IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 5 Ser. V (Sep. – Oct. 2020), PP 28-38
www.iosrjournals.org

Ballistic Analysis of Composite Armor

Muzammil Ahmed Khan[1], Mohammed Imran[2]
[1]*(Department of Mechanical Engineering, Osmania University, India)*
[2]*(Department of Mechanical Engineering, Osmania University, India)*

Abstract:
Background:*Battle of weapon and armor has been continuing from the beginning of the human history. As new weapons are developed, in response to that corresponding armors are been developing. Even Today, development of lightweight armors against kinetic energy caliber projectiles is getting important as mobility is considered. In this work, study regarding the effect of projectile on group of armor and ballistic protection efficiency is performed. The interaction between the kinetic energy projectile and armor plate falls into the domain of terminal ballistics science.*
Materials and Methods: *In this work, set of two different composite armors consisting of Steel, Dyneema, Kevlar, Ceramic materials are of optimized configurations are procured to test against the standard 7.62mm projectile in a 90 degrees angle at normal laboratory conditions of ballistic experiment.*
Results: *Dynamic analysis results helped us to know the stress and stain patterns over the armor system and how energy in armor layers comes down to zero. At the same time investigation of energy losses, reduction of bullet velocity in armor layers is carried out to define the armor stability and performance.*
Conclusion: *Material properties and thickness of armor layers finalized from various journal papers are in good concurrence with the results obtained from experimentation.*
Key Words:*Ballistics, Composite armor, Multi-hit capability,projectile and target failure.*

Date of Submission: 28-10-2020 Date of Acceptance: 09-11-2020

I. Introduction

The work is associated to the domain of terminal ballistics where study dealt with mechanics of projectile and target interaction. Increased protection is possible only using advanced armor technology. Protection creates a shift in the internal paradigm of the soldier and leads to multiplied psychological stamina for moving fearlessly in the battlefield which generates a major force-multiplier effect. Results of ballistic experiment always depends upon the fundamental parameters such as bullet striking velocity on armor, bullet striking angle at armor, bullet and armor material and armor layers thickness, etc. Hence it is mandatory for an examiner to have clear knowledge about these factors so as to finalize the robust target which will withstand the defense standards ammunitions. Use of multilayered armor/composite armor (special combinations of steels or ceramics and other materials to absorb and diffuse the damage caused by the threat) is the fastest emerging technology in the real defense armoring application because it is very difficult to obtain all required mechanical properties in a single layered protection. Armor material must be efficiently Hard, stiff, tough and thick at a time to become safe from bullet diffusion into it, in arresting impact and heat strain waves during impact event. As high velocity projectile hits the target large amount of kinetic energy converted into heat energy which causes the stresses far greater than the material strength because of which pseudo liquid like (sub-hydrodynamic) behavior in the steels could be seen where ceramics materials fails by brittle fracturing as high hard materials do not absorb energy waves and deform. Cost Vs design parameters such as density, availability, ease of material processing also the major consideration while designing of an armor system.

II. Material And Methods

Experiment Location and Duration: Armor testing is done in Ordnance Defense Factory (ODF), Medak, Hyderabad in the duration of complete month and further survey/review work is done in ODC cell of ODF and college laboratory as it is the part of one year M.E/M.tech final year project.

Group 1 Armor:Thickness optimization and material properties selection are the major elements of armor design once the fundamental parameters are known. In the first step present experimental work uses 7.62x54R B32 API caliber which has following data specifications;

When a impact event of 7.62mm (generally has 3:1 L/D ratio) with limit of 1000 m/s muzzle velocity is launched it creates kinetic energies on the order of $10^3 - 10^4$ J, Pressures 20-40 GPa(Peak) and 3-5 GPa(Average), strains 0.2-0.3(Average) and >1(Peak), strain rates 10^4-$10^5 s^{-1}$(Average) and 10^6-10^7 s^{-1}(Peak).[1]

As per STANAG 4569 level-III instructions the standard caliber of bullet chosen for experimental work has following specifications;

Tab 1: Bullet Specifications

Velocity	854 m/sec
Mass of bullet	10.04 grams
Diameter of bullet	7.62 mm
Overall length	54 mm
Core material	Steel

Here immediate next step is the material selection from where defense documentations suggests us the usage of steels, ceramics and composite (fiber matrix combination) material as these materials possess all the required mechanical properties that armor application seek. Since the present work is about fabricating multilayer armor also material availability pushed us to use two layers of steel with an intermediate of dyneema (it is a thin, flexible ballistic composite made from two layers of unidirectional fibers 0 and 90 degrees held in place by flexible resins, then, both are wrapped by thin sheets of polyethylene films. They are Light weight and waterproof, extremely high specific tensile strength and stiffness) material. Their thickness and material properties are considered as follows;

Tab 2: Dyneema properties [2]

Density	0.00097 g/mm^3
Young’s modulus	34257MPa
Poisson’s ratio	0.33
Yield stress	1030 MPa
Tensile Strength	1250 MPa

Armor steel used in ballistic application gives yield strength and maximum tensile strength upto 1320 MPa and 1600 MPa respectively for a sample of 5mm thickness which is specially alloyed and heat treated steels shows around 444 hardness(brinell). This armor steel composition contains 0.20-0.27 %mass of C, 0.90-1.10 %mass of Si, 1.10-1.30%mass of Mn, max 0.025%mass of P, max 0.025% mass of S, 0.75-0.90 % mass of Cr, 0.30-0.40% mass of Mo and iron is balanced.[3]

Final step is the thickness finalization of these materials with respect to the standard bullet, has finalized after survey mentioned here;Regarding the ballistic penetration of hardened steel plates by 7.62 mm AP (Armor Piercing) projectile the AISI4340 samples were procured from the DRDO and then heat treated to varying hardness (39.5, 49.5, 52.5 and 58.5 HRC). Five different areal densities were selected (as55, 70 ,85 ,100 and 115 kg/m2) which correspond to 7.2, 9, 10.8, 12.7 and 14.4 mm thickness.[1]

Advanced ceramic (Al2O3 contents ranging 97–99.7wts.%)of 7-9 mm for armoring with a backing of polyethylene laminates (Kevlar,Twaron). In general, the thinner the ceramic plate, the greater the number of aramid fabric layers or other backing materials is required. They used different thickness armor plates and tested for multi-hit. Ballistic performance of the armor ceramics is defined by the microstructure and phase composition, and physical properties. Armor system performance is defined by the properties and thickness of the system components.[4]

A front ceramic layer (Al2O3) that shatters and spalls the bullet is followed by an intermediate layer, usually an equal thickness layer of 30vol% jute fabric reinforced epoxy composite both of 10 mm thick.[5]

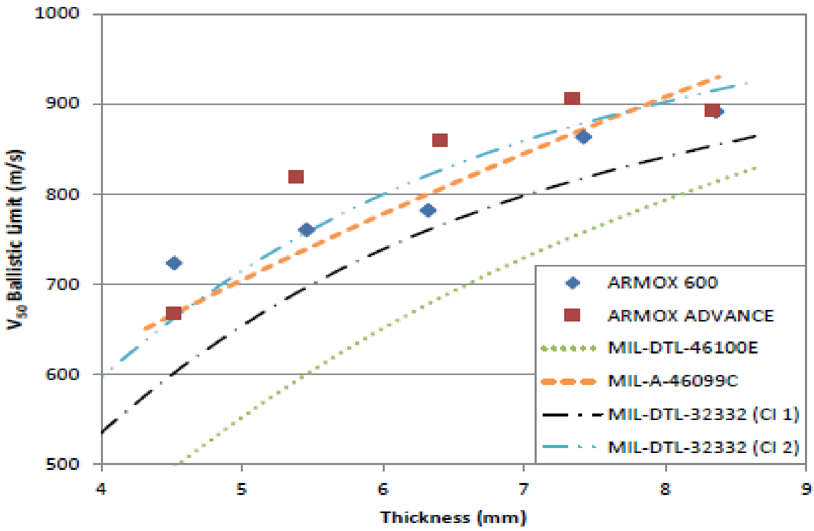


Fig 1: Ballistic performance will generally increase with hardness, this will depend on the threat projectile and armor thickness and toughness.[6]

Figure 1 hints us the use suitable thickness materials with respect to the ballistic velocity. Materials used in the journal referred are high hard but not tough and stiff. Therefore balancing between these properties is taken into consideration with increased thickness keeping ballistic velocity constant in the present experiment to protect the samples failing.

Figure 2 below gives us the information about optimum hardness on materials with respect to the standard velocity of bullet. Keeping this in mind optimum hardness, toughness and thickness plates are procured.

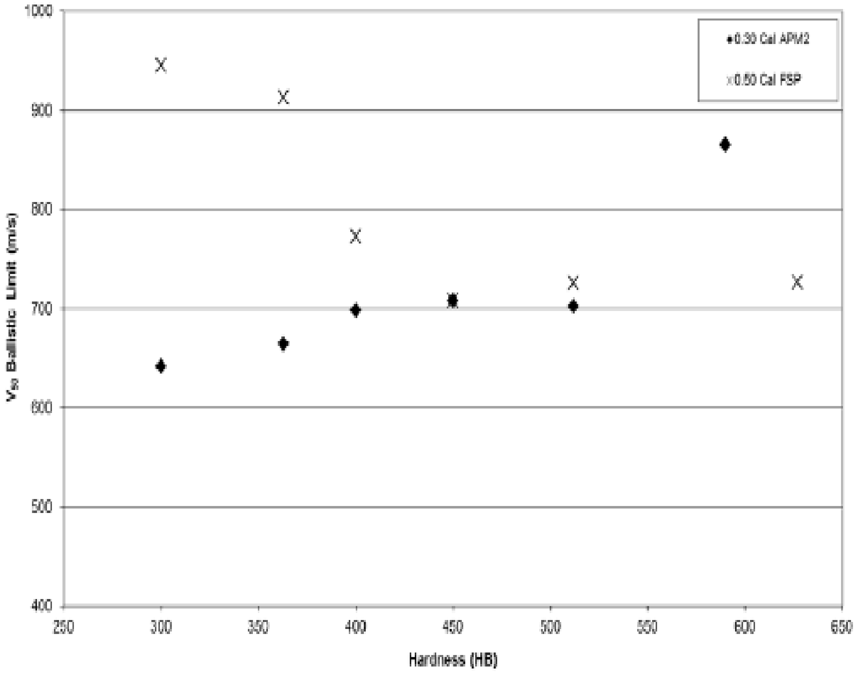
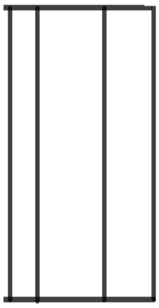


Fig 2: In the fully hardened condition, with hardness between 510 and 710HV, all targets suffered from gross cracking, whereas when tempered back to 380HV, the tool steels.[6]

Group 1 of Sample I - Composite armor consists of 8 mm thick spade armor steel plate (firing surface) – (Size: 200x200x8T), 16 mm thick Dyneema material (size: 200x200x16T) and 2mm thick jackal armor plate (size: 200x200x2T). These plates are joined together by welding with steel strips at side edges keeping Dyneema material between above two. Draganov 7.62x54R B32 API is fired, from a distance of 30 meters and a second firing is done from a 45 meter distance with a 12.7 mm machine gun.



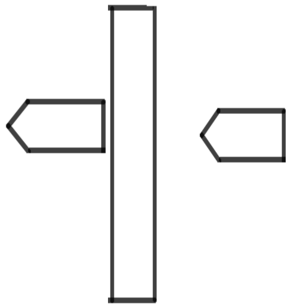


Fig 3: Schematic of Sample I –IV Fig 4:Schematic of Sample V

Keepig all the parameters same the sample sizes were modified, written below;
Sample II – Spade armor steel plate (Size: 250x250x12T), Dyneema material (size: 250x250x20T) and jackal armor plate (size: 250x250x3T).

Sample III – Spade armor steel plate (Size: 300x300x16T), Dyneema material (size: 300x300x23T) and jackal armor plate (size: 300x300x4T).

Sample IV – Spade armor steel plate (Size: 350x350x18T), Dyneema material (size: 350x350x25T) and jackal armor plate (size: 350x350x4T).

Sample - V uses only 16mm thick Jackal Armor plate (size : 500 x 500 x 16T, taken from rear door of BMP vehicle). Weapon Draganov 7.62x54R B32 API, fired from a distance of 30 meters in a two rounds of firing keeping a distance of 180 mm in shots positions.

Group2 Composite armor:Composite armour panel consist of following dimensions:
6mm Jackal armour steel plate (Base Plate), 35mm thick aluminium foam supplied by M/s DMRL, HYD, 6mm thick Al, Alloys plate/ strip of size 150x150x6mm – 9 no.s (3 columns and 3 rows),7.5mm thick ceramic panel/ strips of size 150x150x7.5mm supplied by M/s CGCRI. Nos. (3 columns and 3 rows) and Kevlar cloth – 2 layers.
The above items are glued together one over the other in the above order. Firing has done on Kevlar cloth end using level-III protection in two fire rounds.

Fig5: Composite armor Group 2

Mathematical modeling: Composite armor tested against bullet kinetic energy, the impact force of bullet acting on armor calculated by mathematical equations. Motion of bodies & collision of bodies' concept are used for calculating velocities at different layers, energies .the calculations as follows:

- The impact force excited by the bullet having (7.62×54RB32API, mass 10.04 grams , Velocity 854 m/s).
- Kinetic energy of the bullet = $\frac{1}{2} MV^2$ is K.E = $\frac{1}{2} \times 0.01004 \times 854^2$ so K.E = 3661 58 J.
- Impact force on the armor at a distance of 50m is F = 3661.58 /50 so force becomes F = 72.9316 N.
- Since the experiment is done in a laboratory where normal atmospheric conditions were maintained hence all the factors which effects bullet velocity are neglected.

Energy absorption by armor layers:
Energy absorption by the layer = (fracture toughness of the material x cross sectional area of bullet penetration) / √ (thickness of the layer penetrated by the bullet)

$$E = \frac{F.T \times A \times L}{\sqrt{t}}$$

Where; F = Fracture toughness of the layer, E_a = Absorption energy by layer, A = Area of cross section of bullet L = Distance between target and observer, t = Thickness of layer.

Total energy = Absorptionof energy by first layer + remaining energy

- Remaining energy = Force on the second layer
- Absorption energy by the layer = kinetic energy absorbed
- Absorption energy = ½ M ($V_i^2 - V_r^2$); whereV_r, V_i are residual and initial velocity of projectile respectively.

Similarly the calculations for all the layers can be obtained, here last layer is defense tanker layer.

Tab 3: Energy analysis of composite armor layers by theoretical calculations model 1

S.No	Layers of the composite armor	Layer thickness (mm)	Velocities at layer surface (initial velocity) m/s	Residual velocities at layer surface (final velocity) m/s	Energy loss at each layer (Joules)
1	Kevlar 29	2	854	824	251
2	Ceramic tile	8	824	563	1811
3	Aluminium strips	6	563	374	884
4	Aluminium foam	30	374	292	519
5	Armor steel	4	82	0	196

Group 2 composite armor again analyzed in two stages named as model 1 and model 2. These two models are distinguished on the layers swaping and layers thickness variations. Mathematical analysis and simulation results are directly tabulated below.

Tab 4: Energy analysis of composite armor layers by theoretical calculations model 2

S.No	Layers of the composite armor	Layer thickness (mm)	Velocities at layer surface (initial velocity) m/s	Residual velocities at layer surface (final velocity) m/s	Energy loss at each layers (Joules)
1	Kevlar 29	2	854	824	251
2	Ceramic tile	8	824	563	1811
3	Jackal armour	6	563	292	1161
4	Aluminium foam	30	292	0	438
5	Armour steel	4	0	-	-

Tab 5: Simulation results using Explicit dynamics- model 1

S no	Armour layers	Energy loss (Joules)	Residual velocity (m/s)	Total deformation(mm)	Equivalent stress (Pa)	Equivalent strain
1	Kevlar	294	240	1.508	5.43	0.72
2	Ceramic tile	1950	304	0.528	4.26	0.43
3	Aluminium strips	835	232	0.21	5.37	0.32
4	Aluminium foam	519	162	0.39	2.89	0.34
5	Composite armour plate	3661	806	0.91	3.042	0.58

Tab 6: Simulation results using Explicit dynamics – Model 2

S no	Armour layers	Energy loss (Joules)	Residual velocity (m/s)	Total deformation(mm)	Equivalent stress (Pa)	Equivalent strain
1	Kevlar	294	240	1.508	5.43	0.72
2	Ceramic tile	1950	304	0.528	4.26	0.43
3	Jackal armour	1240	175	0.398	4.43	0.25

4	Aluminium foam	383	160	0.37	2.59	0.32
5	Composite armour plate	3661	854	0.63	2.65	0.36

Tab 7: Kevlar thickness variation

S no	Layer thickness (mm)	Energy loss (Joules)	Velocity reduction(m/s)
1	2	251	29.3
2	4	370	45.1
3	6	585	72.3
4	8	710	88.6
5	10	861	109.2
6	15	945	120.5

Tab 8:Aluminium foam thickness variation

S no	Layer thickness (mm)	Energy loss (Joules)	Velocity reduction(m/s)
1	30	469	306.3
2	28	442	297.1
3	26	418	289.2
4	24	386	278.5
5	22	352	265.2
6	15	258	227.6

III. Results and Discussions

Group 1 Armor:

1. It is observed that that in the sample I and II standard bullet is impinging in all the three layers in both the shots.

Fig 6: Sample 1 and 2 result

2. It is observed that in sample III- In the first shot the bullet frontand back halves lodged betweenDyneema and Spade armor platesrespectively. For second firing of high caliber it is crossing all the three layers.

Fig 7: Sample 3 result

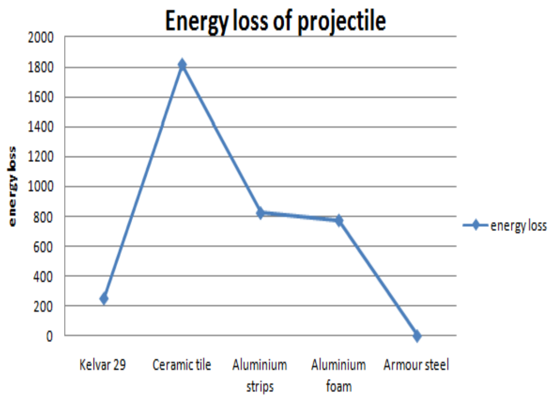
2. Sample V- Sample has failed and not withstood against 7.62x54R B32 API, from a distance of 30 meters.

Fig 8: Sample 5 result

Group 2 Armor

Tab 9: Comparison between Simulation and Theoretical analysis Model 1

S.No	Composite layers	Simulation Results		Theoretical Results		% Variation
		Energy loss at each layer (Joules)	% Energy loss	Energy loss at each layer (Joules)	% Energy loss	
1	Kevlar	251	6.85	274	7.6	4.86
2	Ceramic tile	1811	49.46	1950	50.9	2.86
3	Aluminium strips	824	22.09	835	22.70	2.68
4	Aluminium foam	595	16.25	614	16.77	3.10
5	Steel armour	180	4.91	137	4.74	2.82



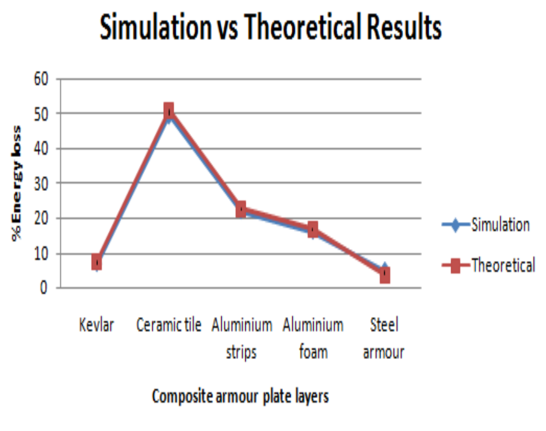
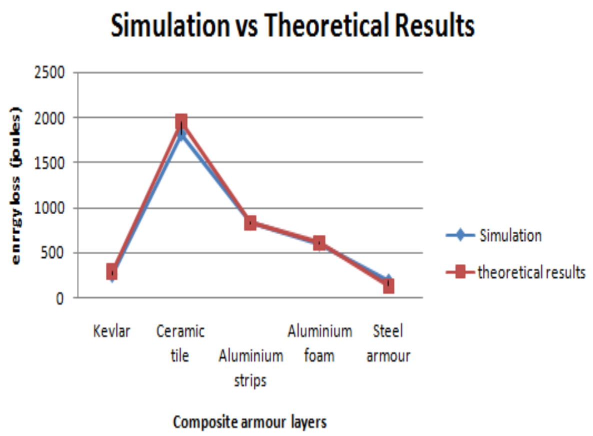


Fig 9: Energy loss of projectile Fig 10: Simulation vs Theoretical modeling-%Energy loss of projectile



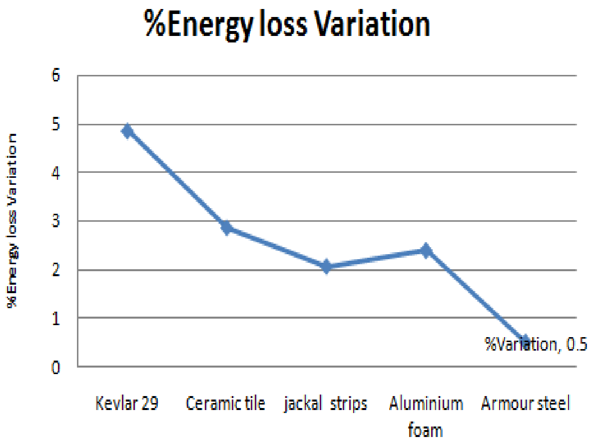
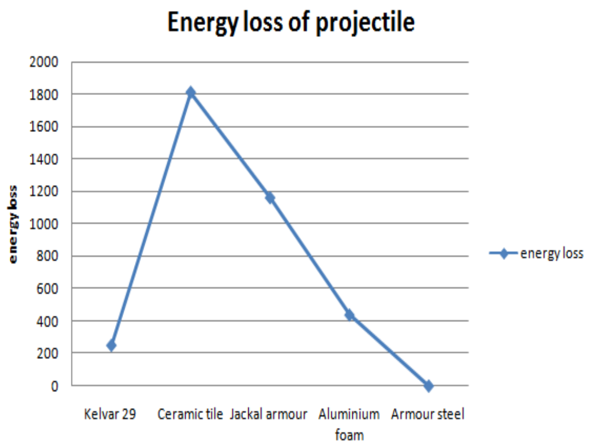


Fig 11: Simulation vs Theoretical modeling- Energy loss of projectile **Fig 12:%Variation Energy loss of projectile**

Tab 10: Comparison between Simulation and Theoretical analysis of model 2

S No	Composite layers	Simulation Results		Theoretical Results		% Variation
		Energy loss at each layer (Joules)	% Energy loss	Energy loss at each layer (Joules)	% Energy loss	
1	Kevlar	251	6.85	274	7.6	4.86
2	Ceramic tile	1811	49.46	1950	50.9	2.86
3	Jackal armour	1161	31.73	1241	32.4	2.06
4	Aluminium foam	438	11.96	345	11.5	2.39
5	Steel armour	0	0	0	0	0



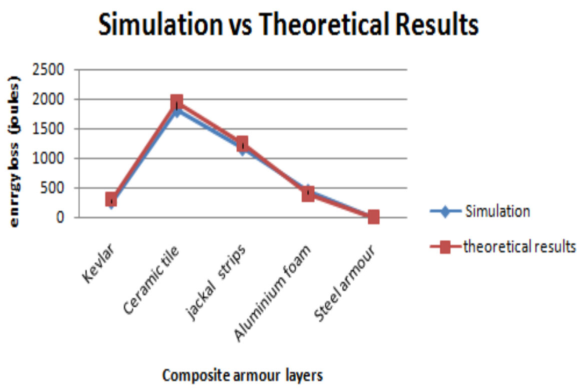
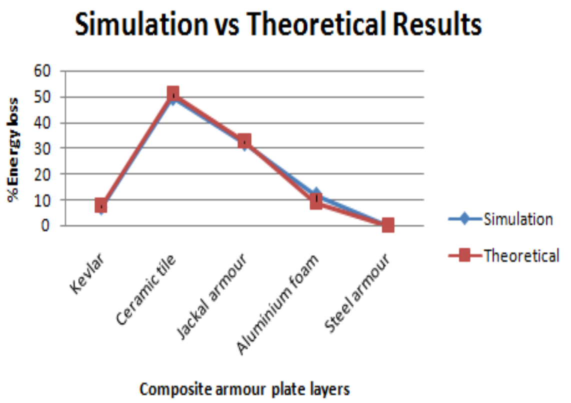


Fig 13: Energy loss of projectile **Fig 14: Simulation vs Theoretical modeling- Energy loss of projectile**



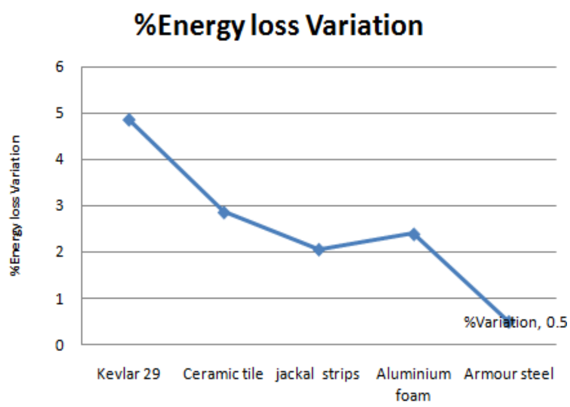


Fig 15: Simulation vs Theoretical modelling- Fig 16:%Variation Energy loss of projectile %Energy loss of projectile

Above diagrams and tables represents schematic of energy loss of projectile and their comparison between mathematical calculations and simulation data. Immediate below diagram compares model 1 and 2 projectile energy loss.

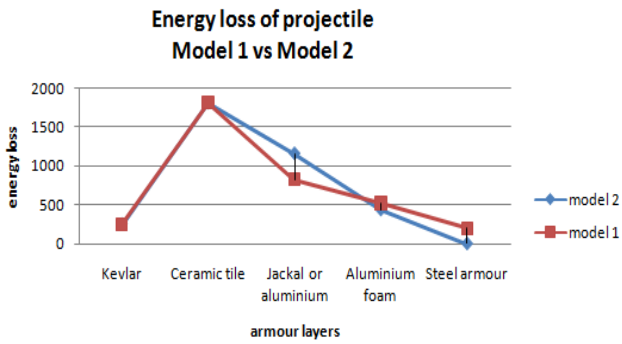
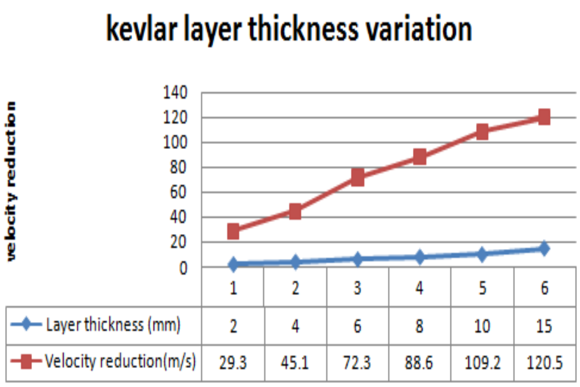


Fig 17: Graph of energy loss in model 1 vs model 2

Tab 11: Kevlar thickness variation

S no	Layer thickness (mm)	Energy loss (Joules)	Velocity reduction(m/s)
1	2	251	29.3
2	4	370	45.1
3	6	585	72.3
4	8	710	88.6
5	10	861	109.2
6	15	945	120.5



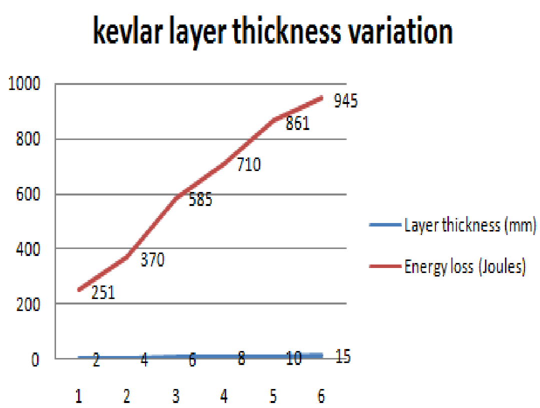
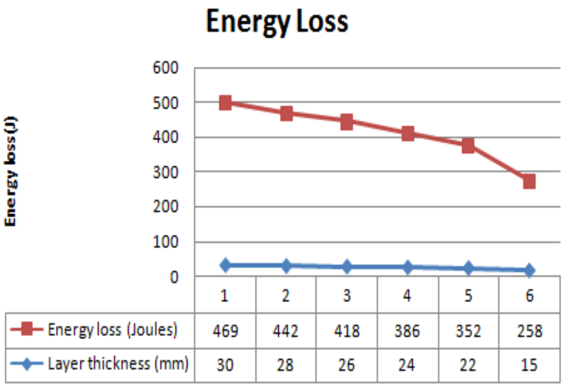


Fig 18: Graph of velocity reduction in projectileFig 19: Graph of Energy loss in projectile

Thickness variation of two layers in armor and due to this variation in energy plots are kept exactly above.

Tab 12: Aluminium foam thickness variation

S no	Layer thickness (mm)	Energy loss (Joules)	Velocity reduction(m/s)
1	30	469	306.3
2	28	442	297.1
3	26	418	289.2
4	24	386	278.5
5	22	352	265.2
6	15	258	227.6



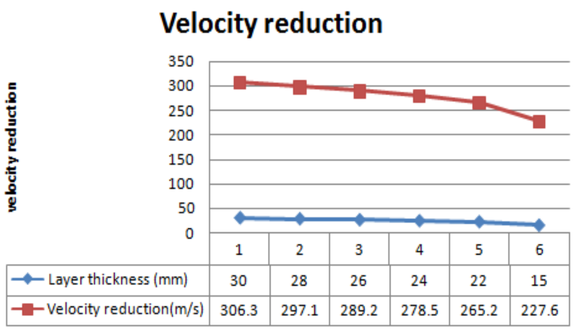


Fig 20: Graph of Energy loss in projectileFig 21: Graph of velocity reduction in projectile

IV. Conclusion

Based on the work presented here, the following main conclusions can be drawn:

1. The results which we are obtaining out of present experimentation are in good concurrence with the journal papers referred.

2. Hardness and toughness properties for steels are selected optimally.

3. Use of higher thickness plates are generally not employed to minimize the cost effects.

4. Very large strain effects could be minimized by the use of stiff backing material in armor.

5. Internal residual stresses during heat treatment of steel plates of armor must be eliminated to reduce the failure effects.

6. Single layer armor doesn't possess all the required mechanical properties to withstand bullet also it is not suitable for multi-hit capability.

7. The % Energy absorbed by each layer as follows:

- Kevlar layer – 7.61 %
- Ceramic tile – 49.12 %
- Jackal armour -31.09 %
- Aluminium foam -12.18 %

8.The velocity of the projectile is reduced to zero and kinetic energy reaches zero in aluminium foam in model 2(composite armour plate with jackal armour), where as some energy was present at steel armour surface in model 1(Composite armour plate with Al strips)

9.The energy loss by the projectile in ceramic layer is maximum is 1961 J (48%) and minimum energy absorbed by Kevlar layer is 251J (7%)

10. The capacity of energy absorption by Kevlar layer is increases when the thickness of the layer is increased. The absorption energy at 2 mm thickness is 251 J and it is 951 J at 15 mm.Energy reduction in Al foam is found when the thickness is reduced to 15mm.

References

[1]. Deniz,Tansel**Ballistic Penetration Of Hardened Steel Plates** Department Of Mechanical Engineering August 2010.

[2]. W.N.M. Jamil, M.A. Aripin, Z.Sajuri, S.Abdullah, M.Z.Omar, M.F.Abdullah and W.F.H **Zamri Mechanical properties and microstructures of steel panels for laminated composites in armoured vehicles** IJAME ISSN:2229-8649, Volume13, issue 3 pp, December 2016.

[3]. ZoranOdanović, BiljanaBobić**Ballistic protection efficiency of composite ceramics/metal armours**Scientific-Technical Review, vol.L III, no.3, 2003, UDC:623.54:539.2:620.198(047)=20COSATI:19-04,13-12,14-02.

[4]. Eugene Medvedovski**Ballistic performance of armour ceramics: Influence of design and structure** Ceramics International 36(2010)2117–2127.

[5]. V.Narayanamurthy*, C.LakshmanaRao, and B.N.Rao**Numerical Simulation of Ballistic Impact on Armour Plate with a Simple Plasticity Model** Defence Science Journal, Vol.64, No.1, January 2014, pp.55-61, DOI:10.14429/dsj.64.4521 2014.

[6]. I.G.Crouch, S.J.Cimpoeru, H.Li, D.Shanmugam**Armour steels** Defence Science and Technology Group, Fishermans Bend, Victoria,Australia.

Muzammil Ahmed Khan, et. al. “Ballistic Analysis of Composite Armor.” *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* 17(5), 2020, pp. 28-38.