
Graphene/Polyurethane Laminar Composite for Transparent Armour

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Overview

1. Motivation
 2. Objectives
 3. Technical Approach
 4. Results
 5. Conclusions and Future Work
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Motivation

The problem:

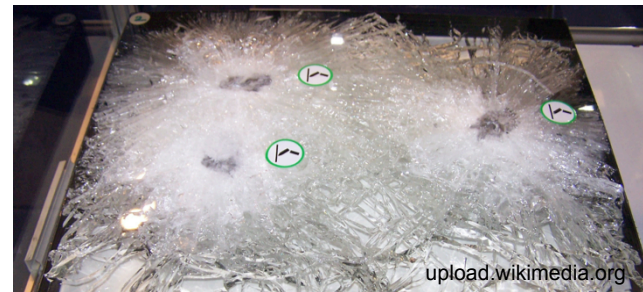
- Current technology cracks and fractures upon impact
- Compromises visibility, decreases the overall strength

The solution:

- Polymers
 - Resistant to crack propagation

Our Idea:

- Graphene-reinforced polyurethane laminated composite
- Lighter and transparent under fire



Objectives

1

Increase impact strength by at least 10%

2

Maintain 90% optical transparency

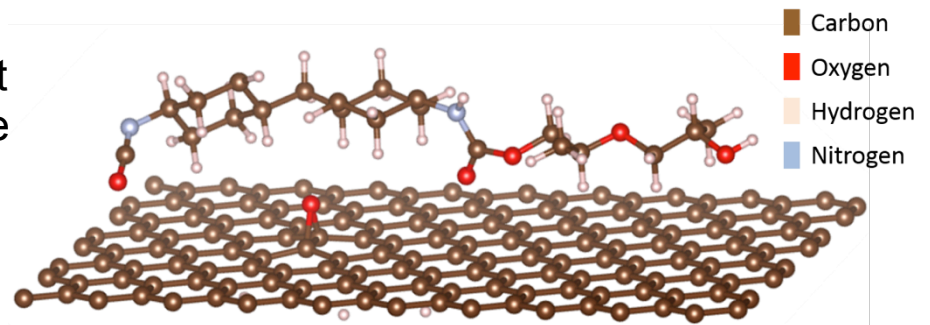
Technical Approach

1. Research
2. Modeling
 - a. Chemical
 - b. Ballistic
3. Fabrication
4. Testing



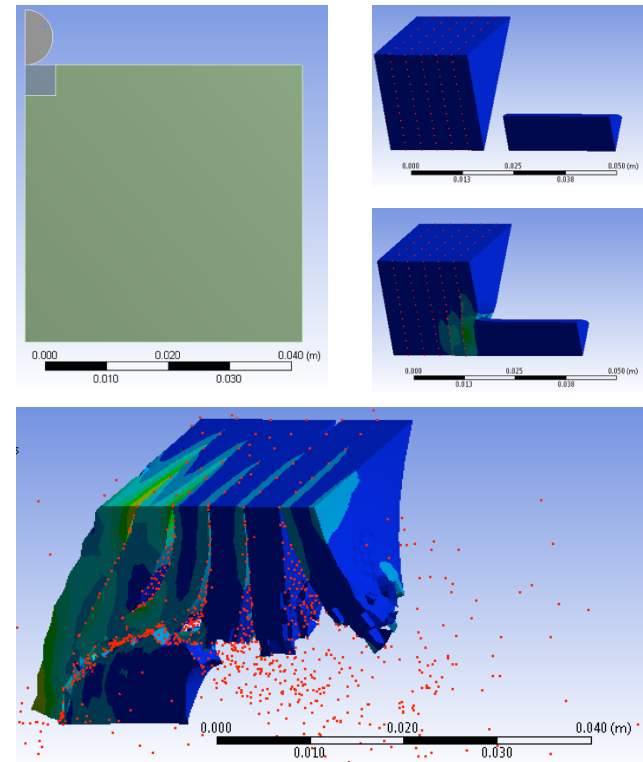
Chemical Modeling

- VESTA
 - Model visualization
 - 3D geometric coordinates
- VASP
 - Multiple bonding simulations to find a molecular spring constant
 - Molecular spring constant relate to elastic modulus through Hooke's Law
- DeepThought
 - Energy minimization
 - Spring constant representing entire system
 - Elastic modulus of the composite



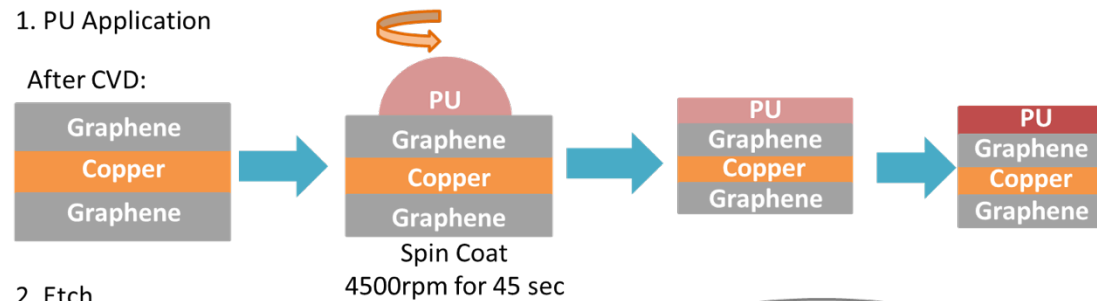
Ballistics Modeling

- Hertzian Contact
 - 2D Axisymmetric
 - Penetration depth
- Impact Testing
 - 300 m/s initial velocity
 - Lead cylinder, graphene, and polyurethane composite
 - PU only

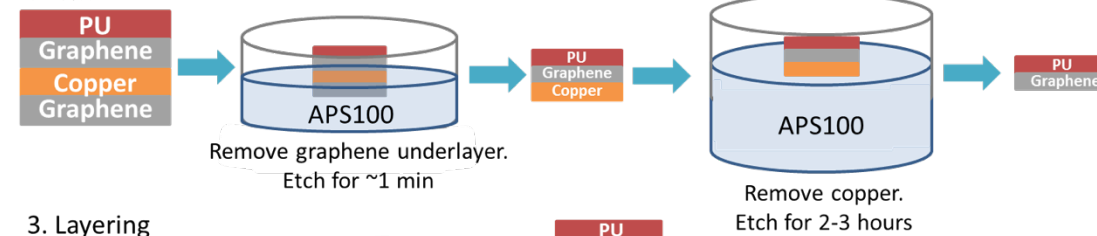


Prototype Fabrication

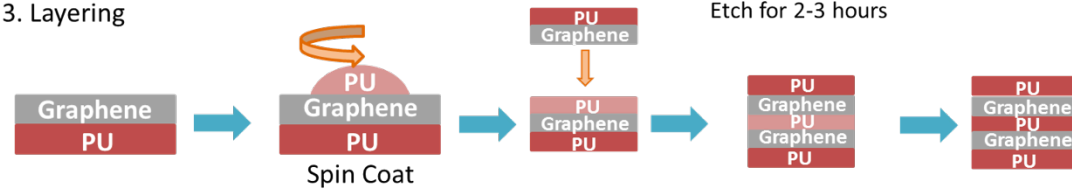
1. PU Application



2. Etch



3. Layering



Results

Chemical Modeling

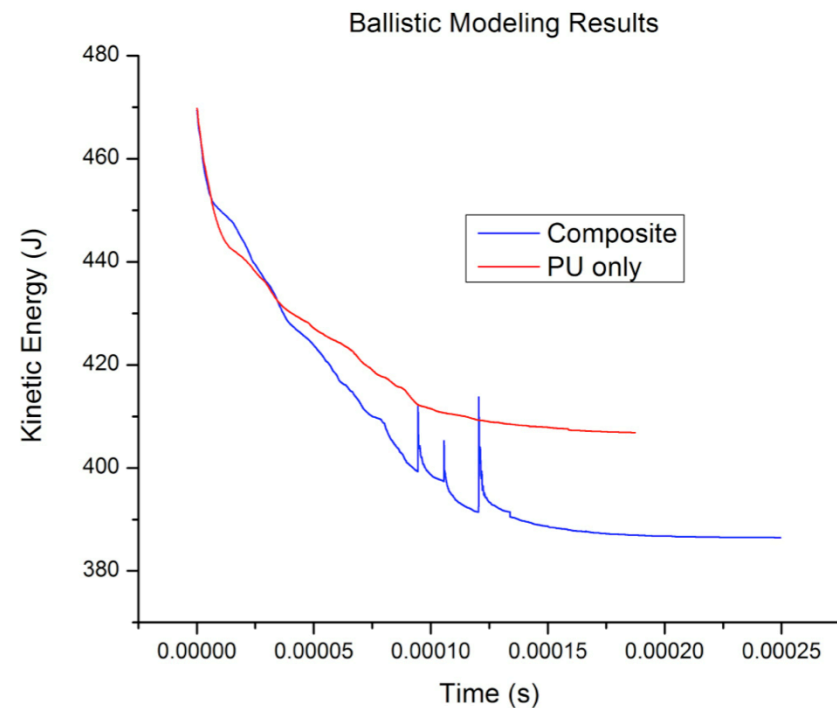
- Edge effects were too large

Ballistics Modeling

- Hertzian: 1.83% error from theoretical
- Impact: 32.4% further reduction in KE with graphene

Fabrication

- Performed CVD to grow graphene
- Tested chemical stability
- Confirmed layer adhesion with newly cast layer



Conclusion

- Composite reduces the kinetic energy and velocity of the bullet compared to PU
 - Developed effective method for lab-scale fabrication
 - CVD, etching, spincoating
 - Promising material combination for transparent armour
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Future Work

- Ballistics Modeling
 - Numerical or experimental method to determine validity
 - Model imperfect graphene and various layer configurations
 - Chemical Modeling
 - Confirm spring constant and elastic modulus
 - Fabrication
 - Test working prototype as proof of concept
 - Lab-scale prototype
 - Scale-up process
 - Meet military standards
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References

- [1] Wu, Huang, Wang, Wu, Yang, Li, Jiang. Hyperbranched-polymer functionalization of graphene sheets for enhanced mechanical and dielectric properties of polyurethane composites. 2012, 7010-7019. J. Mater. Chem., 22, 14.
- [2] Njoroge, Jean L. Atomistic Simulation of Graphene-Polyurethane Nanocomposite for Use in Ballistic Applications. 2012, Doctoral dissertation, Texas A & M University. <http://hdl.handle.net/1969.1/151360>.
- [3] Total Security Solutions. How is Bullet Proof Glass Made? 19, Nov. 2009. <http://www.tssbulletproof.com/how-is-bulletproof-glass-made/>
- [4] Lee J.-H. et al., High strain rate deformation of layered nanocomposites, Nat. Commun. 3:1164 doi: 10.1038/ncomms2166 (2012). <http://www.nature.com/ncomms/journal/v3/n10/full/ncomms2166.html>
- [5] Automotive Tank Purchase Description ATPD 2352, Transparent Armor, Revision R, (U.S. Army, 26 April 2010)
- [6] Lee, Changgu, et al. "Measurement of the elastic properties and intrinsic strength of monolayer graphene." *science* 321.5887 (2008): 385-388.
- [7] Liu, Xiao, et al. "Shear modulus of monolayer graphene prepared by chemical vapor deposition." *Nano letters* 12.2 (2012): 1013-1017.
- [8] Toqueboeuf, W., Mortaigne, B., & Cottenot, C. (1997). Dynamic Behaviour of Polycarbonate/Polyurethane Multi-Layer for Transparent Armor. *Le Journal De Physique IV*, C3-504.
- [9] Craig Lloyd. Polyurethane nanomaterial can stop bullets in their tracks. November 2012. <http://www.slashgear.com/polyurethane-nanomaterial-can-stop-bullets-in-their-tracks-16257367/#>
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