A DEVELOPMENT OF INTEGRAL COMPOSITE STRUCTURE FOR THE RAMP OF INFANTRY FIGHTING VEHICLE

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A Ramp is a typical component of armored vehicle, which simultaneously plays both a structural and ballistic protection role. A ramp must withstand severe structural loading conditions during its life cycle, as well as provide protection from ballistic threats. The design concept for the integral armored ramp, which is composed of spall cover, ceramic tile, rubber sheet and composite plate, is based on hybrid composite technology in order to meet multi-functional requirements such as structure, ballistic protection and EMI (Electro-Magnetic Interference) shielding.

For a reliable estimation of structural performance, a numerical analysis was carried out. The numerical analysis accounted for the interaction effects between the multi-layers and developed a new multi-shell modelling technique to describe the discreet transverse shear deformation of the multi-layers. To validate the new analytic method, a proof test was performed using three-point bending loads. A new process derived from traditional VARTM (Vacuum Assistant Resin Transfer Molding) was developed for fabrication of the integral armored ramp. This new process remarkably reduces the fabrication time, and increases the bonding force between each layer. For ballistic protection, a large number of firing tests were performed using armor piercing bullets, and the optimal thickness ratio of ceramic and composite plate was determined.

The multi-layered integral ramp demonstrates excellent structural and ballistic protection performance while reducing weight and fabrication costs considerably.

INTRODUCTION

Recent advances in IFV (Infantry Fighting Vehicle) include the development of composite ceramic integral armor systems that provide significant improvement over conventional monocoque structures with attached add-on armor [1]. To optimize the weight and performance of the armored vehicle, an integral armored ramp structure was developed. The integral armored system makes use of the structural contribution of the armor tiles in the structural design of the vehicle, and allows the composite structure to perform a role in the ballistic protection of the vehicle to minimize aerial density. The integral armored ramp is based on hybrid composite technology in order to meet system requirements such as structure, ballistic protection and EMI shielding.

The Ramp, shown in Figure 1, plays both a structural and a ballistic protection role. The ramp must withstand severe structural loading conditions during field operation, as well as provide protection from ballistic threats at the level of armor piercing bullets. The integral armored ramp is multi-layered structure which composed of spall cover, ceramic tile, rubber sheet and composite plate. The outer spall cover is a thin glass reinforced composite which improves the ramp’s endurance under both low velocity impact and environmental conditions that may be encountered during its life cycle. The ceramic tile blunts sharp bullet head and generally absorbs impact energy by shattering the projectile into rubble, which is then contained by the spall cover. The composite plate absorbs the remaining impact energy and resists structural load. The flexible rubber sheet alleviates the remarkable stiffness difference between ceramic and composite, and attenuates stress waves that may debond adjacent tiles. In this study, ceramic tile, stitched glass fiber, adhesive film and EMI shielding sheet were considered to meet both the weight saving and the system design requirements. This integral composite structure carries the majority of the structural load of armor, but also absorbs a significant amount of energy from ballistic impacts.

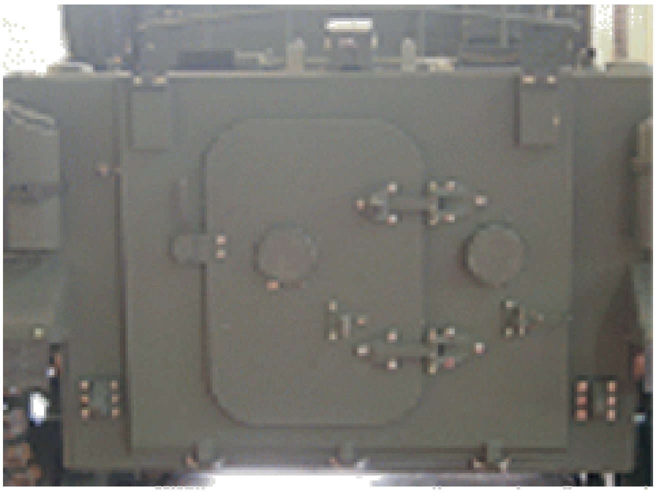


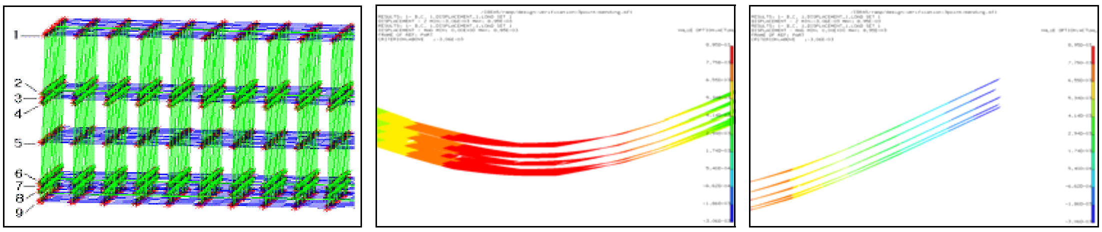
Figure 1. Ramp on the Infantry Fighting Vehicle

NUMERICAL ANALYSIS AND PROOF TEST

For a reliable estimation of structural performance, a numerical analysis and a proof test for the multi-layered structure were carried out. Structural analysis of this type of anisotropic construction poses several challenges. When applied to multi-layered structure, the standard finite element techniques either require extremely high computational resources, or yield unacceptably inaccurate results. Unfortunately, the unusual through-the-thickness strain distributions in laminates with embedded ceramic tiles cannot be represented using conventional shell elements [2]. The complex three-dimensional stress fields can be computed by the use of solid elements, but these elements are computationally too expensive to be practical for analyzing anything except the smallest components [3].

To mitigate the limitations of solid and shell elements, a new multi-shell modeling technique was developed. Each layer was modeled using a Mindlin plate, which has computationally efficient elements, and in which the shell normally remains straight and does not elongate. Each shell element is connected by a rigid element (RBE2) in order to maintain the displacement compatibilities. The RBE2 element ties only through-the-thickness displacements and allows rotation of the shell elements; therefore the multi-shell modeling can show a high degree of transverse shear deformation. This technique accurately accounts for the effects of transverse shear flexibility in the rubber sheets, and provides the computational efficiency necessary to analyze the large ramp structure.

The analysis result for the typical integral armored structure of the ramp, in Figure 2 clearly shows a high degree of transverse shear deformation.



(a) FE Modeling (b) Transverse shear deformation

Figure 2. Multi-shell Modeling Technique

To validate the new multi-shell modeling technique, a proof test for a typical integral armored structure was performed. Of the various loading conditions that the IFV must withstand, heavy bending loads are most prevalent. Therefore, a three-point bending test was performed. The test result, as shown in Figure 3, shows an apparent stepwise deformation and proves that the multi-shell modeling technique properly describes the structural behavior of integral composite ramp.

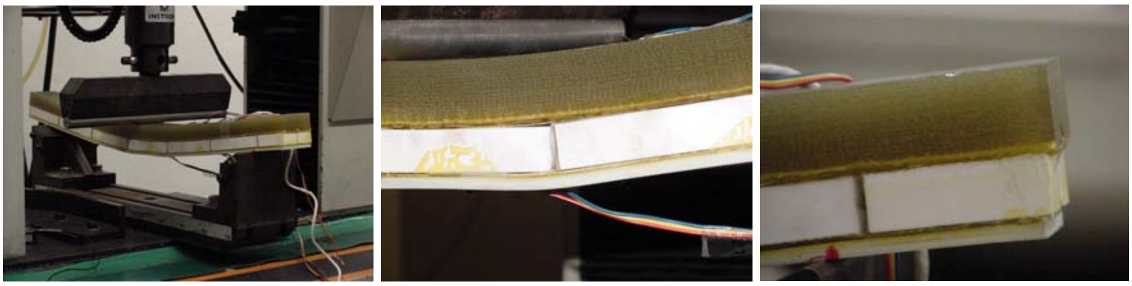


Figure 3. Structural Proof Test for Integral Composite Ramp

FABRICATION PROCESS

The traditional manufacturing process of composite armor involves multiple steps to produce each composite layer. The individual layers are then adhesively bonded together in separate operations, resulting in a conventional composite armored structure. These labor-intensive operations increase costs, pollution, part-to-part variability and dimensional tolerances, and introduce defects at the interfaces.

To avoid the problems created by a multi-step process, a new process derived from conventional VARTM was developed to fabricate the ramp. The sequential fabrication process is shown in Figure 4. First, the spall cover, ceramic tile, composite plate, rubber sheet, and EMI film are positioned in layers within the mold. Then, a high permeable distribution media is placed on glass fiber pre-form to enable rapid resin flow in lateral directions prior to the through-thickness perform infiltration. Finally, resin is infused using ambient pressure, and then co-cured. A resin flow analysis was carried out to determine an effective resin infusion path, and predict infusion time. This analysis also provides basic information about resin inlets, outlets, and air vents in mold design. The new process remarkably reduces the fabrication time and increases the bonding force between each layer.

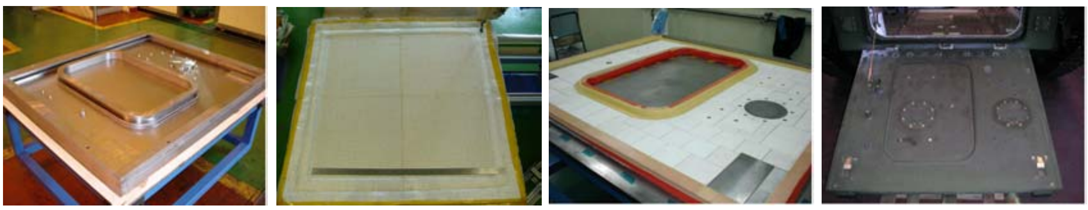


Figure 4. Sequential Fabrication Process of the Ramp

BALLISTIC PROTECTION PERFORMANCE

For the armor design, a large number of ballistic tests were performed and the optimal thickness ratio of ceramic and composite plate was determined based on the test data. To improve multi-hit performance, through-thickness stitching was employed to affix the glass fiber pre-form using aramid strings. Damage from impact by a cal.30 fragment simulating projectile was considerably reduced in the stitched glass fiber reinforcement plate when compared with the non-stitched plate, as shown in Figure 5.

(a) non-stitched plate (b) stitched plate

Figure 5. Ballistic Test Result Showing Effects of Stitching on the Glass Fiber Reinforced Plate

Figure 6 is produced by a typical ballistic impact process which utilizes a high speed camera. It shows no separation nor delamination between the frontal ceramic and stitched glass fiber reinforcement plate under the required threat level impact condition of an armor piercing bullet.

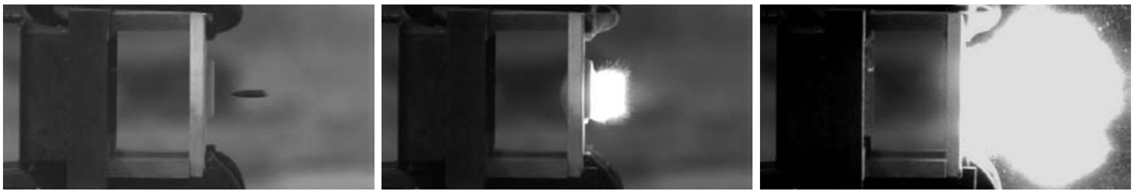


Figure 6. Ballistic Impact Process Showing Required Threat Level Condition

The damaged target plates were nondestructively examined to determine the extent of ceramic crack propagation into tiles adjacent to the projectile impact, as shown in Figure 7. All cracks due to the impact were confined to locally impacted areas, and no secondary crack was found in adjacent tiles. Enhanced multi-hit capability was also confirmed at the given threat level condition.

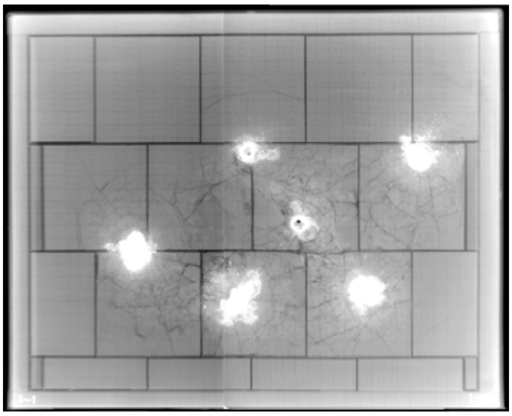


Figure 7. Ballistic Test Specimen after Multi-hit Test

CONCLUSIONS

The integral armored structure of the multi-layered ramp which utilizes the modified VARTM with stitching technology was developed. It improved the damage tolerance, apparently through the significant reduction in lateral delamination, while reducing weight and fabrication costs considerably. It also demonstrated excellent ballistic protection performance, especially an enhanced multi–hit capability.

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