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The Effect of Foaming on Mechanical and Morphological Properties of Polypropylene

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Abstract

The automotive industry is among the priority technology areas of our country, and the reduction of vehicle weight and fuel consumption and thus CO_2 emissions without compromising safety criteria are among the priority research areas. For this reason, R&D studies on increasing the use of polymer-based materials in the automotive industry are of great importance. In order to produce "high strength and weight reduction parts" in plastic moulding technologies, advanced technologies that focus on cost reduction and efficiency are being implemented rapidly. The chemical foaming process, which provides many advantages such as reducing the consumption of plastic material used, reducing the total moulding cycle time, using fewer tonnage injection moulding machines, and thus reducing the energy costs, is one of the innovative technologies that have been implemented since a very recent time. In this study, chemical foaming agents were used at a rate of 1-2-3 wt% in natural fiber-reinforced recycled composite polypropylene raw material. Polypropylene samples were obtained by injection moulding in the sizes and shapes in accordance with the standards. Tensile, hardness, impact and three- point bending tests would be done. With increasing the amount of foaming agent, mechanical properties decreased.

1. Introduction

Manufacturing science has opened up new frontiers, effectively moving component design down to materials design. Natural lignocellulosic fibers are renewable, completely or partially recyclable, and biodegradable because their raw materials consisted of flax, cotton, hemp, and wood materials. Today, natural fiber-reinforced polymer composites are growing rapidly in many studies and industrial applications because they are eco-friendly, sustainable, light, high performance, perfectly versatile, and easy to process at favorable costs [1]-[4].

The plastic injection molding method produces multidimensional and complex geometries in high numbers, and low cycle times. Besides, the injection molding method reduces the consumption of raw materials and improves the lightness of the materials by using chemical admixtures. Microcellular polymers may be the new trend to substitute compact plastics. The contribution of chemical foaming agents in polymer compounds provides their unique properties such as low density, outstanding strength/weight ratio, excellent insulating ability, energy absorptive performance, and splendid impact resistance. It is possible to foam many commercially important polymers using physical or chemical foaming agents. Three methods of producing polymer foams take place in the literature: chemical foaming, physical foaming - MuCell® , and microspheres [5], [6]. In this research we are dealing only with the injection molding proces. The chemical foaming process is similar to the standard injection process. However, when chemical blowing agents are added to create polymer foams, the fluidity and solidification behaviors of the plastic completely change [7], [10]. The injection molding processing

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technology uses a conventional injection molding machine allowing different chemical foaming agents, shaped parts with a compact outer skin, and foamed cores with different mechanical characteristics [11]-[14].

This study will explore the effects of chemical foaming agent content on the mechanical and morphological properties of microcellular natural fibre-reinforced polypropylene composites.

2. Material and Methods

A commercial 20wt% hemp fibre-reinforced polypropylene compound (NAFIlean-PF2 555, Karel Kalıp SAN.A.Ş., Turkey) was used in this work. ITP825-818, HYDROCEROL, Clariant A.Ş. were used not only as a nucleating agent but also as a chemical foaming agent. ITP 825 includes 40% active material and good distribution in the melt. However, ITP 818 has 65% active material and it shows very high gas efficiency.

Table 1. Samples ratios of 20wt % hemp fibre reinforced PP with different ITP loading

Groups	PP+20% Hemp fibre (wt%)	ITP 825 (wt%)	ITP 818 (wt%)
1	100	-	-
2	99	1	-
3	98	2	-
4	97	3	-
5	99	-	1
6	98	-	2
7	97	-	3

The commercial natural fibre-reinforced recycled polypropylene matrix composite which is given in Figure 1(a), was dried in an oven at 105 ℃ for 24 hours. Figure 1(b) shows Hydrocerol. Afterwards, 20wt% hemp fibre-reinforced polypropylene matrix composite was mixed with each chemical foaming agent due to the ratio of 1-2-3 wt%, which is given in Table 1. Each mixture was prepared at 2 kg and was charged as to the plastic injection moulding machine which was given in Figure 1(f), Table 2 showed the process conditions. Figure 1(c) shows the tensile strength test's mould and the obtained sample. Figure 1(d) was illustrated plate moulds which were used to produce hardness and three-point bending test samples. In figure 1(e), are shown the moulds for obtaining the Izod impact test samples.

Elasticity modulus, yield strength, tensile strength at break, and hardness properties of each sample were examined by the mechanical tests at room temperature. The tension tests were applied according to ASTM D638 standards (Zwick Z010, Germany). The hardness test was performed by ASTM D2240 (Zwick, Germany). In order to investigate fracture behaviour, the Izod impact test was carried out at room temperature and unnotched according to the ASTM D256 method via the Zwick B5113 impact tester (Zwick, Germany). The bending strength, elasticity modulus, and % bending strain analyses were performed by using the three-point bending method to ASTMD 790.

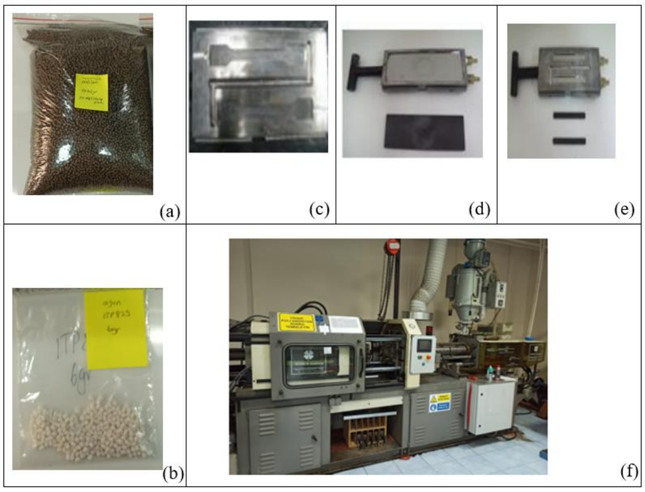


Figure 1. Sample Preparation: (a): The commercial 20 wt% hemp fibre reinforced polypropylene, (b): Hydrocerol, c): Tensile strength test mould, (d): Plate mould, (e): Izod impact test mould and sample, (f): Plastic injection moulding machine

Table 2. Process condition of 20wt% hemp fibre reinforced PP with different ITP loading

Process Condition	Injection
Temperature (°C)	190-220
Hold pressure (bar)	75
Hold time in mould (s)	8.6
Screw speed (rpm)	75
Mould temperature (°C)	45-50
Filling speed cm^3/s	23

3. Results and Discussion

Figure 2 shows tensile strength properties 20wt% hemp fibre reinforced PP and ITP loading. The tensile strength of the composite decreased with increasing Hydrocerol content. The tensile strength of 20%wt. hemp fibre PP decreased from 28 MPa and 20.5 MPa to 21.8 MPa and 24.1 MPa, respectively with ITP 825. The tensile strength of 20wt% hemp fibre PP decreased from 28.0 MPa and 25.6 MPa to 24.0 MPa and 26.2 MPa respectively, loaded with ITP 818. The tensile strength is sharply decreased for the samples loaded with ITP 825. The obvious decrease in the tensile strength for the samples loaded with not only ITP 825 but also ITP 818 may be the result of formed bubble size and or bubble distribution. Bledzki et al. have studied microcellular injection moulded PP/wood fibre composites on cell morphology and the effect of physical properties and mechanical properties, and was shown to decrease the tensile strength of PP by wood fibre and microcellular structure [15].

After foaming, the tensile modulus of all of 20wt% hemp fibre reinforced PP foams was lower than that of neat 20%wt. hemp fibre reinforced PP. However the trends were change, Zeng et.al. reported that tensile strength tends to be increased with decreasing cell size [17]. Chen et.al. have studied microcellular polylactic acid (PLA) foams with various cell size and cell morphologies and figured out different trends of tensile strength might be ascribed to the heterogeneities of macrostructural changes resulting from the changes in cell microstructure [18].

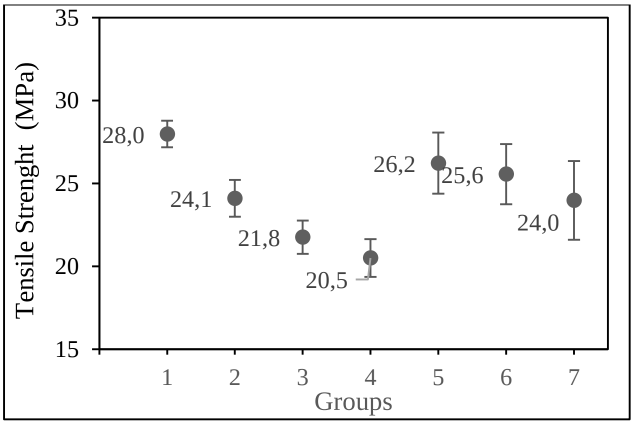


Figure 2. Tensile strength of 20wt% hemp fibre reinforced PP with different ITP loading

The effects of ITP on the elasticity modulus hemp fibre-PP is given in Figure 3. The elasticity modulus of hemp fibre-PP decreases from 1152 MPa and 623.4 MPa to 780.2 MPa to 756.8 MPa loaded with ITP 825, corresponding to 1152 MPa, and 739 MPa to 807.4 MPa, and 831.4 MPa loaded with ITP 818. It can be observed that the addition of Hydrocerol decreased elasticity modulus significantly. For both types of Hydrocerol 1wt% and 2wt% doping ITP samples, elasticity modulus decreased as the same however, 3wt% ITP 825 reinforced samples are greater than 3wt% ITP 818 elasticity modulus decreased. The elastic modulus of sample 1 was the highest because includes no chemical foaming agent. However, the chemical foaming agent action causes dissolved CO_2 to get between the polymer chains, such as plasticization, polymer chain mobility leads to decreased crystallinity and imperfect crystals with more close-packed lammeals. [18].

Because of the fact, include chemical foaming agent in 20wt% hemp fibre reinforced PP, decrease the elastic modulus.

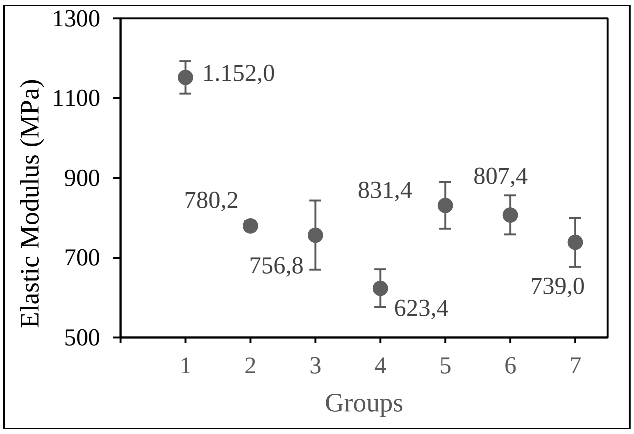


Figure 3. Elasticity modulus of 20wt% hemp fibre reinforced PP with different ITP loading

Figure 4 shows the hardness (Shore D) behavior of 20wt% hemp fibre reinforced PP with different Hydrocerol loading. The hardness of the hemp fibre-PP mixed with (1,2,3 wt%) ITP 825 decreased from 62.4 shore D and 61.0 Shore D to 60.8 Shore D and 59.5 Shore D, respectively. On the other hand, the hardness of the hemp fibre-PP (1,2,3 wt%) ITP 818 samples are measured as 59.5 Shore D, 59.0 Shore D, and 58.9 Shore D. In comparison between ITP 825 and ITP 818 samples hardness is increased greater than ITP 818. Cakir et.al have been explained the decrease in shell layer thickness as a result of an increase in the amount of foam agent so, increasing the softer cellular region with decreasing shell layer thickness is effective in reducing hardness [16].

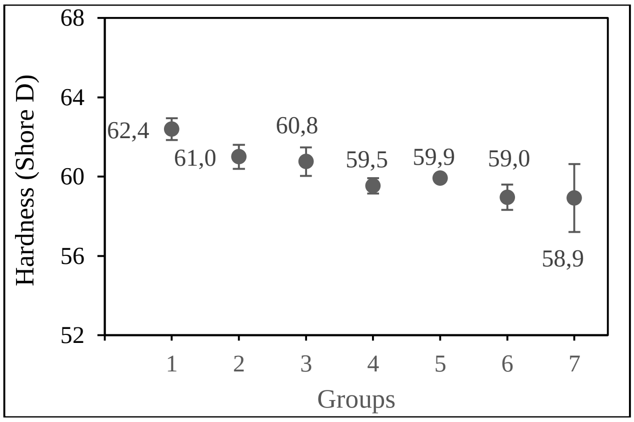


Figure 4. Hardness properties of 20wt% hemp fibre reinforced PP with different ITP loading

The relationship between the unnotched Izod impact strength and the hemp fibre-PP with different Hydrocerol (ITP 818 and ITP 825) contributions are shown in Figure 5. Generally, the inclusion of ITP in the hemp fibre - PP Izod impact strength of the composite is found to be decreasing. For example, the Izod impact strength of the samples with (1,2,3 wt%) ITP 825 is measured as 17.6 kJ/m^2, 14,3 kJ/m^2, and 12.6 kJ/m^2 respectively. On the other hand, Maruf Billah et. al. have studied polypropylene matrix natural fibre-reinforced composited V-notch specimens sample for impact test. Polypropylene was reported 10-14 times more brittle with the notch [19].

The Izod impact strength of 20%wt. hemp fibre reinforced PP is 19.1 kJ/m^2. On the other hand, the Izod impact strength of the three samples with (1,2,3 wt%) of ITP 818 is measured as 18.4 kJ/m^2, 16,3 kJ/m^2, and 12,5 kJ/m^2 respectively. In comparison with the Izod impact strength of 2 % wt. ITP 825 and ITP 818 samples decreased greater at ITP 825. Maruf Billah et. al. have studied effect of PET fibre content on the impact resistance of hybrid PP composites with the coupling agent. They showed good adhesion with coupling agent MAPP increasing the impact resistance of the composites [20]. However, the chemical foaming agent increased the free volume in the structure, according to free volume increase, impact resistance decreased.

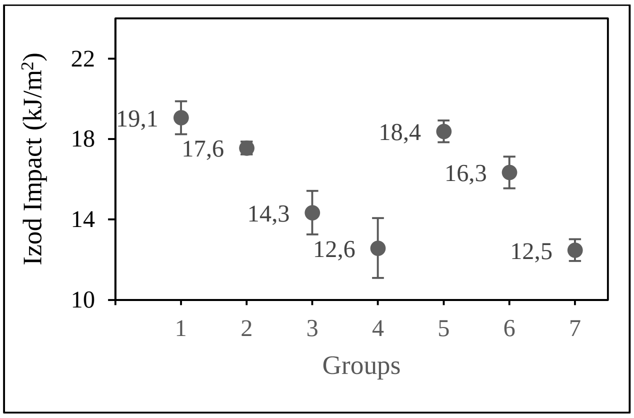


Figure 5. Izod Impact test of 20wt% hemp fibre reinforced PP with different ITP loading

Figure 6, 7 and 8 are shown the three-point bending test measurements on the samples. The bending strength properties are shown in Figure 6. According to the three points bending tests hemp fibre-PP at 1 wt% Hydrocerol increased the bending elasticity modulus which is shown in Figure 7. However, the addition of 2wt% and 3wt% ITP 818 are decreased the bending elasticity modulus. The effect of ITP types and contribution on the the % bending strain illustrates in Figure 8. Also, the % bending strain is developed of ITP 818 (1,2,3wt%) addition samples. However, ITP 825 (1,2,3wt%) is decreased the % bending strain.

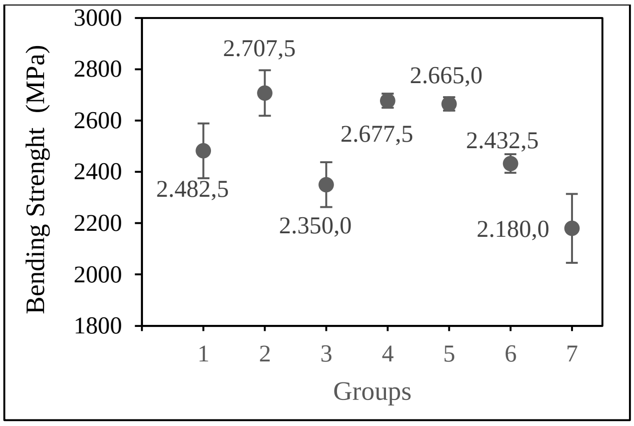


Figure 6. Three-point bending test of 20wt% hemp fibre reinforced PP with different ITP loading: bending strength

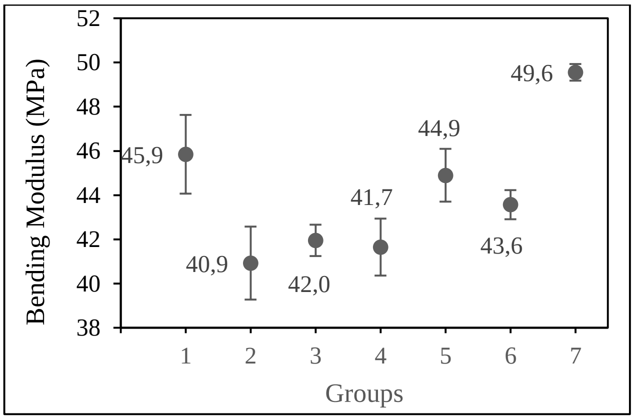


Figure 7. Three-point bending test of 20wt% hemp fibre reinforced PP with different ITP loading: bending modulus

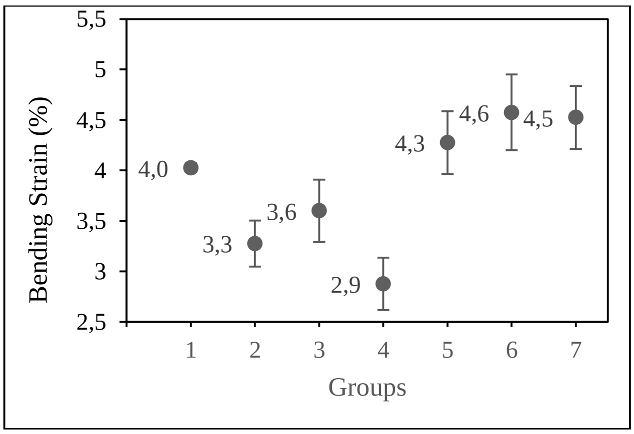
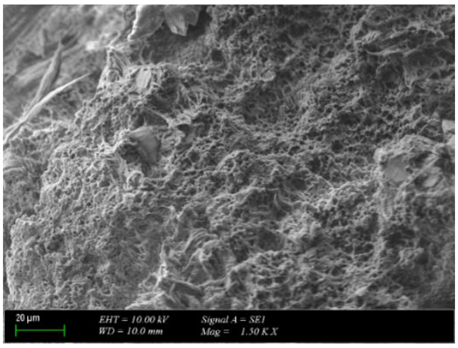
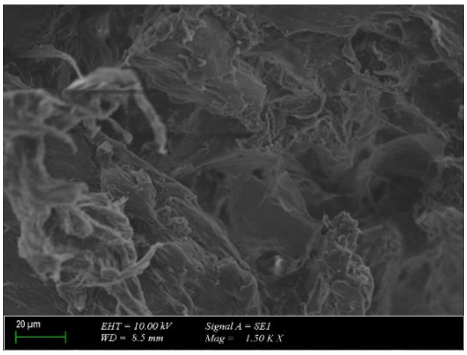


Figure 8. Three-point bending test of 20wt% hemp fibre reinforced PP with different ITP loading: bending strain (%)

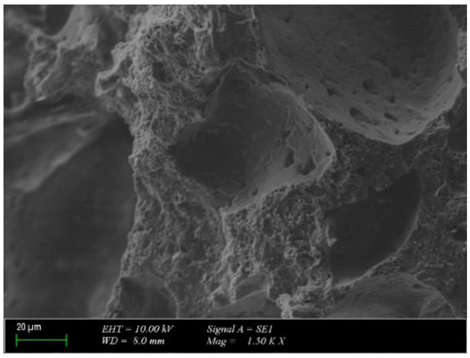
The micrograph of 20wt% hemp fibre reinforced PP with different ITP loading is presented in Figure 9. The influence of ITP types and contribution on the structure and size of the microcells on a surface was observed by SEM micrographs. Figure 9(a) illustrates 20wt% hemp fibre reinforced PP composite structure, there is no microcellular structure. Figure 9(b) is given hemp fibre reinforced PP with 2wt% ITP 825 which is the cell size of about 60 μm. On the other hand, Figure 9(c) is shown 3 wt% ITP 825 addition which is cell size of about 60-140 μm. It seems that when the ratio of ITP 825 foaming agent's increases, the bubble's size increases. Figure 9(d) and Figure 9(e) are shown 2 wt% and 3wt% ITP 818 addition, respectively. When the foaming agent addition increases in the wt% ratio, bubble size decreases and bubbles dispersion is nonhomogeneous and also opened-cell and closed-cell distribution is nonhomogenous in the structure. This cell structure distribution influences trend of mechanical properties of the composites.



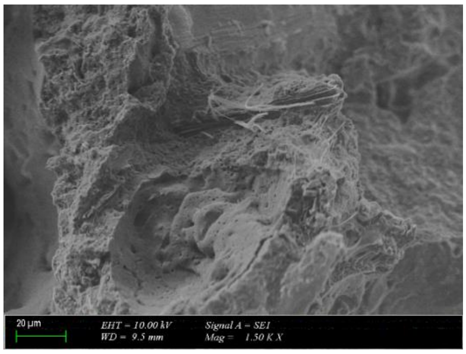
(a) PP+20wt% Hemp fibre (without ITP)



(b) ITP 825 (2wt%)

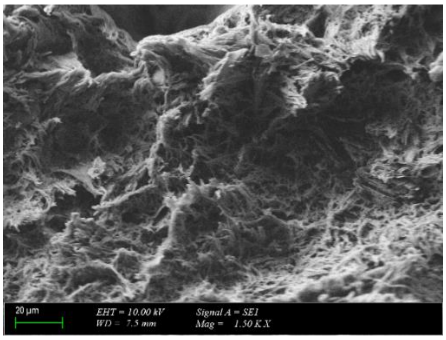


(c)ITP 825 (3wt%)



(d) ITP 818 (2wt%)

Figure 9. Micrograph photo of 20wt% hemp fibre reinforced PP with different ITP loading



(e) ITP 818 (3wt%)

Figure 9. (continue)

4. Conclusion and Suggestions

This study aimed to investigate the mechanical behaviour of the chemical foaming agent in polypropylene matrix composites. Hydrocerol (ITP 818 and ITP 825) was used as a potential foaming agent in natural fibre-reinforced polypropylene matrix composites at the range of 1, 2, and, 3wt% The samples were obtained by injection moulding. The effect of Hydrocerol on the mechanical properties such as; the tensile elastic modulus, tensile strengths, hardness, Izod impact strength, and the bending test of 20wt% hemp fibre reinforced polypropylene was investigated. The following results were the elasticity modulus, the tensile strength, the hardness, Izod impact strength 20wt% hemp fibre reinforced PP decreased, as the Hydrocerol concentration increased. Microcellular structure, increase polymer chain distance, decrease the crystallinity. On the other hand, the presence of bubbles containing gas and whose mechanical characteristics become very weaker. The bending strain of 20wt% hemp fibre reinforced PP increased as the ITP concentration increases. The bending elasticity modulus improved by 1wt% Hydrocerol addition until 2 wt% dropped the bending elasticity modulus. The bending strength ITP 825 (1,2,3wt%) greater decreased than ITP 818 (1,2,3 wt%). In the studies, the chemical foaming effect on the mechanical properties was expected. According to morphological analysis, the foaming agents were shown to created bubbles on the microstructure. On the other hand, the advantages of chemical foaming at weight reduction will be examined, and the effect of chemical foaming on physical properties will be studied.

Contributions of the Authors

Authors did the work together and co-authored the publication

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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