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Comparison Foaming Behaviour of Polylactic Acid and Polypropylene

M. Eryildiz[a,*], M. Altan[a] and T. Osswald[b]

[a]Yildiz Technical University, Department of Mechanical Engineering, 34349 Istanbul, Turkey

[b]University of Wisconsin-Madison, Department of Mechanical Engineering, Madison, USA

Polymer foams have wide application area due to their light weight, resistance to impact, ability of insulation, and damping properties for specific applications. In this study, two different thermoplastic materials, polylactic acid (PLA) and polypropylene (PP), were used to compare their foaming ability in foam injection molding. Chemical foaming agent, azodicarbonamide, was used in foam injection molding and tensile test samples were obtained. Mechanical strength of the polymer foam samples were investigated by tensile test. Scanning electron microscopy was applied in order to observe the differences in cell morphologies of PLA and PP foams. It has been seen that 23.4% higher cell density and 151.2% higher cell size have been seen in the PLA foam when the results were compared with PP foam. This induced sharp reductions in mechanical strength of PLA foam while PP foams gave smooth decreases in the mechanical strength. Weight reduction in PLA was also 366.6% higher than that of PP foam due to its higher cell density.

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PACS/topics: polymer foam, polylactic acid, polypropylene, injection molding, chemical foaming, cell morphology, mechanical strength

1. Introduction

Polymeric foams are widely used in several fields due to their lightness, reduced thermal conductivity, high energy absorption, and damping properties [1–4]. Two common thermoplastic foams used in industry are PP and PLA foams. Polypropylene foams are used due to their rigidity and stiffness that make them suitable for structural applications [4–6]. PLA foams are used in food, cosmetic, pharmaceutical packaging, and biomedical applications due to their biobased property [2–5]. However, both thermoplastic materials, PP and PLA, show different foaming behavior in foam injection molding and give different cell morphology and skin layer generation. Polymers can be foamed by any of the existing foaming processes using either physical or chemical foaming agents [7]. Physical foaming agents provide expansion by undergoing changes in their physical state [8] such as volatilization of a liquid or release of a compressed gas after its incorporation into a polymer under pressure. Chemical foaming agents are generally solid substances that generate a gas or mixture of gases through a chemical reaction. Injection foam molding is one the most preferred manufacturing methods in foam processing for polymer foams for obtaining complex geometrical parts [9–11]. There has been a large number of studies about foam injection molding, either by chemical [12–15] or physical foaming agents [4, 16–18]. In this study, two different thermoplastic materials, PLA and PP were foamed by chemical foam injection molding and their foaming ability was compared.

*corresponding author; e-mail: mdemirci@yildiz.edu.tr

2. Experimental procedure

The polypropylene (PPC 4660) with 3.5 g/10 min of melt flow index and 0.90 g/cm^3 of density was obtained from Total Inc. PLA (3001D Natureworks supplied by Resinex Inc. Turkey) with 22 g/10 min of melt flow index and 1.24 g/cm^3 of density was used in the experiments. In order to obtain tensile bars of PLA and PP foams, foam injection molding with chemical foaming agent of azodicarbonamide (AC, 1 wt%) was carried out. The mold temperature was 208 °C and cooling time 20 s. Holding pressure was not applied. The tensile properties were determined by using a universal tensile machine, Sintec 10/GL. ASTM 638 Type I tensile bars, and 50 mm/min of test speed was used. The scanning electron microscopy (SEM) investigations were made on JEOL Neoscope SEM (Nikon) with an accelerating voltage of 10 kV.

3. Results and discussion

The fracture surfaces of the polymer foams were investigated by scanning electron microscope, as shown in Fig. 1. Area measurements of the cells are performed using Image J which is an open source image processing program designed for scientific multidimensional images

$$N_{\text{cell}} = \frac{\rho_p}{\rho_f}\left(\frac{n}{A}\right)^{3/2}. \tag{1}$$

Cell densities N_{cell} of the polymer foams were calculated using the following Eq. (1), where n is the number of cells on the SEM image, A is the area of the image, and ρ_p and ρ_f are the densities of PLA and PP foams, respectively [10, 11]. The cell densities of the PLA and PP samples were calculated as 5.99×10^7 and 4.59×10^7 cell/cm^3, respectively. It has been seen that the increased cell

density induced higher weight reduction for PLA samples. PLA gave 28% of weight reduction while PP foams showed 6% as reported in Table I. When the cell size of two foams were compared, PP foams gave 3.53×10^{-3} mm of cell size and PLA foam gave 8.87×10^{-3} mm. This result showed that cell density and cell size were lower in PP foam due to the hindrance of the cell generation under the higher viscosity (or lower MFI value) of the polymer melt. Skin layer of polymer foams do not contain foam cells due to the rapid solidification of the polymer melt in the cavity and as a consequence, foaming of the polymer is hindered in skin layer. In this study, the skin layer showed different thickness values in both polymers, as given in Table I. In Fig. 1a and c the skin layer thickness was measured as 296.209 μm, while 313.040 μm of skin layer was obtained in Fig. 1b and d. This result is related to the thermal and rheological properties of the polymers. Tensile properties of the unfoamed (solid) and foamed polymers are given in Fig. 2. When PP is solid, its tensile strength is 23 MPa and as it was foamed the tensile strength reduced to 18 MPa, naturally due to the generation of the foam cells. On the other hand, solid PLA gave tensile strength about 53 MPa and when it was foamed, tensile strength decreased to 20 MPa. This result could be verified by the cell morphology of the samples, as shown in Fig. 1 and Table I. It has been seen that increment in cell size decreased the mechanical strength of the polymer foam. In order to improve the mechanical strength of the PLA and PP foams, researchers have been studying on reinforcement of polymer foams with nanofillers [19–21]. Besides, for PLA, improving the melt strength of the polymer would enhance the cell morphology of the material.

TABLE I

PP and PLA foam results.

Material	Skin layer [μm]	Weight reduction [%]	Cell size [mm]
PP foam	296.209	6	3.53×10^{-3}
PLA foam	313.040	28	8.86×10^{-3}

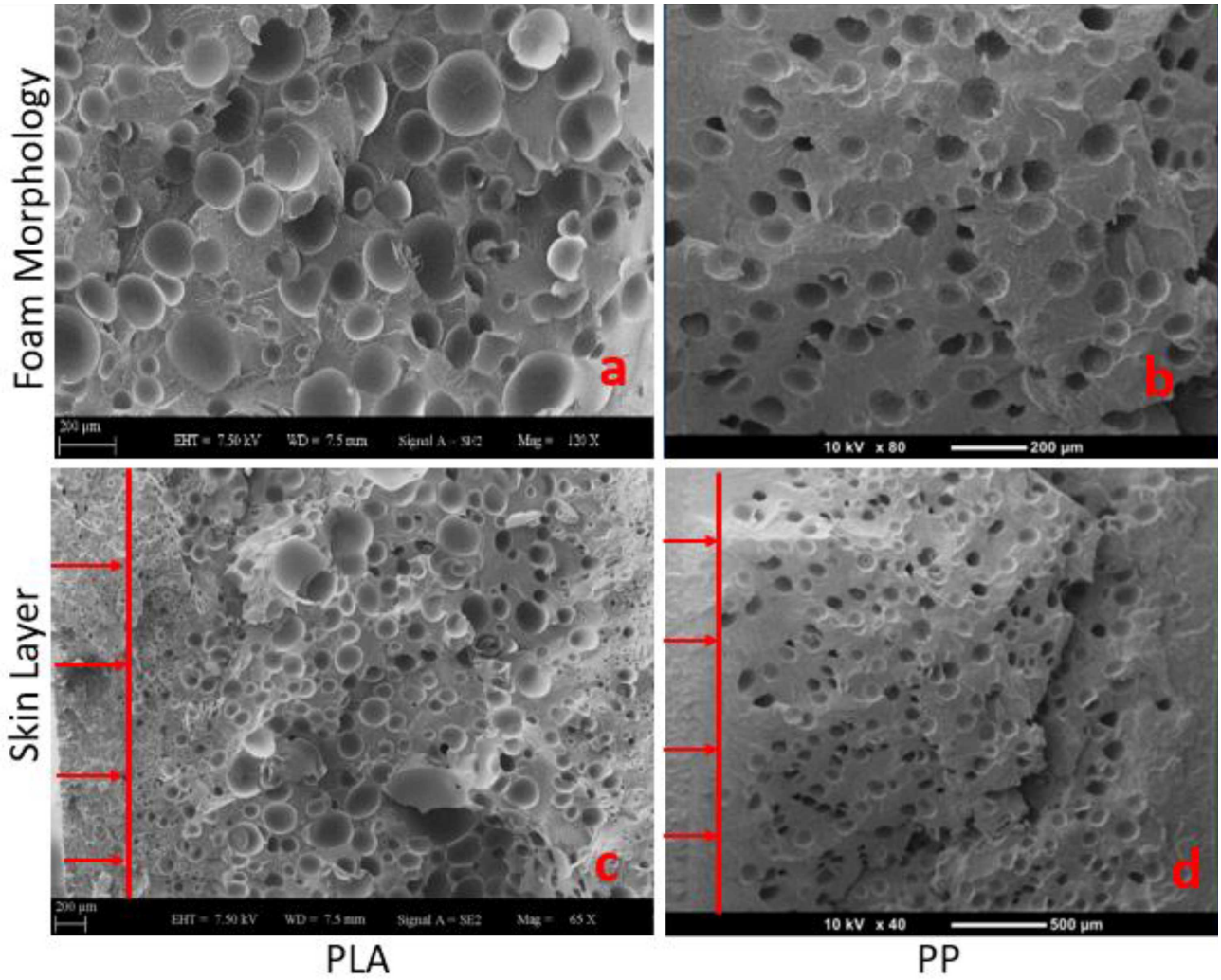

Fig. 1. Foam morphology and skin layers of samples: (a) PLA 120×, (b) PP 120×, (c) PLA 50×, (d) PP 50×.

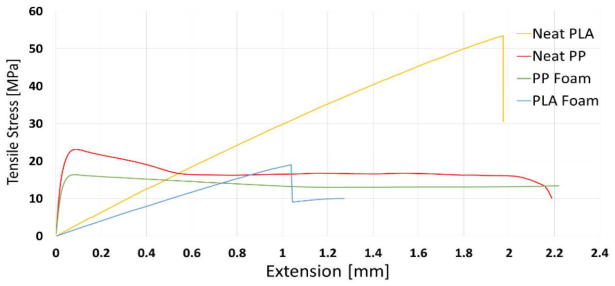

Fig. 2. Tensile properties of the solid and foam polymers.

4. Conclusion

Cell morphology and mechanical strength of PP and PLA foams were compared. Different results in cell size, cell density, and skin layer were obtained due to the different thermal, rheological, and mechanical properties of the two polymers. It has been seen that 23.4% higher cell density and 151.2% higher cell size have been seen in the PLA foam when the results were compared with PP foam. Weight reduction was also higher in PLA foams because of the higher cell density and cell size. PLA showed sharp reductions in mechanical strength when it was foamed. On the other hand, PP foams gave smooth decreases in the mechanical strength when the results were compared between foamed and unfoamed PP. In PLA foam, the skin layer thickness was 296.209 μm while in PP foam it was 313.040 μm. Therefore, it could be concluded that the reduction in mechanical strength of the foamed polymers was not only due to cell size and cell density, but also due to lower skin layer thickness.

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