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Effect of Injection Molding Parameters on the Chemical Foaming of Acrylonitrile Butadiene Styrene (ABS) Using Breathing Mold Technology

Sándor K. Jakab*, Gábor Dogossy

Department of Materials Science and Engineering, Széchenyi István University, Győr, Hungary
jakab.sandor.kalman@sze.hu

Manufacturers have to adapt very quickly to the accelerating world and use specialized machines for production to meet the demands. This also means that those machines are not used as often as their mass-producing counterparts and sometimes become obsolete. In the case of foaming with injection molding, a complicated system has to be built around the machine and has to be structured in a specific way, which is not always cost-efficient. In this paper, two methods of chemical foaming of Acrylonitrile Butadiene Styrene (ABS) were performed on a regular injection molding machine. Chemical Blowing Agent (CBA) and Expandable Microsphere (EMS) were used with breathing mold technology. Injection molding parameters were modified, and specimens were produced for mechanical and morphological examinations. Properly selected parameters for foaming play an important role in retaining the mechanical strength of the product. With low switch-over volume and using the core-back method, it is possible to foam ABS using a Chemical Blowing Agent.

1. Introduction

Polymer foaming is a widely used technology, mainly because it reduces weight and, most of all cost of the manufactured product. The basic premise of this process is to introduce a blowing agent into the plasticized polymer that generates gases inside the material or is itself a gas that expands within (Standau and Altstädt, 2019). The goal is to create a hollow, homogenous cell-like structure inside the produced good, maintaining the strength and/or functionality of its solid counterpart. This technology can be used on extrusion and injection molding product lines (Jin et al., 2019).

Physical and chemical foaming are the most used methods for mass production. Mixing, heating, and pressuring of materials is carried out in the by means of a screw in the extrusion/injection equipment. Therefore, separate and sometimes complicated systems are used by the manufacturers to guarantee the proper introduction of the foaming material into the melted plastic (Altan, 2017). Most of the time, the foaming happens at the end of the extrusion part, so the whole system requires unique parts assembled in a way that cannot be easily tampered with (Rohleder and Jakob, 2015).

To combat this issue, the foaming system has to be simplified, and the current easiest solution is chemical foaming, pre-mixing the polymer with a Chemical Blowing Agent (CBA), usually in the form of pellets. Although this technique is simple, finding proper parameters is quite challenging since improper temperatures, speed, and mold structure lead to imperfect or no foaming at all (Roch et al., 2014).

The main takeaway from most of the literature is that the process has to be fast and continuous. The Chemical Blowing Agent (CBA) can easily dissolve if left for a long time in the heating zone, and gases can escape or merge with the plastic. Selecting the proper amount of blowing agent is also important since the required percentage differs from plastic to plastic. Generally, a low amount can be used and later increased with a trial-and-error method until the desired foaming is achieved. However, the injected amount of polymer has to be adjusted parallel to the changing of blowing agent content so the blowing agent can truly expand inside the die. The whole clamping and pressuring system of the mold have to be lower so the hollow parts are not crushed inside.

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Most of the articles about foaming with chemical blowing agents discuss new technologies, such as microcellular foaming and core-back technologies. The usage of supercritical fluid allows foaming with smaller cellular sizes but much denser, while the mechanical properties barely change (Llewelyn et al., 2020). Although this method is quite efficient, it still requires a separate system to dispense the blowing agent. The other method is the core-back or breathing mold method. During the injection molding, while the melted plastic cools inside the die, its two parts open, making a small gap for cooling airflow to pass through the molds and allowing space for the foaming agent to take effect, and the product can expand freely along the shape of the die. This method can be used on conventional injection molding machines (Wu et al., 2019).

Most of the polymers can be foamed, but each of them has their own requirements. Polystyrene can be easily foamed because of its amorphous crystallinity (Chung et al., 2021). Polyamide (Jiang et al., 2021) and polypropylene also can be foamed, but there is not much research about Acrylonitrile Butadiene Styrene (ABS) foaming, as the previous works available in literature report failures of foaming of ABS (Aycicek et al., 2018). The reason for the failure of foaming can be traced back to the parameters used for manufacturing. Therefore, it is reasonable to research the effects of parameters. Too much blowing agent causes the foamed cell structure to collapse, while too little amount does not form enough. The mold temperature also influences foaming by allowing it if it is low enough (Ronkay et al., 2017). The mass volume injected in the mold also plays an important role, as the too-small amount doesn’t fill out the mold properly and allows the escape of gases from the part. Injection speed plays an important role in the surface quality of the product, while the holding pressure ensures the proper filling of the mold. The main parameter that can greatly affect of foaming in the case of core-back technology is a core-back rate, in other words, how much and how fast the mold opens. The increase in mold opening allows better foaming, but if it happens too fast, the melt polymer doesn’t have time to solidify, which leads to improper captivity fill (Wu et al., 2019).

The reason for failure, specifically in the case of ABS, is their poor heat conducting property (Lendvai and Rigotti, 2023), and it needs a high processing temperature, which can hinder the foaming process, as opposed to the low-temperature requirement for successful foaming to occur. However, the lack of articles and research into the topic of ABS foaming with CBA gives enough reason to conduct an investigation into this topic.

In this paper, foamed ABS injection molding was researched using a conventional injection molding machine and chemical blowing agents with the core-back method. The research aims to find the proper parameters for this method (for example, mold opening, switch-over volume, and foaming agent used) and make mechanical and morphological measurements on the produced specimens to obtain data about the rate of foaming possible with this technique. With this contribution, the unexplored parameters of ABS foaming were expected to be clarified and expand knowledge about this operation type.

2. Materials and methods

For this research, foamed ABS specimens with injection molding were produced. The used ABS was Terluran GP35 type polymer from BASF Chemical Company. This was mixed with a chemical blowing agent (CBA) called PRISMA AD PE Expansor 91205 from ICC-CHEMOL Ltd., which was mixed with the ABS at a 2 % rate. We also produced a few specimens with the same ABS mixed with an Expandable Microsphere (EMS) type blowing agent called Expancel 980 MB 100 from the Nouryon Gmbh. The used machine for injection molding was an Arburg Allrounder 420C Golden Edition injection molding machine, equipped with a mold capable of manufacturing specimens corresponding to EN ISO 527-2 international standards and having a mold cavity of 42 cm^3. The main settings of the machine for manufacturing can be seen in Table 1.

Table 1: Main settings for injection molding (with highlighted variable data)

Settings name	Unit	Value	Settings name	Unit	Value
Mold opening	**mm**	**0.4/0.6**	Injection pressure	bar	1,400
Drying temperature	°C	80	Switch-over	cm^3	2
Drying time	h	9	Holding volume rate	cm^3/s	10
Clamp force	kN	700	Holding pressure (p1)	bar	500
Mold temperature	°C	35	Holding pressure (p2)	bar	400
Nozzle temperature	°C	220	Holding time (t2)	s	1
Switch over	**cm^3**	**34/36/38/40**	Holding Pressure (p3)	bar	150
Screw rotation	m/min	20	Holding time (t3)	s	1
Back pressure	bar	20	Residual cooling	s	20
Injection speed	cm^3/s	35			

As can be seen in Table 1, we tried different mold openings and switchovers to determine how these parameters affect foaming. The summary of the main difference between the made specimens can be seen in Table 2.

Table 2: Summary of manufactured specimens

Materials/Mold opening/Switch over	Designation
ABS/0/38	ABS
ABS+CBA/0.4/34	ABS_434
ABS+CBA/0.4/36	ABS_436
ABS+CBA/0.4/38	ABS_438
ABS+CBA/0.4/40	ABS_440
ABS+CBA/0.6/34	ABS_634
ABS+CBA/0.6/36	ABS_636
ABS+CBA/0.6/38	ABS_638
ABS+CBA/0.6/40	ABS_640
ABS+EMS/0.6/40	ABS_EMS

The produced specimens were examined via tensile, bending, and impact testing, and their density was measured. The tensile test was done under the guidance of the ISO 527, while the bending was under the ISO 178 standard. 5-5 specimens were collected from each sample for the test. Both measurements were done with an Instron 5582 universal testing machine, with 10 mm/s constant crosshead speed, but while the gauge length for tensile was 100 mm, the span between the supports for the bending test was 64 mm. For the impact test, the ISO 179 standard was followed, and a Ceast 6545 impact testing machine was used with a 15 J hammer and a support span of 62 mm. The required 80 mm length unnotched rectangular specimens were made from the injection molded specimens. 5 measurements were performed from the produced specimens of each sample. The standard deviation of measurements was calculated and served as a comparison of the change in properties, assuming normal distribution with 1 standard deviation (68 % confidence).
Densities of raw material and foamed samples were determined by mass measurement with Ohaus Explorer analytical scale, calculated by Eq(1) according to Archimedes Principle:

$$\rho_s = \frac{\rho_e m_a}{m_a - m_e} \tag{1}$$

where ρ_s (g/cm^3) is the density of the sample, ρ_e (g/cm^3) is the density of ethanol, m_a (g) is the measured mass of the sample in air, m_e (g) is the measured mass of the sample in ethanol.

3. Results and discussion

From the manufacturing and early inspection of the created specimens, visible increases in thickness and small foam structures can be observed in the case of ABS+CBA specimens. Unfortunately, the ABS+EMS blend did not show any change in structure, and it was determined that no foaming occurred during the production of these specimens, even with varying parameters like temperature, mold opening, and switchover.

3.1 Density measurement

The density measurements showed a decrease in the properties of all foamed ABS mixtures when compared to the pure ones. Table 3 shows the measurements result for all the evaluated materials, with the designation at the first and third column and the corresponding density right to the second and fourth column.

Table 3: The density of the materials

Designation	Density [g/cm3]	Designation	Density [g/cm3]
ABS	1.002±0.0093	ABS	1.002±0.0093
ABS_434	0.919±0.0021	ABS_634	0.906±0.0061
ABS_436	0.920±0.0019	ABS_636	0.915±0.0049
ABS_438	0.950±0.0055	ABS_638	0.949±0.0045
ABS_440	0.958±0.0006	ABS_640	0.966±0.0030
ABS_EMS	0.975±0.0014	ABS_EMS	0.975±0.0014

The biggest decrease is shown at the lowest mass volume injected into the mold in the case of ABS_434 and ABS_634, with their 0.919 and 0.906 g/cm^3. Although the ABS_EMS specimens didn't foam, they show a decrease in density compared to the 1.002 g/cm^3 of the ABS with their 0.975 g/cm^3. The reason for that is in the carrier of the blowing agent. The carrier of the microspheres is made of Ethylene-Vinyl Acetate (EVA), which has a lower density than ABS, and mixing with it decreases this value.

3.2 Tensile test

The results of the tensile test can be seen in Table 4. The specimens made with expandable microsphere foaming achieved one of the largest property improvements. However, when compared with the density values, it can be concluded that no foaming was achieved, the improvement being due to the EMS substrate (EVA). Of the foamed samples, the best results for both mold openings were obtained with the 36 cm^3 switchover.

Table 4: Summary of results of tensile test

Designation	Tensile strength [MPa]	Tensile modulus [MPa]	Elongation at tensile strength [mm]
ABS	27.16	1,521.58	2.56
ABS_434	27.72	1,527.29	2.50
ABS_436	29.85	1,613.15	2.70
ABS_438	29.12	1,531.39	2.85
ABS_440	26.79	1,454.04	2.83
ABS_634	27.83	1,505.08	2.83
ABS_636	30.57	1,629.56	3.02
ABS_638	29.71	1,575.97	2.75
ABS_640	38.59	1,853.90	3.08
ABS_EMS	30.61	1,836.07	2.85

3.3 Bending test

The results of the bending test can be seen in Figure 1 and Figure 2. Figure 1 shows the properties of the specimens with 0.4 mm mold opening, compared to pure ABS and ABS_EMS. It can be depicted that the changed switch-over value did not affect the bending properties for any of the samples as they remained between 50-60 MPa. The modulus values were also similar, except for the ABS_440, which decreased to 1,906 MPa. The only noticeable change was in the case of ABS_438 labeled specimens with 57 MPa flexural strength and 2,008 MPa flexural modulus. The reason for ABS_EMS surpassing even the pure ABS is because the failed foaming within the specimens and the added EVA simply increased its flexural properties.

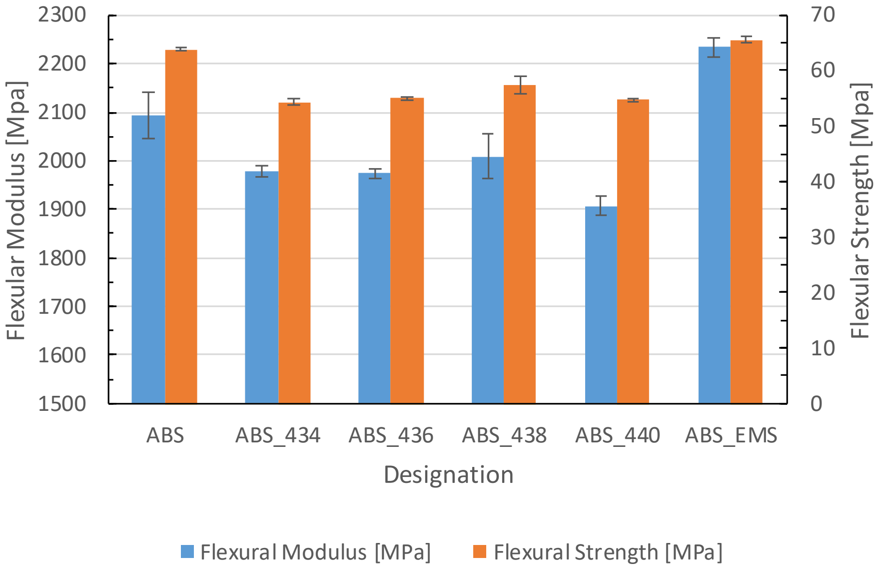

Figure 1: Flexural test results for pure ABS, ABS foamed with CBA using 0.4 mm mold opening and distinct switchover volume (increasing from left to right), and ABS foamed with EMS

In the case of the 0.6 mm opening, depicted in Figure 2, we do not see a change in tensile strength, as it remains between 50-60 MPa, with only a slight decrease in modulus, with the lowest amount presented by the ABS_634 labeled specimen's 1,872 MPa.

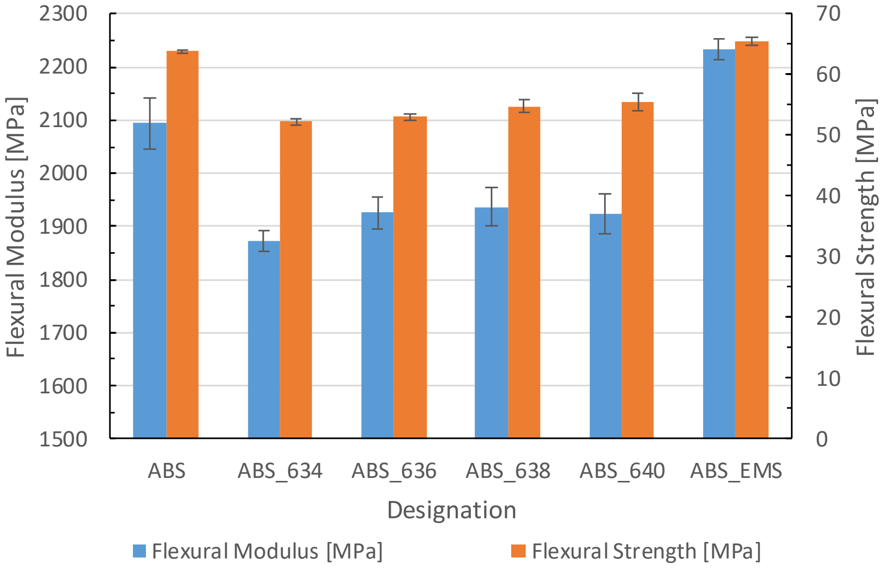

Figure 2: Flexural test results for pure ABS, ABS foamed with CBA using 0.6 mm mold opening and different switchover volume (increasing from left to right), and ABS foamed with EMS

3.4 Impact test

The results of the impact test can be seen in Figure 3. The impact strength of pure ABS is around 121 kJ/m^{2,} according to the test, towering above all the measurements. Therefore, it is not shown in the graph. The ABS_EMS has around the same impact strength (32 kJ/m^2) as all the other foamed specimens. From the size of the standard deviation, it can be concluded that the parameters did not affect this property.

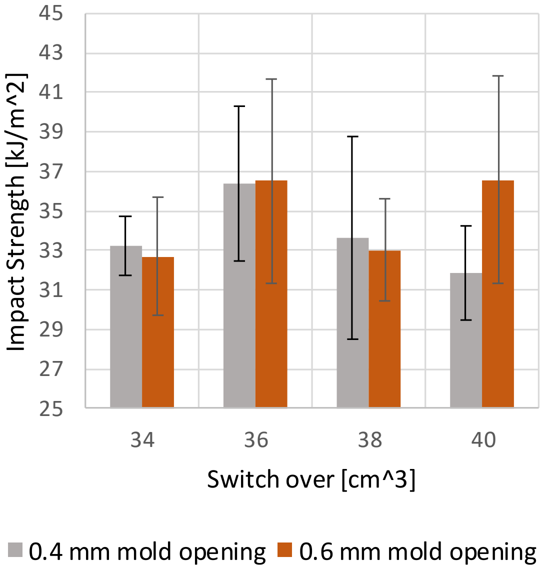

Figure 3: Summary of results of impact test

4. Conclusion

Different properties of chemical foaming were investigated using conventional injection molding with breathing mold technique. Based on the results, it was found that foaming with expandable microspheres (EMS) is not feasible for the chosen material due to the too-large processing temperature difference. When using the Chemical Blowing Agent (CBA), the use of the smallest switchover point, i.e., the least amount of material injected into the mold cavity, results in the largest density reduction. Contrary to expectations, the mechanical properties did not always decrease in proportion to the density reduction. For both mold openings, the tensile properties associated with the 36 cm^3 switchover showed an improvement compared to the original material. This may be a consequence of the homogeneous distribution and small cell structure. Further morphological studies are needed to confirm this.

In summary:

- Acrylonitrile Butadiene Styrene (ABS) foaming with a Chemical Blowing Agent (CBA) is possible using the core-back method.
- ABS foaming with Expandable Microsphere (EMS) was unsuccessful because of the main difference between the processing temperature of the foaming agent and ABS.
- The most favorable injection molding was with 0.4 mm mold opening and 36 cm^3 switch-over rate, which is around 7 % volume reduction.

References

Altan M., 2017, Thermoplastic Foams: Processing, Manufacturing, and Characterization. In: Cankaya N. (Ed.), Recent Research in Polymerization. IntechOpen Limited, London United Kingdom,117 – 137, DOI: 10.5772/intechopen.71083.

Aycicek M., Cakir S., Akinci A., 2018, Prepare foam with injection molding method in Acrylonitrile-Butadiene-Styrene (ABS) matrix using chemical foam agent. Materials Science: Advanced Composite Materials, 2(4), 1-4.

Chung C.-Y., Hwang S.-S., Chen S.-C., Lai M.-C., 2021, Effects of Injection Molding Process Parameters on the Chemical Foaming Behavior of Polypropylene and Polystyrene. Polymers, 13, 2331.

Jiang T, Zhang H., Zeng X., Zhang C., Gong W., He L., 2021, The effect of injection process for microcellular foaming on the cell morphology and surface quality of Polyamide 6, Mater. Res. Express, 8, 045311.

Jin F.-L.; Zhao M.; Park M.; Park S.-J, 2019, Recent Trends of Foaming in Polymer Processing: A Review. Polymers, 11, 953.

Lendvai L., Rigotti D., 2023, Thermal and thermomechanical properties of boron nitride-filled acrylonitrile butadiene styrene (ABS) composites. Acta Technica Jaurinensis, 16(3), 123–128.

Llewelyn G., Rees A., Griffiths C. A., Scholz S. G., 2020, Advances in microcellular injection moulding. Journal of Cellular Plastics, 56(6), 646-674.

Roch A., Huber T., Henning F., Elsner P., 2014, LFT foam - Lightweight potential for semi-structural components through the use of long-glass-fiber-reinforced thermoplastic foams. AIP Conference Proceedings, 1593, 471 – 476, DOI: 10.1063/1.4873824.

Rohleder M., Jakob F., 2015, 2 - Foam Injection Molding, Chapter In: Heim H.-P. (Ed), Specialized Injection Molding Techniques. William Andrew Publishing, Norwich, NY, United States, 53-106.

Ronkay F., Molnár B., Dogossy G., 2017, The effect of mold temperature on chemical foaming of injection molded recycled polyethylene-terephthalate. Thermochimica Acta, 651, 65-72.

Standau T., Altstädt V., 2019, Foams., In: Karger-Kocsis J., Bárány T. (Ed.), Polypropylene Handbook. Springer, Cham. Switzerland, 579 – 641.

Wu H., Zhao G., Wang J., Wang G., Zhang W., 2019, Effects of process parameters on core-back foam injection molding process. eXPRESS Polymer Letter, 13(4)., 390-405.