DDGS Biocomposite 3D Printing Filament

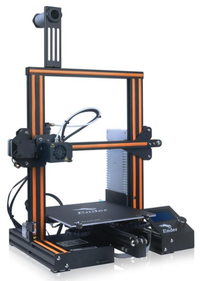
Martin Eichers

Department of Mechanical Engineering, North Dakota State, Fargo, ND 58108.

Email Address: martin.eichers@ndsu.edu

Abstract

Additive manufacturing, also known as 3D printing, is a rapidly evolving technology with applications in many different industries. The market for 3D printing material, filament, is expected to grow to $4.4 billion by 2023. The lack of local, low-cost, bio-based material for 3D filaments is a significant limitation to the widespread implementation of 3D printing. Research is being conducted at NDSU to study the feasibility of developing a biocomposite filament using DDGS (Dried Distillers Grains with Solubles) and PLA (Polylactic Acid). DDGS is an abundant coproduct from dry-milled ethanol. Producing a PLA-DDGS filament will decrease the operating cost of 3D printing by reducing material costs. Polyethylene glycol, glycerol, and epoxidized soybean oil are being introduced to the PLA-DDGS blend to improve the filament properties through plasticization and coupling. The filament is extruded in a twin-screw extruder and then slowly cooled in a hot water both. The filament is then 3D printed and evaluated through mechanical testing. A viable formulation will have equivalent or superior properties compared to standard PLA filament.



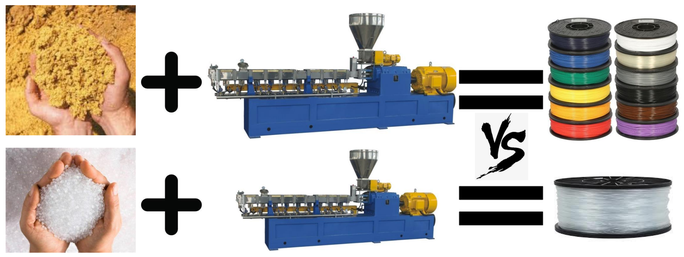
Ender 3 3D Printer

PLA Filament Spools

Introduction

3D printing is often used for prototyping new designs or producing components to complex for traditional manufacturing techniques. One drawback to the technology is the excessive operational costs for 3D printing. A one kilogram (2.2lbs) spool of PLA filament typically costs from $20-50. DDGS is a low-cost additive that can be introduced to PLA formulations to lower the filament production costs.

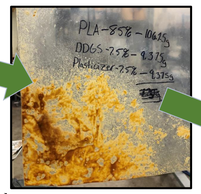
Currently, DDGS is only consumed as animal feed due to its low cost. With an abundant amount of DDGS in North Dakota, creating a product for a new market with this material could generate significant revenue for the state. If only 50% of the 1.3 million tons of DDGS produced in the state is sold at $0.25/lb, over $325 million in revenue could be generated for the state and its farmers. With PLA typically costing over $2/lb, filament manufacturers would be eager to introduce DDGS into their formulations.



Method

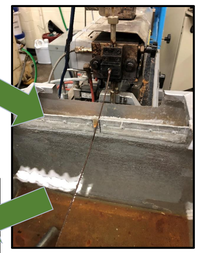
- DDGS is micronized to a 60 µm particle size.
- Formulation of PLA pellets, DDGS powder, and plasticizer is determined.
- The formulation is thoroughly blended and then extruded using a twin screw extruder.
- The filament is extruded into a hot water bed and then pulled by a motor. This allows the filament to maintain a constant diameter.
- The filament diameter sensor displays the diameter of the filament passing through it. Adjustments are made to the motor speed if necessary. Target filament diameter is 1.75 mm.
- Filament with a consistent diameter of 1.75 mm can be used as 3D printing filament for testing. An Ender 3 3D printer is used to print the filament.
- Various shapes are 3D printed to determine print quality. Dogbone tensile and impact test specimens are 3D printed to test mechanical properties using an Instron 5567.

1. Material preparation and formulation determination

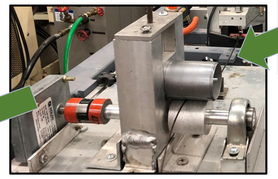


2. Formulation blending

3. Hopper loading

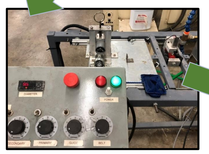


4. Filament extrusion

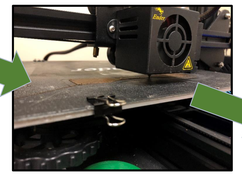


5. Motor pulls extruded filament at a constant rate.

6. Filament diameter sensor records filament diameter

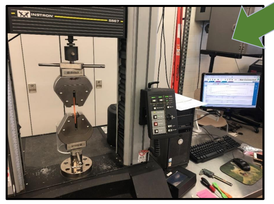


7. Speed adjustments are made on the control panel to maintain a 1.75mm filament diameter.



8. Shapes are 3D printed on an Ender 3 to determine print quality.

9. Dogbone test samples are 3D printed for mechanical tensile testing.



10. Mechanical testing

Materials - DDGS

DDGS composition includes 30% proteins, 10-13% fat, and 35-39% fibers. The proteins act as a resin, the fat acts as a natural plasticizer, and the fiber reinforces the matrix. As a plant based material, DDGS is biodegradable. Adding DDGS to PLA filaments will improve the composite biodegradability, reduce environmental impact, and reduce cost.

Glycerol

Glycerol is often used as a bioplasticizer in plastics and as a sweetener in foods and pharmaceuticals. It is generally obtained from plant or animal sources. This plasticizer will also contribute to the biodegradability of the filament, further reducing environmental impact.

Polyethylene Glycol

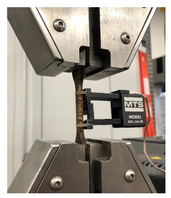
Polyethylene glycol (PEG) is frequently used as a lubricating coating for surfaces in many different environments. It is a biobased, nontoxic plasticizer often made from sugar cane stalks.

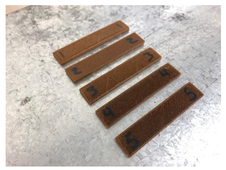
Epoxidized Soybean Oil

Epoxidized soybean oil (ESO) serves as both a plasticizer and a coupling agent. It is commonly used as a plasticizer in PVC and coupling agent in recycled polymers and composites. As a coupling agent, it is expected to improve the adhesion of the DDGS powder to the PLA during processing, creating a stronger biocomposite.

Results

Tensile and impact tests were performed in accordance with ASTM D638 and E2248 standards. PEG-DDGS formulations provided the greatest tensile strength. The ESO-DDGS formulations provided the greatest impact strength and a tensile strength slightly less than the PEG-DDGS formulations. The PEG-DDGS formulation provided the best 3D print quality. Glycerol performed poorly in every aspect compared to the other plasticizers. Nozzle jamming occurred only when 3D printing glycerol, complicating the printing process. The PEG-DDGS formulations were selected as the best option due to the overall superior strength and print quality. Further studies will explore 3D printer parameters and formulation composition changes.





Acknowledgment

Dr. Dilpreet Bajwa and Dr. Jamileh Shojaeiarani for helping me to conduct this research and North Dakota Corn Council for supporting this research.

References

1. B. Tisserat, Z. Liu, V. Finkenstadt, B. Lewandowski, S. Ott, L. Reifschneider, 3D printing biocomposites, Society of Plastics Engineers (2015), Plastics Research Online, 10.2417/spepro.005690
2. M. Maiza, M. Benaniba, G. Quintard, V. Massardier-Nageotte, Biobased additive plasticizing polylactic acid (PLA), Polímeros 25(6) (2015) 581-590, DOI:10.1590/0104-1428.1986
3. V. Tanrattanakul, P. Bunkaew, Effect of different plasticizers on the properties of bio-based thermoplastic elastomer containing poly(lactic acid) and natural rubber, eXPRESS Polymer Letters Vol.8, No.6 (2014) 387–396, DOI: 10.3144/expresspolymlett.2014.43
4. M. Vieira, M. Silva, L. Santos, M. Beppu, Natural-based plasticizers and biopolymer films: A review, European Polymer Journal 47 (2011) 254-263
5. F. Seixas, F. Turbiani, P. Salomao, R. Souza, M. Gimenes, Biofilms composed of alginate and pectin: Effect of concentration of crosslinker and plasticizer agents, The Italian Association of Chemical Engineering Vol. 32 (2013), DOI: 10.3303/CET1332283
6. R. Darie-Nita, C. Vasile, A. Irimia, R. Lipsa, M. Rapa, Evaluation of some eco-friendly plasticizers for PLA films processing, Journal of Applied Polymer Science (2015), DOI: 10.1002/app.43223
7. M. Garcia-Campo, L. Quiles Carrillo, J. Masia, M. Reig-Perez, N. Montanes, R. Balart, Environmentally friendly compatibilizers from soybean oil for ternary blends of poly(lactic acid)-PLA, Molecular Diversity Preservation International (2017)