Ballistic performance of Bi-layer Alumina/aluminium and Honeycomb sandwich Armours

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Abstract - *This work presents numerical simulations on ballistic response of Aluminium honeycomb sandwich with ceramic(alumina) faced laminates of total 12 mm thick against 7.56mm blunt shape projectile. All numerical simulations are performed for an impact velocity of 712 m/s. Performance evaluation is done based on residual velocity of the projectile. This work is focused to study the effect on residual velocity of projectile for changes in foil thickness of Aluminium honeycomb, thickness of honeycomb. Process is simulated by using a finite element code HyperWorks-Radioss. To ensure the set-up procedure a bilayer Alumina/aluminium armour is taken from reference and is validated with an error percentage of 2.5 which is allowed. Results from the simulation showed that decrease in thickness of honeycomb foil caused decrease in residual velocity and also increasing thickness of honeycomb with total thickness as constant, reduces ballistic performance.*

Key Words: **Ballistic response, Honeycomb Sandwich, Armour, Hyperworks, Radioss.**

1.INTRODUCTION

At present light weight armours are made of composite materials but these stand alone cannot withstand to high velocity impacts. So ceramic faced armours backed by low density metal or composite laminates are being used for armour design. Tools based on finite element approaches are widely spread and as well as they are appropriate and cost effective, numerical simulations are being used to represent the behaviour in impact problems also. Hyperworks-Radioss solver is used for the current simulation. A Bilayer Al_2O_3/Al armour from J. Venkatesan et al. [1] work is considered for validation and current solver could approximate the results with an error percentage of 2.5. An aluminium honeycomb sandwich with alumina face plates is considered for armour application and simulated against the same projectile configuration as in the validation case.

1.1 Literature Review

Godrej [3] present the NIJ level III steel plate behaviour against the dynamic loading of 7.62 x 39mm steel core AK47 ammunition using Radioss explicit non-linear analysis and it was found that the steel plate behaviour in Radioss explicit non-linear analysis is very much similar with actual test results.

J. Venkatesan et al. [1] simulated the ballistic performance of two bilayer SiC/Al and Al_2O_3/Al armours against blunt and ogive nose projectiles and concluded that the ballistic performance of SiC/Al armour is superior than that of Al_2O_3/Al armour irrespective of the projectile nose shape.

There are so many researches regarding bi-layer armours and optimum thickness of front layer etc., But there are very few researches considering honeycomb sandwich structures for impact applications. Recep Gunes et al. [2] investigates damage mechanism and deformation of honeycomb sandwich structures reinforced by functionally graded plates under ballistic impact effect by means of explicit dynamic analysis using ANSYS LS-DYNA. Materials data used in the current simulation is referenced from J. Venkatesan et al. [1] work. Failure criteria for ceramics (Al_2O_3) is taken from report [4].

An attempt has been made in this work to compare the performance among bi-layer armour and honeycomb sandwich structures based on residual velocity of the projectile for a total armour thickness of 12mm.

1.2 Objectives of Current Work

To ensure the setup procedure in Radioss, primary objective is considered to be the validation of Bi-layer Al_2O_3/Al armour performance with the reference value from J. Venkatesan et al. [1] work. Second objective is to Setup the problem of interest, Al honeycomb with ceramic (Al_2O_3) face plates as a sandwich panel of 12mm thick and simulate the ballistic performance against the same projectile configuration. Third objective is to check how the honeycomb foil thickness, thickness of honeycomb affects residual velocity of projectile.

2. FINITE ELEMENT MODELING

For all the numerical analysis, Lagrangian approach is used to simulate the projectile impact on armour plates to assess their energy absorption through Hyperworks-Radioss software. The details of geometry, meshing, boundary conditions and material models are mentioned below.

2.1 Modeling of Bi-layer Al_2O_3/Al armour

Numerical simulation with the yaw angle of -9.9 degree about y axis and +1.1 about x axis of blunt nose steel projectile impacting Al_2O_3/Al is shown in figure 1 for the purpose of validation

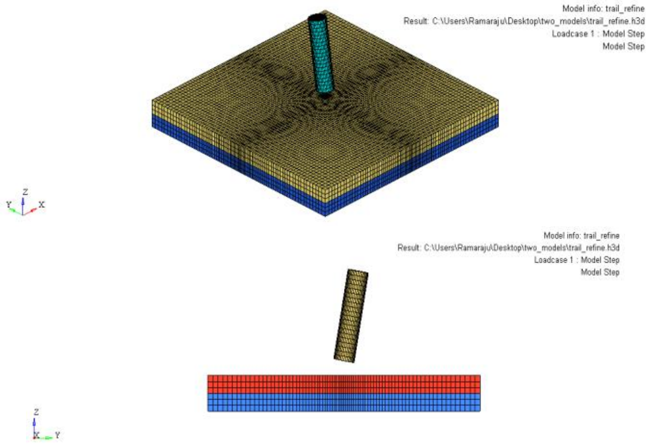


Fig-1: Modelling of bilayer armour against 7.56mm blunt shape projectile

Geometric description [1]

Dimensions of plates: 100mm x 100mm
Front plate (Al_2O_3) thickness: 6.1mm
Back plate (Al) thickness: 5.87 mm
Projectile (steel) diameter: 7.56 mm
Projectile length: 30.54 mm

Meshing

A Three dimensional 8 noded hex element is used for meshing both the plates and projectile. Two-way biasing is used to have a dense mesh at central portion of the plates where the impact is going to happen. Solid element formulation used in this work is I_{solid} =24; HEPH 8-node solid element, Co-rotational, under-integrated (1 Gauss point) with physical stabilization

2.2 Modeling of Honeycomb Sandwich Structure

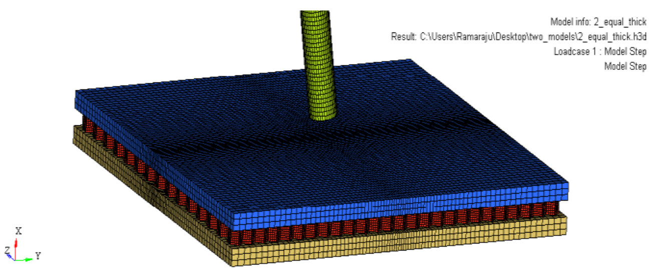


Fig-2: Modeling of Honeycomb Sandwich Structure

Dimensions of plates are 100mm x 100mm. Honeycomb thickness is 4mm and it is varied further, considered as different cases. Different cases are considered for honeycomb foil thickness like 0.04mm, 0.1mm and 0.5mm. Plates and projectile are idealized with solid elements and metal honeycomb is meshed with 2D shell elements as shown in figure 2. Unit system used in the simulation consists length in mm, force N, pressure Mpa, density g/mm^{3,} time in ms.

Table-1: Material properties of ceramics (Al_2O_3 95%) [1]

Material law	Johnson Holmquist-2
Density	0.003741
Shear modulus, G	120340
Intact strength constant, a	0.589
Fracture strength constant, b	0.29
Fracture strength exponent, m	0.53
Intact strength exponent, n	0.764
Strain rate constant, c	0.0045
Reference strain rate, Epsilon_0	0.001
Normalized Max. fracture strength, Sigma_f_{max}	1
Hydro tensile limit, T	300
HEL	6000
P_HEL	1460
Damage constant, D1	0.005
Damage exponent, D2	1
Bulk modulus, K1	184560
Pressure constant, K2	185870
Pressure constant, K3	157540
Beta	1

Table-2: Material properties of aluminium (Al 2024-T3) [1]

Material law	Plas_Johns_zeril
Density	0.002785
Young's modulus, E	71607.2
Poison ratio, nu	0.33
Static yield strength, a	167
Strain hardening constant, b	596
Strain hardening exponent, n	0.551
EPS_max	0.75
Strain rate constant, c	0.001
Reference strain rate	0.001

Table-3: Material properties of steel (steel 4340) [1]

Material law	Plas_Johns_zeril
Density	0.0079
Young's modulus, E	200200
Poison ratio, nu	0.3
Static yield strength, a	950
Strain hardening constant, b	725
Strain hardening exponent, n	0.375
Strain rate constant, c	0.015
Reference strain rate	0.001

Failure criteria for ceramics [4]

Criteria	Tensile strain
Eps_t1	0.5
Eps_t2	0.6

Failure criteria for steel [1]

criteria	Johnson cook
D1	-0.8
D2	2.1
D3	-0.5
D4	0.002
D5	0.61

Type 7 interface is defined between projectile and plates. Projectile is considered for slave nodes, ceramic plates and metal honeycomb are considered for master segments.
Type 2, tied interface is used to connect the 2D shell elements to 3D elements top and bottom of the honeycomb. All degrees of freedom constrained at plate edges and translational degree of freedom in one direction is allowed for projectile movement and velocity of projectile 712 m/s is given as initial velocity for all the simulations.

3. RESULTS AND DISCUSSION

Case 1: Validation of ballistic performance of bilayer Al_2O_3/Al armour against 7.56mm blunt shape projectile with certain angle of inclination

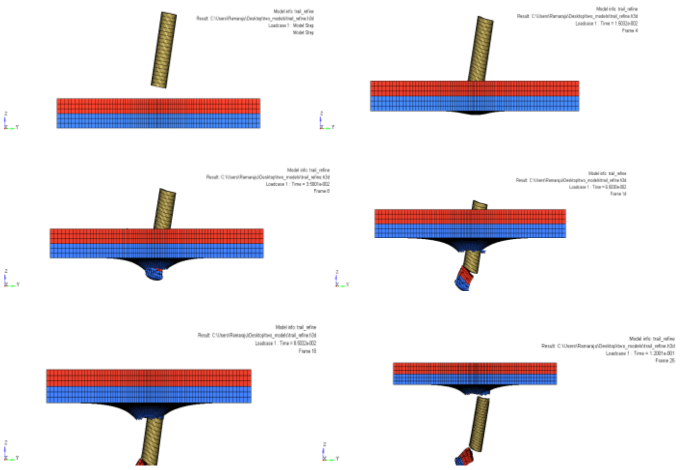
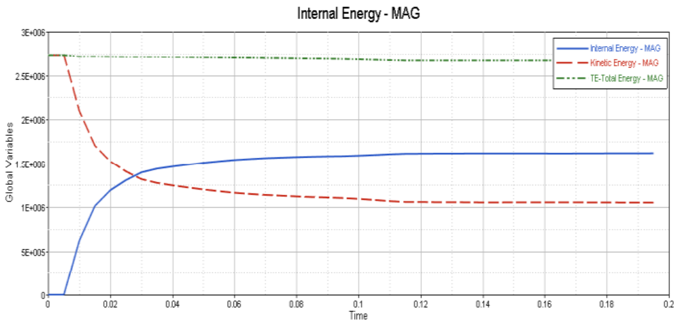


Fig-3: Simulation of bullet penetration into bilayer armour plates



Graph-1: Kinetic Energy, Internal Energy and Total Energy for case1

Initial velocity of projectile is 712 m/s and residual velocity of projectile obtained from kinetic energy in graph 1 is 441 m/s. Experimental value from the reference is 430 m/s. This set up could approximate the impact behaviour, particularly residual velocity with an error percentage of 2.5

Case 2: ballistic performance of honeycomb sandwich panel of total 12mm thick against same projectile configuration. Thickness of the honeycomb is 4mm and thickness of two plates is 4mm each. Al honeycomb foil thickness is 0.5mm

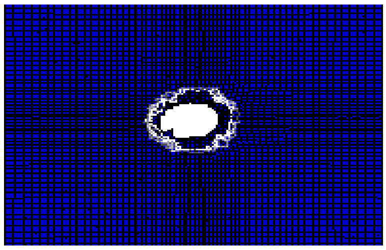
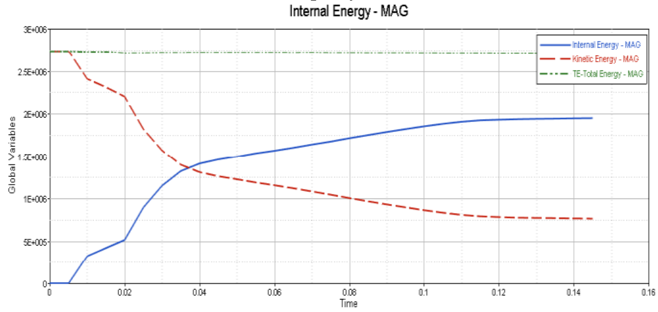


Fig-4: Failure mode of sandwich target against 7.56mm blunt projectile



Graph-2: Kinetic Energy, Internal Energy, Total Energy for case 2

Residual velocity of projectile in this case is approximately 377 m/s calculated from the graph 2, which is less compared to the previous case of bilayer armour.

Case 3: Effect of honeycomb foil thickness on ballistic performance of honeycomb sandwich armour against the same blunt shape projectile. (Honeycomb thickness is 4mm, thickness of each ceramic plate is also 4mm)

Table-4: Effect of honeycomb foil thickness

S. No	Foil thickness (in mm)	Residual velocity (approximately in m/s)
1	0.04	356
2	0.1	366
3	0.5	377

From table 4, reduction of foil thickness results in slight decrease in residual velocity of projectile indicates energy absorption by Al honeycomb

Case 4: Effect of honeycomb thickness on ballistic performance for a foil thickness of 0.04mm and of total thickness 12mm.

Table-5: Effect of honeycomb thickness

S. No	Honeycomb thickness (in mm)	Thickness of each ceramic plate (in mm)	Residual velocity (approximately in m/s)
1	4	4	356
2	6	3	576
3	8	2	595

From table 5, Increase in honeycomb thickness causes considerable variation in residual velocity and reduces the ballistic performance of sandwich structure.

Table-6: Performance comparison for different cases

Case No.	Weight of target or armour (in grams)	Residual velocity of projectile (in m/s)
Case 1	391	441
Case 3.1	449	356
Case 3.2	452	366
Case 3.3	474	377
Case 4.2	338	576
Case 4.3	227	595

Performance comparison is based on residual velocity of the blunt shape projectile coming with an impact velocity 712 m/s and certain inclination angle. From the table 6 it is clear that case 3.1 shows better performance with slight increase in target or armour weight. It indicates honeycomb sandwich is capable to absorb the projectile kinetic energy compared to the bilayer armour target.

4. CONCLUSION

RADIOSS solver can be used to simulate the ballistic response. Reducing the foil thickness of honeycomb results in decrease of residual velocity of projectile after impact, indicates absorbing characteristics of honeycomb between the ceramic plates. Increasing the thickness of honeycomb results in slight increment in residual velocity which is not recommended. After comparing the residual velocities for different cases, case 3.1 shows better characteristics with slight increase in weight that is, honeycomb sandwich target with each plate 4mm thick and foil thickness of 0.04mm. This indicates honeycomb sandwich target is capable to absorb the kinetic energy of projectile compared to the bilayer armour.

Scope of future work

This work is done by using tied interface to connect shell elements of honeycomb and sold elements of ceramic plate. Further it is recommended to find the different modelling possibilities and to study their effects on ballistic performance.

5. REFERENCES

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