Polyurethane-Graphene Laminar Composite as Transparent Armour

**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

**Fabrication**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Polyurethane (PU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphene Sheets</td>
<td>Part A</td>
</tr>
<tr>
<td>Hydrogen Gas</td>
<td>Polypropylene glycol</td>
</tr>
<tr>
<td>Methane Gas</td>
<td>Part B</td>
</tr>
<tr>
<td>Argon Gas</td>
<td>Dicyclohexylmethane</td>
</tr>
<tr>
<td>Copper Foil</td>
<td>-4,4-di-isocyanate</td>
</tr>
</tbody>
</table>

**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

**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.

**Laminating**

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

**Conclusions & Future Work**

**Conclusions**

- Composites considerably reduce 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**

**Ballistic Modeling**

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

**Fabrication**

- Lab-scale impact test
- Full-scale ballistic test
- Transference before and after ballistic testing

**Scale-up process**

- Meet military standards
- Use high molecular weight PU

**Environmental Impact**

- Disposal
- Recycling
- Lifetime analysis

**Resources**


**Acknowledgments**

- Dr. Cummings, Jeremy, Duy, Dr. Feelies, John Meehan, Steven Lacy, Shelly Villenave, MSE Staff, Dr. Ruboff, Dr. Bonerberger

**Faculty Advisor**

- Dr. Raymond Phanhuat