



Research Paper / Makale

Using Foamed Polypropylene to Reduce Weight and Injection Moulding Cycle Time in Toyota CH-R SUV Door Panel Production

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Abstract: In recent years, new technologies that encourage the use of cheaper and less raw materials have emerged in the automotive industry, with the increase in raw material costs because of the consumption of natural raw material resources and the occurrence of environmental problems. This study aimed to lighten the door panel and reduce the injection cycle time by using foam in the door panel production of the Toyota CH-R model car. Injection parameters such as barrel temperature, injection speed, injection back pressure, holding pressure and holding time were changed. 1%, 1.5% and 2% by weight chemical foaming agent (CFA) were added to the polypropylene (PP) matrix. Approximately 4% lightening and 5.5 sec/shot injection cycle time reduction was achieved using foaming agents. Also, it was observed that cell morphologies, mechanical properties and sample weights changed due to changes in parameters and CFA ratio by weight.

Keywords: Cell morphology, chemical foaming agent, injection moulding, light-weight material, polymer foam

Toyota CH-R SUV Kapı Paneli Üretiminde Ağırlığı ve Enjeksiyon Kalıplama Çevrim Süresini Azaltmada Polipropilen Köpük Kullanımı

Öz: Son yıllarda doğal hammadde kaynaklarının tüketilmesi sonucu hammadde maliyetlerindeki artış ve çevre bilincinin oluşması ile ucuz ve daha az hammadde kullanımını teşvik eden yeni teknolojiler otomotiv endüstrisinde ön plana çıkmaktadır. Bu çalışmada Toyota CH-R model arabanın kapı paneli üretiminde köpük kullanılarak kapı panelinin hafifletilmesi ve enjeksiyon çevrim süresinin kısaltılması amaçlanmıştır. Silindirik orta sıcaklığı, enjeksiyon hızı, enjeksiyon geri basıncı, tutma basıncı ve tutma süresi gibi enjeksiyon parametreleri üzerinde değişiklikler yapılmıştır. Polipropilen (PP) matrise ağırlıkça %1, %1,5 ve %2 oranında kimyasal köpük ajanı (KKA) ilave edilmiştir. Köpük ajanı kullanımı sonucu ağırlıkta yaklaşık olarak %4 hafiflik ve enjeksiyon çevrim süresinde ise 5,5 s düşüş sağlanmıştır. Aynı zamanda hücre morfolojilerinin, mekanik özellikler ve numune ağırlıkları; proses parametreleri ile ağırlıkça CFA oranındaki değişime bağlı olarak farklılık gösterdiği gözlenmiştir.

Anahtar Kelimeler: Hücre morfolojisi, kimyasal köpük ajanı, enjeksiyon kalıplama, hafif malzeme, polimer köpük

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1. Introduction

Organic or inorganic materials used to create the foam structure in polymer foams are defined as foaming agents. The quality, nature and quantity of the foaming agents used in the final foamed polymer material have importance for obtaining a foamy structure and desired properties [1]. Physical and chemical foaming agents are used in polymer foam production. However, additional accessories (such as a gas unit) are required to produce polymer foams with the use of a physical foaming agent (PFA), and this situation causes an increase in cost [2]. Additionally, gas traces on the surface of the final product cause another disadvantage by restricting its use in areas where surface appearance is important, as it disrupts the surface quality [3].

Organic and inorganic solid substances in powder or granule form, in which thermal decomposition reactions release gases such as carbon dioxide and nitrogen, is called chemical foaming agent (CFA). Although being very expensive creates a disadvantage for CFAs, the use of CFAs reduces production costs compared to PFAs. Additional accessories and special storage equipment are not required in the machine to be used [4].

The physical or chemical foaming agent is mixed with the polymer matrix at low temperature and pressure. Then, the polymer chain movement and foaming agent molecules are increasing at high temperature and pressure. The diffusion rate increases of the foaming agent into polymer chains with increasing foaming agent concentration, and a homogeneous polymer/gas solution is obtained. When the solution becomes supersaturated, nucleation and cell growth occur with varying temperature, pressure, and gas content [5].

The density, distribution and size of foam cells determine the quality of the final product. For this reason, the formation of a homogeneous foam structure, uniform distribution of foaming agent and small cells are essential [5, 6]. Han et al. [7] obtained more foam cells and larger cell sizes in the sample moulded at 220°C compared to 180°C. They attributed this to the decrease in melt viscosity at the temperature suitable for cell formation and growth by increasing the melt temperature. Yetgin et al. [8] examined the densities and cell diameters of the samples produced in PP matrix with 1% CFA by weight at three different melt temperatures (160°C, 170°C and 180°C) and injection pressure (60 bar, 80 bar, 100 bar). They discovered that the highest injection pressure and samples with small cell sizes had been obtained at the lowest melt temperature. Also, a decrease in density was observed with increasing melt temperature. Although the nucleation mechanism of foam cells dependent on the type of injection process (low pressure and high-pressure foam injection), on the type and amount of foaming agent, also injection process parameters such as melt temperature, injection speed, injection pressure, mould temperature and screw pitch affect the cell morphology and mechanical properties of plastic foams [9]. Wang et al. [10] examined the flexural properties of injection speed and injection temperature on PP foam and woven fibre-reinforced PP foam composites using a supercritical nitrogen foaming agent. Higher flexural strength was observed in PP foam composites at high injection temperature and high injection speed. Bledzki et al. [11] investigated the effects of chemical foaming agent content on cell morphology, density, and mechanical properties of injection-moulded wood flour reinforced polypropylene (PP) composites. The effects of the amount of chemical foaming agent (2% and 5%) on the properties of composites were investigated. As a result, the foaming agent of 2% by weight showed a better microcellular structure due to the wood flour content. Additionally, the mechanical properties increased by about 80%.

In this study, polypropylene foam materials were produced by injection moulding by adding a chemical foaming agent to the polypropylene raw material used in the automotive industry. The

effects of foaming agent addition on cell size, skin layer thickness, impact strength and weight reduction were examined.

2. Experimental Methods

2.1. Materials

Polymeric materials are widely used in many industries due to their high strength, good thermal and corrosion resistance [12-16]. In this study, copolymer polypropylene manufactured by TOTAL Company used in automotive applications was used. The melt flow index of polypropylene is 25 g/10 min. (230 °C/2.16 kg). Moreover, its density is 0.905 g/cm³. An endothermic chemical foaming agent provided by Clariant Turkey Company (Hydrocerol ITP 812) was used (Table 1). The decomposition temperature of the foaming agent is 160°C.

Table 1. Used materials

Materials	Trade Name	Supplier
PP	PPC 9710	TOTAL
CFA	ITP 812	Clariant

2.2. Experimental Work

Before mixing polypropylene and chemical foaming agent to produce polymer foam, polypropylene was dried for two hours at 100°C. Afterwards, PP and CFA in granule form were mixed mechanically for a homogeneous mixture. CFA was added at 1%, 1.5% and 2% by weight to the matrix. Engel trademark plastic injection machine was used for polypropylene foam production. DIN 2738 plastic mould steel was used as the mould material. The door panel of the Toyota CH-R model vehicle shown in Figure 1 (a) was produced, and the experiments were carried out by removing the test samples from the marked part.

First, polypropylene without additives was produced at 220°C barrel temperature, 64 mm/s injection speed, 110 bar holding pressure and 5.5 s holding time. Injection parameters used for PP foam are included in Table 2. The barrel temperature was changed depending on the decomposition temperature of the foaming agent used.

Table 2. Injection moulding parameters

Injection Parameters	PP	PP/CFA
Barrel temperature (°C)	220	200
Injection speed (mm/s)	60	80
Injection back pressure (bar)	0	10
Holding pressure (bar)	100	0
Holding time (s)	5.5	0

In the chemical foaming process, the injection speed has been increased to 80 mm/s to prevent the early expansion of the gas in the structure and to prevent traces on the surface. The injection back pressure must be high to prevent foam cells from forming inside the screw. The time between two plastic parts coming out of the mould is called the cycle time [17]. The parameters determining the cycle time are cooling time and holding time. Holding time is 0 second in this work.

After the door panel production of PP and PP-CFA samples moulded by injection method, impact test samples were cut by CNC device according to ISO 180 [18] standard (Figure 1 (b)). The test samples had been notched in the shape of "v" for the notched Izod impact test, and then tests were carried out at the Alarge impact tester using a 5.5 kJ hammer. Fracture surfaces of impact test specimens were examined by an optical microscope (Huvitz HDS-5800) to investigate the foam morphology of polypropylene foam materials. The Image J program determined average foam cell diameters, foam cell number and skin layer thickness.

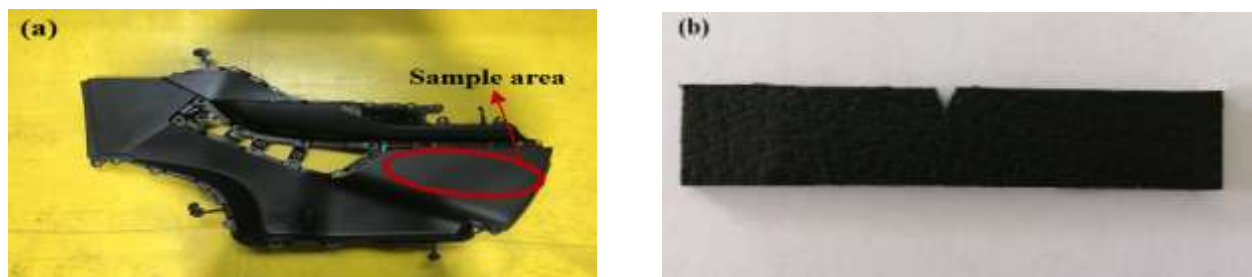


Figure 1. (a) Toyota CH-R model vehicle door panel and (b) notched Izod impact sample

3. Results and Discussion

Optical microscope images of foam cell sizes of fracture surfaces resulting from impact tests of PP foam samples with 1%, 1.5% and 2% foam agent added by weight are shown in Figure 2. The diameters of cells apparent in optical microscope images had been measured.

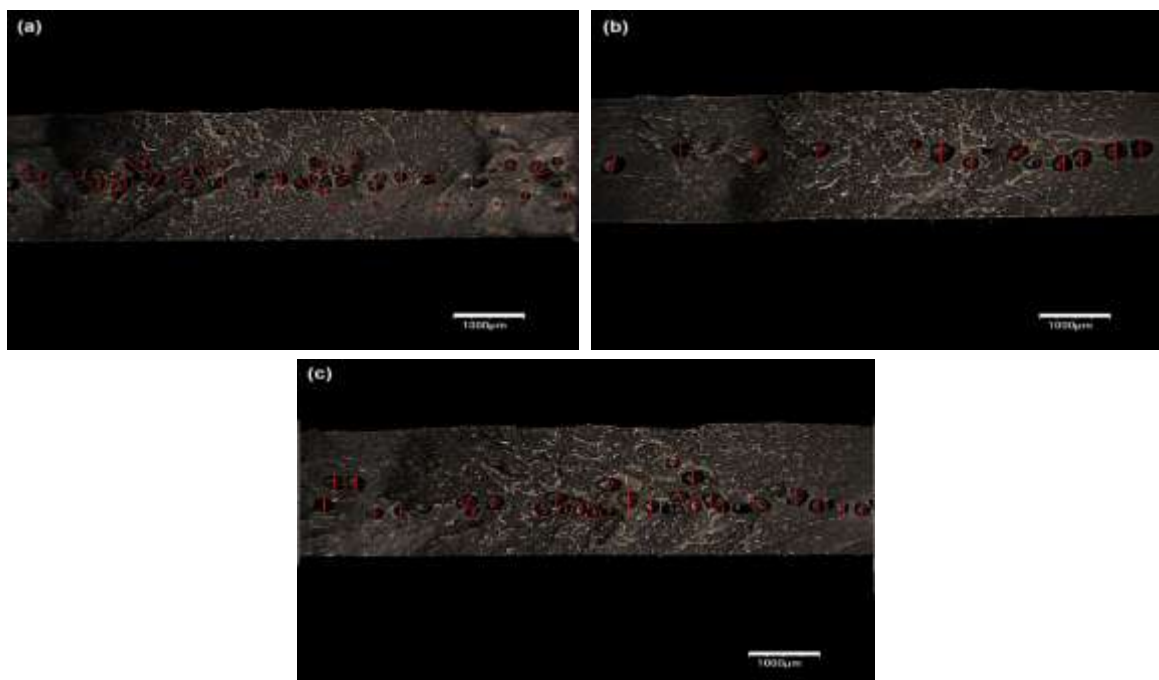


Figure 2. Foam cell size analysis from interface of PP samples (a) 1% CFA, (b) 1.5% CFA and (c) 2% CFA

Figure 3 shows the average foam cell diameters by measuring the diameters of prominent cells 50 foam cells in 1%, 12 foam cells in 1.5% and 29 foam cells in 2%. The data regarding the effect of CFA ratio on foam morphology are given in Table 3.

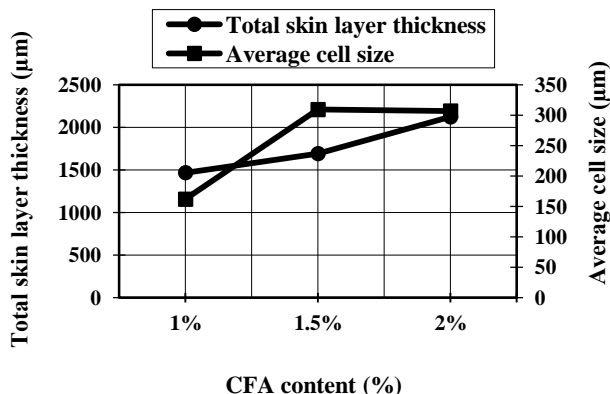


Figure 3. Total skin layer thickness and average foam cell diameters for different CFA contents in PP

Table 3. Effect of CFA ratio on foam morphology

	1%	1.5%	2%
Number of cells	50	12	29
Average cell size (µm)	161.9	309.3	306.9
Standard deviation	57.4	53.6	50.5
Min cell size (µm)	63.5	204.2	198.2
Max cell size (µm)	267	376.9	402.3
Upper layer thickness (µm)	785.2	770.6	1239.6
Sublayer thickness (µm)	683.1	921.7	883.6
Total skin layer thickness (µm)	1468.3	1692.4	2123.3

As shown in Figure 2 and Figure 3, average foam cell size increases when the amount of foaming agent increases by weight. The smallest average foam cell size was 161.9 µm in the sample with 1% CFA addition by weight. The excessive amount of foaming agent content causing cell fusion, resulting in few and large cell formation [7, 19]. As the foaming agent concentration change, the average cell size and foam cell density changes [18]. Chang et al. [21] investigated the foam morphology, mechanical properties, and surface quality of parts in their study using PP matrix and chemical foaming agent (1%, 3%, 5%, 7%, 9%) automotive applications. As a result of the study, an increase in foam cell sizes was observed with the increase in CFA content. Babaei et al. [22] produced samples by adding 2% and 4% chemical foaming agents by weight to HDPE / nano clay composites. They found that the average cell size and cell density in the produced samples increased with the increase in CFA ratio.

Optical microscope images of the skin layer thickness of the foaming agent added PP foam samples are shown in Figure 4. While the central part of the moulded parts is porous, the skin layer consists of solid (non-foamed) material. This solid skin layer is formed due to gas diffusion, rapid cooling of the molten polymer because of contact with the mould wall and breaking of gas cells near the surface [5]. The change in skin layer thickness varies depending on the foam cells formed in the central part of the samples. To determine whether the obtained skin layer was formed homogeneously on all surfaces, the skin layer thickness was measured using the Image J program.

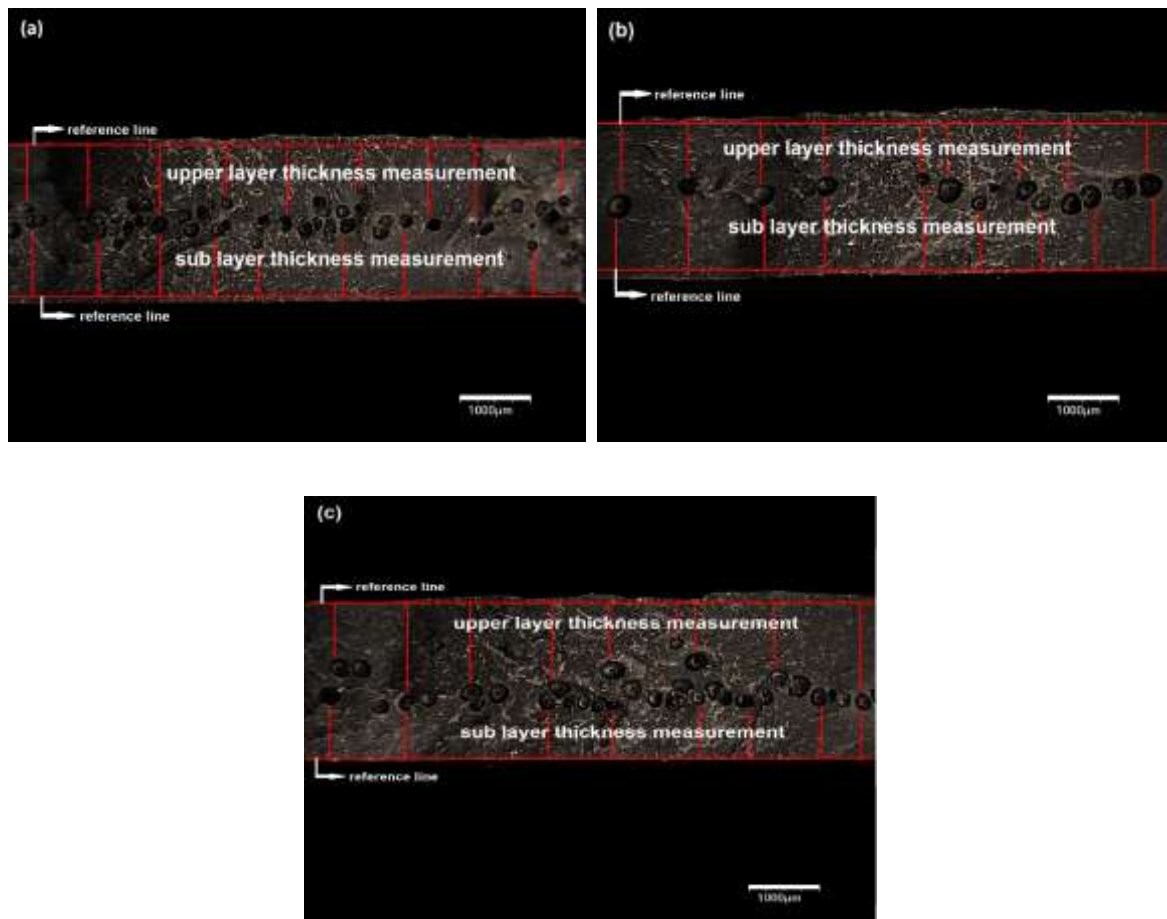


Figure 4. Measurement of upper and sub layer thickness of PP samples (a) 1% CFA, (b) 1.5% CFA and (c) 2% CFA

As shown in Figure 4, upper and sub skin layer thicknesses were determined by measuring the distance from the point where the sample ends (reference line) to where the first cell was seen. By taking random measurements from different places, the sums of average upper and sub skin layer values and total skin layer thickness are given in Figure 3. With the addition of foaming agent varying in weight, skin layer thickness between 1468 μm and 2123 μm was obtained.

The change in the obtained skin layer thickness is related to the number of cells in the structure [5]. As the thickness of the skin layer increases, foam cell formation decreases [23]. Due to the higher number of cells in 1% CFA, less skin layer thickness was obtained.

Figure 5 shows the relationship between foaming agent and Izod notched impact test results. The impact energy of the sample unfoamed PP was recorded as 11 kJ/m^2 . The impact strength of the foam samples varies between 12 kJ/m^2 -19 kJ/m^2 . The impact strength is higher in the foamed samples compared to the unfoamed samples. This situation is thought to be due to the differences in production parameters of the parts unfoamed and with foamed. This situation is compatible with the literature. Unal et al. [24] used different process parameters for unfoamed PP, and 1% CFA added samples. As a result of the process, there was no decrease in the impact strength value with the addition of CFA. In Figure 5, the impact strength decreases with the increase of CFA content. Chang et al. [21] observed in their study that the impact resistance decreased with the increase of foaming agent by weight. Yetgin et al. [25] found in their study that the impact strength decreased with the increase in the CFA ratio from 1% to 2%. Xu et al. [26] found that the impact strength was affected by the skin layer thickness, small and homogeneous distribution of the foam cells. The

small and homogeneous distribution of foam cells in the sample with 1% CFA is the result of a higher value of impact strength than the others.

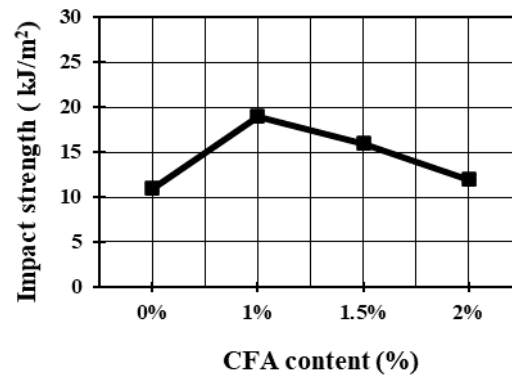


Figure 5. Notched Izod impact strength for different CFA contents in PP

Figure 6 shows the graph of the door panel changes in weight depending on the increasing foaming agent. The weight without the foaming agent additive the door panel is 790 g. When the graph above is examined, the weight was measured as 756 g for samples with 1% and 1.5% CFA addition, and 764 g for 2% CFA addition. Thus, a maximum of 4.3% weight reduction was achieved.

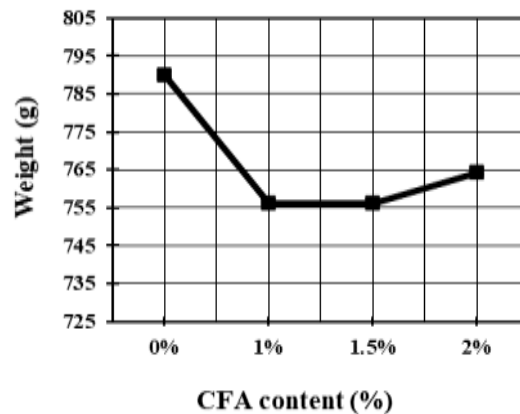


Figure 6. Weight change of the PP door panel in different CFA contents

3. Conclusions

This study aimed to improve impact resistance, weight, and cycle time by adding chemical foam to polypropylene during the production of the Toyota CH-R model vehicle door panel by plastic injection. The findings of the study are summarized as follows.

As the foaming agent ratio increased, foam size also increased. Average foam cell sizes are between 161-309 μm . The smallest foam cell size is 161.9 μm and obtained with the addition of 1% CFA.

The skin layer thickness was obtained between 1468 μm -2123 μm with the addition of foaming agent varying in weight. Due to the higher number of cells in 1% CFA, less skin layer thickness was obtained.

Impact strengths in PP foam samples are between 12 kJ/m² - 19 kJ/m². It can be said that the higher the number of foaming agents, the lower the impact strength.

While a door panel of the CH-R model vehicle without additive is 790 g, it is between 756-764 g with the addition of the foaming agent. 4.3% weight reduction was achieved with 1% CFA by weight.

By ignoring the holding time, 5.5 seconds of gain was achieved from the cycle time in the production of one door panel.

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Authors' Contributions

SÇ conducted impact tests, optical microscope examinations. MA made literature survey. NO conducted weight tests. MO prepared the test samples. MU made injection moulding. AA is project manager and idea owner. SÇ and MA wrote the paper. NO and AA made controls.

All authors have read and approved the final version of the article.

Conflict of Interest

The authors declare that there is no conflict of interest.

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