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LIGHTWEIGHT COMPOSITE CREW FLOOR FOR GROUND COMBAT VEHICLES

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ABSTRACT

This paper focuses on the development of a lightweight, composite floating crew floor designed to withstand the severe loading requirements of an underbody blast. Energy absorbing devices decouple the floor from the surrounding vehicle structure; therefore, in the event of an underbody blast, the impulse is spread out over a longer period of time, thus reducing the loads into the floor where the crew seats are attached. The composite floor development included: characterizing candidate materials for structural and flame/smoke/toxicity characteristics, design optimization of the composite floor geometry, modeling the response of the floor assembly during a simulated underbody blast event, and manufacturing of a physical composite crew floor. Based on this effort, the composite floor was able to meet the structural requirements of the underbody blast event, while reducing weight by more than 55% compared to the baseline aluminum floor. Moreover, due to the significant reduction in mass and efficient design, the raw material cost of the composite floor was approximately cost neutral compared to the baseline aluminum floor that was machined from solid aluminum billet.

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1. INTRODUCTION

The need of the Army to be more lethal, expeditionary, and agile, with greater capability to conduct operations that are decentralized, distributed, and integrated is as critical today as ever. Lightweight material technologies are critical to Next Generation Combat Vehicle's (NGCV) objectives in close combat capabilities in manned, unmanned and optionally-manned variants, and ability to fight and win against any foe [1]. The impact of weight on its ability to achieve a combat vehicle force with smaller deployment, employment and sustainment footprints is a well-recognized and accepted fact. Gerth and Howell outlined four operational considerations where lightweight vehicles are advantageous: air

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transportability, operational energy usage, freedom of movement, and combat effectiveness [2]. When lightweight material solutions are used to provide equivalent survivability performance, lightweight ground combat vehicles may have improved mobility in combat, thus leading to fewer hits sustained and more favorable outcomes [3]. Recent studies have shown that lightweight material technologies can result in better vehicle fuel economy, thus reducing lifecycle costs [4]. However, lifecycle cost benefits are likely only realized when the material technologies are inserted at the start of a program of record, because the costs of inserting new technology during a later retrofit typically outweigh operational cost savings [4]. Threats continue to grow at a fast pace, and advanced capabilities like Active Protection Systems (APS) are being added to combat vehicles to counter them. Today, there is an urgent need to add performance at the lightest weight possible, as well as find weight reduction opportunities elsewhere in the vehicle to counter the weight added by these new countermeasures.

Lightweight composite materials are often sought out by both commercial automotive and defense industries to solve their respective weight issues. For instance, in an electric vehicle design, a woven carbon fiber reinforced plastic (CFRP) structure has been demonstrated to realize 28% weight savings over a baseline design [5]. Weight savings in ground vehicle applications is achieved through a combination of low material density and high structural performance (i.e., high specific stiffness and strength). Under axial crushing during a vehicle crash event, composite structures are able to absorb more energy using less mass when compared to sheet metal structures. This trend has been shown to hold true for both thermoset [6, 7] and thermoplastic [8, 9, 10] composites. Despite the known benefits of lightweight composite materials, these materials are often passed over during trade-studies in favor of metals due to some common barriers to implementation, including: raw material cost, manufacturing & maintenance costs, design and modeling tools, and flame/smoke/toxicity concerns. In order for the Army to utilize high-performance, lightweight composites in ground combat vehicles, these barriers must be addressed. This paper focuses on the development of a lightweight, composite floating crew floor designed to withstand the severe loading requirements of an underbody blast while also addressing the aforementioned barriers that have hindered the application of composite materials in past efforts.

2. METHODS

The objective of this effort was to design and manufacture a lightweight composite crew floor (see Fig. 1) using fiber-reinforced thermoplastic composite materials. Thermoplastic composites have attractive characteristics such as high toughness and potential for low manufacturing cost, which makes thermoplastic composites specifically suitable to this application. Due to the severe operating environment of a combat vehicle, the crew floor would need to be tolerant of extreme dynamic loads (mobility + blast), varying thermal loads (from arctic to desert climates), as well as resistance to flammability, smoke generation, and toxicity (FST). The development effort included

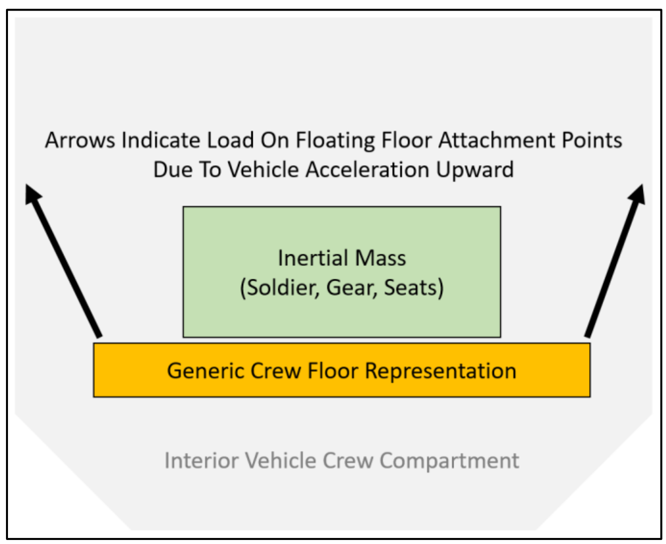

Figure 1: Generic representation of floating crew floor.

selecting appropriate composite materials and characterizing their FST and mechanical properties. Next, the material information was used to develop an optimized geometric design and laminate stack to meet necessary structural requirements. The design was then validated under a simulated underbody blast event using finite element (FE) methods, and the final floor design was manufactured for future live testing.

2.1. Material Characterization

Six different fiber-reinforced thermoplastic composite materials were considered for the crew floor application, including: glass fiber reinforced polyphenylene sulfide (GF/PPS), carbon fiber reinforced PPS (CF/PPS), GF reinforced polyethylene terephthalate (GF/PET), GF reinforced polyethylene terephthalate glycol (GF/PETG), GF reinforced polypropylene (GF/PP), and GF reinforced polycarbonate (GF/PC). The first screening test used in selecting the appropriate material for the crew floor was to perform FST testing according to relevant ASTM standards. Vertical burn tests were conducted according to ASTM D3801 [11], Smoke Density testing was conducted according to ASTM E662 [12], Surface flammability was assessed through ASTM E162 [13], and heat and visible smoke was observed through ASTM E1354 [14]. The overall highest performing composite materials were the GF/PPS and CF/PPS materials. These materials had exceptional performance in all FST tests, which follows intuition, because the thermoplastic PPS polymer has excellent high temperature performance and resistance to burning. The GF/PC composite material performed well against several test criteria, however the performance in heat and visible smoke release (ASTM E1354) and vertical burn (ASTM D3801) did not meet the requirements of an interior vehicle application based on criteria adapted from commercial vehicle interiors [15]. The GF/PET, GF/PETG, and GF/PP in general performed poorly in the FST tests. Table 1 shows a summary of the FST testing with suggested Pass Outcome Ranges.

Table 1: ASTM FST screening test results. F = fail; P = pass.

		SAMPLE ID																	
Test Title	ASTM	PPS/CF			PPS/GF			PETG/GF			PP/GF(FR)			PET/GF			PC/GF		
Vertical Burn (V-0 Rating)	D3801	P			P			F			F			F			F		
Vertical Burn (V-1 Rating)	D3801	P			P			F			F			F			P		
Vertical Burn (V-2 Rating)	D3801	P			P			F			F			F			P		
Suggested GVSC FST Std.		L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
Smoke Density	E662	P	P	P	P	P	P	P	P	F	P	P	P	P	P	P	P	P	P
Surface Flamability	E162	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Heat and Visible Smoke	1354	P	P	P	P	P	P	P	P	F	P	P	F	P	P	F	P	P	F

In consideration of FST results, thermal-mechanical properties, and vehicle requirements, only the carbon and glass-fiber reinforced PPS was deemed sufficient for application to the floor.

2.2. Composite Floor Design

Figure 2 shows a representation of a quarter-scale composite crew floor. Floor design utilized a phased approach. First, geometry of the floor was optimized through multiple design-simulation-redesign loops. The optimization was conducted to minimize mass of the floor while limiting total dynamic deflection, thus ensuring that the floor would not contact surrounding vehicle structure during a blast event. The floor's optimized design utilized overlapping geometric features which increased the overall floor stiffness without the need for increased material thickness (see Fig. 2). After the geometry of the design was considered optimized for the floor application, then laminate material layers were designed to maximize their stiffness-to-cost ratio. Raw material cost of GF/PPS is lower than CF/PPS, due to the lower cost of GF compared to CF. However, CF/PPS material has higher stiffness and lower density than GF/PPS; therefore, utilizing CF/PPS in the design led to a lighter floor. Bending stiffness was an important consideration in the floor's design. Analogous to the flanges in an I-beam, the surface layers of the

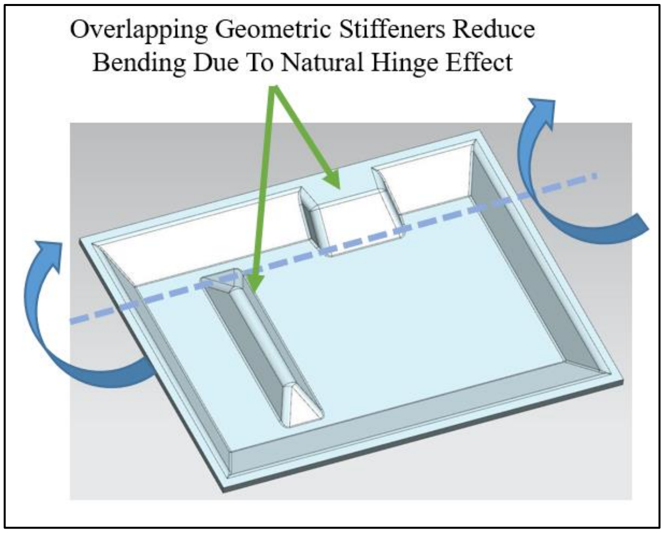

Figure 2: Quarter-size composite floor design to be used for manufacturing development prior to full-size floor fabrication.

Table 2: Cost versus Mass Tradeoff Comparison of Laminates with Varying Percentages of Carbon and Glass Fiber PPS relative to the Baseline Aluminum Floor.

CF/PPS % Mass	GF/PPS % Mass	Relative Mass	Relative Raw Material Cost
0%	100%	-56.7%	-19%
10%	90%	-57.5%	-9%
20%	80%	-58.3%	+1%
30%	70%	-59.2%	+11%
40%	60%	-60.0%	+21%
50%	50%	-60.8%	+31%
60%	40%	-61.6%	+41%
70%	30%	-62.4%	+50%
80%	20%	-63.3%	+60%
90%	10%	-64.1%	+70%
100%	0%	-64.9%	+80%

composite stack contribute more to the overall stiffness than the interior layers. Therefore, it was desired to use CF/PPS layers on the top and bottom surfaces of the floor and GF/PPS layers on the interior layers. Table 2 shows a tradeoff between floor mass and relative cost for various combinations of CF and GF in the composite stack.

2.3. Modeling & Simulation

FE methods were used to simulate the structural performance of the crew floor during a simulated underbody blast event. In the case of this floating floor application, the floor itself is decoupled from the vehicle and attached using energy absorbing (EA) devices which help to reduce the overall peak load imparted to the floor and spread the load out over a longer duration of time. Therefore, the load amplitude (see Fig. 3) represents the load transferred to the floor attachment points from the EA devices over a 14 millisecond duration. For the FE model, the floor was loaded with two crew seats and the equivalent mass of two 95-percentile soldiers with combat gear in a seated position. The 95-percentile soldier was used in the models to provide a worst case load into the seat attachment points and to cause the greatest amount of floor deformation. The appropriate center of gravity of the solider/gear/seat combination was determined, and the inertial mass was applied as a concentrated mass tied to the floor's seat mount locations. Dynamic structural finite element analysis to design the floor's geometry and laminate, and predict deformation and strength, was performed using Siemens Simcenter 3D software (Siemens Digital Industries Software), ADINA solver (ADINA R & D, Inc.), and LMS Samtech Samcef Mecano solver. Dynamic simulations compared predicted responses of the baseline aluminum floor design to a baseline composite floor design, an improved composite floor design, and an optimized composite floor design. Material properties used in the FE models were determined from experimental characterization tests, which were reduced by a knockdown factor to account for a worst-case elevated temperature, wet environment.

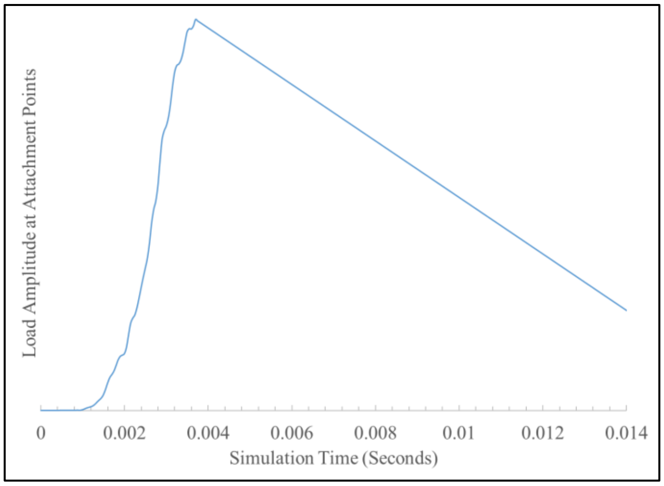

Figure 3: Load amplitude applied to each attachment point for floating crew floor.

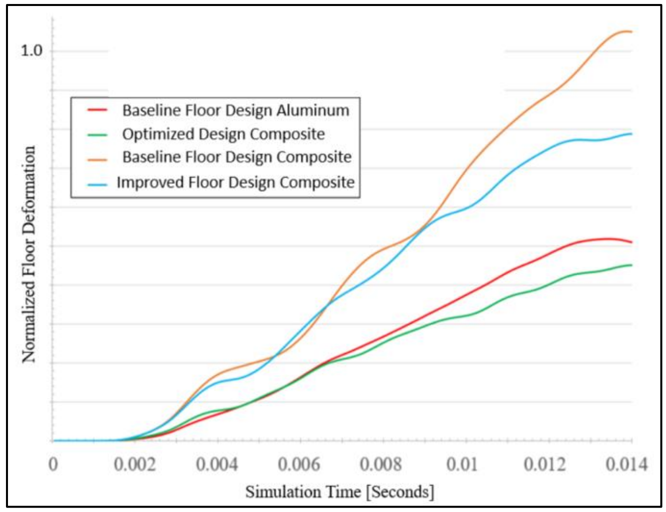

Figure 4: Comparison of floor deformation during simulation for different floor designs.

3. RESULTS AND DISCUSSION

FE simulation results were evaluated for two criteria: (i) damage to the composite laminate and (ii) maximum dynamic deflection of the floor. Figure 4 shows the relative deformation of the center of the floor to the EA devices. This metric was used to judge the total dynamic deflection of the floor to ensure that during a blast event, the floor would not deform excessively to contact the surrounding vehicle structure. From the results in Figure 4, it is clear that the original baseline design with aluminum was stiff enough to withstand the simulated blast event without excess deformation. However, if that same design was converted to a lightweight composite material as a pure material swap, the stiffness of the floor would be reduced enough that the floor would deflect approximately twice as much as the baseline aluminum. An improved floor design was developed to take advantage of the formability of the thermoplastic composite material, which utilized a stiffening rib in the center of the floor to add geometric stiffness without increasing the material thickness. While this design improved stiffness of the floor, the center stiffening rib acted as a hinge point which still allowed the floor to deflect more than the baseline design. A final optimized floor design was created with overlapping geometric stiffening features (see Fig. 2) which were able to effectively increase the geometric stiffness of the floor, minimize the required laminate thickness, and reduce bending of the floor below the baseline aluminum design while reducing mass by over 55%.

4. CONCLUSIONS

This paper has presented the methods and results of an effort to develop a lightweight, continuous fiber-reinforced thermoplastic composite crew floor for a ground combat vehicle. Thermoplastic composites offer key advantages such as high toughness and potential for low cost manufacturing. Several candidate thermoplastic composite materials were characterized for both mechanical and FST properties. Simulated blast events were conducted using FE methods on a baseline aluminum floor design as well as several design iterations of composite floors. It was shown that if the baseline floor's geometric design was kept constant a simple material swap from aluminum to composite would not provide sufficient floor stiffness to meet the maximum deflection criteria. Through a robust redesign, stiffening features were added to the floor which allowed its overall thickness to be reduced while providing increased bending stiffness over the baseline aluminum floor. When the optimized floor's reduced thickness was combined with composite materials' lower density compared to aluminum, more than 55% weight savings was realized while remaining nearly cost-neutral in raw material cost compared to a baseline machined aluminum floor.

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