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SIMULATION ON THE SHOCK ATTENUATION BEHAVIOR OF COUPLED RHA AND SANDWICH COMPOSITE PANEL UNDER BLAST LOADING

M. F. M. Isa*, M. S. Risby, M. N. Norazman, S. Khalis, M. N. Hafizi and S. Arif

Protection and Survivability Research Unit (PROTECT), Faculty of Engineering, UniversitiPertahananNasional Malaysia, Sungai Besi Camp, 57000 Kuala Lumpur, Malaysia

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ABSTRACT

This paper presents the shock attenuation behavior of engineering materials namely Rolled Homogenous Armor (RHA) and sandwich composite when subject to blast loadings. Blast loading on sandwich composite structure and monolithic material are investigated using LSDYNA 3D with Arbitrary LagrangianEulerian (ALE) method. Dynamic response in terms of shock was analyzed in order to understand the shock attenuation of monolithic structure and sandwich structures. Based from the results, coupled RHA and sandwich composite structure configuration exhibit highest attenuation capability of 61.3% respectively. The study can be used as reference tool for the application related to automotive, naval and aeronautical structures, oil and gas industry.

Keywords: shock attenuation; composite; survivability; honeycomb.

Author Correspondence, e-mail: gfahmee123@gmail.com

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1. INTRODUCTION

Improvised explosive device (IED) and anti-vehicular landmine attack can lead to failure on military vehicles structure or injury to vehicle crew as the explosive detonated under a vehicle,

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a shock wave consists of energy burst is produced.

The shock wave travels in high speed, passing through vehicle floor in microseconds and lead deflection and acceleration on the flooring. This eventually results in high loads and shock to the lower extremities injury criteria of the occupants. Although, armored vehicle possesses its own armored plates or made from toughened steel alloy for ballistic and blast protection landmine attacks can also capsized or produce rollover effect to the vehicle [1]. Therefore, this paper presents the shock attenuation capability of secondary armor using sandwich composites on vehicular floor subjected to the blast loadings.

Sandwich composites structure has been recognized as one of the feasible solution for structural design [2-6]. It is typically made of thin facings called as facesheet sandwiched together with core materials such as honeycomb. The face sheet material properties are consisting of high-strength material, for example steel and composites; the core is made of thick and lightweight materials such as cardboard, plywood, foam and etc. The purpose of sandwich core is when bending moment act on panel or beam, the maximum stress act at the bottom and top surfaces. Thus, a high tensile strength material is placed at the top and bottom while a high compressive strength material placed in the middle of the structures. Honeycomb core for blast protection have been studied by many researchers, where honeycomb sandwich structures provides a remarkable strength and energy absorbing over the monolithic structures of equal mass for blast protection [7-11]. The honeycomb core prevents crushing effect more effective at lower impulse condition.

Sandwich structures have reportly shown good performance compared the monolithic structures of equal mass when subjected to blast [12]. However, most of the studies do not report much on the shock transmitted between sandwich composite and monolithic structures. This study focuses on the comparison of shock responses of vehicular floor with additional of sandwich composites (aluminium honeycomb core and carbon fiber facesheet) compare with a stand-alone Rolled Homogeneous Armor (RHA) steel plate when subjected to blast loadings.

2. NUMERICAL SIMULATION

The numerical simulation was conducted using finite element analysis software LSDYNA3D. The software is able to predict the dynamic structure response using various blast method available in its solver such as absolutely Lagrange, absolutely Eulerian and coupled Lagrange-Eulerian methods. The absolutely Lagrangian approach with simplified engineering blast model is commonly used because it reduces the computational time. Multi-material Eulerian formulation is used as part of the Arbitrary LagrangianEulerian (ALE) solver whereby combining the ALE solver with an EulerianLagrangiancoupling algorithm, a structural or Lagrangian mesh can interact with the ambient element or Eulerian mesh. In [13] found that by using this method simplified blast model produce uncertain impulse duration due to the target was close to the blast proximity.

2.1. Material Models for Air and Explosive

Detonation of explosive create a shock wave in the surrounding fluid and its interaction with lag range structural is a complex phenomenon. In this case, the fluid medium is applied a very short but intense pressure field which depends on its chemical composition, explosive geometry and fluid properties such as wave speed and density. The formulation of Arbitrary Lagrange Formulation (ALE) is suited for this case which involving several types of interaction consists of three different types represents explosives, air and examined structure. The TNT explosive charge is modeled via Jones_Wilkins_Lee (JWL) semi-empirical equation of state (*EOS_JWL) can be expressed in the form Equation (1) [14],

$$p = A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega}{V}E \tag{1}$$

where$p$ is the pressure, V is the relative volume and B, A, R_1 and R_2 are constants and the material card *MAT_HIGH_EXPLOSIVE_BURN is used as shown in Table 1.

Table 1. JWL and material parameters for trinitrotoluene, TNT [14]

EOS_JWL					
A	**B**	**R_1**	**R_2**	ω	**E**
3.710 E+11	3.231 E+9	4.15	0.95	0.3	4.294 E+6
MAT_HIGH_EXPLOSIVE_BURN					
RO(kg/m^3)		**D(m/s)**		**PCJ(GPa)**	
1630		6930		21	

The air acting as medium transfer by blast wave propagation is model using eight-node brick elements *MAT_NULL material model card. The equation of state of air model via *EOS_LINEAR_POLYNOMIAL for the linear internal energy [14]. The gamma law EOS is used for pressure of perfect gas as in Equation (2).

$$p = (\gamma - 1)\frac{\rho}{\rho_0}E_0 \tag{2}$$

2.2. Material Models for RHA and Sandwich Honeycomb Composites

There are several material coefficients for Rolled Homogenous Armor (RHA) steel that was based on the Johnson-Cook material model, commonly used due to its simplicity [15-16]. The Johnson-Cook model can show important material responses in impact and penetration based on strain hardening, strain effects and thermal softening. Table 2 show the Johnson-Cook model constant for RHA steel where A, B, C, *n* and M are the constant.

Table 2. Johnson-Cook model constant for RHA steel [13]

Material	A (MPa)	B (MPa)	C	n	M
RHA steel	1000	500	0.014	0.26	1

A finite element model of RHA steel panel couple with sandwich composite panel in Fig. 1 was developed using 1250 solid eight node brick element for the RHA steel, while sandwich composite panel was modeled using combination of 1250 shell element for the facesheet and 1875 solid elements as for the honeycomb core. The interfaces between RHA, facesheet and honeycomb core on sandwich panel are consider as perfectly bonded. As for the sandwich composite, the structure was modeled using pre-processor software namely LS-PrePost4.3 by using combination of two different material model consists of MAT_Composite_Damage that represent the facesheet and MAT_Honeycomb for the honeycomb as shown in Table 3.

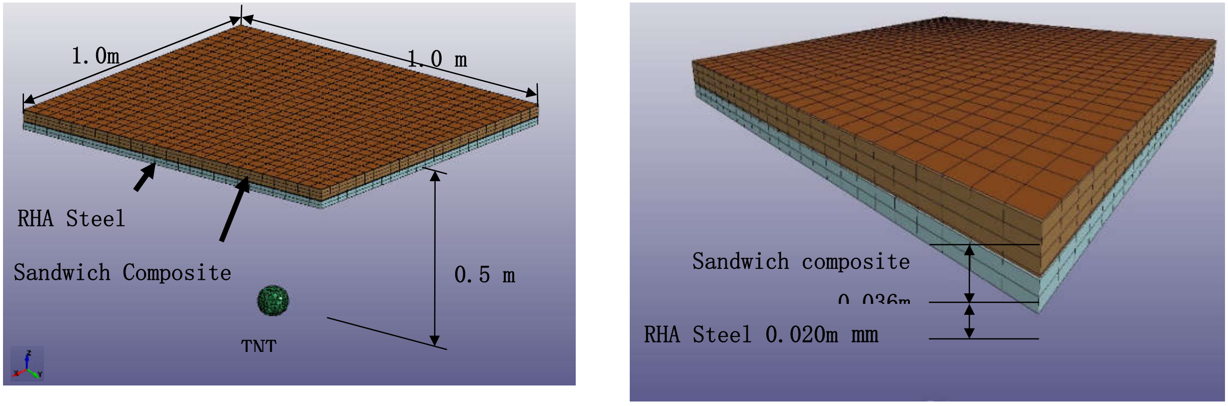


Fig.1. Defense structure model

The facesheet is modeled as 3D orthogonal weave fabric composite with total of 1250 elements. A perfect circular clamped boundary condition is set at the top and bottom of facesheet on the outside circle diameter of 1 meter from the center. The core material is modeled based on aluminium foam with mass density 730 kg/m^3, young modulus 6.9E+10Pa and Poisson ratio 0.28. LS Dyna version R8.0.0 solver is used for all computational simulation for a total duration with 15 millisecond. In order to verify the model, three different level of scaled distance is conduct as to verify the model by compare with experimental and numerical data collected by [18]. Next, a proposed model which is couple RHA steel and sandwich composite based on parameter [17] are simulate as to prediction the shock attenuation behaviour of the couple structure.

Table 3. Mechanical properties of sandwich composite [17]

***MAT_Composite_Damage**											
RO	**E_A**	**E_B**	**E_C**	**PR_{BA}**	**PR_{CA}**	**PR_{CB}**	**G_{AB}**	**G_{BC}**	**G_{CA}**		
1850	2.75E+10	2.75E+10	1.18E+10	0.11	0.18	0.18	2.9E+10	2.14E+9	2.14E+9		
***MAT_Honeycomb**											
RO	**E**	**PR**	**SIGY**	**VF**	**MU**	**E_{AAU}**	**E_{BBU}**	**E_{CCU}**	**G_{ABU}**	**G_{BCU}**	**G_{CAU}**
710	6.9E10	0.28	2.68E8	2.63E-7	0.05	2E+8	2E+8	2E+8	8E+7	8E+7	8

3. RESULTS AND DISCUSSION

For the numerical simulation, a RHA model is developed with 8 nodes brick element solid mesh size and verified using [13] experimental data. The results are shown in Table 4 and it can be observed that the percentage difference of numerical approximation conducted and collected data by [18] is below than 13% and 32% for the experiments and numerical respectively as shown in Table 4.

Table 4. Verification of monolithic structure (RHA steel) model based on [13, 18] (Exp=Experiment, Num=Numerical, Comp=Computed, Diff=Diferrent).

Z **(m/kg$^{1/3}$)**	**Charge Weight, TNT (kg)**	**Standoff Distance (mm)**	**Displacement, x (mm)**				
			Exp, A	**Num, B**	**Comp Result LS DYNA, C**	**% Diff A and C**	**% Diff A and B**
0.13	3.75	200	54.0	52.4	52.0	3.7	0.76
0.10	8.75	200	107.0	104.8	93.2	12.9	11.06
0.06	8.75	130	165.0	123.0	179.9	8.2	31.6

Fig. 2 shows the midpoint deflection of RHA subjected to three different scaled distance which is 0.06, 0.1 and 0.13. All three level of blast show a good agreement in compare with experimental data collect by [18] as the trend almost the same but resulting a different amplitude.

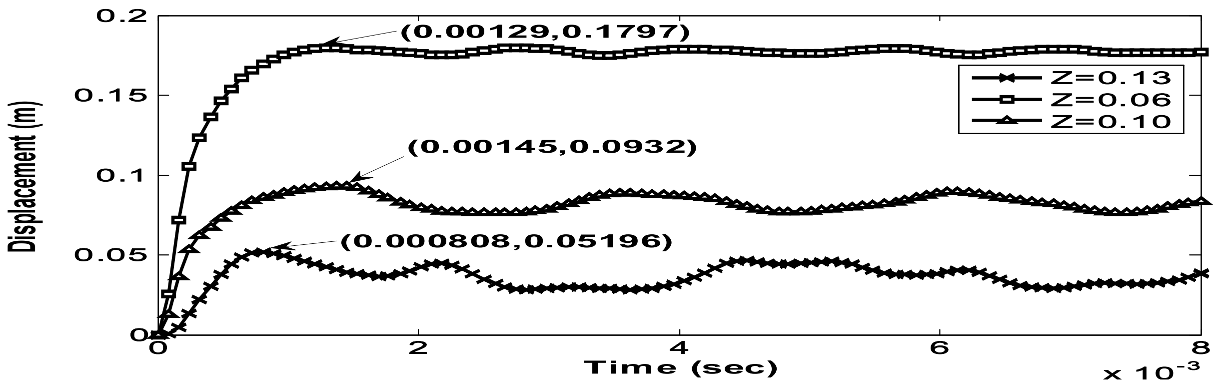


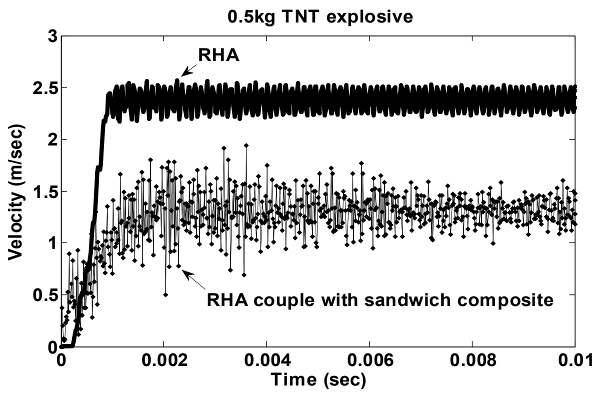
Fig.1. Midpoint deflection against time at different scales distance

Table 5 presents the shock acting on the leg of the crew based on the [18] setup. As lower the scaled distance, Z the shock increased and resulting a large force acting on the crew leg.

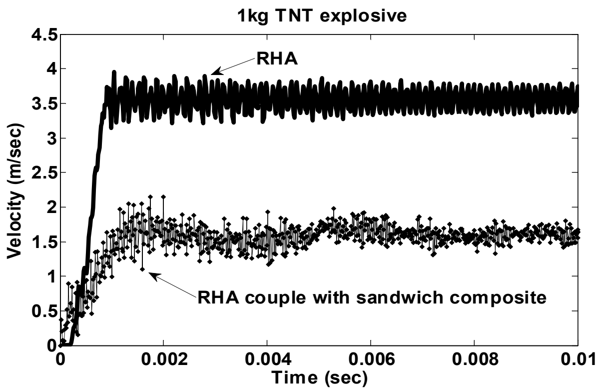
Table 5. Shock acting on the leg of the crew

Z (m/kg$^{1/3}$)	**TNT (kg)**	**Standoff Distance (mm)**	**Numerical LS DYNA**	
			Acceleration (m/s)	**Shock (g)**
0.13	3.75	200	7.1721 x10^5	73 110
0.10	8.75	200	1.8693 x10^6	190 550
0.06	8.75	130	3.8252 x10^6	389 929

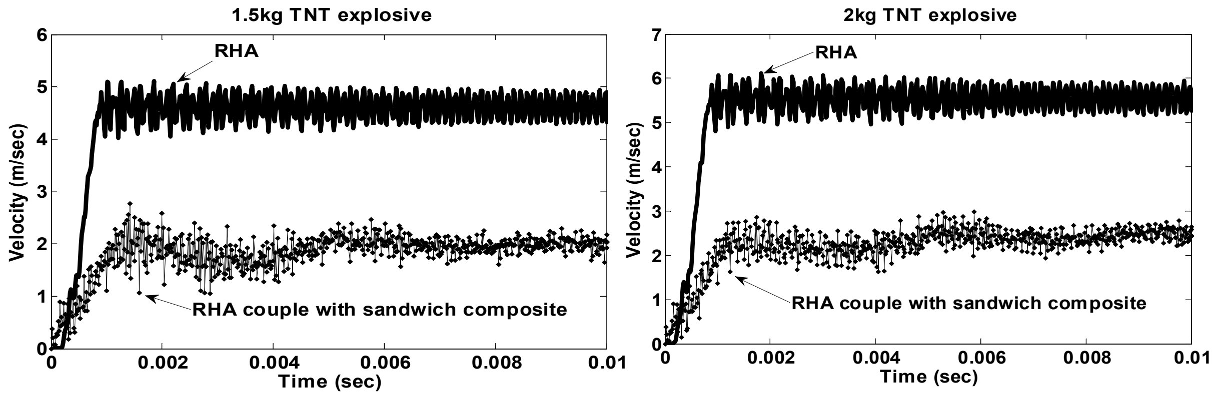
As for the composite, the geometry of sandwich composite is modelled using shell element for the facesheet and solid element for the core material. The constraint used in this model is the contact to cylinder solid with weight is 70 kg represent an occupant standing on the structure. The coupled RHA and sandwich structure was subjected to blast loading simulation using 0.5kg, 1kg, 1.5kg and 2kg at 0.5m standoff distance. The resultant velocity at maximum center displacement of cylinder solid are plotted in Fig. 3. All velocity curves in Fig. 3(a), (b), (c) and (d) show a good agreement where the shock velocity transmitted to the cylinder solid can be reduce when adding sandwich composite as secondary armour on the vehicular floor.



(a)



(b)



(c) (d)

Fig.2. Mid-point velocity on the panel against time with standoff distance 0.5m. (a)0.5kg TNT, (b)1kg TNT (c) 1.5kg TNT (d) 2kg of TNT

Since the changes of magnitude of the velocity at cylinder solid with addition of sandwich composite are lower than the RHA stand alone, the shock attenuation will be increase as the blast wave passing through the medium. Table 6 shows the shock attenuation of 0.5, 1.0, 1.5 and 2 kg of TNT explosives with standoff distance 0.5 m. By coupling the sandwich composite to the RHA steel, the compute results showed that it significantly increases the shock attenuation capability of the structure. This may be due that honeycomb core possesses void or air gap in its core and retard the shock wave propagation in the coupled structure.

Table 6. Shock attenuation of blast wave with 0.5-meter standoff

TNT (kg)	Acceleration (m/sec) RHA Alone	Acceleration (m/sec) Sandwich Composite (RHA)	Shock (g) RHA Alone (Datum)	Shock (g) Sandwich Composite (RHA)	% Reduction
0.5	2288.5	1187.5	233	121	48.1
1.0	3852.8	1491.1	393	152	61.3
1.5	4824.3	1626.0	492	166	66.3
2.0	5417.5	2147.8	552	219	60.3

4. CONCLUSION

Blast loading on monolithic materials alone (RHA steel) and with additional sandwich composite as secondary armor was analyzed on its shock attenuation, blast resistance acceleration and dynamic displacement. The shock attenuation by sandwich composite structures was found to be higher than the stand-alone monolithic material (RHA). The coupled RHA and sandwich structure concept showed good potential in improving shock.

5. ACKNOWLEDGEMENTS

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