NDnano
Center for Nano Science and Technology

ND*nano* Summer Undergraduate Research
2019 Project Summary

1. Student name & home university: Stephen Koch, University of Notre Dame

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

3. Summer project title: Fabrication of ductile yet tough polymer nanocomposites

4. Briefly describe new skills you acquired during your summer research:

One major new skill that I acquired during my summer research was learning the physical research process itself, and the steps that it takes to write a scientific paper. Throughout the summer, I conducted a literature review, incorporated this knowledge into the introduction for our paper, and applied these findings as I worked in the lab. Another new skill that I learned through this research was applying the scientific method to independent research. This project was my first research experience, and my only previous lab experience was for physics and chemistry classes. These classes were much different then the research I conducted this summer, as one usually knows the correct answer or desired answer before they start the class. In contrast, this summer I learned how to conduct research with an unknown answer.

5. Briefly share a practical application/end use of your research:

A practical application that I focused on throughout my research was the incorporation of the composite material I created into wearable, flexible electronics. Because of the unique properties of the composite, which are its flexibility and high tensile strength, it would be well suited for such an application. In addition, conductive patterns can easily be printed on the material and subsequently flex and move in response to outside forces.

6. 50- to 75-word abstract of your project:

Polyethylene (PE) and polydimethylsiloxane (PDMS) are two polymers with very different mechanical properties. A composite of these two materials could incorporate desirable properties of both, creating a material that is both flexible but also has a high ultimate tensile strength. Such a material would be useful to create wearable electronics, especially when electrical components are integrated into the material through aerosol jet printing.

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

1. Rogers, J. A., Someya, T., & Huang, Y. (2010). Materials and mechanics for stretchable electronics. Science, 327(5973), 1603-1607. doi:10.1126/science.1182383
2. Agarwala, Shweta; Guo, Goh Liang; Yeong, Wai Yee. (2018). Aerosol jet printed ph sensors based on carbon nanotubes for flexible electronics. Nanyang Technological University. doi:10.25341/D4Q59F
3. Lötters, J. C., Olthuis, W., Veltink, P. H., & Bergveld, P. (1997). The mechanical properties of the rubber elastic polymer polydimethylsiloxane for sensor applications. Journal of Micromechanics and Microengineering, 7(3), 145–147. doi:10.1088/0960-1317/7/3/017

4. Pang, Y., Yang, J., Curtis, T. E., Luo, S., Huang, D., Feng, Z., . . . Luo, T. (2019). Exfoliated graphene leads to exceptional mechanical properties of polymer composite films. ACS Nano, 13(2), 1097-1106. doi:10.1021/acsnano.8b04734
5. Haubert, K., Drier, T., & Beebe, D. (2006). PDMS bonding by means of a portable, low-cost corona system. Lab on a Chip, 6(12), 1548-1549. doi:10.1039/b610567j
6. Gutowski, V., & R. Pankevicius, E. (1993). A novel surface treatment process for enhanced adhesion of ultra-high modulus polyethylene fibres to epoxy resins. Instrumentation Science & Technology, 1 doi:10.1163/156855493X00031

One-page project summary that describes problem, project goal and your activities / results:

The major problem that I investigated in this research was the incorporation of two dissimilar materials into one composite material. These two materials - polyethylene (PE) and polydimethylsiloxane (PDMS) – are quite different, as PE is an extremely strong film that resists stretching, while PDMS is a very flexible polymer but also has a low tensile strength. The goal of this project was to refine an existing process for creating the PE-PDMS composites and investigate other areas that would increase the materials' versatility.

I began the summer by conducting a literature review and attempting to replicate the existing procedure for creating the PE-PDMS composites. PDMS is primarily used within the field of microfluidics, which shares some overlap with this project as many microfluidic projects require the bonding of dissimilar materials to PDMS. In order to accomplish this, several different techniques have been explored by researchers. Some of these techniques had already been incorporated into the existing procedure, while other were potential areas to explore in my research. For example, the corona treatment of PDMS, which uses a plasma beam to form a surface coating on PDMS, had already been tested and incorporated into the procedure. An example of a technique that had not been explored is silane treatments for both PE and PDMS. Silane treatments form a layer of reactive groups on the surface of polymers which could potentially strengthen the bonding between PE and PDMS. Overall, this literature review was helpful in terms of giving me a background in the project and preparing myself for the research.

As I worked on the literature review, I also began to make PDMS-PE composites using the procedure created by previous researchers. This procedure is summarized below in Figure 1.

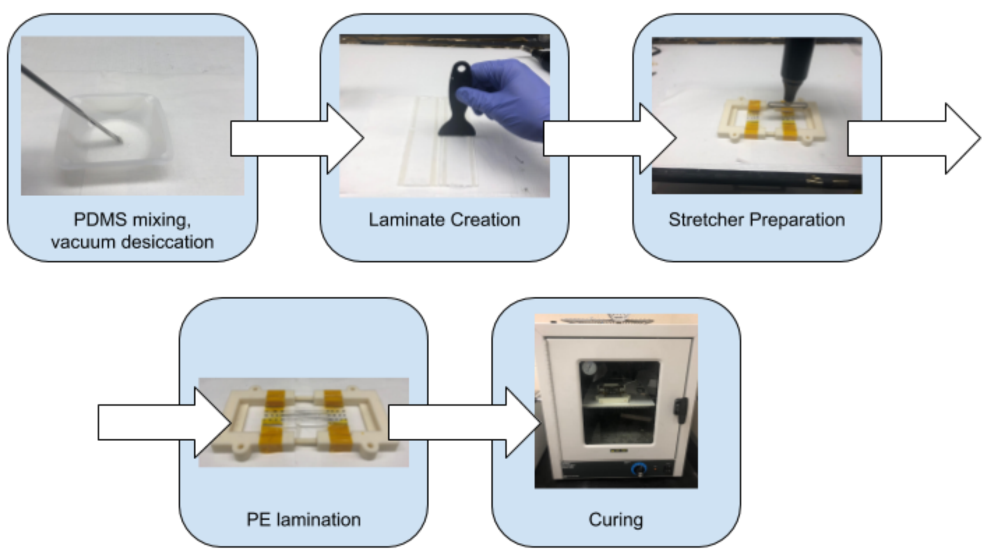

Figure 1. Creation of PDMS-PE Composites

Over the course of the summer, several minor revisions to this process occurred in order to increase the consistency and quality of the composites produced. These revisions included the creation of cutting guides and alignment markers to precisely place the laminates within the stretching device. In addition, as I personally acquired more experience with the process, the quality of the composites improved.

A major part of my summer research was the characterization of the mechanical properties of the composite. This was accomplished by using a combination DMA/rheometer at the Notre Dame Materials Characterization Facility. A DMA/rheometer is a machine (shown below in Figure 2) which exerts a force on a material and measures the subsequent deformation in order to produce a stress-strain curve. These curves can then be used to calculate the modulus of elasticity and tensile strength of the material. A sample curve is displayed below in Figure 3.

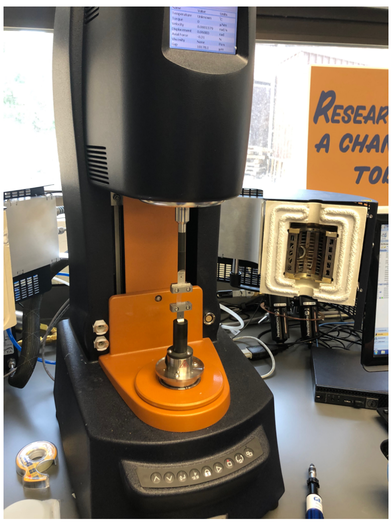

Figure 2. DMA/Rheometer

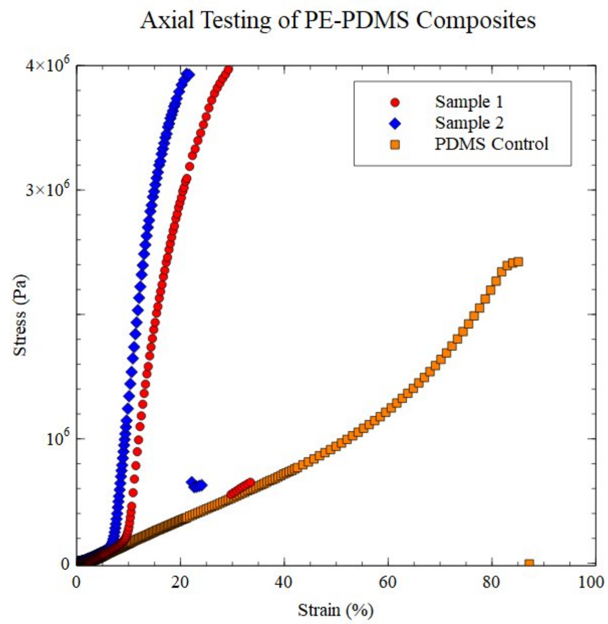

Figure 3. Sample Stress/Strain Curve

The final area explored over the course of this project was printing graphene conductive layers onto the composites. This process enables the creation of flexible electronics using the composite, which was one of the main applications of this material. The printing itself is accomplished with an aerosol jet printer (shown below in Figure 4). A thin layer of graphene is deposited onto the PDMS substrate and subsequently laminated with another layer of PDMS (shown below in Figure 5). This process was only successful when printing under a limited set of conditions, so a future challenge is to improve the quality and range of uses of this process.

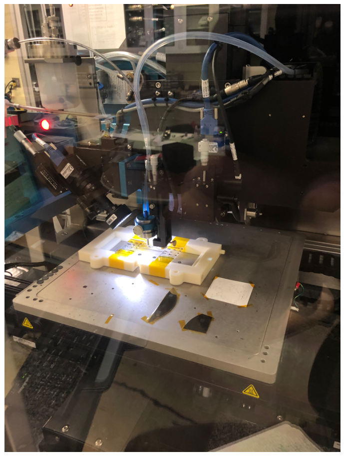

Figure 4. Aerosol Jet Printer

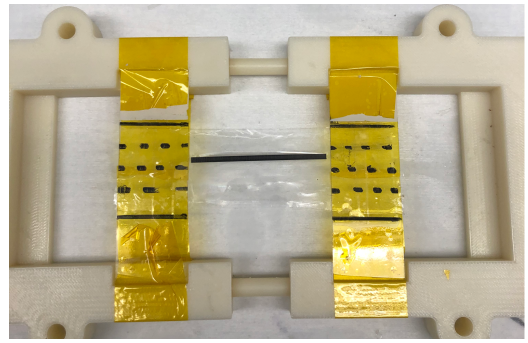

Figure 5. Graphene Printed on PDMS

Future research in this area could focus on several topics. First, there are still some problems with the bonding between the PE and PDMS in the composite. Further exploration of surface treatments like silanes could improve this bonding and thus improve the overall compound. Also, mechanical characterization techniques could be used with composites composed of varying PDMS:PE ratios in order to determine the optimal range. Finally, the graphene printing process needs further optimization before the material could be incorporated into flexible electronics.

I am very grateful for this research opportunity and would like to thank Professor Tengfei Luo for introducing me to this project and letting me work on this throughout the summer. I would also like to thank Heidi Deethardt and NDnano for supporting this research fellowship. I personally feel like I have grown as a student and researcher through this experience, and look forward to applying my experience in future endeavors.