Polyurethane-Graphene Laminar Composite as Transparent Armour

DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
CAPSTONE
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Motivation

1. Current transparent armour is comprised of alternating layers of glass and polymer which crack and shatter upon impact
2. Once the layers have been fractured, the visibility through the window is severely reduced
3. Polyurethane is shatter resistant and bulletproof at thicknesses too large to be practical
4. We propose a design for the next generaton of bulletproof windows by creating a graphene/polyurethane layered composite

Objectives

1. Increase fracture strength ≥ 10%
2. Maintain 90% optical transparency






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Technical Approach

Chemical Modeling

VESTA
-Multiple bonding simulations to find a molecular spring constant through Hooke's Law which relates to elastic modulus

VASP
-3D visualization and geometric coordinates

DeepThought
-Spring constant representing entire system
-Elastic modulus of the composite

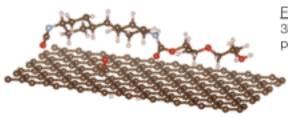


Figure 1: 3D model of graphene/polyurethane system

Ballistic Modeling

ANSYS
-Penetration depth
-Energy reduction vs # of layers

Hertzian Contact
-2D Axisymmetric simulation
-Compare to known relation

Impact Testing
-300 m/s, 6e-4 s, one-eighth symmetry
-Lead cylinder, graphene, and polyurethane composite

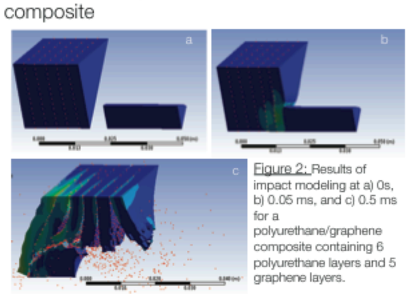


Figure 2: Results of impact modeling at a) 0s, b) 0.05 ms, and c) 0.5 ms for a polyurethane/graphene composite containing 6 polyurethane layers and 5 graphene layers.

Fabrication

Materials

Graphene Sheets	Polyurethane (PU)
Hydrogen Gas Methane Gas Argon Gas Copper Foil	**Part A** Polypropylenglycol **Part B** Dicyclohexylmethan-4,4-di-isocyanate

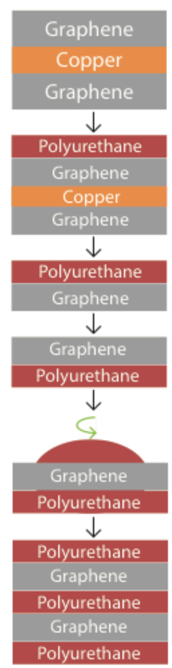
CVD
Flush: Add copper foil to chamber. Purge with 1435 sccm argon for 2 min. Add 814.4 sccm hydrogen and flow at constant rate for 10 min.
Ramp: Continue gas flow. Raise chamber to 1000°C.
Growth: Turn on methane to 60.6 sccm. Reduce H to 211.2 sccm, Ar to 421.2 sccm. Let gasses flow for 1 min to achieve monolayer of graphene.

Spin Coat
Mix: Part A & B of polyurethane in a 1:1.2 ratio by volume.
Cure: 17 minutes.
Coat: Place copper foil on spin coater. Drop 5 mL of polyurethane. Spin for 45 sec at 4500 rpm.
Cure: 2 days at STP.

Etch
Place: Underlayer facing down in APS100 for 1 min (to remove graphene and foil).
Soak: Transfer to new bath of APS100 for 2 hours.

Repeat
All steps above.

Layering
Spin Coat: Polyurethane adhesion layer onto graphene side.
Place: Another polyurethane/graphene module onto adhesion layer.
Cure: 2 Days at STP.



Results

Chemical Modeling
-Oxygen bonds to graphene on defect sites via epoxide bonding
-Polyurethane will bond to epoxide oxygen
-Energy minimization will allow for spring constant calculation

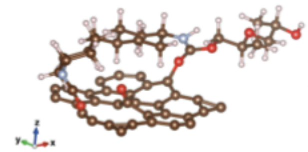


Figure 3: Graphene platelet with epoxide interaction and polyurethane unit

Time restraints did not allow us to complete calculations, the following steps are what we would have done

-Energy minimization to find eqilibrium distance (r_o)
-Energy calculation at r_o and ± 5Å from r_o
-Fit data to parabola to find spring constant
Energy=1/2kx²
-Use spring constant to find elastic moduous
λ= -kx/A

Ballistic Modeling
-Our Hertzian mechanics results showed a penetration depth of 5.619 microns, while the theoretical value comes to be 5.518 microns, giving us an error of 1.83%.
-Impact Modeling
-The kinetic energy of the bullet can be seen to decrease 1.324 times more with the graphene incorporation.

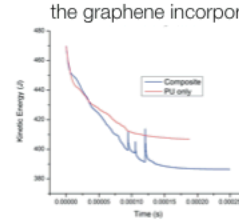


Figure 4: Ballistic modeling results showing energy reduction through a 1-inch PU block compared to a 1-inch PU block with 4 graphene layers, equally spaced.

Resources:
-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
-Liu, Xiao, et al. "Shear modulus of monolayer graphene prepared by chemical vapor deposition." Nano letters 12.2 (2012): 1013-1017.
-Military Detail Specification MIL-DTL-11352, Block, vision: Bullet-resistant, Revision K, (Tank Automotive Research, Development and Engineering Center, 01 April 2013)

Conclusions & Future Work

Conclusions
- Composite considerably reduces the kinetic energy of the bullet compared to just PU
- Developed cost-efficient method of lab-scale fabrication
- Promising material combination for transparent armour

Future Work

Ballistics Modeling
- Numerical method to validate results
- Model imperfect graphene (grain boundaries)

Fabrication
- Lab-scale impact test
- Full-scale ballistics test
- Trasmittance before and after ballistic testing

Scale-up process
- Meet military standards
- Use high molecular weight PU

Environmental Impact
- Disposal
- Recycling
- Lifetime analysis

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