A computational study of ballistic transparencies

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Abstract

A computational study of ballistic transparencies was undertaken to explore the current capabilities and limitations of such simulations. Ballistic impacts into a selected number of laminate transparency designs were simulated using the Lagrangian hydrocode EPIC, and comparisons made to experimental data. The results are discussed, along with recommendations for future work.
Keywords: ballistic transparencies, simulations, hydrocodes.

1 Introduction

The spectrum of ballistic threats that may be encountered by ground vehicles runs from small arms and low-velocity shrapnel from a variety of sources to high-energy kinetic penetrators. Transparent armor systems are a critical component of all current ground combat and tactical vehicles, and their battlefield survivability can be highly dependent on the development and fielding of new lightweight systems that offer equivalent or improved ballistic protection when compared with existing components. With the present military situation, designing, integrating and fielding a new transparent armor configuration in ever decreasing time has become paramount. In order to meet this requirement in a timely and affordable fashion, increased reliance is being placed on simulation and modeling to replace the expensive and time consuming process of build, shoot, rebuild and re-shoot.

The capability of high performance computations and codes to successfully model ballistic events and contribute to the design of armor systems has gained increasing importance [1] and success in the past few years. Unfortunately, although significant investigations of ballistic impacts into various glasses have long been done [2], a similar process for the simulation and modeling of transparent armor systems has been limited [3]. This study looks at the capability of a specific Lagrangian hydrocode widely used by the U.S. Army and others for ballistic event simulations to successfully predict the ballistic performance of several notional transparent laminate armor systems.

As new transparent materials have emerged and become available for use, they have demonstrated improvements in ballistic performance as compared to traditional float (soda-lime) glass, with a concurrent savings in weight. Along with the bulk performance of these new compositions, their use in laminate systems can provide a significant potential increase in ballistic capability. As there are a large number of potential combinations of materials, layers, thicknesses – all with possible effects on the overall ballistic effectiveness of the final configuration – modeling and simulation rapidly emerges as the only practical path for evaluating and optimizing such constructions. Modeling prospective designs also allows the investigator to acquire some insight into the laminate system response during impact and potentially use those failure processes in system design optimization.

2 Computational approach

Numerical simulations of various monolithic and laminate transparent armor designs were performed with the 2003 version of the EPIC Lagrangian hydrocode. The computations used 2D Lagrangian finite elements [4], meshless particles [5], and the Johnson-Holmquist glass model [6]. The simulations involved severe distortions, and the finite elements were automatically converted into meshless particles during the course of the computation. The simulations were performed using a penetrator impacting monolithic, and layered, float glass and polycarbonate, both common laminate armor transparency components. The complete simulation matrix is shown in Table 1. An ordered sequence progressing from monolithic blocks of glass and polycarbonate through two and three layers of each material (separated by a thin polyvinyl butyral layer) was done in order to gain possible insight into damage processes. Two runs of mixed layered materials (glass/ polycarbonate/ glass and polycarbonate/ glass/polycarbonate) was also done. Finally, simulations were done with an actual transparency design to see how well the computational prediction would compare with actual experimental data.

2.1 Material models and data

A limitation of the study conducted here is the materials used in all of the simulations for both penetrator and modeled transparent systems were only those available in the EPIC material library. An initial assumption was that the appropriate materials models and properties were included in EPIC. It became evident early on that all of the desired materials were not available and needed to be added. This effort is currently underway to provide additional glass (soda-lime of varying composition, borosilicate, and aluminaslicate), interlayer (primarily polyurethane), and more exotic (ALON, sapphire) transparent materials.

Table 1: Simulation matrix.

	material	penetrator	impact velocity (m/s) 200	300	400	500	600	700	800	900	1000
mono	*glass*										
	20mm	lps	x	x	x		x		x		x
	62mm	lps			x	x	x		x		x
	75mm	apm2				x	x		x		x
	polycarb										
	20mm	lps	x	x	x		x				
	31mm	lps			x		x				
	62mm	lps		x	x	x	x				
2 layers	*glass*										
	2x9mm	lps	x		x		x		x		x
	2x 12mm	lps	x		x		x		x		x
	2x31mm	lps		x	x	x					x
	2x36mm	apm2					x		x		x
	polycarb										
	2x9mm	lps	x		x		x				
	2x 12mm	lps	x		x		x				
	2x31mm	lps			x	x					
3layers	*glass*										
	3x6mm	lps	x		x		x		x		x
	3x8mm	lps	x		x		x		x		
	polycarb										
	3x6mm	lps	x		x		x		x		
	3x8mm	lps	x		x		x		x		
	glass/poly										
	3x8mm gl/poly/gl	lps				x					
	3x8mm poly/gl/poly	lps				x					

2.2 Simulation setup

All of the results presented here were performed using a 2-D axisymmetric geometry and used a medium mesh (approximately 10 elements across the penetrator) with converted particles. Use of the element to particle conversion eliminates potential issues with the discarding of highly distorted elements, which can lead to premature failure of the target due to tensile failure. Most of the computations were done using a penetrator surrogate of the 7.62mmx54R LPS (Lyokhkaya Pulya Obrazets) Russian projectile core (Figure 1). This core material is a relatively soft low carbon steel. Additionally, a small number of computations were performed using an APM2 surrogate. These are not discussed here, but serve to illustrate the flexibility of the simulation setups. Targets were constructed using EPIC material entries of float glass [6], polycarbonate (Lexan), and polyvinyl butyral resin (PVB) used as an interlayer and layers within targets were bonded (no sliding). A typical layered geometry problem is shown in Figure 2. Impact velocities were varied from 200 meters per second (m/s) up to 1000 m/s. In general, if the target was perforated at the first attempted velocity, no additional runs at higher velocity were done. Run times varied from 10 minutes to 6 hours for thicker targets at the highest impact velocities.

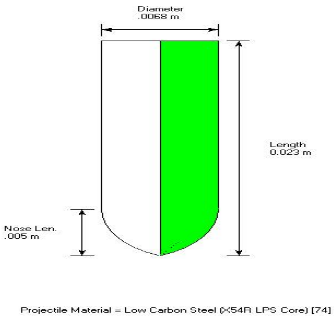

Figure 1: Penetrator geometry.

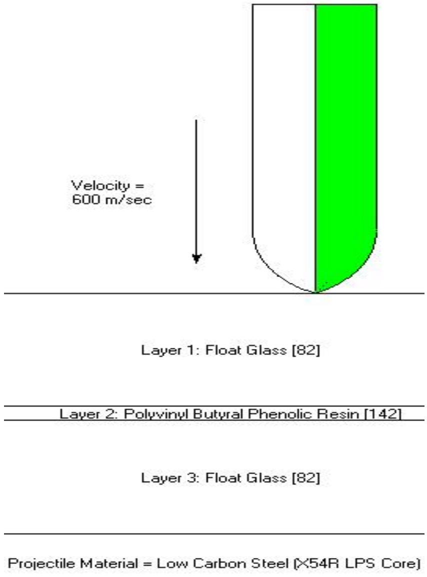

Figure 2: Typical simulation geometry.

Correctly predicting the performance of the transparency system depends greatly on the choice of appropriate material models and related input data. Limited material choices can lead to results of low fidelity, if not incorrect. Availability of experimental data to calibrate and validate computational predictions is also key. This study focuses on the float glass and polycarbonate in an attempt to gain initial insights into the current efficacy of EPIC to assist in the design and optimization of the transparent armor system. The contribution of the interlayer, while essential, did not, at least here, appear to be heavily related to the actual material used. Since PVB is a common interlayer material and is in the EPIC library, it was used as the standard interlayer. The use of polyurethane, another common interlayer material was considered, but the EPIC material library currently only include non-optical foam compositions, which are inappropriate for this work.

3 Computational results

A compilation of selected computational results are shown in Figures 3 through 6. As shown in Table 1, runs were done at various impact velocities with up to three layers of either float glass or polycarbonate using interlayers of PVB. Figure 3 shows a comparison of single plates of glass and polycarbonate of 20mm thickness. In these simulations, glass is about 33% more ballistically efficient. Vr is the residual velocity of the penetrator. Similar results were observed for the 62mm thickness of each material.

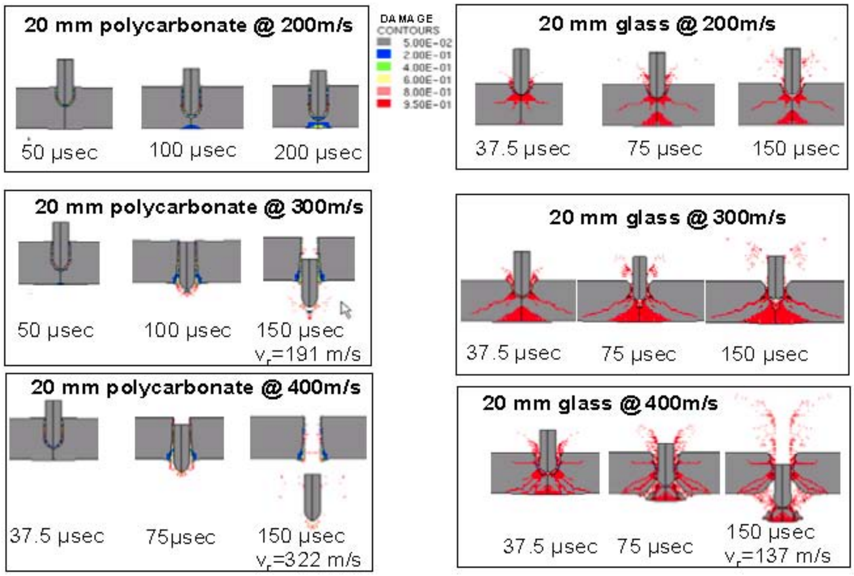

Figure 3: Ballistic performance of monolithic material.

Figures 4 and 5 show comparisons of 2 layers and 3 layers respectively. The location of the PVB interlayer is shown in the figures. In all cases, as expected, the glass configurations are the superior performers. The layered compositions also appear to be tending toward somewhat better performance as compared to the monolithic samples at the same impact velocities, with greater improvement in the glass constructions. The importance of the interlayer in improving this performance can be seen in the three layer glass results. Time plots of the velocity profile of the penetrator clearly show the effect of the interlayer regions, with the penetrator slowing until material directly underneath fails, regaining velocity, and then repeating the process as each layer interface is approached. Figure 6 compares mixed layer constructions of float glass and polycarbonate. The results are consistent with the previous simulation results, with the sample having two glass layers showing slightly better ballistic performance.

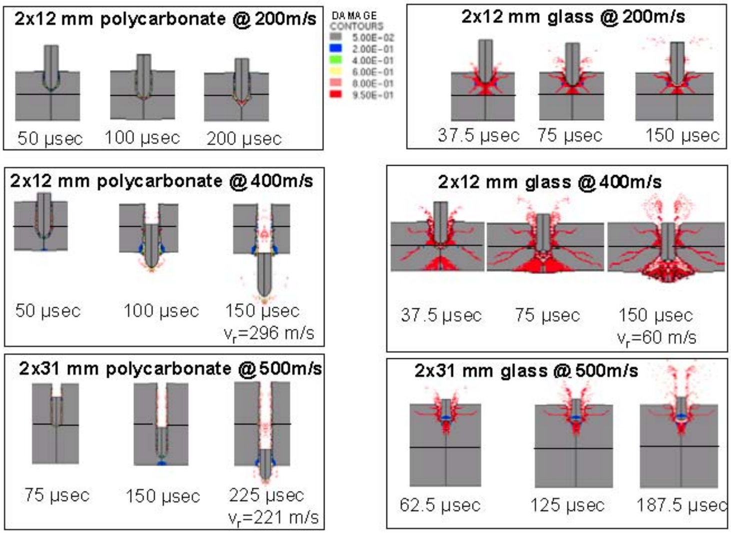

Figure 4: Two layer configurations.

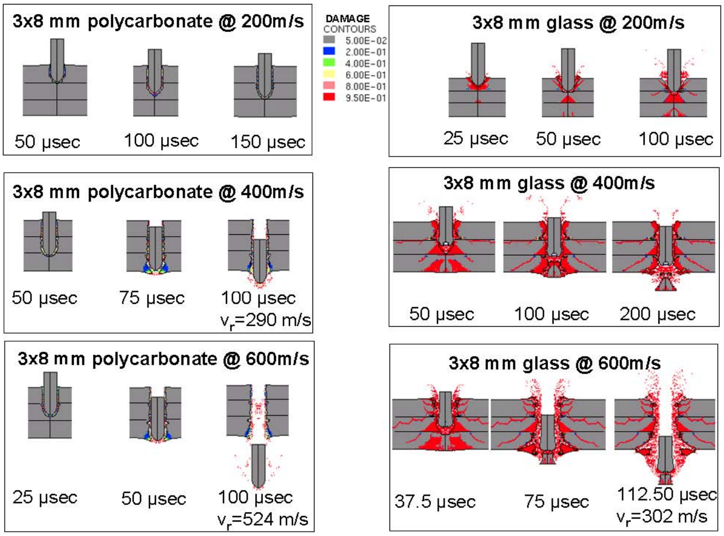

Figure 5: Three layer configurations.

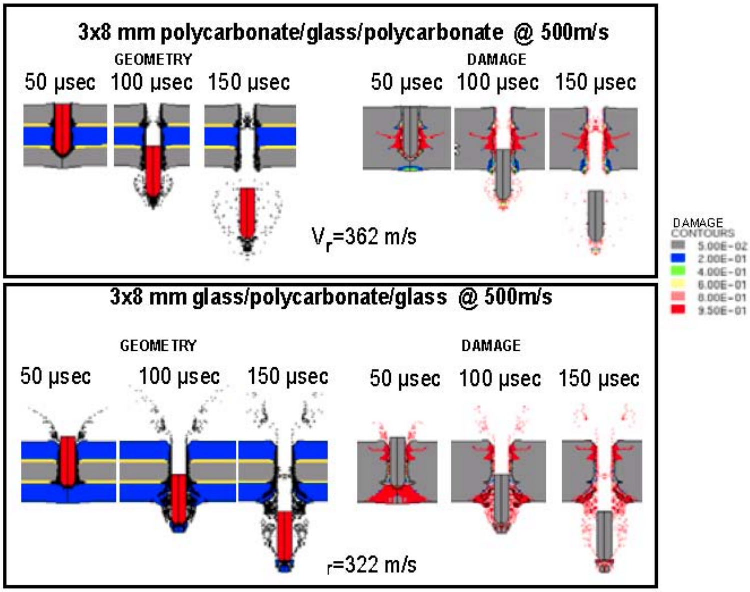

Figure 6: Mixed layer configurations.

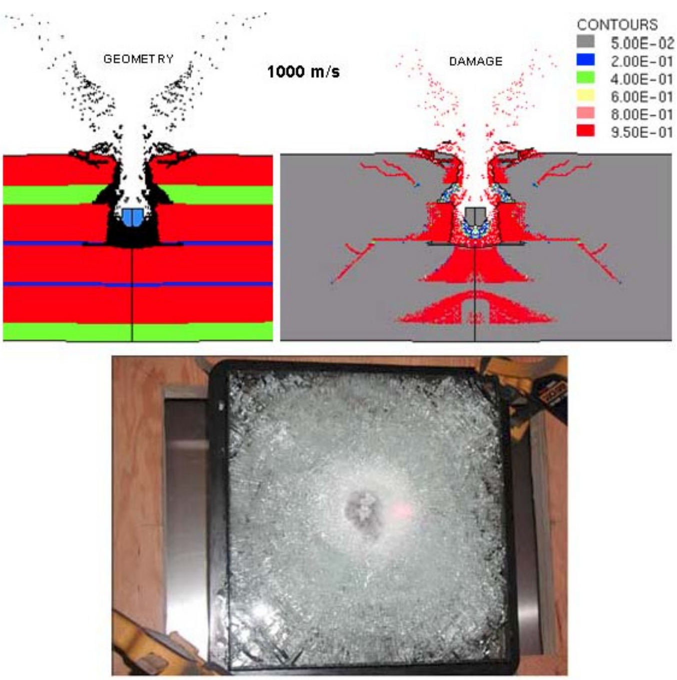

Figure 7: Comparison of transparency simulation to experimental result.

4 Comparison to experimental results

As a comparison to a real design, a currently used transparency was modeled and the computational results compared to experimental shots with actual penetrators. The simulations predicted single shot defeat at over 1500 m/s, which represents a velocity well over that obtainable with a real threat. A computational run using the LPS surrogate at actual round muzzle velocity shows that that the design could likely defeat the first round, with low level residual velocity for a second round impacting at or near the same location. Figure 7 shows a comparison of the simulation with a post mortem photograph of the transparency. The actual hardware was shot twice with the actual LPS round at approximately 900 m/s. The first round was defeated. The second round hit 3mm from the initial round impact site and resulted in a complete penetration with a round residual velocity of 100 m/s.

5 Conclusions

The results obtained for the simulations run in this study appear to compare well with the limited number of experimental results. This demonstrates the capability of a limited number of well-defined simulations, along with a concise set of ballistic experiments, could be used to develop, optimize, and validate new transparent armor systems. A significant limitation was the availability and definition of a full spectrum of appropriate materials for use in the simulations. As a result, a comprehensive program to more completely populate the material library has been initiated. Additional work to expand the simulation capability to multi-shot impacts is also underway.

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