Mechanical properties and foaming behavior of Poly(lactic acid) blend Polybutylene Succinate

W. Bualuang1, P. Threepopnatkul1,*, and A. Sittatrakul1

1Department of Materials Science and Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom, 73000, Thailand

*Corresponding author: poonsopt@yahoo.com

Abstract. The extensive use of non-biodegradable plastics has been causing serious environmental pollutions because of the degradability issue from especially consumable food packaging. In this research, biodegradable materials i.e., Poly(lactic acid) (PLA) and Polybutylene succinate (PBS) are chosen for the study. PLA/PBS foam was prepared using Azodicarbonamide (ADC) and Poly(ethylene glycol) (PEG) 20 wt% as a blowing agent and plasticizer, respectively. Foamability of different content PLA/PBS blend were investigated. PLA/PBS foam were characterized by Water absorption, Flexural testing, Scanning Electron Microscope (SEM). Flexural properties of PLA/PBS foam (70/30) showed the highest flexural modulus of 384 MPa due to the smallest cell size while PLA/PBS foam (20:80) showed the highest flexural stress of 11 MPa. PLA/PBS foam showed uniform cell size distribution. PLA/PBS foam had water absorption ability due to its porous structure.

1. Introduction

The plastic packaging industry has been continuously developed to suit for the products and consumers needs in the markets and lifestyles. Fresh has been developed and improved to have properties that are more suitable for use. General, the improvement and development of the packaging properties still focus on reducing pollution to the world. In this research, the properties of the packaging will be developed to be more versatile, focusing on the packaging that is used to store fresh food or foods that contain the liquid in the package. Foam packagings are generally porous materials which have a high surface area, high permeability, and lightweight, leading to lower cost of processing. According to Zhou et al.[1], the packaging will be developed in this research that expected to capable of absorbing any excessive liquid to reduce such problem in the fresh produces. However, environment friendly packagings will also be considered as part of this research. In this recently years, the plastic industries slowed down quite considerably due to behavioral changes of environmental concerns and lifestyle. Basic packagings such as plastic bags with handles that are more likely to be used lesser than before due to the global trend including public and private campaigns. Therefore, it is necessary to search for the innovative ideas of creating more versatile yet less polluted for the nuvo packaging. In this study, biodegradable plastics will be used to mold into foam packages. The bioplastics used in this research is biodegradable plastic namely Poly(lactic acid). Currently, Poly (lactic acid) or PLA has been used widely due to its production bases globally. Still, there are some limitations in terms of mechanical properties because of its brittleness if the end product is molded by using only PLA. As a result, the foam packages would be susceptible to crack in the end user’s hands. This will definitely cause the hesitation for consumers of not wanting to use PLA for foam packaging. Therefore, it is technically necessary to raise its overall
properties mechanically into the packages. Polybutylene Succinate (PBS) is a biodegradable plastic as same as Poly(lactic acid). Only PBS cannot be produced from natural materials. PBS possesses good flexibility and better thermal stability than Poly(lactic acid) [2]. Stability of foaming is another important property related to its elasticity. Therefore, PBS is selected for blending with PLA in this study. In this research, mechanical properties, foaming behavior and water absorption are thoroughly investigated on the PLA/PBS foam.

2. Experimental

Materials
Poly(lactic acid) (PLA) (2003D, \( \rho = 1.24 \text{ g cm}^{-3} \), and MFI = 6 g 10 min\(^{-1} \)) and Poly butylene succinate (PBS) (FZ91PM, \( \rho = 1.26 \text{ g cm}^{-3} \), and MFI = 5 g 10 min\(^{-1} \)) was supplied by Nature Works and PTT MCC BioChem, Thailand, respectively. Poly ethylene glycol (PEG) (Mw = 8,000) were supplied by A.C.S.Xenon Limited Partnership was used as a plasticizer. Azodicarbonamide (ADC) (Sunfoam SB00P, Lautan Luas Co., Ltd., Thailand) was used as a chemical foaming agent. PLA, PBS, ADC, and PEG were dried at 70°C for 24 h. before use.

Compounding and foaming processes
The mixture of various PLA and PBS proportions were prepared as seen in Table 1. The contents of ADC and PEG at 1 phr, 20%wt respectively. PLA/PBS blend was extruded by a co-rotating twin-screw extruder (L/D = 32, LTE20-32, Labtech Engineering Co., Ltd.) with the temperature profile of 110, 120, 130, 140, 145, 150, 160, and 150 °C from hopper to die and the screw speed of 150 rpm. The extrudate was dried at 70°C for 24 h and then sequentially foamed by compression molding (PR1D-W300L350) with the temperature profile of 150 °C preheat 3 min and compression time 5 min.

Table 1. The composition of compounding formulations.

| Sample      | PLA (wt%) | PBS (wt%) | PEG (wt%) | ADC (phr) |
|-------------|-----------|-----------|-----------|-----------|
| PLA100/PBS0 | 100       | 0         | 20        | 1         |
| PLA80/PBS20 | 80        | 20        | 20        | 1         |
| PLA70/PBS30 | 70        | 30        | 20        | 1         |
| PLA60/PBS40 | 60        | 40        | 20        | 1         |
| PLA50/PBS50 | 50        | 50        | 20        | 1         |
| PLA40/PBS60 | 40        | 60        | 20        | 1         |
| PLA30/PBS70 | 30        | 70        | 20        | 1         |
| PLA20/PBS80 | 20        | 80        | 20        | 1         |
| PLA0/PBS100 | 0         | 100       | 20        | 1         |

Foam morphology analysis
To investigate the foam microstructure, samples were cryo-fRACTured under liquid nitrogen and then coated using a Gold (Au) sputtering technique. Samples were observed by using a scanning electron microscope (SEM, TM3000, Hitashi). The micrographs were also used to calculate the number of bubbles per cm\(^3\) of foam using Eq. (1).

\[
N_f = \left( \frac{nM^2}{A} \right)^{\frac{3}{2}}
\]  

(1)
where \( N_f \) is the number of bubbles, \( n \) is the number of cells, \( M \) is the magnification factor, \( A \) is the area of the micrographs.

**Water absorption**

Weight of the samples was recorded at different time intervals and compared with the initial dry weight. The weight gain was then calculated. Water absorption ratio was calculated using the following Equation (2).

\[
\text{Absorption ratio} = \frac{W_t - W_0}{W_0} \times 100
\]

Where \( W_t \) is the weight gain at time \( t \) and \( W_0 \) is the initial dry weight before treatment.

**Mechanical properties**

Flexural tensile strength and Flexural modulus of the PLA/PBS foam were tested according to ASTM D790 using a universal testing machine (Instron model 55R4502) at the crosshead speed of 10 mm min\(^{-1}\) with 5 kN.

3. Results and discussion

3.1. Mechanical properties

![Figure 1. (a) Flexural modulus, (b) Flexural stress of PLA-PBS blend foam samples](image)

The mechanical properties of foam samples are shown in Figure 1. The results showed that flexural tensile strength and flexural modulus of PLA/PBS foam. Flexural tensile strength increased with increasing PBS fraction because the structure of PLA/PBS foam at PBS-rich has porous less than PLA/PBS foam at PLA-rich due to large pore size may be stress concentration\[3\]. Moreover, the Flexural modulus of PLA/PBS blend foam follows approximately the rule of mixtures over the whole composition range. Flexural modulus of PLA/PBS blend foam decreased with increasing PBS fraction due to pore size. The small pore size has a larger cell wall than the large pore size which PLA-rich has pore size larger than PBS-rich therefore PLA-rich has higher flexural modulus than PBS-rich\[4\].
3.2. Scanning Electron Microscope

![SEM micrographs of different weight percent of PLA-PBS blend at 120x magnification](image)

Figure 2. SEM micrographs different weight percent of PLA-PBS blend at 120x magnification a) 100:0, b) 80:20, c)70:30, d) 60:40 e) 50:50, f) 40:60, g) 30:70, h) 20:80, j) 0:100

PLA-PBS blend foam morphology was investigated as shown in Figure 2. All samples showed uniform cell size distribution. PLA foam has a cell size of about 125 microns and cell density about 2.4 x10⁴ cell/cm³ while PBS foam has cell size about 150 microns and cell density about 1.8 x10⁴ cell/cm³ as shown in Figure 3. The cell size of PLA-PBS foam increases with PBS fraction increase while the cell density of PLA-PBS foam decreases with PBS fraction increase as shown in Figure 3 as a result of the difference between viscosity of PLA and PBS phase and temperature processing of PLA/PBS. PLA has a melting temperature at 160°C and PBS have a melting temperature at 115°C when forming the specimen, using temperature processing at 150°C leading to PBS-rich couldn’t hold and agglomerated into larger cell size when compared to high PLA fraction results in higher cell size and lower cell density in PLA-PBS foam with higher PBS fraction but cell size of PLA-PBS at 80:20 have the larger more than pure PBS because ADC is compatible with PLA more than PBS thus number of porous in PLA-PBS at 80:20 more than pure PBS and agglomerated. One more reason PBS showed lower viscosity than PLA[5], PBS-rich have larger pore size more than PLA-rich as a result of the viscosity PLA-PBS foam decreased with PBS fraction increase[6].
3.3. Water absorption

The water absorption of PLA/PBS blend foam is shown in Figure 4. All samples had water absorption ability due to its porous structure. Water absorption of PLA/PBS foam with PLA-rich and PBS-rich has been investigated and it was found to decrease with increasing PBS content due to the polarity of PBS less than the polarity of PLA[7], leading to water can absorb into PLA-rich more than PBS-rich. PLA100/PBS0 increased in weight by 35%, it’s the highest absorption ability while PLA0/PBS100 increased in weight by 4.98%, it’s the lowest absorption ability.
4. Conclusion

PLA/PBS foams at different PLA and PBS ratios were prepared by compression molding. Foam samples showed more uniform cell morphologies and higher flexural modulus of PLA-rich samples, whereas flexural stress of PLA/PBS foam increased with increasing PBS fraction. The cell size of PLA/PBS foam increases with PBS fraction increase while the cell density of PLA-PBS foam decrease with PBS fraction increase. Water absorption of PLA/PBS foam was found to increase with increasing PBS content.

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