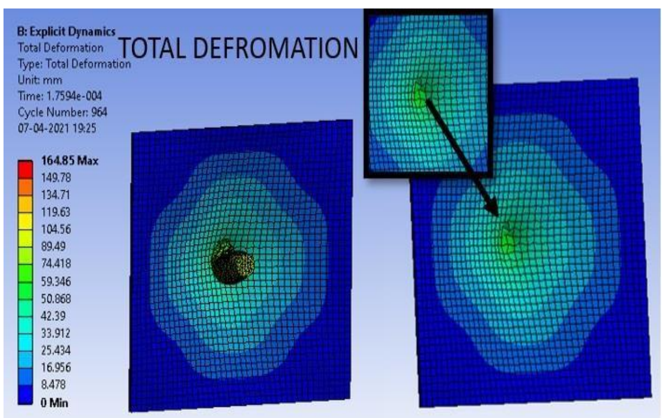
Single Layer Results


B: Explicit Dynamics
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1.7594e-004
Cycle Number: 964
07-04-2021 19:26
STRESS
37229 Max
34575
31920
29265
26610
23955
21300
18645
15990
13335
10680
8025
5370
2715.1
60.132 Min

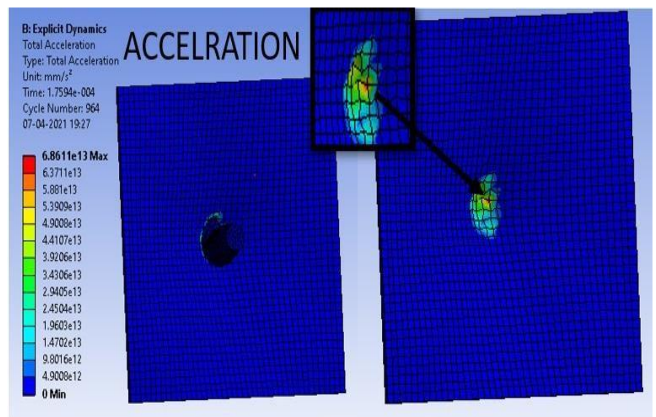

B: Explicit Dynamics
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: mm/mm
Time: 1.7594e-004
Cycle Number: 964
07-04-2021 19:27
STRAIN
1.6986 Max
1.5776
1.4566
1.3357
1.2147
1.0938
0.97279
0.85183
0.73086
0.6099
0.48894
0.36797
0.24701
0.12605
0.005085 Min

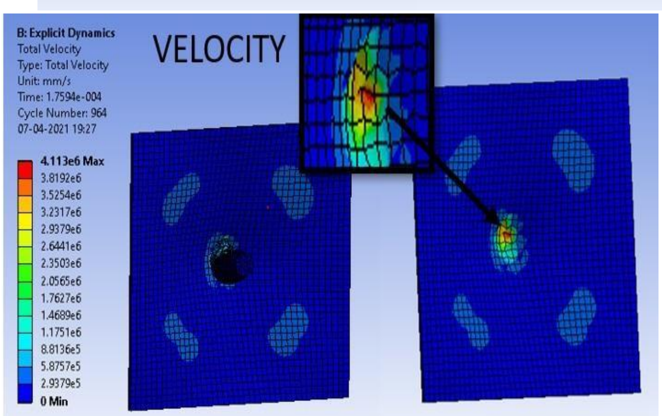
(a) (b)

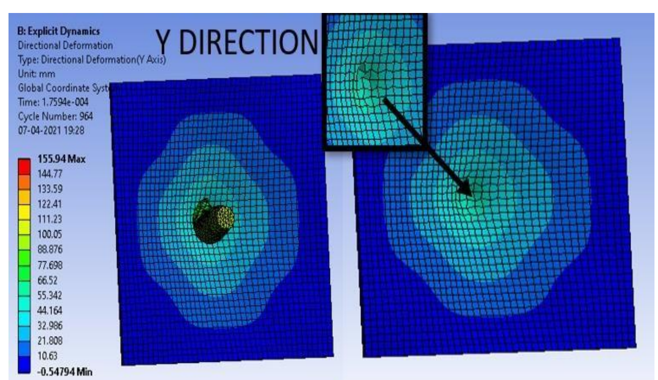
(c) (d)


B: Explicit Dynamics
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1.7594e-004
Cycle Number: 964
07-04-2021 19:25
TOTAL DEFROMATION
164.85 Max
149.78
134.71
119.63
104.56
89.49
74.418
59.346
50.868
42.39
33.912
25.434
16.956
8.478
0 Min

(e)


B: Explicit Dynamics
Total Acceleration
Type: Total Acceleration
Unit: mm/s²
Time: 1.7594e-004
Cycle Number: 964
07-04-2021 19:27
ACCELRATION
6.8611e13 Max
6.3711e13
5.881e13
5.3909e13
4.9008e13
4.4107e13
3.9206e13
3.4306e13
2.9405e13
2.4504e13
1.9603e13
1.4702e13
9.8016e12
4.9008e12
0 Min


B: Explicit Dynamics
Total Velocity
Type: Total Velocity
Unit: mm/s
Time: 1.7594e-004
Cycle Number: 964
07-04-2021 19:27
VELOCITY
4.113e6 Max
3.8192e6
3.5254e6
3.2317e6
2.9379e6
2.6441e6
2.3503e6
2.0565e6
1.7627e6
1.4689e6
1.1751e6
8.8136e5
5.8757e5
2.9379e5
0 Min


B: Explicit Dynamics
Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate Syst
Time: 1.7594e-004
Cycle Number: 964
07-04-2021 19:28
Y DIRECTION
155.94 Max
144.77
133.59
122.41
111.23
100.05
88.876
77.698
66.52
55.342
44.164
32.986
21.808
10.63
-0.54794 Min

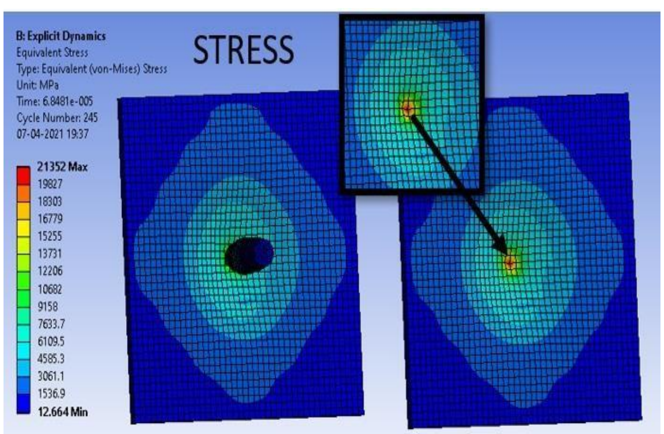
(f)

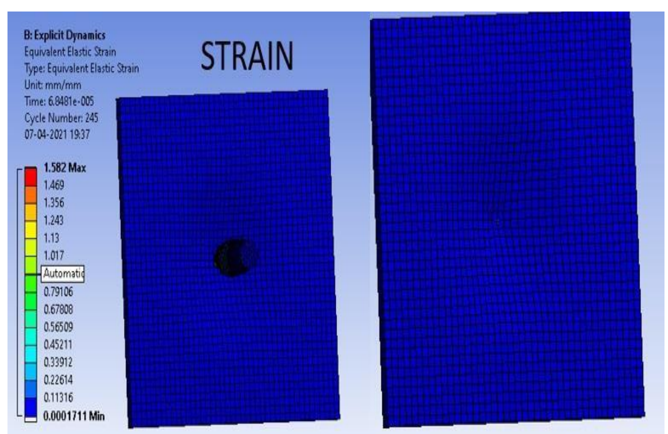
FIGURE 5 Simulated (a)stress parameter (b) strain (c) velocity(d) acceleration (e) total deformation (f) directional deformation for the single layered sheet of K-149 lamina

TABLE 3 Results summary for single layer sheet

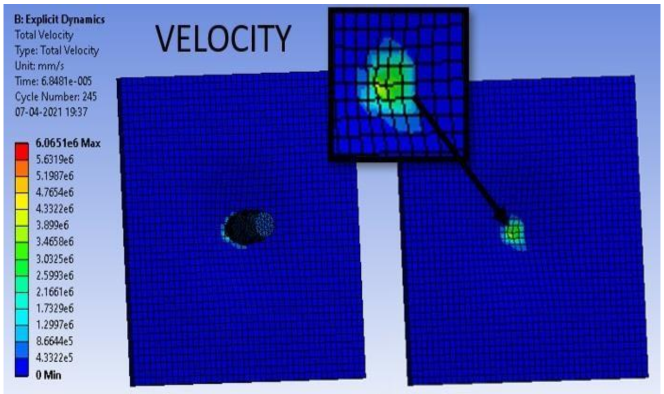
Parameters	Unit	Maximum Value
Stress	MPa	37229
Strain	mm/mm	0.36797
Velocity	mm/s	4.113e6
Acceleration	mm/s^2	6.3711e13
Total Deformation	mm	89.49
Y-Axis Deformation	mm	66.52

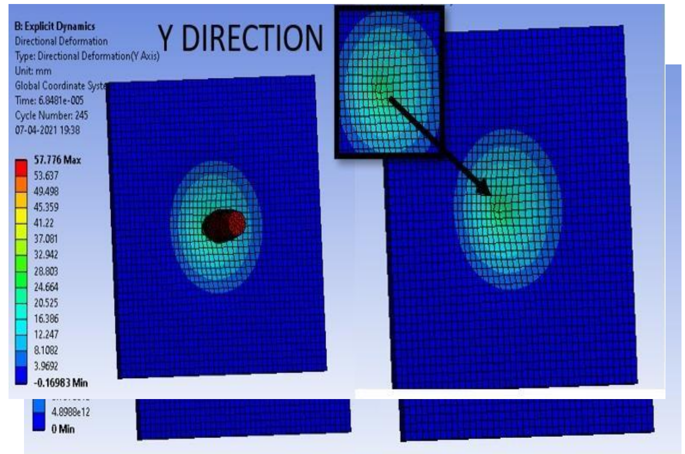
Double Layer Results



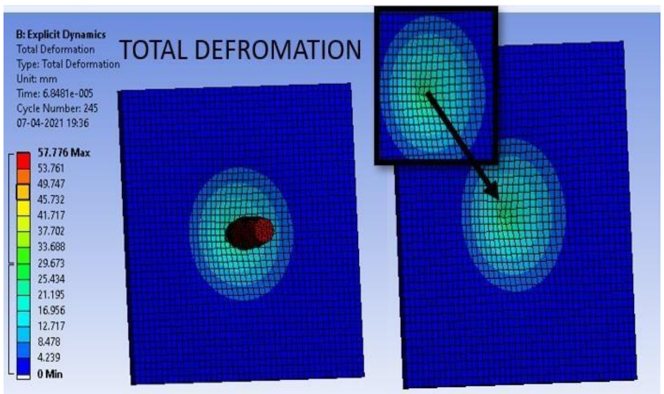


(a)





(b)



(e)

(f)

FIGURE 6 Simulated (a)Stress Parameter, (b) Strain, (c) Velocity, (d) Acceleration, (e) Total Deformation, (f) Directional Deformation for the double layered sheet of K-149 lamina.

TABLE 4 Results summary for double layer sheet

Parameters	Unit	Value
Stress	MPa	21352
Strain	mm/mm	0.11316
Velocity	mm/s	3.8990e6
Acceleration	mm/s^2	4.4089e13

(c)

(d)

Total Deformation	mm	25.434
Y-Axis Deformation	mm	24.664

CONCLUSION

The laminated sheet of Kelvar-149 has been analyzed after the impact of 0.303 caliber rifle bullet made from the lead-antimony alloy. The analysis is conducted through simulationbased on the finite element approach. Two sheets of Kelvar-149 have been analyzed, first is single layered and the second one is double layered. It is found that the maximum stress and strain in the double layered case are less than the single layered lamina of Kevlar 149. In addition, the double layered sheet shows less deformation after the bullet impact, comparedto the single layered sheet.

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