Development of bio-based PLA/NR blends and DIY mini-extruder for fabrication of 3D printing filaments

Pattiya Pibulchinda

Supervisor: Sarun Nounjeen

Kamnoetvidya Science Academy, Rayong/Thailand, p.pibulchinda@gmail.com

1. Introduction

3D printing is an innovative technique that is applicable to many fields, e.g. prototype shaping and automotive part manufacturing. Biodegradable polylactic acid (PLA) is widely used as a filament in 3D printing, but some of its properties, such as its high brittleness, poor crystallization and cost, make it unsuitable for making commercial products. Herein our project studies way to minimize the cost of 3D printing filament as well as ways to improve toughness of PLA, so that it will be appropriate for many purposes. To improve the properties of PLA, we develop "do it yourself" (DIY) filaments containing PLA and natural rubber (NR), using low cost GreenHero Mini-Extruder, which has been designed and assembled by our team.

2. Objectives

2.1. To design and develop a mini-extruder for small-scale production, and research optimum conditions for DIY filament processing of PLA/natural rubber blends for 3D printer.

2.2. To improve brittleness of commercial PLA 3D printing filament by blending with natural rubber.

3. Experimental

3.1. Blend of PLA and natural rubber

PLA (4043D, 3D Filament grade from NatureWorks, LLC.). Natural rubber slices were cut into small pieces before blending. PLA/NR blends at compositions of 90/10, 85/15, and 80/20 % w/w were mixed using an internal mixer at 170°C and a rotor speed of 50 rpm. The total mixing time was 10 minutes. PLA/NR blends was ground into small pellets using a Plastic Grinder Machine. PLA/NR pellets was, then, dried to remove moisture before extrusion processing.

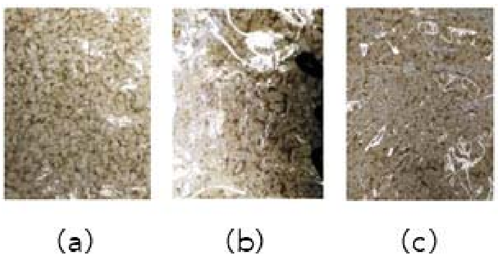

Figure 1: PLA/NR blends at different ratios: a) PLA90/NR10, b) PLA85/NR15, c) PLA80/NR20.

3.2. GreenHero Mini-Extruder design and assembly

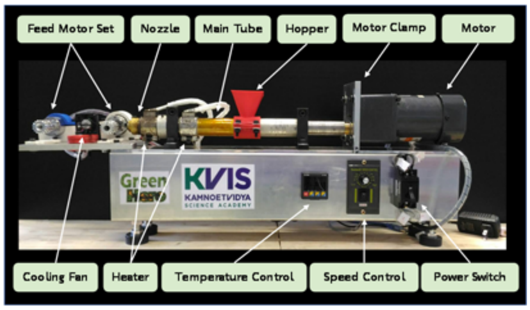

Figure 2: Components of GreenHero Mini-Extruder (Size: 20x79x30 cm, Weight: 11.5 Kg)

3.3. Extrusion of filaments using the GreenHero Mini-Extruder

The pellets of PLA/NR blends were introduced into the system through a hopper of the GreenHero Mini-Extruder. Pellets were forced and heated through a screw and barrel at certain temperatures to melt and mix. The optimum conditions were 145°C, 50 rpm, and 38 rpm for a die temperature, a screw speed, and a feed motor speed, respectively. The molten polymer was formed through a nozzle into filament with a diameter of 1.75 mm.

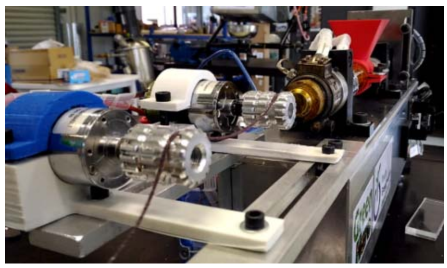

Figure 3: Overall extrusion process using GreenHero Mini-Extruder

3.4. Characterization of PLA/NR blends filament

3.4.1. Morphology of PLA/NR blends

Cryogenic fractures of compressed samples and fractured surface of stretched samples were examined using an SEM (Scanning Electron Microscope) at 2000X magnification.

3.4.2. Mechanical property

Tensile properties of PLA/NR filaments obtained from the GreenHero Mini-Extruder were tested for tensile strength, elongation at break, and Young's modulus, according to ASTM D638, using a universal testing machine model Testometric, with a test speed of 5.00 mm/min.

3.4.3. Application of the filaments in 3D Printer process

Applying filaments to fused-deposition modeling (FDM) 3D Printer is the most popular use. The resulting PLA/NR blend filaments can be used with the same 3D Printer that uses commercial PLA filaments.

4. Results and Discussion

4.1. Morphology of PLA and PLA/NR filaments

The cross-section surfaces of PLA and PLA/NR blend filaments were observed by SEM. Figure 4 (a) shows smooth and homogeneous surfaces of PLA filament. Figures 4 (b, c, d) show the phase of NR domains dispersed in the PLA matrix, as small droplets, reflecting immiscible binary polymer blend.

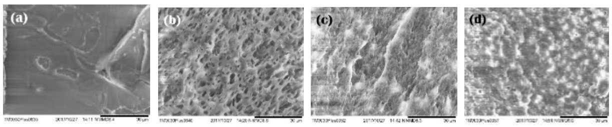

Figure 4: Morphology of PLA and PLA/NR filaments, examined by SEM at 2000X, (a) Pure PLA (b) PLA90/NR10 (c) PLA85/NR15 (d) PLA80/NR20

4.2. Optimal conditions for extrusion

Table 1: Comparison of optimal condition in extrusion process between PLA and PLA/NR blend

4.3. Mechanical properties of PLA and PLA/NR blends filaments

Sample	Raw Material	Tensile Strength (MPa)	Elongation at break (%)	Young's Modulus (MPa)
1	PLA	37.47	3.31	1134.88
2	PLA90/NR10	48.82	4.01	1213.94
3	PLA85/NR15	48.74	3.72	1319.75
4	PLA80/NR20	56.20	3.60	1519.45

Table 2: Tensile strength, Elongation at break, and Young's modulus of PLA and PLA/NR blends

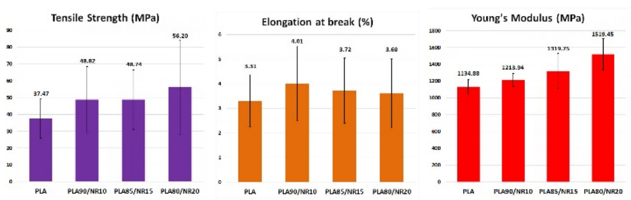

Figure 5: Mechanical properties of PLA and PLA/NR blends

PLA80/NR20 blend provided high strength and modulus (56.2 MPa and 1519 MPa, respectively). However, PLA90/NR10 had the highest elongation at break (4.01%), which was higher than pure PLA.

With the addition of NR, a reduction in brittleness of PLA was evident. The PLA/NR filaments showed higher toughness, according to the results of tensile tests and SEM micrographs.

4.4. Applying PLA/NR blend filament to 3D printer and comparison of each model. There were no distinguishable differences between the three models of PLA90/NR10, PLA85/NR15 and PLA80/NR20, when printed of products with 30 x 30 x 1 mm dimension for 8 minutes. The product from neat PLA filament was hard but brittle.

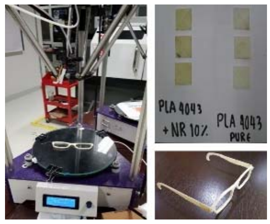

Figure 6: PLA/NR blends products fabricated by a Fused-Deposition Modeling 3D printer.

5. Conclusions

The bioplastic PLA/NR filaments prepared in this study can be extruded using the GreenHero Mini-Extruder. The optimal conditions for extrusion were 145°C, 50 rpm, and 38 rpm for die temperature, screw speed, and feed motor speed, respectively. The extruded PLA/NR filaments were produced at a diameter of 1.75 mm, at a speed of around 64-79 cm/min, and a production rate was approximately 2.66 gram/min.

SEM images show that NR phase was dispersed in PLA as an immiscible characteristic. For mechanical properties, tensile strength increased with increasing of NR content. The elongation at break of PLA90/NR10 filament showed the greatest improvement, compared to neat PLA. The PLA/NR blended filament is estimated to cost about 40-41 USD/kg. Now, this filament is four times cheaper than commercial filaments. The final product is more elastic than the original PLA. This process produces better plastic and adds value to the Thai natural rubber.

6. Future Plan

In our future work, recycled PET from local waste will be developed for use as DIY 3D printing filaments and make this process applicable at commercial scale.

7. Acknowledgements

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