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ND*nano* Summer Undergraduate Research
2018 Project Summary

1. Student name & home university: Jacob Galden, University of Notre Dame

2. ND faculty name & department: Professor Tengfei Luo, Aeronautical and Mechanical Engineering

3. Summer project title: Stretchable Polymer Composite Film with Extreme Ductility and Toughness

4. Briefly describe new skills you acquired during your summer research:
I became acquainted with using 3D printing to fabricate custom research devices and I learned how to use the mechanical testing geometry on the Discovery HR-2 hybrid rheometer.

5. Briefly share a practical application/end use of your research:
The composite developed in this project displays both ductility and high tensile strength, which usually are not present in the same material. The composite's unique properties make it useful in flexible electronics and other fields where flexible yet strong materials are needed.

6. 50- to 75-word abstract of your project:
Composite films were prepared to have superior strength and ductility by laminating PE fibers between PDMS films. The process includes stretching the PDMS while it is bonding and then relaxing it afterwards in order to produce wrinkles that preserve the PDMS's ductility in the final composite. The composite displays two distinct behaviors depending on its strain ratio: low strain behaves like PDMS but higher strains behave similar to PE.

7. References for papers, posters, or presentations of your research:

1] Li, Xinming , et al. (2016), Large-Area Ultrathin Graphene Films by Single-Step Marangoni Self-Assembly for Highly Sensitive Strain Sensing Application. Adv. Funct. Mater., 26: 1322-1329. doi:10.1002/adfm.201504717Advanced Functional Materials. 26. 1322-1329. 10.1002/adfm.201504717.

[2] Pang, Yunsong, et al. (2018) Exfoliated Graphene Leads to Exceptional Mechanical Properties of Composite Polymer Films.

[3] Yang, Chenying, Wang, Wei & Li, Zhihong. (2009). Optimization of corona-triggered PDMS-PDMS bonding method. 319 - 322. 10.1109/NEMS.2009.5068586.

Currently, flexible electronics are instrumental to medical applications, particularly diagnostic tools. Unfortunately, many of these flexible electronic devices are single-use as removing the device from the patient destroys it. Therefore, developing a material that is flexible and strong enough to offer numerous cycles of use as part of a flexible electronic device would be extremely cost-effective for the industry. However, ductility, toughness, and high strength are rarely found in one material, so a composite must be developed. By combining the ductility of PDMS with the strength and toughness of PE, a composite suitable for flexible electronics and many other applications can be produced.

While the ultimate goal of this project is the implementation of the composite into actual medical devices, for the summer our project was much more focused on optimizing the procedure for manufacturing the composite and characterizing the resulting materials. Working with Paula Murphy (TCD), we developed the procedure from start to finish. Most of the applications of PDMS revolve around microfluidic chips, so using the material for its mechanical properties is relatively uncommon; Paula and I had to solve any issues we encountered largely on our own due to the lack of research and references available. While our process is relatively simple, PDMS introduces many unique challenges that we had to overcome.

To produce a composite sample, we start by combining the PDMS monomer with a cross-linking agent. The liquid mixture is then spread onto glass slides lined with plastic film spacers; the thickness of the spacers can be varied but 100-150 micron is preferred with higher thicknesses required for films with greater surface area. Once the PDMS is cured it is bonded to glass slides using corona surface treatment and subsequently placed into the stretching device as seen in **Figure 1**.

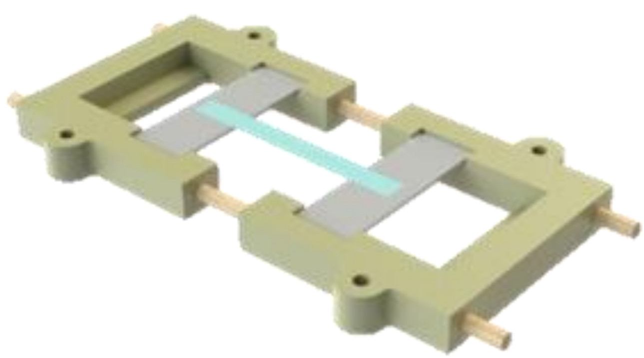

Figure 1: This stretching device was custom made for this project using SolidWorks.

The stretched PDMS surfaces are then corona treated again and a PE fiber is added to one side. Two stretching devices are placed one on top of the other allowing the PDMS to contact one another; the entire assembly is placed into an oven to bond. When the devices are relaxed, distinct wrinkles should form in the composite, otherwise the material will not properly maintain the ductility of the PDMS.

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After making numerous samples, Paula and I went to the SEI MCF to begin testing the best ones. After a few iterations, we found that coating the PE fiber in a thin layer of uncured PDMS provided an excellent bond that prevented the PE from becoming dislodged. Paula and I tested these improved samples against raw PDMS films of similar thickness and obtained astonishing results. The composite behaved almost exactly as anticipated with high ductility displayed at low strain ratios and higher strength once a certain threshold was passed. The PE was able to reinforce the PDMS and withstand forces much beyond that of raw PDMS without compromising ductility. **Figure 2** displays some of our preliminary results, illustrating the superior strength and two-part behavior of the composite.

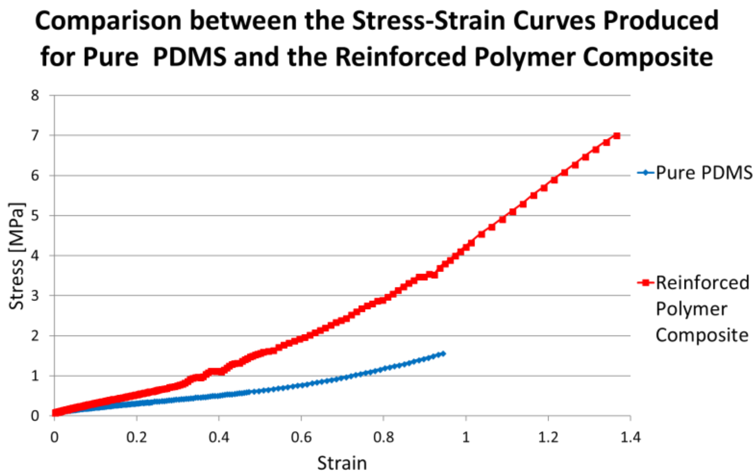

Figure 2: The composite demonstrates similar ductility to the PDMS up until the PDMS breaks at about a 1.0 strain ratio, following that the PE properties dominate.

Ultimately, the produced composite demonstrates many of the properties it was manufactured to possess. Further testing is needed to finish characterizing the material and determine its suitability for flexible electronics. The composite seems to be a promising solution for future innovations in the field and the results suggest that this stage of the project has been a great success.

Acknowledgements:

I would like to thank Professor Luo, Yunsong Pang, and Paula Murphy for their support of this project. It has truly been a pleasure working with all of you. I would also like to thank the SEI MCF for their facilities and equipment and NDnano for providing me with this excellent opportunity.