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ENHANCED BLAST PROTECTION WITH POLYMER COMPOSITES CONTAINING XGNP® GRAPHENE NANOPLATELETS

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ABSTRACT

Fiber reinforced thermoset composites are well known for delivering 50% or more weight savings when compared with steel components while also providing strength, stiffness, and toughness. Nanoparticle additives have been shown to significantly increase the mechanical properties of thermoplastic and thermoset polymer matrices over the base matrix values. Extensive testing and characterization of composites containing graphene nanoplatelets (GnP) has been conducted and reported by XG Sciences' (XGS) collaborators at the Michigan State University (MSU) Composite Materials and Structures Center. In a recent program with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC), MSU investigated lightweight composites for blast and impact protection. High strain rate test facilities as well as high speed photography and non-destructive interferometry-based evaluation techniques were used to evaluate blast performance. The experimental results are presented here. The graphene nanoplatelets were shown effective in two distinct approaches for improving the toughness of lightweight composite components.

INTRODUCTION

Graphene nanoplatelets dispersed in a polymer matrix can improve the stiffness, strength, and/or toughness while at the same time providing additional functional enhancement (thermal conductivity, electrical conductivity, barrier properties, and flame retardancy) [1, 2]. Most vehicle manufacturers today have strategic programs seeking to reduce vehicle weight and increase gas mileage which include the increasing use of lightweight composites. The U.S. Army also has strategic programs to reduce the weight of ground vehicles. The TARDEC Advanced Lightweighting Program supports the goal of "An Expeditionary, Scalable & Ready Modern Army" by seeking to develop a weight-informed vehicle design optimization process and architecture for the Army, to develop and execute strategies to enable a 10 -30% weight savings [3].While the military performance requirements are different from those of the commercial applications, graphene-enhanced lightweight composites likewise have the potential to help reduce the weight and improve the performance of U.S. Army ground vehicles.

The manufacturing process[A] used to produce graphene nanoplatelets can have a significant effect of the nanoplatelet properties. For example, basal plane imperfections and holes within the honeycomb-shaped atomic structure can result during manufacturing that have the potential to diminish functional properties. The graphene nanoplatelets considered here are short stacks of graphene produced from natural graphite using a process that preserves the integrity of the graphitic basal planes (see Figure 1).

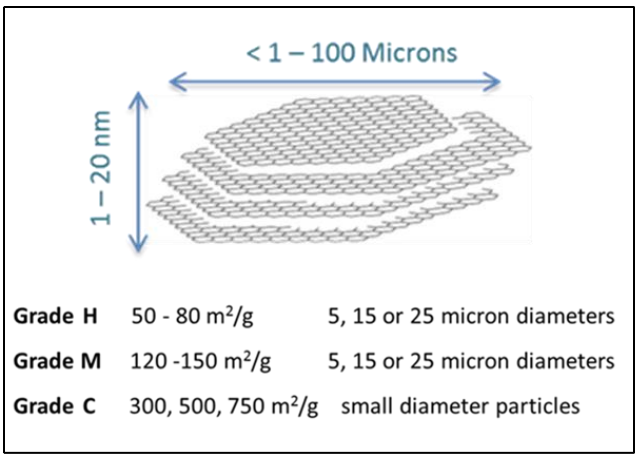

Figure 1 Graphene nanoplatelets.

The graphene basal plane is critical for imparting strength as well as functionality such as electron and phonon mobility and barrier properties. The physical and chemical characteristics of the nanoplatelet is important to matching with the polymer matrix for tailoring to specific applications (see Figure 2).

COMPOSITE LAMINATES AND SHOCK TUBE FACILITY

MSU fabricated 5- to 10-layer, 15 x 15 cm multilayer composited laminate samples using ShieldStrand® balanced weave fabric (Owens Corning S glass, 0.025-inch thick), vinyl ester matrix (DER 411-350) from Ashland Specialty Chemical and 2-butanone peroxide (Luperox®) and cobalt octotate accelerator. The laminate samples subjected to blast testing reported here were:

- A - Glass fabric/ vinyl ester composite, type-4 laminate construction;
- B - CTBN-modified GnP-15, type-11 laminate construction; and
- C - 40-micron GnP paper with 10% holes of 6-mm diameter in type-14 laminate construction,

(see Figure 3).

The MSU shock tube facility was used to create the blast pressure wave. The tube consists of a circular cylinder divided into two sections separated by a diaphragm section. Figure 4 shows a schematic of the shock tube test facility at MSU. After raising the pressure in the high-pressure section, a shock wave is generated by venting the diaphragm chamber causing the diaphragms at the high-pressure and low-pressure chambers to burst. Once the diaphragms burst, the high-pressure gas flows rapidly into

[A] Such as a graphene oxide process.

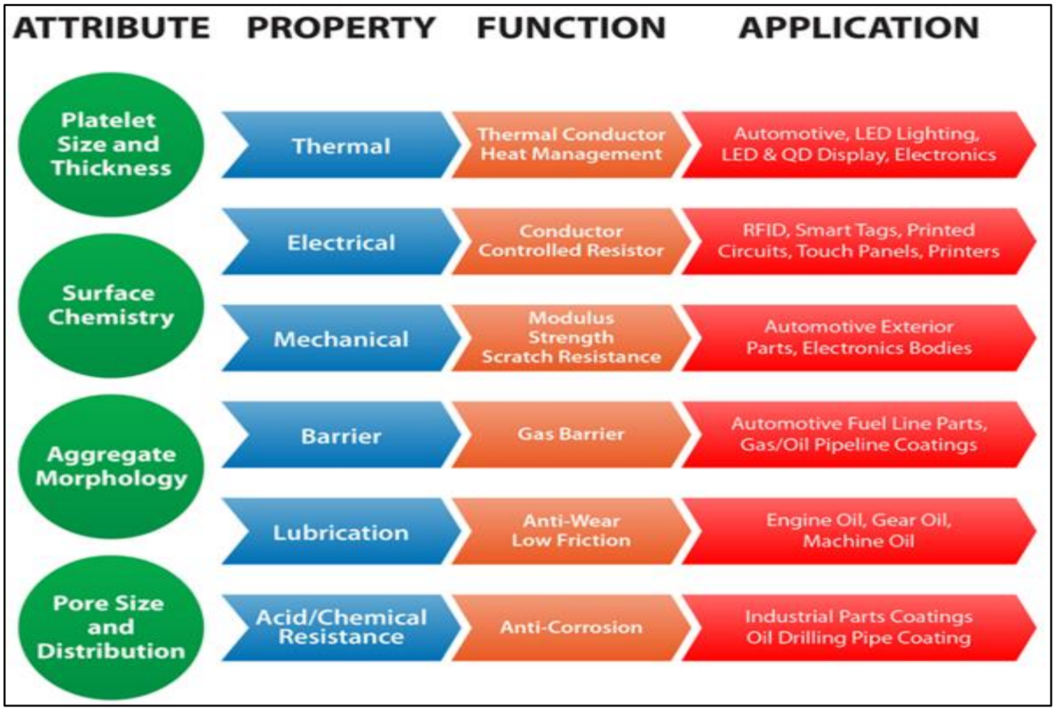

Figure 2 Graphene nanoplatelets: attributes, properties and example applications.

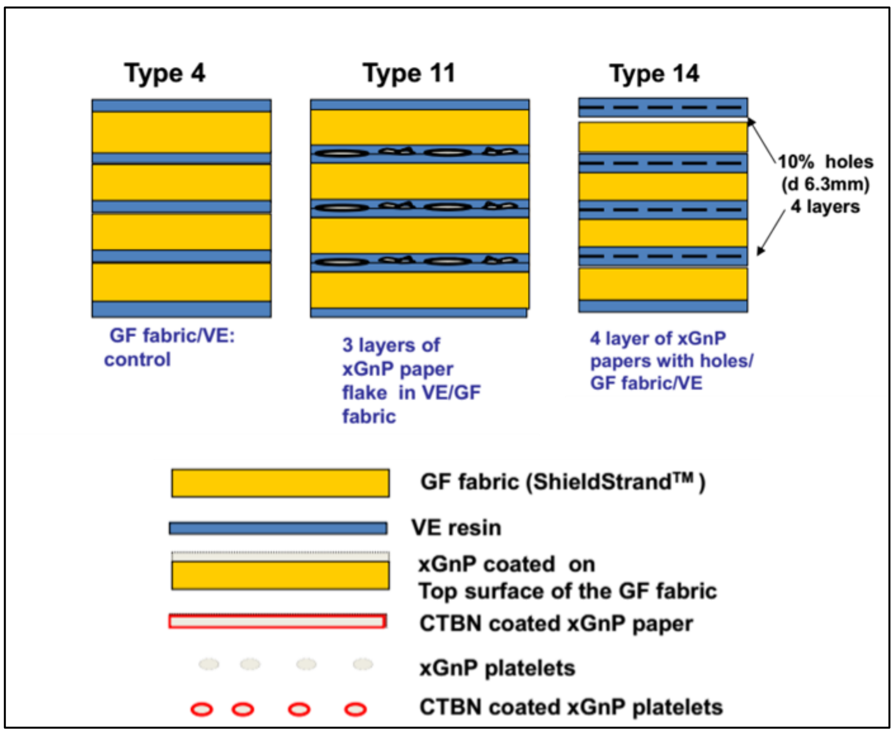

Figure 3 GnP-enhanced glass fiber reinforces vinyl ester composite construction types.

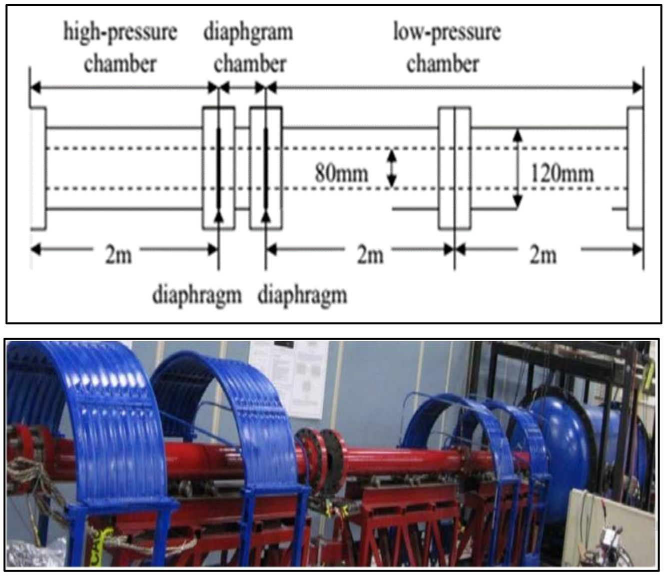

Figure 4 Schematic and photo of MSU shock tube facility used for conducting high strain rate blast studies.

the low-pressure chamber. A detailed description of this test facility has been reported previously [4]. The simulated pressure history for tests with laminates A, B, and C are shown in Figure 5. The blast wave used in the testing reported here attained a speed of approximately 1000 m/s.

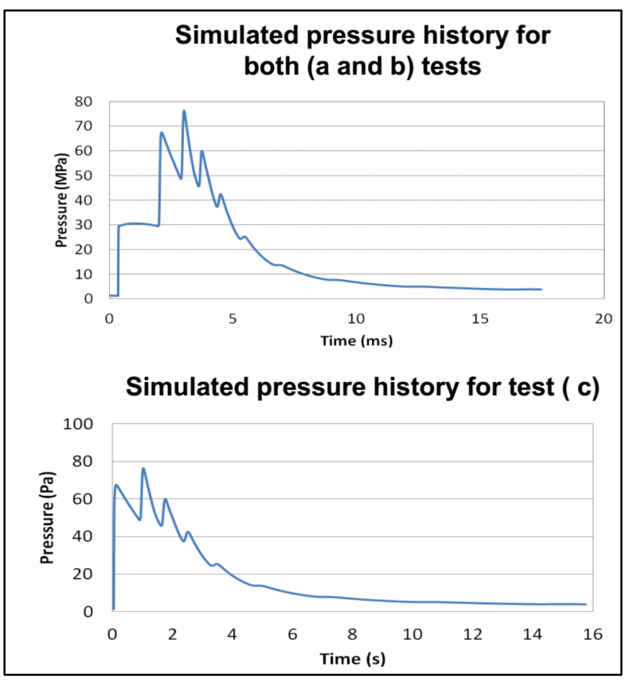

Figure 5 Simulated blast pressure histories.

TEST RESULTS

Following blast exposure the unmodified composite (a) showed evidence of severe delamination, fiber and matrix cracking, and front surface damage due to the interaction of the high-temperature blast front with the front surface of the composite laminate. Figure 6 shows images of the composites before (row 1) and after (rows 2 and 3) the blast testing.

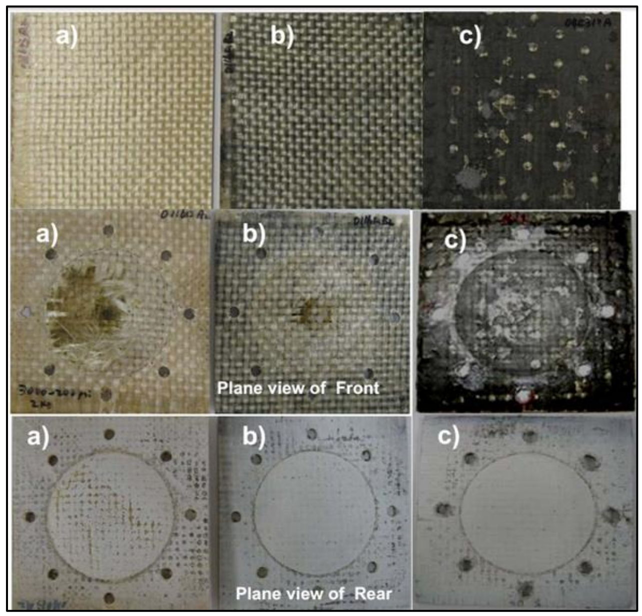

Figure 6 Views of composite laminates prior to and following blast testing.

Figure 7 shows edge view of the composites following blast exposure. The incorporation of CTBN-modified GnP particles between lamina (b) reduced damage and out-of-plane deformation under blast loading compared to the standard composition (a). However, the incorporation of GnP paper with holes between the lamina (c) reduced damage and out-of-plane deformation under blast loading. The GnP paper produced controlled delamination perpendicular to the propagating blast front and the addition of holes allowed the matrix resin to form a bond through the holes truncating the through-the-

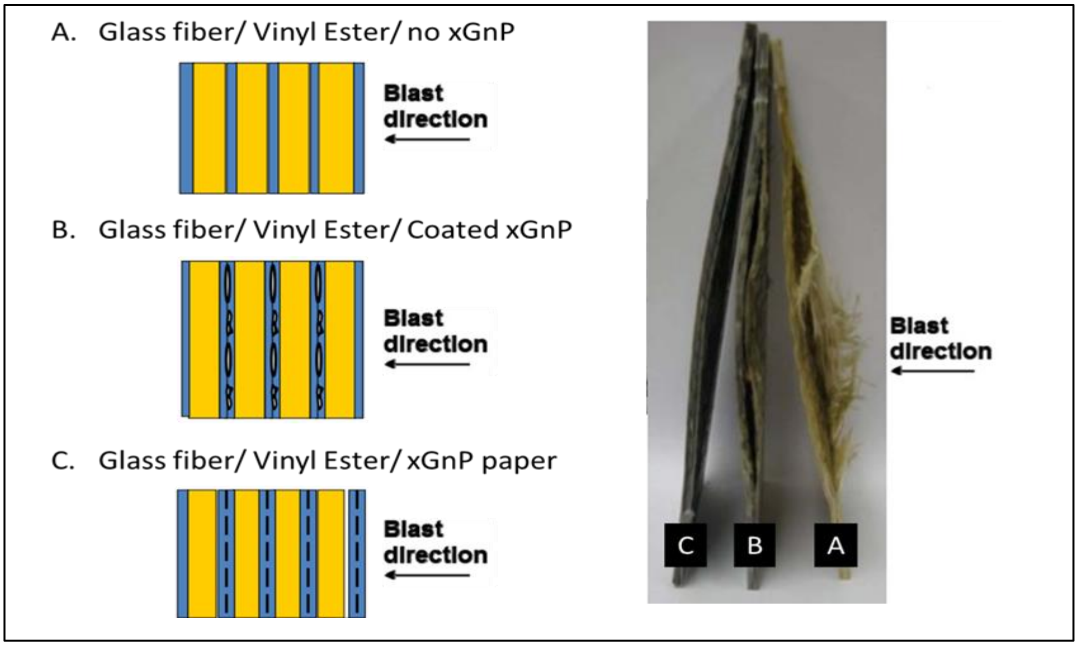

Figure 7 Edge-wise view of composite laminates following blast impact.

thickness damage. These points provide resistace to complete lateral crack propogation. The high thermal conductivity of the GnP paper in this composite appeared to improve the damage reduction from interacting with the hot gasses at the blast front.

The out-of-plane displacement history captured through fringe projections (See Figure 8) provides quantified data that support the visual evidence shown in Figures 6 and 7. The front surface damage resulting from the blast produced displacement of approximately 40 mm in sample A. The same measurement for the two composite samples containing graphene (samples B and C) showed approximately 10-14 mm displacement.

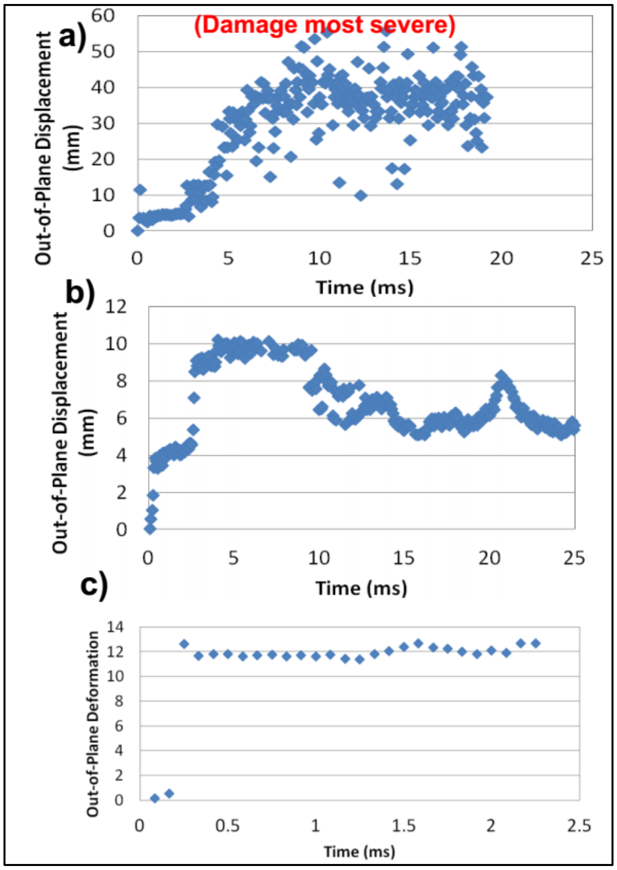

Figure 8 Out-of-plane displacement history as captured through fringe projection.

SUMMARY

Selective placement of appropriate graphene nanoplatelets can be used to modify and enhance the mechanical properties of composite laminates. Graphene nanoplatelets both added to the vinyl ester matrix and used as a thin graphene sheet inserted between glass fiber reinforced laminates enabled controlled lateral delamination and high lateral heat conduction resulting in significantly reduced blast damage compared with laminates that did not contain GnP material.

Improved utilization of the high strength fiber reinforcement during blast loading is achieved by locating graphene nanoplatelets around the reinforcing fibers. The graphene nanoplatelets enable facile separation of the fibers from the thermoset matrix during a blast, thereby reducing fiber fracture associated with rigid fiber polymer bonding. This debonding mechanism absorbs energy during a blast event, improving the toughness of the system.

An additional method for improving blast protection using involves adding a graphene nanoplatelet-containing layer between adjacent lamina of the composite. The graphene was shown to redirect the blast energy laterally and thereby reduce the concentration of energy perpendicular to the blast direction resulting in reduced damage through the thickness of the composite.

These results show promise for optimized GnP enhanced lightweight composites that can contribute to vehicle weight reduction while mitigating structural damage under blast conditions.

DISCLAIMER

REFERENCES

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[4] A Shock Tube Based Facility for Impact Testing, W. Li, D. Liu, D. Templeton, and B. Raju, 2006 SEM Annual Conference, Saint Louis, Missouri USA.