Study material ratio green bean powder and polylactic acid powder for the 3D printing technology selective laser sintering

Ba Bach Dinh1,2,*, Yanling Guo1, a, Tat Thang Nguyen2,3, b, Hui Zhang1, c and Yueqiang Yu1, d

1 College of Mechanical and Electrical Engineering, Northeast Forestry University, Harbin 150040, China
2 Vietnam National University of Forestry, Hanoi 156200, Vietnam
3 Key Laboratory of Bio-based Material Science and Technology of Ministry of Education, Northeast Forestry University, Harbin 150040, P.R. China.

*Corresponding author e-mail: bachfuv@gmail.com, *nefugyl@nefu.edu.cn, b nguyenthathangvu@yahoo.com, c zh1226419340@163.com, dyuyaoqiang.1228@163.com

Abstract. The world's population is increasing, so the demand for material also increases. Currently scientists are therefore searching for new materials that have a stable supply of large quantities. The combination of green bean powder with polylactic acid powder has a composition ratio (10/90; 20/80; 70/30 and 40/60 (wt/wt)) used as input material for 3d printing technology SLS. High-power laser experiments were performed on a mixture of green bean powder and polylactic acid powder (GBCP), which produced a new synthetic material both biodegradable. Then, the GBCP composite material was tested for mechanical properties in each type of mixing ratio, observing the cross section of the material structure. Results obtained at 20/80 (wt/wt) mixing ratio of GBCP composite have a tensile strength of 2.5705 MPa, bending strength of 5 MPa and impact strength of 0.501kJ/m2.

1. Introduction
Selective laser sintering (SLS) is an additive manufacturing (AM) process invented by Carl Deckard at the Mechanical Engineering Department of the University of Texas at Austin. Selective Laser Sintering is an additive manufacturing technique used to build 3-D parts taken from a computer-aided design (CAD) model [1]. Therefore, technology (SLS) can produce complex shapes and designs, prototype parts, etc [2-4]. SLS technology has outstanding advantages over traditional manufacturing techniques: the first being the ability to create complex shapes and designs that are not feasible with most subtractive manufacturing methods. Second, is the ability to go quickly from design to fabrication, often in a matter of hours. These two characteristics make the potential of laser sintering very attractive as a mainstream manufacturing method. [1].

To meet the needs of society, manufacturers and companies are constantly researching new products to stimulate the consumer market, especially in the field of science and technology, with many products, many areas in which are areas of laser printing, used in manufacturing applications, used in manufacturing applications [5-11].
At present, the development of materials for SLS is mainly focused on metals, ceramics, polymers and their corresponding composites [8, 11, 12]. However, material preparation technology is still commercially guarded and very expensive, which restrict the development and application of SLS. Therefore, there is an urgent need to develop new natural and environmentally friendly materials with low cost [2, 4, 9].

The difference between building prototypes versus manufactured Selective Laser Sintering has two main advantages over traditional manufacturing techniques: the first being the ability to create complex shapes and designs that are not feasible with most subtractive manufacturing methods. Second, is the ability to go quickly from design to fabrication, often in a matter of hours. These two characteristics make the potential of laser sintering very attractive as a mainstream manufacturing method.

* Green bean powder is a product of the agricultural sector that is nutritious, good for digestion, small grain size. Based on these advantages, green bean powder is chosen as a component of 3d printing material [13, 14].

* Polylactic acid (PLA) is emerging as one of the most promising alternatives to petroleum-based polymers for various potential applications. Major advantages of PLA include its biodegradability and recyclability, as it is derived from plant-based resources, which are renewable and sustainable. Biopolymers exhibit properties like many petrochemical-based polymers composites. They are being used in the 3-Dimensional Printing industries and as renewable materials in the packaging applications, Bio-composites [6,8,10,15].

Based on the advantages of Green bean powder and Polylactic acid (PLA) ratio fractional by the weight of weight, in use as a feedstock for SLS. New BGCP composite material created after the testing process: Test the mechanical properties of GBCP materials Observe the cross-sectional structure of the material. Results of testing and analysis of material structure is the scientific basis to select the mixing ratio of green bean powder meal with poly lactic acidic powder in GBCP composite material has good quality best bangs.

2. Materials and Methods

2.1. Experimental Materials

Green Bean powder and Polylactic acid (PLA) powder are the main ingredients of the material GBCP (Green Bean Composite).

Polylactic acid powder (PLA) (03052D density 1.24 g/cm3; melt-flow index (MFR) 14 g per 10 min at 210°C) was supplied by Nature-Works (Minnetonka, Minnesota) as a semi-crystalline grade. Biomax (Strong 120) was supplied by Dupont while (Shanghai, China).

Green bean powder: A kind of food powder bought in the market, produced by KangHua Food Company, the company's products are certified product standard ISO9001 products no. NY / T906-2006 raw materials and green beans. The address of the company Wang Heng Economic Development Zone, Xinghua, Jiangsu, China.

![Figure 1. (a) Green Bean powder (b) PLA powder](image)
Before the green bean powder was mixed with PLA powder it was dehydrated for 5 h in an incubator of Beijing Longyuan Technology Ltd. (Beijing, China) at a temperature of 50°C. During dehydration, the green bean powder was weighed at 1 h intervals until the mass kept constant. Then, the dried green bean powder was mixed with PLA according to specific formulas (10/90; 20/80; 30/70; 40/60). These materials were mixed in SHR50A high-speed mixer from Zhangjiagang Hongji Machinery Ltd. (Dongying, China) for 10 min.

2.2. Laser sintering experiment
Laser sintering experiments: The sintering process of the GBCP parts with different ingredient proportions were conducted on an AFS-360 rapid prototyping equipment produced by Beijing Longyuan Technology Ltd. (Beijing, China). The equipment and description of the components that integrate of the printer AFS-360 during product printing shown in Fig. 2.

The principle of technology of laser sintering experiment: The process is started by heating up a flat surface of powder to a temperature below but near the melting point, and then melting those particles that form the desired cross section with a laser. The surface is then lowered, a new layer of powder is rolled on top of the old one, and the process begins again. These steps are repeated often thousands of times to build an entire part.

![Figure 2. The equipment and description of the components that integrate of the printer AFS-360 during product printing.](image)

2.3. Mechanical testing
Mechanical testing was performed on a CMT5504 testing machine from TMS System Company and a TCJ-4 impact touching screen testing machine with simply a supported beam produced by the Tai He Testing Machine Limited, Jilin Province.

The test standards are as follows: Tensile strength was tested according to the ISO527-2 Standard, crosshead speed was 5 mm/1 min, and the gauge length was 50 mm.

Flexural strength was tested under three-point bending according to the ISO178 Standard. Crosshead speed was 0.1 mm/1 min, and span length was 64 mm.

Unnotched impact strength was tested according to the ISO179-2 Standard. Pendulum impact energy was 4 J, and span length was 60 mm. Fig.3 showed that Mechanical tests include (Tensile strength; Flexural strength; and impact strength).
2.4. Microstructure characterization

The cross sections of the sintered GBCP structure composite samples were analyzed with scanning electron microscopy (SEM). The GBCP parts with different ingredient proportions. The extrusion cross sections of the sintered GBCP of the samples were sputter-coated with gold and analyzed under a scanning electron microscope (SEM; FEI QUANTA 200) at the working distance of approximately 25 mm, voltage of 12.5 kV, and probe current of 6 × 10-10 A (high vacuum, detectors of ETD, and spot size of 6.5). Electronic scanning microscope produced by the Dutch company was used to observe and obtain images of the microstructures of cross sections in the material GBCP composite.

3. Results and discussion

3.1. The fabrication of the specimens

The STL-format tensile specimens (dimension: 170 x 13 x 4 mm³) were designed according to ISO527-2 standard. The STL-format flexural specimens (dimension: 80 x 13 x 4 mm³) were designed according to ISO178 standard and the STL-format unnotched impact specimens were designed (dimension: 80 x 10 x 4 mm³) according to ISO179-2 standard [8].

The specimens of neat polylactic acid and GBCP composites were fabricated by an AFS-360, equipped with a 55 W carbon dioxide laser (wavelength: 10.6 mm; laser beam diameter: 2.6 + 0.4 mm³). Through a lot of single-layer experiments, the suitable processing parameters of SLSTM for the GBCP composites were found, which were as follows: laser power of 23 W, scanning speed of 2000 mm/s, layer thickness of 0.1 mm, scan spacing of 0.2 mm, preheating temperature of 82°C, and processing temperature of 105°C.

The observation in Fig. 4 shows that the color of the product surface after the printing process becomes denser as the composition of the green bean powder increases.
3.2. Mechanical property analysis

![Figure 5](image)

**Figure 5.** The mechanical properties change
(a) Tensile strength; (b) bending strength; (c) impact strength

Fig. 5a shows that traction is always reduced as a straight line as the percentage of ingredients in the bean pulp mass increases gradually. The tensile strength value decreases from 3.50 MPa, 2.57 MPa, 1.63 MPa, 0.74 MPa by the ratio 10/90, 20/80, 30/70, 40/60.

Fig. 5b shows that the bending strength of green bean powder and polylactic powder was decreased from 6.50 MPa, 5.00 MPa, 2.17 MPa, and 1.35 MPa by the ratio 10/90, 20/80, 30/70, 40/60.

Fig. 5c shows the value of continuous cutting force by changing the soybean starch composition. At 30/70. The impact strength value decreases from 0.59 kJ/m², 0.50 kJ/m², 0.46 kJ/m², and 0.23 kJ/m² by the ratio 10/90, 20/80, 30/70, 40/60.

Mechanical property analysis showed that the data demonstrate that the average mechanical properties of green specimens of GBCB composite decrease with the increase in the proportion of green bean powder. This may be explained by the increased green bean powder, associate between green bean powders with PLA powder is reduced, so that the mechanical properties also decreased. This is also demonstrated in the analysis of the microstructure analysis material structure in the bottom.

Comparing 4 ratios together, the ratio of 10/90 to the highest mechanical value, the ratio of 40/60 is the smallest value. However, to ensure that the material is environmentally friendly, reducing the PLA powders, increasing the rate of bean powder that mechanical value remains a priority for selection. Therefore, the ratio of 20/80 is the optimal rate that we choose.

3.3. Microstructure analysis

Observations on the image of the structure of materials GBCP through the mixing ratio of green bean powder and polylactic powder.
Fig. 6 (a-f) shows the SEM image of the cross section of the GBCP sintered components with the input of the weight ratio of green bean powder and polylactic acid, from which microstructures can be observed in detail.

Fig. 6a and b showed that the mixing ratio of 10/90 (green bean powder/PLA powder): The presence of pea starch between the two layers makes the gap narrower and distributing in less polylactic resins. Therefore, at this mixing ratio, the mechanical properties are at their highest performance Fig. 5. The glossy surface, the product after the laser embossing process is much more curved. Observations showed that the PLA powders completely covered the bean powders. In addition, the PLA powders also linked together in the form of polymer linking. Therefore, the mechanical properties at this rate reached the highest value.

Figure 6. The scanning electron microscopy (SEM) diagrams of cross-sections of GBCP parts with different ingredient proportions: GBPC parts 10/90 (a and b); GBPC parts 20/80 (c and d); GBPC parts 30/70 (d and e); GBPC parts 40/60 (e and f).

At the ratio of 20/80 as shown in Fig. 6c and 6d, bean powder is still covered with PLA powders, but there are air holes due to the PLA powders does not cover completely. This leads to resulting in porosity.
As a result, the spacing between the layers of the printed material is wider, which in turn reduces the mechanical properties of the material. The surface observation of the product is illustrated in Fig. 3, which shows that at this ratio the product is fresher, the quality of the samples is the best.

At 30/70 and 40/60 ratios (Fig.6 c,d,e,f), the content of green bean powder in GBCP increased and the weight of polylactic resin decreased in inverse proportion. Therefore, the amount of polylactic acid in the melting process is not sufficient to cover the amount of green bean starch, and the porosity of the foam material increases in accordance. This reduces the mechanical properties of the material. The ratio of 30/70 for mechanical properties is lowest. The cause of the bond between beans is very poor. Therefore, this ratio is not recommended for 3d print products.

It Fig.6 can be seen that, in every photograph image, the Green bean starch remain intact and there is no decomposition. The void fraction between the bonding of the material is the main cause of the mechanical deterioration of the GBCP composite material.

4. Conclusion
The study successfully embroidered green bean powder and polylactic acid with a successful laser printer, creating a new synthetic GBCP biodegradable material. After checking the mechanical properties and the structure of the GBCP synthetic material, we come to the following conclusions:

1) GBCP synthetic materials with mechanical properties are reduced in inverse proportion to the porosity of the material while increasing the proportion of green bean powder weight.

2) At a mix ratio of 20/80 of green bean powder and polylactic resin, GBCP showed good color, and good bond between bean starch and polylactic resin, leading to these mechanical properties: tensile strength was 2.5705MPa, bending strength is 5Mpa and impact strength is 0.501 kJ/m2.

3) The experiment has demonstrated that the GBCP composites can be sintered by AFS-36.

4) GBCP composites are sustainable, environmentally friendly, nontoxic, and biodegradable materials with low cost.

Acknowledgments
This study was supported by the National Natural Science Foundation of China (51475089), the Basic Research Funds of the Central University (2572015AB12) and the Doctoral Special Fund (20130062110006). This study was supported by the National Natural Science Foundation of China (51475089), the Basic Research Funds of the Central University (2572015AB12) and the Doctoral Special Fund (20130062110006).

References
[1] D. Zhao, Y. Guo, K. Jiang, H. Zhang, Preparation and selective laser sintering of bamboo flour/copolyester composite and post-processing, Journal of Thermoplastic Composite Materials 30(8) (2015).
[2] J.P. Wojciechowski, L.G. Lacerda, E. Schnitzler, I.M. Demiate, Physicochemical, structural and thermal properties of oxidized, acetylated and dual-modified common bean (Phaseolus vulgaris L.) starch, Ciência E Tecnologia De Alimentos 38(1) (2018).
[3] Y. Yu, Y. Guo, T. Jiang, K. Jiang, J. Li, S. Guo, Laser sintering and post-processing of a walnut shell/Co-PES composite, Rsc Advances 7(37) (2017) 23176 - 23181.
[4] Z. Zhang, R. Chen, L. Sun, Y. Sun, L. Li, X. Li, M. Li, Study on sintering process optimization of Beiying sinter, Sintering & Pelletizing (2017).
[5] S.K. Bhatia, K.W. Ramadurai, 3D Printing and Bio-Based Materials in Global Health, Springerbriefs in Materials (2017).
[6] S. Khalid, L. Yu, L. Meng, H. Liu, A. Ali, L. Chen, Poly(lactic acid)/starch composites: Effect of microstructure and morphology of starch granules on performance, Journal of Applied Polymer Science 134 (46) (2017) 45504.
[7] J.P. Kruth, P. Mercelis, J.V. Vaevenbergh, L. Froyen, M. Rombouts, Binding mechanisms in selective laser sintering and selective laser melting, Rapid Prototyping Journal 11(1) (2005)
[8] F. Kucherov, E. Gordeev, A. Kashin, V.P. Ananikov, 3D printing with biobased PEF for carbon neutral manufacturing, Angew Chem Int Ed Engl (2017).

[9] F.A. Kucherov, E.G. Gordeev, A.S. Kashin, V.P. Ananikov, Three-Dimensional Printing with Biomass-Derived PEF for Carbon-Neutral Manufacturing, Angewandte Chemie 129 (50) (2017).

[10] K. Oksman, M. Skrifvars, J.F. Selin, Natural fibres as reinforcement in polylactic acid (PLA) composites, Composites Science & Technology 63(9) (2003) 1317 - 1324.

[11] K. Makoto, K. Yutaka, M. Hiroshi, Y. Koichi, E. Philipd, Surface deterioration of wood-flour polypropylene composites by weathering trials, J. Wood. Sci 53 (3) (2007) 234 - 238.

[12] S.O. Akande, K.W. Dalgarno, J. Munguia, J. Pallari, Assessment of tests for use in process and quality control systems for selective laser sintering of polyamide powders, J. Mater. Process. Tech 229 (2016) 549 - 561.

[13] F. Rengier, A. Mehndiratta, H. Von Tengg-Kobligk, C.M. Zechmann, R. Unterhinninghofen, H.-U. Kauczor, F.L. Giesel, 3D printing based on imaging data: review of medical applications, International journal of computer assisted radiology and surgery 5 (4) (2010) 335 - 341.

[14] S. Sumardiono, I. Pudjihastuti, A.R. Poerwoprajitno, M.S. Suswadi, Physichemical properties of analog rice from composite flour: Cassava, green bean and hanjeli, World Applied Sciences Journal (2014).

[15] S.K. Bhatia, K. Ramadurai, 3D printing and bio-based materials in global health, SpringerBriefs in Materials. Google Scholar (2017).