

The effect of foaming agent on mechanical and physical properties of Polypropylene

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Abstract: In this study, Polypropylene (PP) foam materials were used with injection parameters such as melting, molding and injection temperatures. To produce foam materials, chemical foaming agents were used, and added to polymer materials as 1wt.%, 1.5wt.%, 2wt.%, 2.5wt.%, 3wt.%. The mechanical properties of foam samples were determined based on the parameters. Cell morphology characterization such as cell diameter, cell count, skin layer thickness and cell density, and mechanical properties such as tensile and impact strength of polymer foams were examined.

Generally, the closed-cell foam structure was obtained. The most important parameters affecting the cell morphology have been injection pressure, melt temperature and amount of foaming agent. With increasing the amount of foaming agent, cell density increased, foam density and mechanical properties decreased.

Keywords: Polypropylene; Foam; Mechanical; Physical; Injection Molding.

1. Introduction

Cellular or expanded plastics containing at least two phases, the solid polymer matrix and the gaseous phase produced by the foam agent, are described as polymer foams^[1]. The interest in polymeric foams is increasing day by day due to its unique properties such as low density, superior strength/weight ratio, excellent insulating ability, energy absorptive performance, superior impact resistance. It is possible to foam many commercially important polymers using physical or chemical foaming agents^[2]. The preparation of the polymer foams is a two-step process including mixing and molding. The foam structure is formed during the molding process^[3]. The voids in the polymer together with foam formation reduce the density and provide less raw material usage. In this way, the product price is reduced and the density of the polymer (PP, PE, PVC, PS, PU, PC), which are important for commercial use, can be adjusted by methods such as injection, extrusion, rotation molding, polymer foams with different properties can produced^[3-5]. Among these production methods, parts with desired geometric dimensions can be produced by advantages such as decreasing weight, faster cycle time, part size stability and high strength/weight ratio by injection foam molding method^[2]. The polymer matrix used determines the basic composition and basic properties for the polymer foams. The processing and application properties of polymer foams depend on the physical and chemical properties of the polymer^[3]. Changes in process parameters such as melt temperature, mold temperature, amount of foam agent, screw pitch, injection rate and injection pressure affect the cell morphology and mechanical properties of polymer-based foams produced by injection molding with foam^[2].

In many experimental investigations, the effects of parameters such as nucleating agent, injection conditions^[2,6], melting temperature, mold temperature^[2,7] are investigated. Guo *et al.*^[6] examined the effect of nanocomposite composition and injection conditions on cell structure and properties of branched and linear polypropylene (PP) foams contain-

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ing organically modified nano tin and maleic anhydride grafted polypropylene (PPMA). As a result of the study, high cell density and low cell size were reached with nano tin addition as a nucleus and more smooth cell structure was obtained. Yetgin *et al.*^[2] examined (PP-T) composite material and endothermic chemical foam agent using 20% by weight of unmodified polypropylene (PP) and 20% by weight of polypropylene, the production parameters such as the injection pressure and the melt temperature are used to determine the average cell size of the foam materials, the number of cells, the foam layer thickness, and their examined of effects on mechanical properties. As the melt temperature increased, the cell diameter increased and material density, shell layer thickness, cell density and impact resistance decreased. As the injection pressure increased, foam density, shell layer thickness, cell diameter and impact resistance decreased while cell density increased. Kharbas *et al.*^[8] investigated the process conditions and the effect of nanoclay fillings on microstructure and mechanical properties in a study using polyamide-6 (PA-6) as matrix. The samples were molded at various melting temperatures, shot sizes, melt plasticization pressures and injection speeds. As a result of the study, microstructure and mechanical properties were found to be dependent on the process conditions and nano-clay. Bledzki *et al.*^[9] investigated the effects of chemical foaming agent content on cell morphology, density and mechanical properties of intracellular injection molded wood fiber reinforced polypropylene (PP) composites. The effects of exothermic chemical foam agent amount (2% and 5%) on the properties of composites were investigated. As a result, the foam agent of 2% by weight showed a better microcellular structure due to the content of wood fibers. In addition, mechanical properties have increased by about 80% by the addition of binder. Li *et al.*^[10] investigated the effects of types and forms of chemical foaming agents in a study of high density polyethylene (HDPE)/wood flour using extrusion methods. The foam agent type and form did not affect cell morphology in both HDPE and HDPE/wood composites.

In this study, polypropylene (PP) was used as matrix. Depending on the amount of chemical foam agent, cell morphology, shell layer thickness and mechanical properties were investigated.

2. Experimental data and experiments

2.1 Materials and methods

In this study, polypropylene as matrix was used provided from the Toyota Boshoku Turkey. ITP as foam agent was used provided from Clariant company. Test specimens were produced by melting at 210 °C and using injection molding at 220 °C mold temperature and 230 °C using 1%, 1.5%, 2%, 2.5% and 3% by weight of the foam agent.



Figure 1. Tensile and impact test specimens

Hardness test was carried out in accordance with the ASTM D2240 standard. The hardness test was applied to 3 samples of test samples at 25°C temperature for each parameter by using Shore D scale which is preferred for thermoplastics.

Impact tests were performed to determine the amount of energy absorbed by the material during fracture and Izod unnotched impact tests were applied to the Alarge brand device in accordance with the ISO 180 standard by using 5.5 J hammer in 2 samples with dimensions of 3x12x64 mm for impact tests.

3. Results and discussions

The mean values of the Shore D hardness test results for the three test specimens produced for each parameter are shown in **Figure 2** below and the average values of the unnotched Izod impact test results for the two test specimens are shown in **Figure 5**.

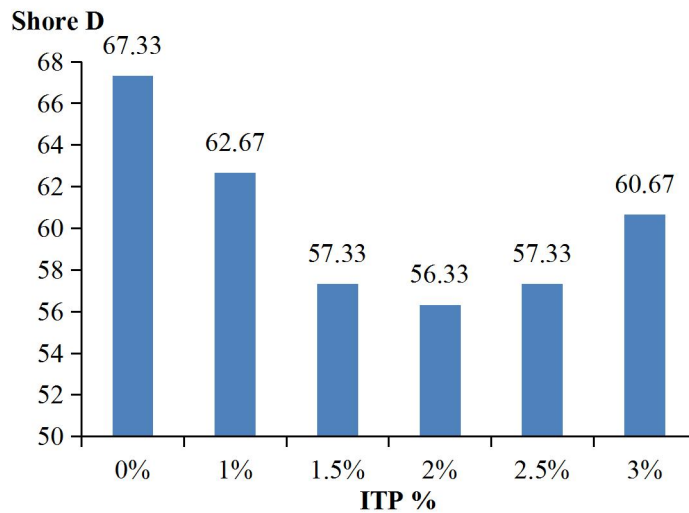


Figure 2. Hardness test results

When **Figure 2** is examined, the highest hardness value is obtained as 62.67 Shore D in 1% ITP added PP-ITP polymer. The lowest hardness value was obtained as 56.33 Shore D in 2% ITP added PP-ITP polymer. This can be explained by the reduction in shell layer thickness as a result of an increase in the amount of foam agent. Increasing the softer cellular region with decreasing shell layer thickness is effective in reducing hardness. This shell layer thickness is due to the rapid cooling of the hot molten polymer by contact with the cold mold wall. In addition, an increase in the number of cells also leads to a decrease in the thickness of the shell layer^[1,11]. Chien *et al.*^[7] investigated polypropylene foams. In the study of using polypropylene as matrix, the amount of foam agent increased from 0.8% to 1.6%, resulting in a decrease in hardness.

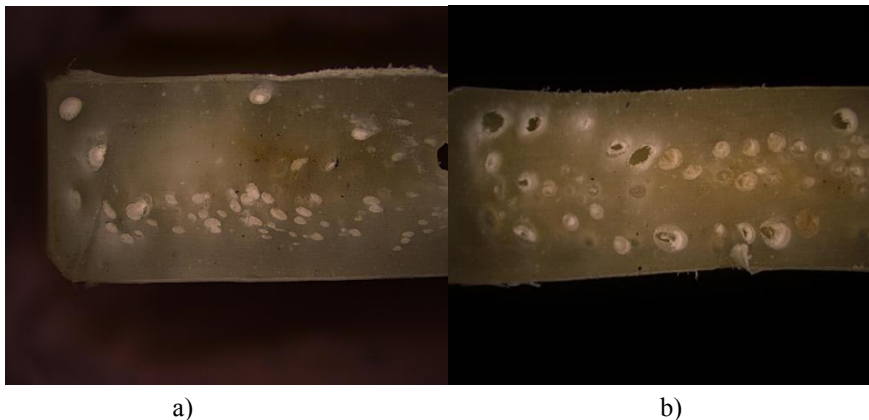
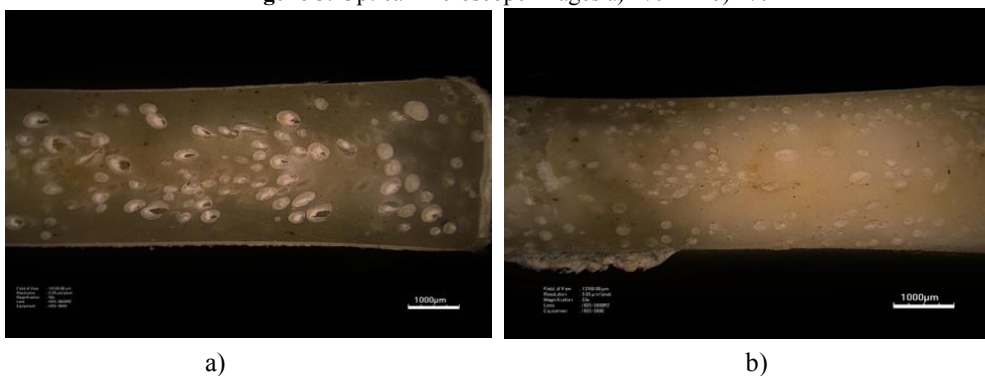


Figure 3. Optical microscope images a) 1% ITP b) 2% ITP





c)

Figure 4. Optical microscope images a) 1.5% ITP b) 2.5% ITP c) 3% ITP

In **Figure 4** the microstructure containing 1.5% ITP is examined, it can be seen that foam cells increase as the amount of foam agent increases. Thus, the hardness values are reduced compared to the 1% ITP ratio. The high mold temperature at microstructure with 2.5% ITP ratio causes the foam cells to be small and spherical in shape. The value of the stiffness expected to decrease with increasing foam agent quantity increases due to the morphology of the foam cells in the structure. When microstructure with 3% ITP ratio is examined, less foam cells are observed. Despite the increasing amount of foam agent, insufficient time does not allow the nucleation of foam cells. For this reason, the increase in shell thickness causes an increase in hardness.

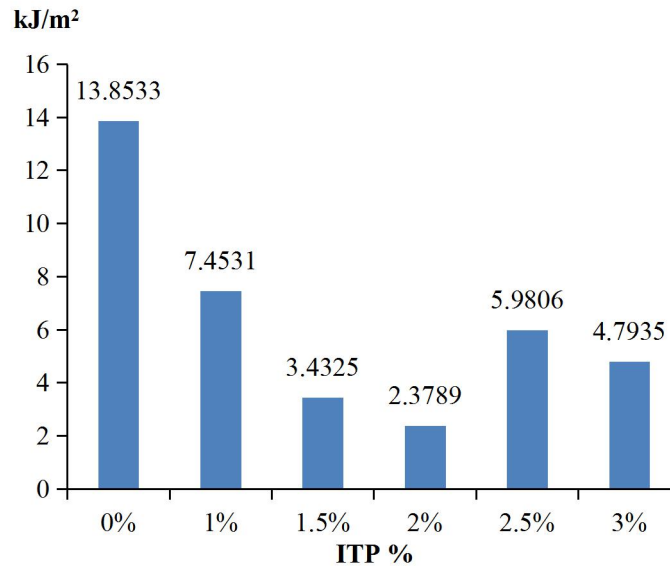
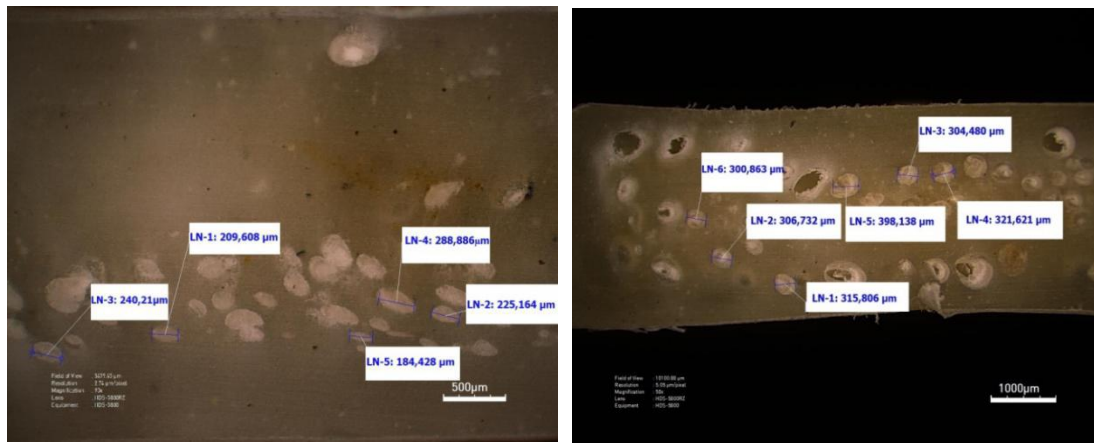


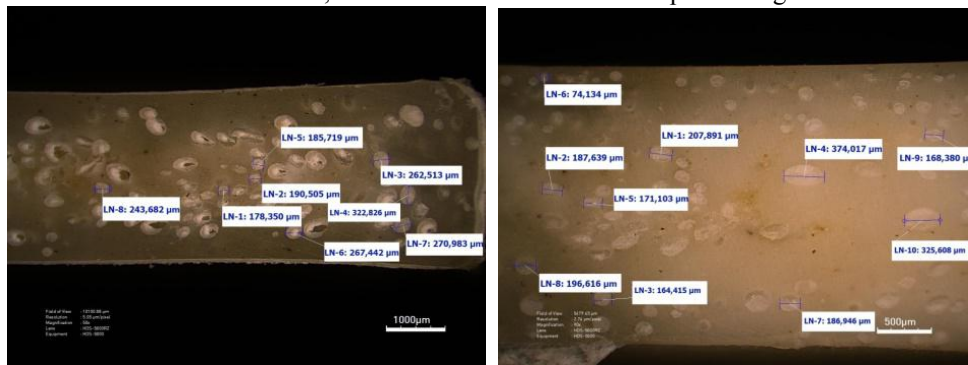
Figure 5. Impact test results

When **Figure 5** is examined, the highest impact strength in specimens containing weighted foam agent is 7.45 kg/m² in the PP-ITP polymer with 1% ITP ratio. The lowest value of impact strength is the PP-ITP polymer with 2% ITP ratio. The amount of high foam agent increases the amount of gas and obtained more gas than is required. The excess amount of foam agents brings the small bubbles to the point of merging. Because of the large cell size distribution and irregular morphology in the foam, the irregular structure creates stress stacks. When the bubble size decreases, the tension concentration around the bubble also decreases. Thus, the impact resistance increases^[1]. In Gardner's study with PVC, it was observed that impact strength decreased with increasing foam density^[12]. As shown in **Figure 6**, the small amount of foam agent causes small cell size distribution and regular morphology formation at 1%, whereas at 2% cause is strain accumulation with increase of cell size distribution and irregular morphology. In this case too, the impact strength decreases. Xu *et al.*^[13] have determined that small cell size and uniform cell distribution are critical factors for high impact strength.



a) b)
Figure 6. Optical microscope images a) 1% ITP b) 2% ITP

Looking at **Figure 7** below, an increase in foam cell size is seen in the structure containing 1.5% ITP. This increase leads to a decrease in impact strength, while the foam cells formed at the rate of 2.5% ITP have small dimensions due to the high mold temperature, thus increasing the impact strength. Looking at the microstructure of the 3% ITP doped sample, there is an increase in foam cell size, which leads to a decrease in impact strength.



a) b)



c)

Figure 7. Optical microscope images a) 1.5% ITP b) 2.5% ITP c) 3% ITP

Change in weight depending on the amount of foam agent is given **Figure 8**. In the 1% ITP added sample, a lightness of up to 10% compared to the pure sample was obtained.

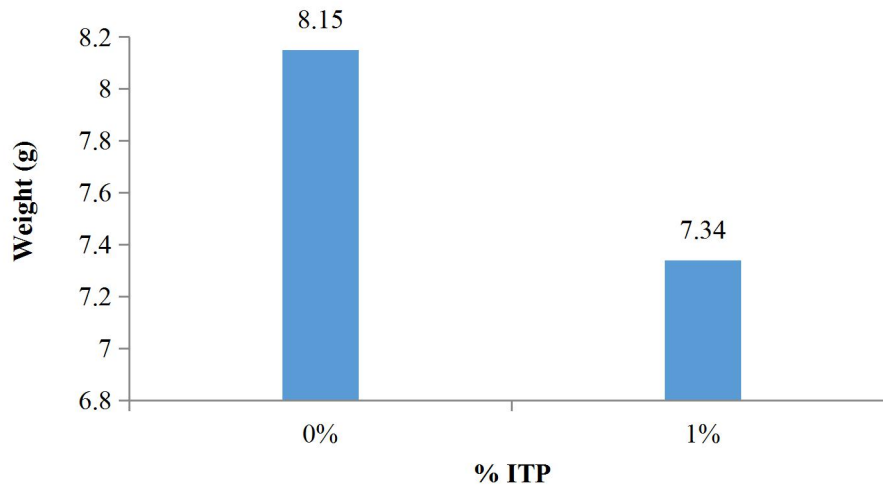


Figure 8. Change in weight depending on the amount of foam agent

4. Conclusions

In this study, foamed samples with different ITP ratios were produced. Hardness values and impact strengths of the samples produced at 210 °C melting temperature, 230 °C injection temperature and 220 °C mold temperature were determined and microstructures were investigated.

The changing ratio of the amount of foam agent has been found to be a factor affecting cell morphology, shell layer thickness and mechanical properties.

As a result of the tests made, the highest stiffness and impact strength values were seen in polymer foams containing 1% ITP. The lowest values were obtained in samples with a 2% ITP ratio. After 2%, the hardness values of samples with 2.5% and 3% ITP ratios increase.

The weight of PP is reduced by foaming.

Alterations in the amount of foam agent and changes in mechanical properties and cell sizes and distributions can be examined by changing injection parameters such as injection and mold-melt temperatures, injection speed, injection pressure. In addition, studies can be made to reduce the cell diameter despite the increased amount of foam agent by adding nano-sized fillers to the structure to serve as a heterogeneous nucleating agent.

Acknowledgement

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