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DDGS Based 3D Printing Biocomposite Filament
Undergraduate Research Award
Reflective Essay

My research began in Fall 2018, the first semester of my sophomore year at North Dakota State University (NDSU). I was meeting with my academic advisor, Dr. Dilpreet Bajwa professor of Mechanical Engineering, to determine which courses to register for in the spring. During the meeting, I informed him that I was the vice president of Project P, the 3D printing club at NDSU. With this proven background in 3D printing, he offered me a position as an undergraduate researcher to develop a 3D printing filament out of Dried Distillers Grains with Solubles (DDGS) and polylactic acid (PLA). DDGS is an abundant coproduct from dry-milled ethanol. It is low-cost and used almost exclusively for animal feed. Introducing this low-cost material to a 3D printing filament would reduce the operating costs of 3D printing. Selling DDGS into the 3D printing market would generate significant revenue for local farmers and the state of North Dakota, and provide 3D printer users with biobased materials that strain the environment less.

I refined my research by using the NDSU library resources. To make a filament out of DDGS, I needed to understand previous work completed with the material as well as its properties. I accessed academic articles and journals that the library was subscribed to and searched my topic. After reading several articles, I was aware of the material properties and shortcomings of previous work. Learning about other researchers discovers was crucial, because it prevented me from losing time on discoveries they made that lead to failure. Working with Dr. Bajwa, we decided that the DDGS-PLA 3D printing filament properties can be improved by adding a plasticizer. He tasked me with identifying three biobased plasticizers, extruding them into a filament, and mechanical testing and classifying them.

My first task was to determine three biobased plasticizers to add to the DDGS-PLA filament. Initially, I was unaware of which ones to select due to the wide variety. I returned to the NDSU library academic articles and journals to search for the information I needed. I employed several research strategies to discover the most relevant and beneficial information for my research. First, I limited my articles to the last five years to prevent my findings from being outdated. Second, I searched keywords describing my research such as DDGS, PLA, 3D printing, and biobased plasticizers. Dr. Bajwa provided the names of several past researchers that worked with DDGS. I was able to add these names to the search engine and find articles written by them that the NDSU library had access to. Finally, I focused on academic articles and journals that related to the fields of engineering, chemistry, and polymers. These fields were the most related to my line of research. After evaluating the abstract and conclusion section of prospective papers, I determine the ones that would be the most beneficial to my project. Carefully examining the selected articles, I was able to determine three biobased plasticizers to use: glycerol, polyethylene glycol, and epoxidized soybean oil.

The next step in my research was to manufacture different filament formulations composed of PLA, DDGS, and the different plasticizers. I had to learn how to use the twin-screw extruder in Dolve Hall to extrude the filament. Dr. Bajwa and his PhD student Jamileh Shojaeiarani showed me how to operate the extruder and helped me determine the extruder processing conditions. Initially, the extruded sample was air cooled. These samples came out very hard and brittle. To resolve this problem, I reached out to Dr. Chad Ulven, professor of mechanical engineering. Several years ago, one of his senior design teams constructed a heated water bath for slowly cooling extruded filament. This makes the samples more ductile because

of the slower cooling rate. The water bath also had a diameter feedback sensor and motors to pull the filament at a constant rate to maintain the diameter. Dr. Ulven allowed me to use the piece of equipment, and his graduate student Joe Fehrenbach showed me how to operate it. The assistance of these professors, PhD, and graduate students allowed me to successfully extrude over ten different filament formulations in 500 gram batches. Without their assistance, it would have taken more time to manufacture the filament. The 3D printers require filament to have a diameter of 1.75mm, otherwise it can not be used. The ease of filament extrusion from the correct manufacturing setup made this part of the project a positive experience.

The final task for my research was to 3D print parts and specimens for tensile and impact testing. The tensile and impact testing were performed in accordance with ASTM D638 and E2248 respectively. The tensile testing was completed on an Instron 5567 with a 2kN load cell and the impact testing was completed on a notched Charpy impact pendulum. Robert Sailor, NDSU's test engineer, trained me on how to safely operate the test equipment and obtain the best data for analysis. In addition to these destructive tests, non-destructive tests were used to determine the filament densities and melt flow indices. After finishing all the tests and analyzing the data, it was determined the PEG-DDGS formulations were the best due to their overall high strengths and excellent 3D print quality.

My research at NDSU paved the way for the rest of my academic and professional career. Due to my research in polymeric materials with NDSU's library, I decided to declare a minor in Coatings and Polymeric Materials to focus my mechanical engineering degree on this field. I received a test engineering internship at Stratasys, a leading company in 3D printing, where I applied my skills in research, materials testing, and analysis. These skills that I developed working on this project played a major role in receiving the internship.

Looking back at my research, there is not much I would change. My research was an excellent experience because of the faculty I worked with and skills I developed. It would have been beneficial if the library had a 3D printer available for me to 3D print my filament with. Most of the 3D printing services at the library are paid by the customer for a part to be made. If the library could offer 3D printers and training to students, it would be an excellent resource for all students interested in research.