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EXPLOSIVE REACTIVE ARMOR ENCLOSURE SIMULATION

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ABSTRACT

Heavily armored vehicles contain a thick base armor, yet it is insufficient for protection against shaped charges of high explosive anti-tank warheads. Add on armors such as non-explosive reactive armors (NERA) and explosive reactive armors (ERA) have been developed to increase protection levels of armored vehicles. ERA elements are composed of plates and explosive materials. ERA requires a rugged enclosure that reduces the collateral damage during a ballistic event by controlling the effects of the ensuing blast. An attempt is made to simulate the enclosure tests and capture sandwich plate's behaviors subjected to detonating energetic explosives by using LS-DYNA nonlinear explicit solver, widely used in simulating detonation, impact, ballistics, and other structural problems. Successful simulation of ERA enclosures will allow an evaluation of the influences of some of the parameters, such as thickness of plate and attack angle, and different materials to improve design solutions. Numerical simulation will help in identifying the parameters necessary to achieve the best enclosure design.

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1. INTRODUCTION

Today's armored military vehicles are exposed to a wide variety of threats on missions, most commonly mine blasts, improvised explosive devices (IED), and guided and unguided missiles such as shoulder fired missiles to rocket propelled grenades (RPG). Detonation and penetration of these products will cause the vehicle structure to undergo damage ranging from minimal to catastrophic, depending on the size of the threat and impact location. Soldiers inside these vehicles are subjected to very high impulsive loading during mine blast or secondary impact due to fragment penetration[1,2,3] Passive armors mounted to the vehicle hull are sufficient to stop many kinetic energy threats. Defeat of some chemical energy (CE) threats and large caliber munitions require heavy armors, nonexplosive reactive armors (NERA) and explosive reactive armors (ERA). ERA [4, 5] can save armor weight by being efficient against threats, but it comes with significant challenges integrating to existing vehicle hulls such as added weight which can decrease the vehicle's speed and maneuverability.

Reactive armor internal materials need to be contained in a safe enclosure to protect the armor elements and limit collateral damage. The enclosure is mounted as an appliqué to the vehicle hull, thereby increasing protection levels. A well designed enclosure will prevent excessive damage from occurring in adjacent tiles, after a ballistic event. Traditional ERA [6, 7] enclosures are fabricated from welded steel or aluminum. Therefore, the enclosure must be the proper material and thickness to prevent this from occurring.

The Ground Vehicle System Center (GVSC) of the U.S Army's Combat Capability Development Command (DEVCOM) has performed extensive design and testing efforts on reducing the weight of the explosive reactive armor enclosures. In this study, an attempt is made to numerically simulate the enclosure designs using finite elements methods and compare the numerical results to the experimental tests. The goal of the study is to successfully develop a numerical method to simulate the enclosure tests, and analyze different materials for enclosures and add value to the design and development of ERA.

2. SIMULATION METHOD DEVELOPMENT

GVSC Survivability designed and evaluated many different enclosure designs [8] with the intent of weight reduction. Four of the designs showed significant promise. Evaluation of the enclosures involved the detonation of explosives inside the center box of a 3 box array. This was both a cost effective and unclassified manner of evaluation, simulating a ballistic engagement. Figure 1 shows the enclosure box test set up.

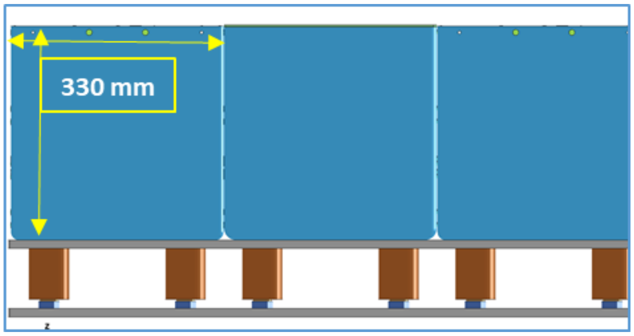

Figure 1: Enclosure test set up

Interior dimensions of the box is 330 mm x 330 mm x 330 mm four different materials and their thicknesses are shown in the Table 1

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Table 1: Material Choices

Material	**Thickness**
Steel (304 Stainless)	0.0625” (1.5875 mm)
Titanium (Ti6Al4v)	0.125” (3.175 mm)
Aluminum (6061-T6)	0.125” (3.175 mm)
Fiberglass (S2 + Epoxy)	0.165”(4.191 mm)

Location and placement of the spherical explosive is show in figure 2. C4 a common variety of the plastic explosive family known as Composition C, mainly consists of cyclotrimethylene trinitramine (RDX) is the high explosive used in the test and in the simulations. It is placed in the center of the box volume. The two adjacent boxes are placeholders for ERA tiles.

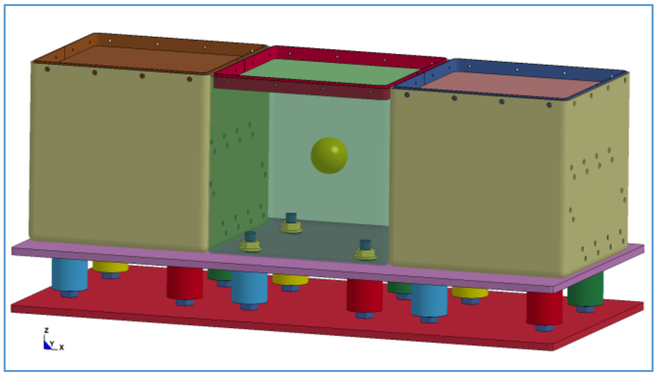

Figure 2: Location of explosive

One of the challenges in these simulations is getting the right material properties for the tested assets. Most of the materials analyzed are derived from publicly available reports and documents. [9] Most of the strength and damage properties are very close to the test specimens. Variations in material properties between the test and simulation is normal given the lack of coupon tests for each tested specimens. Since minimal data is available from the test, it will be challenging to do any stochastic analysis to study the variations. Posttest pictures are the only data available.

As the charge is contained inside the enclosure box and is small, three different methods can be used to simulate this test, Arbitrary Lagrange in Euler (ALE), smooth Particle Hydrodynamics (SPH) or Particle Blast Methods (PBM). LS_DYNA [10] user's manual has detailed description of all these three methods and how to use them. ALE and PBM methods are used to simulate this test and both provided similar responses. Results from ALE method is shown in this report.

The initial set of analyses were performed by using theoretical values of explosives such as Chapman Jouguet (CJ) pressure and detonation velocity (V). Adjacent enclosure boxes were severely damaged by using the theoretical values, which was not observed in the test. Since the C4 used in these tests was hand packed, the detonation velocity was lower than the theoretical value of 8193 m/s [11]. A detonation velocity of 7600 m/s, which is 7 percent below the theoretical value, seems to capture the enclosure deformation very well. This value was also confirmed by the test group. Table 1 summarizes the values used

Table 2: Explosive properties

	Density (kg/m$^{3)}$	C-J Pressure (Pa)	Detonation Vel (m/s)	Energy/volume (J/m^3)
Theoretical	1600	2.60E10	8193	9.10E10
As tested	1600	2.60E10	7600	9.10E10

3. RESULTS AND DISCUSSION

Figure 3 and 4 shows the test and simulation results for Al 6061-T6 enclosure boxes. Simulation captures both the deformation and rupture of the center boxes very well. Rupture starts to initiate at the corners of the center box starting at 0.0013 seconds after initiation and completes at 0.013 seconds.

3.1 Al 6061 –T6 Enclosure

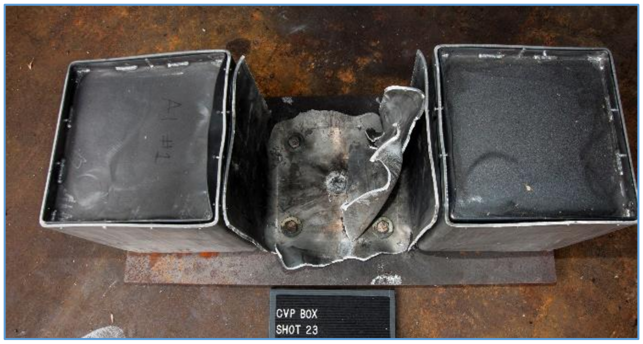

Figure 3: Posttest – Al 6061-T6

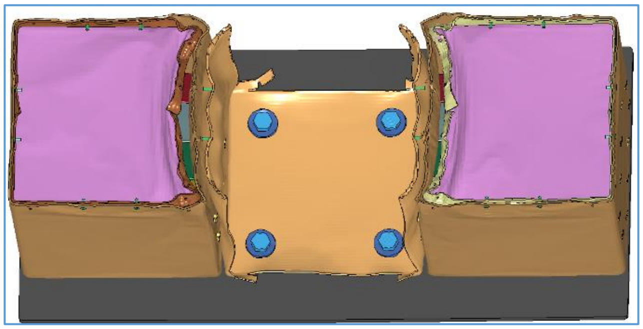

Figure 4: Post simulation – Al6061-T6

Figures 5 to 8 shows the deformation process of the Al 6061-T6 box at different time stamps. Center box starts to rupture initiates from the corners at 0.002 seconds onwards and completely opens up at 0.005 seconds

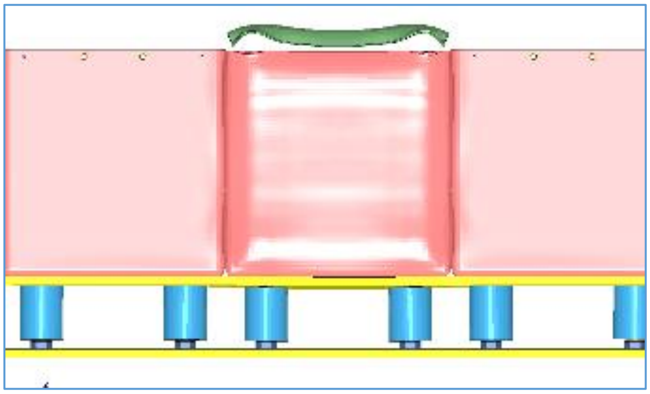

Figure5: At 0.001Second

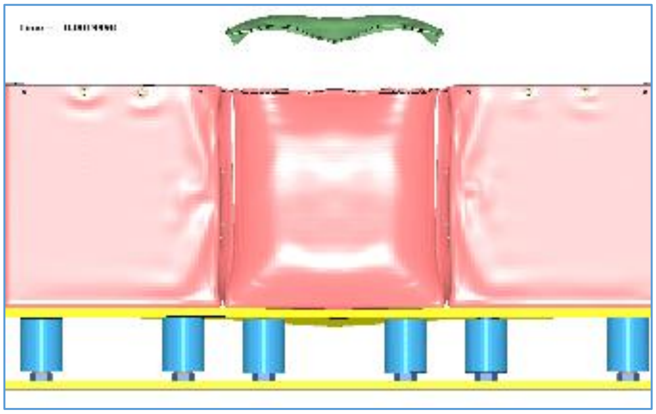

Figure 6: At 0.002 seconds

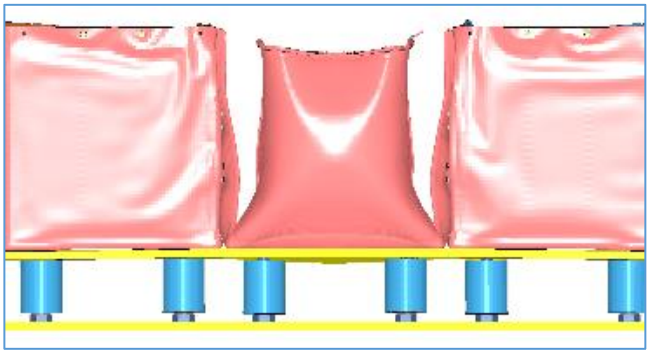

Figure 7: At 0.005 Seconds

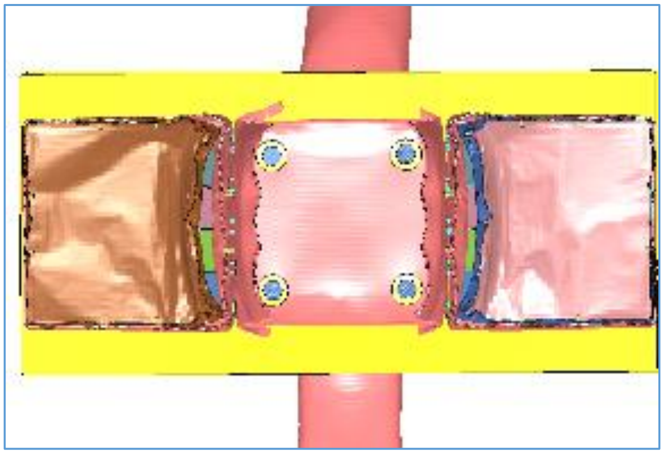

Figure 8: A0.05 Seconds

3.2 Ti6Al4V Enclosure

The Ti6Al4v enclosure rupture pattern is similar to AL 6061-T6, but delayed slightly in time due to high stiffness of Ti6Al4v. Figure 9 shows the deformed Ti6Al4v box and corresponding M&S pictures are shown in Figure 10. A few selected time stamps shown in Figures 11-14 captures the deformation process.

Figure 9: Ti6Al4V post test

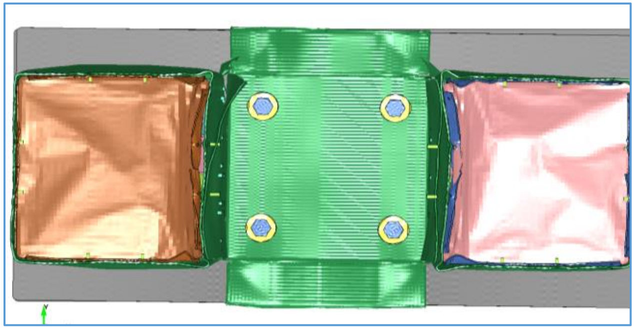

Figure 10: Ti6Al4V M&S

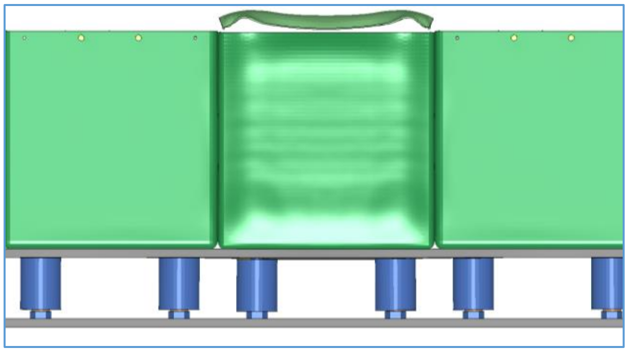

Figure 11: Enclosure at 1 millisecond

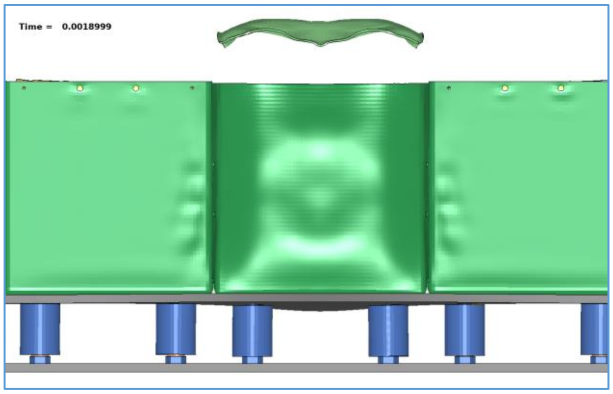

Figure 12: Enclosure at 2 milliseconds

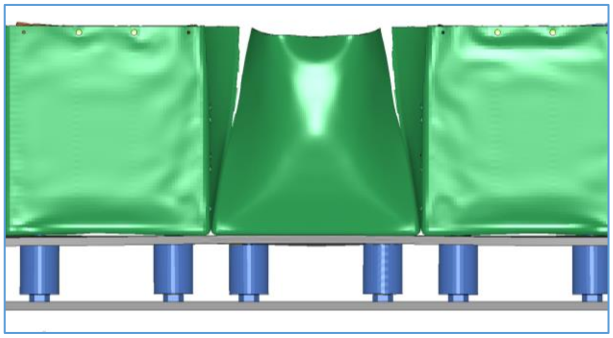

Figure 13: Enclosure at 5 milliseconds

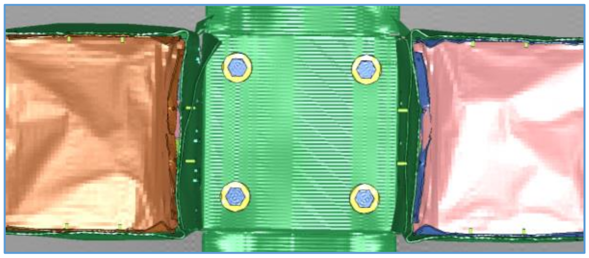

Figure 14: Enclosure at 125 milliseconds

Overall, in M&S the deformation process in good agreement with that of the test. Figure 12 shows the post-test deformation of the Ti6Al4v enclosure box.

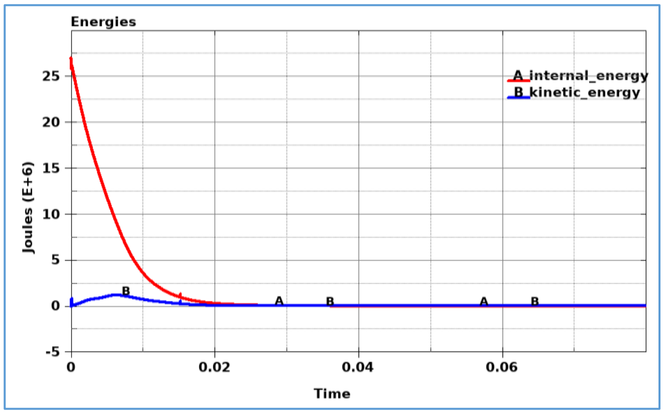

Figure 15: Internal and kinetic energies

Initial stored internal energy from the C4 explosive and energy dissipation after detonation is shown in figure 15.

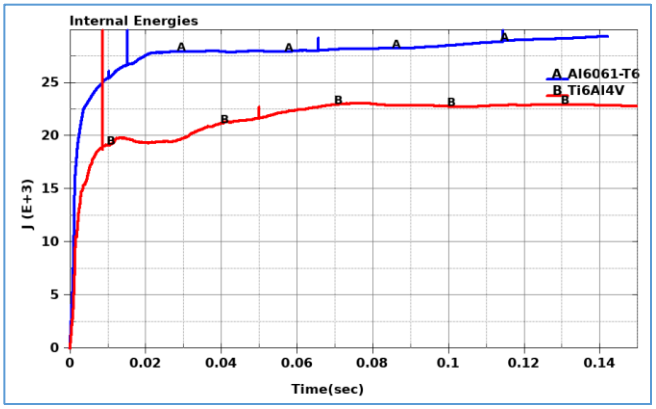

Figure 16: Internal energies of the enclosures

Internal energies of AL6061-T6 and Ti6Al4v enclosure are shown in Figure 16. Higher stiffness of Ti6Al4v results in lower internal energy absorption compared to Al6061-T6 for the same thickness. Ti6Al4v is as strong as steel as and twice stronger than Al6061-T6, but is heavier than Aluminum.

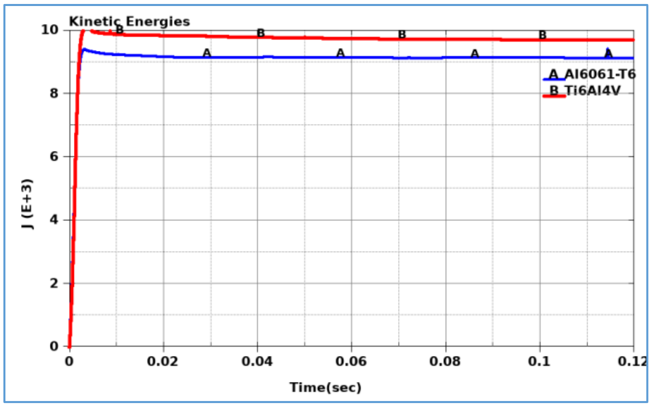

Figure 17: Kinetic energies of the enclosures

Figures 17 is the kinetic energies of the Al6061-T6 and ATi6Al4v enclosure boxes. Only 1/10th of the stored energy is being converted into internal and kinetic energies of the enclosure box and other energy absorbing components. The rest of the energy will be dissipated in air. This small amount of energy is sufficient to cause damage to the box. The explosive content of the armor should be carefully chosen to ensure desired performance of the internal materials.

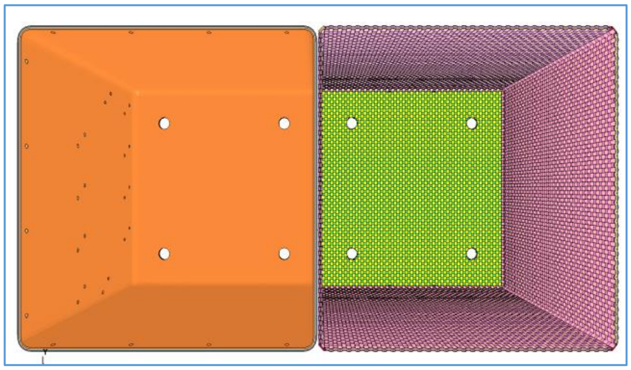

Figure 18: S2/Glass-epoxy composite enclosure

S2-Glass/epoxy composite woven fabric enclosure analysis is in progress for performance evaluation. Two model simplifications are utilized for the composite design: one approach model's the material as a woven composite material using meso-scale modeling [12, 13] while in the other model it as composite embedded with epoxy matrix. Analysis in ongoing and complete results were not available in time for publishing. Figure 18 shows both the composite designs in analysis.

4. SUMMARY AND CONCLUSIONS

GVSC Survivability has conducted blast tests for four different enclosure design utilizing different materials 304 stainless steel, Al 6061-T6, Ti6Al4v and S2/Glass-epoxy composite for explosive reactive armor. The main objective is to reduce the weight of the enclosure while maintaining minimal collateral damage protection. Numerical simulations were performed to simulate the Al6061-T6 and Ti6Al4v boxes and correlate the responses using LS_DYNA3D. Results from Al 6061-T6 and Ti6Al4V enclosure designs correlate favorably to the test responses. Post-test pictures from test and simulations are shown for the both these enclosures. Further simulations are ongoing for 304 stainless steel and S2/ Epoxy design and authors were not able to complete the analysis due to time constraints. In the future, it is anticipated that these simulations will help to identify viable solutions for housing explosive reactive armor to minimize weight. This will help the design and development teams to reduce cost and save significant development time.

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