Development of Novel Polypropylene Foaming/Molding Technologies and Products for Sumiceller®

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Plastic foaming products (polystyrene, polyethylene and polypropylene) are used in various fields in items such as food-packaging materials, distribution packaging materials, automotive parts and construction materials.

Each product has its own characteristics such as light weight, flexibility (cushioning properties), heat insulation properties and sound absorption properties, which depend on factors such as the resin properties and foaming processes in each application field.

In automotive parts applications in particular, polypropylene foaming technologies and products are becoming the center of attention from the points of view of weight reduction and recyclability.

In this paper, we review the novel polypropylene foaming/molding technologies and products for Sumiceller®, and give our consideration to the requirement of weight reduction for automotive parts.

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Introduction

Foam manufacturing processes for resins started with the production of polystyrene foam and polyethylene foam at Dow Chemical Company in 1959, and after that, various technologies for foam manufacturing processes and products were developed ranging from thermoplastic resins to thermosetting resins.

Giving an overview of the plastic foaming products market, a variety of resin processing products having functions such as light weight, flexibility (cushioning properties), insulating properties and sound absorbing properties which make use of the characteristics of the amount of expansion and cell diameter and shape derived from the properties of the resin and the foaming processes are being used in food-packaging materials, distribution packaging materials, automotive parts, construction materials, etc. The scale of the market was approximately 630 billion yen in 2005.

While Sumitomo Chemical supplies the market with polyethylene, polypropylene and polystyrene as the raw material resins for plastic foaming products, Sumiceller®, which is a polypropylene extrusion foam sheet, was brought to the market in 1990 through a combination of Sumitomo Chemical's own materials design technology and foaming process technology. In 1997, operations for it moved to Sumika Plastech Co., Ltd.

Since Sumiceller® went on the market, the authors have progressed with investigations for improving quality, developed high additive value products and, further, developed new applications. At the same time, we have accumulated a large amount of diversified and integrated elemental technology (catalyst and material design, polymerization processes, devices for molding processes, molding process methods, etc.) related to polypropylene extrusion foaming. In particular, new molding process technology that has made advancements and integrated reduced pressure molding process technologies like vacuum molding processes increase the additive value of Sumiceller® as well as opening the door to the development of new applications for polypropylene extrusion foam sheets. It has been the driving force behind the development of highly value added automotive parts with weight reduction, higher rigidity and higher heat resistance.

In this paper, we will give an overview of the characteristics of Sumiceller® polypropylene extrusion foam sheets, which were developed through a combination of our own materials technology and molding process technology as well as introduce our work on the development of new process products using new molding process technology. Furthermore, we would like to touch upon our thinking about the development of foaming/molding technologies and products for the requirement for weight reduction in automotive parts.

Foaming Technology

1. Classification of technology

Essentially, plastic foaming is generating gas in the resin material and forming an expanded body (foam) where these voids (bubbles) are hardened with a targeted shape and size. Here, we classify plastic foaming technologies according to the source generating the foaming gas and the state of the resin material during the foaming process (**Table 1**).

Table 1 Classification of expansion processing thechnologies

Expansion agent		State of material under foaming process		
		riquid	melted	solid
Chemical		—	Injection/Extrusion foaming	—
Physical	CFC	Polymerization foaming (Polyurethene)	Extrusion foaming	Beads foaming
	Hydrocarbon	—		
	CO_2/N_2	—	Injection/Extrusion foaming	—

The technology is classified according to the method for generating the gas in the foaming process and the substance generated as "chemical foaming methods," where the gas is generated by a chemical reaction, and the broader sense of "physical foaming methods," where the volatile substance is dissolved in the resin material and the gas formed.

The compounds used in chemical foaming methods include organic foaming agents such as azodicarbonamide (ADCA) and inorganic foaming agents such as sodium bicarbonate. In addition, Freon gas, hydrocarbon based organic solvents, carbon dioxide and nitrogen may be cited as foaming agents used in physical foaming methods in the order of the era in which the technology was developed. Since Freon gas and hydrocarbon based organic solvents typically have a high latent heat when volatilizing (vaporizing and evaporating), they effectively lower the temperature of the resin, which is in a molten plastic state and rapidly solidify the void (bubble) walls, so they have the characteristic of making it possible to stably obtain products with high expansion ratios of 30×.

On the other hand, carbon dioxide and nitrogen have the characteristics of (i) not being toxic, (ii) reaching a critical state at a comparatively low temperature (critical temperature of carbon dioxide being 31.0°C with a critical pressure of 72.9atm and the critical temperature of nitrogen being –147°C with a critical pressure of 33.5atm), and (iii) having a comparatively high solubility in resin materials, so investigations into them as "volatile substances" that are friendly to the Earth's environment have been actively pursued in recent years. Moreover, carbon dioxide is mainly used in extrusion foaming process, while nitrogen is mainly used in injection foaming process. In addition, since it is known that the glass transition temperature of polymers is lowered because carbon dioxide is dissolved, use of carbon dioxide in extrusion foaming process can be thought of as being not only a source of gas generation, but also a method that modifies the foaming process properties accompanied by a reduction in the viscosity of the system.[1), 2)]

In the background of these changes in volatile substances, are an increase in new societal needs that are aimed at sustainable global growth and development that takes into consideration the Earth's environment of which the Montreal Protocol (related to substances that damage the ozone layer, issued in 1989), the revised Air Pollution Control Law (regulating volatile organic compounds, revised in 2004) and the Kyoto Protocol (concerning the reductions in greenhouse gases which are a cause of global warning, issued in 2005) are representative.

In addition, we can make classifications according to the state of the material during foaming into "molten foaming methods," where foaming takes place in a molten state, "solid foaming methods," where there is foaming in a solid-state and, further, "cast foaming methods," where a liquid material is foamed during cast molding. In addition, molten foaming molding can be roughly divided into "cross-linking foaming methods," such as "chemical cross-linking" and "electron beam cross-linking," and "non-cross-linked foaming methods" such as extrusion foaming. Moreover, Sumiceller®, which is introduced in this paper, is classified as a non-cross-linked extrusion foaming method.

2. Polypropylene foaming

Polypropylene is a general-purpose resin that is widely used as a low-cost and environmentally friendly resin with excellent heat resistance, chemical resistance, light weight and recyclability, and it has uses in a wide variety of fields of application and a high growth rate. In addition, polypropylene foaming products include (i) low expansion products (within an expansion ratio of 5× or less, non-cross-linked, continuous processes), (ii) high expansion products (expansion ratios greater than 5×) and (iii) bead expansion products (expansion ratios of 15× to 45×, non-cross-linked, batch process). Since the recyclability and productivity for foaming products using non-cross-linked, continuous processes such as Sumiceller® is superior, we can expect growth in the future.

However, since polypropylene is a crystalline resin, sudden changes in the viscosity arise around the melting point, and since the gas that is generated cannot be solidified effectively as voids (bubbles), it has inferior expansion molding properties in terms of expansion ratio and independent bubble ratio. It is thought that it would be effective to improve the melt strength and increase the gas holding ability to make improvements in these, so there have been proposals for material that focus on strain hardening properties during extensional flow. Specifically, there have been proposals for methods such as (i) widening the molecular weight distribution, (ii) producing long chain branches, for example, by electron beam irradiation treatment and (iii) creating composites with other resins (materials with ultrahigh molecular weights) having a high molten tensile strength.[3)–6)]

There is a long history of investigations into controlling molecular weight distribution using polymer blends and multistage polymerization, and there is a wealth of actual results in improvements (drawdown control) to the vacuum molding properties of polypropylene sheets.

In recent years, a new high melt strength polypropylene known as New-foamer® (reactor made HMSPP) from Japan Polypropylene Corp. has appeared on the market. In addition to the characteristics of a high melt strength and high strain hardening properties in extension deformation, New-foamer® is superior to conventional HMSPP in terms of having less reduction in MFR during recycling (repeated kneading).[7)]

In addition to moving forward with environmental responsiveness such as reduction in energy and reduction in resources maximizing the characteristics of polypropylene materials, it is necessary to develop low-cost catalysts and polymerization processes and develop materials with superior foaming processability and fitness for recycling. To do this, it is important to examine the improvements in the foaming processability for polypropylene materials focusing on melt strength and strain hardening properties.

3. Sumiceller® polypropylene extrusion foam sheet

Sumiceller® is a polypropylene material developed through Sumitomo Chemical's own catalyst material design and polymerization process and is a polypropylene extruded foam sheet developed by combining this with our own expansion molding technology.

Besides a 1.3× expansion foaming product that is mainly used for protective materials in floor and wall surfaces and a 3.0× expansion foaming product that is used in boxes, partition, cushioning material, etc., there are functional materials, such as functional films and nonwoven cloth, and special laminated grades of Sumiceller®. It is also used in a wide variety of fields such as distribution packaging materials, signboards, display materials and automotive parts. The authors have concentrated their energy on the technical development of lamination and integration with different types of materials, which are considered as important elemental technologies for new application fields with the objective of providing surface improvements and better design characteristics.

Fig. 1 is a cross-sectional photograph of Sumiceller® and typical polypropylene foam sheet products in the market. Moreover, the specifications for each of the products are constant with an expansion ratio of 3× and a thickness of 3.0mm, but there is a definitive difference in the size of the cells (cell wall thickness).

If we calculate the number of cells per unit cross-sectional area for reference, we can see that the number of cells in the Sumiceller® is 10 to 100 times larger than that of others. This difference in cell diameter can be thought of as arising because of the melt properties of the resins used and the foaming process (foaming agent and device), therefore the uniform and fine cells of Sumiceller® have a great advantage not only for the quality of the foam sheet, but also in the new molding process that will be discussed in the following section.

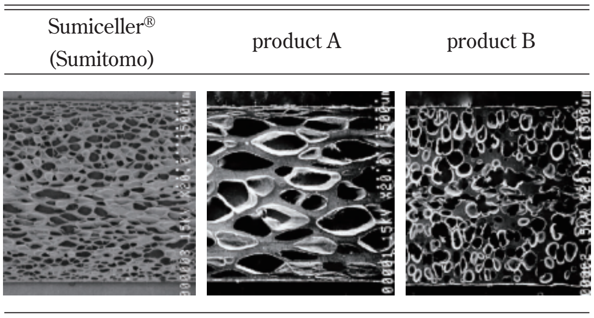

Fig. 1 Cross section of PP foam product

Fig. 2 arranges the relationship between Sumiceller® and typical polypropylene foam sheet products according to the relationship between product thickness and expansion ratio. Up to this point we have put our main efforts into the field of materials for distribution and packaging with the core being products with 3× expansion and a thickness of 2 to 5mm. We have not participated in the high expansion ratio area that exceeds 3× and the high thickness area exceeding 10mm. The authors settled on a technical development strategy and market development strategy for development with the superior cell quality of Sumiceller® as its strength.

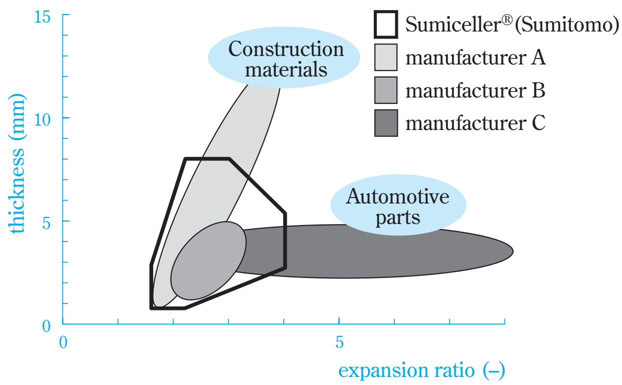

Fig. 2 Product coverage of Sumiceller® (Target areas and applications)

Currently, we have set our targets on the area of high expansion ratios, targeting an expansion in the automotive field and the area of high thickness, envisioning applications for construction materials, and are moving forward with the development of new foaming product using new foaming/molding technology.

Development of New Processed Products Using New Molding Process Technology

1. Back molding (BM) technology

Based on the Sumitomo Press Molding (SPM) process, Sumitomo Chemical has moved forward with the development of reduced pressure molding process technology for automotive parts. In addition, we have carried out development on various types of foaming technology with the goal of reducing the weight of automotive parts.

Injection foaming technology is already used in many automotive parts, and deepening of the technology is progressing. At present, with the method known as the core back process that carries out control by linking the mold clearance to the foaming process, the expansion ratio is 2× to 3×. If we focus on the expansion ratio, the rate of weight reduction for the extruded foam sheet is superior. In addition, with the core back process, the expansion ratio can be comparatively accurately controlled on the projected surface of the mold, but with surfaces perpendicular to the projected surface of the mold (known as vertical walls in the product), the expansion ratio cannot be achieved. In terms of this point, it is advantageous for the molded bodies obtained with vacuum molding of extruded foam sheets because the expansion ratio is stably maintained regardless of the part of the product.

Conversely, while a shape can be created in vacuum molding of extruded foam sheets, single unit formation of ribs (reinforcing parts) and clip bases (parts used in assembly and attachment) cannot be done as in injection molding. This is the problem we have to overcome as a molding technology for automotive parts.

BM technology overcomes this flaw and was developed for use by vacuum molding technology for the purpose of establishing both reduced weight and increased function at high levels for automotive parts. It is Sumitomo Chemical's own unique reduced pressure molding process technology.

The manufacturing of automotive parts by reduced pressure molding processes is not only controlling the cost of capital investments in facilities such as molds and molding machines, but also molding large parts with little distortion. When covering materials such as nonwoven cloth and fabric materials and further thermoplastic polyolefin elastomer (TPO)/electron beam cross-linked polypropylene foam sheet (PPF) laminates are made to adhere and molded in a mold, there is merit to controlling the damage (breakdown of the nonwoven cloth fabric, to the covering material and puncturing of the PPF) and increasing the designability. In particular, the parts around the inner panels of doors for which there are many opportunities for being looked at by passengers among the interior parts of automobiles have a high standard of requirements for appearance.

As a result of the authors making progress in deepening and advancing molding process technology to respond to these requirements, BM technology that integrates and combines vacuum molding and extrusion molding into a series of processes has been brought to fruition.[8)]

Fig. 3 shows the flow of the BM process. First of all, Sumiceller® that has been softened by heating to a prescribed temperature in a heating process is sandwiched in a core and cavity mold pair and partial molding is carried out by applying a vacuum. (In this diagram, the case of vacuum forming pulled towards the core mold is shown, and the vacuum is applied from the cavity surface, which is the design surface. In addition, the core mold is used as a plug-assist supporting the application of the vacuum.) Next, plasticized resin is supplied from the side opposite to the design surface (core mold) to the Sumiceller® that has been partially molded by vacuum forming, and ribs, clip seats and other functional parts are molded as a unit.

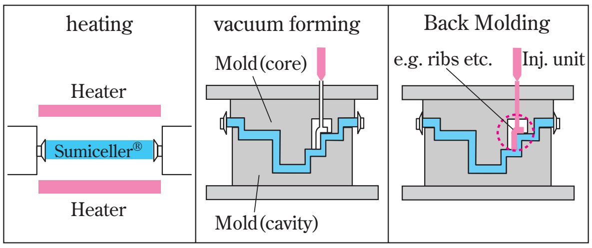

Fig. 3 Back Molding Process (Combination of vacuum forming and injection molding)

Fig. 4 is a photograph of a door panel (rear side) obtained using BM technology. The ribs and clip bases are formed as a unit and connected to the surface of the Sumiceller® that has been partially molded into the door shape by vacuum forming. In this example, ribs are selectively formed on parts requiring strength such as the armrest part, and it shows that there can be an increase in function for the door part.

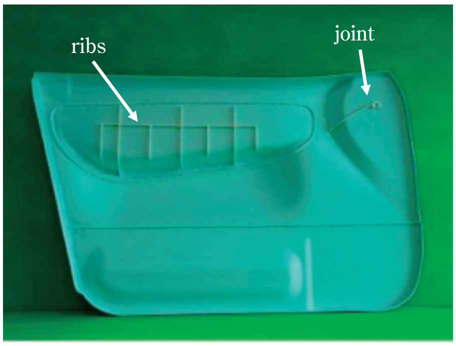

Fig. 4 Back side of door panel by Back Molding Process

Supplying pressure to a plasticized resin on the surface of a solid injection molded body or a vacuum formed body surface of a solid extruded sheet and unitizing is comparatively easy, but precise control of the pressure when supplying the plasticized resin is necessary for foam sheet surfaces so that compression and expansion do not arise.

In other words, if excessive pressure is applied, the compression of the foam sheet (Sumiceller®) is released and a bulging deformation arises in the design surface after the mold is released. On the other hand, if the pressure is insufficient, volume compression caused by crystallization of the ribs stands out, and a concave deformation arises in the design surface (**Fig. 5**).

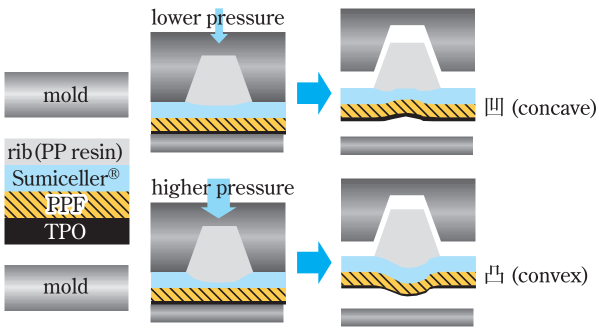

Fig. 5 Unevenness of surface depends on molding pressure

In addition, as a result of measuring the amount of surface roughness after applying a jig that had been heated to 170°C to Sumiceller® that had been heated to 60°C for 10 seconds at a prescribed pressure, envisioning a temperature of 170°C for the resin that is plasticized and supplied and a surface temperature of 60°C for the Sumiceller®, to obtain guidelines for pressure control during the molding process, it was confirmed that the bulging deformations where less than 0.5mm if the pressure was 3MPa or less and that it could be controlled to a minute deformation of an extent that was not visually discernible (**Fig. 6**).

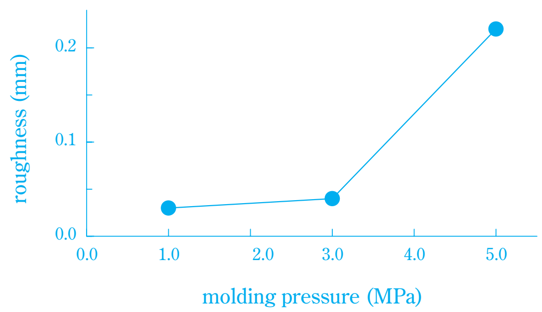

Fig. 6 Roughness (convex) vs. molding pressure

When molding is done with multiple channels of different channel lengths through a single point gate, it is known that bulging deformations caused by pressure excesses at the short channels and concave deformations and the long channels arise. Therefore, not letting the channels be too long and making them uniform reduces the damage to the Sumiceller®, and can also be thought of as being effective in stabilizing the contact between parts. In addition, by controlling the supply pressure for the plasticized resin in a stepwise matter, it is possible to obtain high quality molded parts without losing the appearance of the design surface or the strength of the product.

Furthermore, it is possible to apply typical injection molding technology such as multi-point gate and valve gate (individual control of opening and closing timing possible), and in addition by applying a vacuum from the cavity mold side, it is possible to use vacuum/blow molding that combines this with air pressure blown from the core mold side.

BM technology of this sort forms a linked group of techniques from the elemental technologies forming the core and optional peripheral technologies for solving problems. Sumitomo Chemical provides licenses to molding process makers through Sumika Plastech Co., Ltd., along with promoting the dissemination of the technology, and continuing to think in terms of putting effort into brushing up the technology so as to increase the attractiveness of Sumiceller® sales promotion cards.

2. Form expansive molding (FEM) technology

Sumitomo chemical developed polypropylene extruded foam sheets for food product packaging containers targeting the trays that are used for packaging meat, fish and side dishes in supermarkets and convenience stores and the bowls for instant noodles. In addition, with the goal of making increased additive value in foam sheets, we carried out parallel investigations into the vacuum molding processes for various types of containers.

The important points when vacuum molding foam sheets are maintaining a uniform product thickness and independent bubble ratio. Typically, in deep drawing (high draw ratio) molding such as that for bowls, the problems are that localized thick parts arise and there is a drop in the independent bubble ratio. To counteract this, we developed technology for controlling the thinning out of the strong parts that are pulled down strongly, by using a core and cavity mold pair and by applying a vacuum from both sides of the mold.

Fig. 7 is a comparison of vacuum molded product cross-sections with the same bowl shape and conventional technology (vacuum application on one side) and the improved technology (vacuum application on both sides). While a localized thinning can be seen at the corner part that was draw down strongly in the cross-section of the molded product using conventional technology, the cross-section of the molded product using the improved technology has a thickness of twice that of the molded product from the conventional technology (expansion ratio also being twice that of the initial sheet), and the thickness is uniform.

The authors focused on the point that the thickness multiple and expansion ratio multiple were achieved with good precision by molding with the vacuum applied from both sides, and have proposed a molding

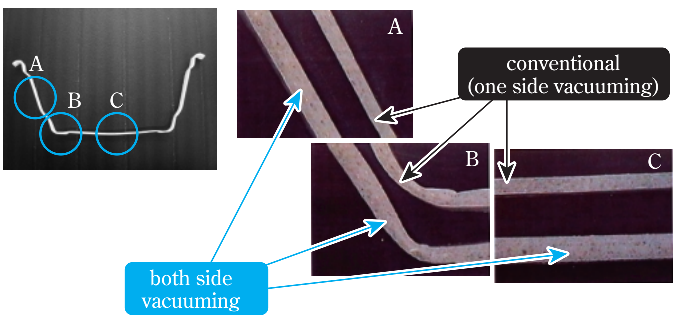

Fig. 7 Cross section of vacuum formed product (noodle bowl)

process technology that selectively expands foam sheets in the direction of thickness using the application of the vacuum from both sides. We have called this Foam Expansive Molding (FEM).

Fig. 8 shows the flow of the FEM process. First of all, Sumiceller® that has been softened by heating to a prescribed temperature in a heating process is sandwiched between a core and cavity mold pair. Next, by applying a vacuum from both the core and cavity sides, partial molding of the shape and expansion molding (forming a high expansion ratio and forming greater thickness) are carried out simultaneously.

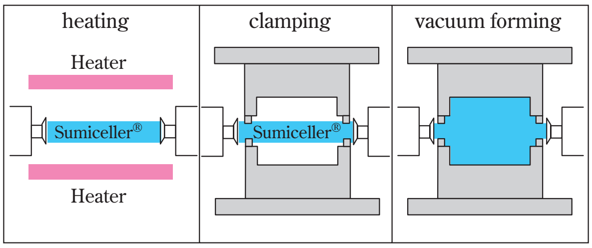

Fig. 8 Foam Expansive Molding Process (Both side vacuum forming)

Moreover, by linking the process of vacuum application and operation of the mold clearance (increase), it is possible to promote a greater expansion ratio and increase in thickness. Furthermore, by partially operating (increasing) the mold clearance, it is possible to increase the expansion ratio and increase the thickness selectively in specific parts of the molded product (**Fig. 9**).

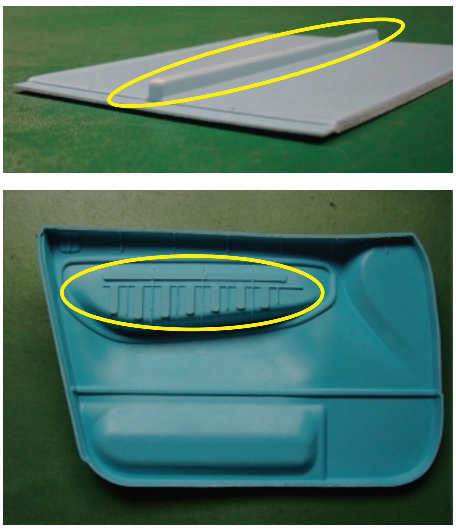

Fig. 9 FEM products (partial FEM)

As was explained in Fig. 1, Sumiceller® has the characteristic of the diameter of the expansion cells being extremely fine and uniform. The quality of these cells is also an important characteristic in FEM technology, and deformation (expansion in the direction of thickness) of the cells during FEM can be thought of as being easy. In addition, with Sumiceller®, the presence of an optimally designed skin layer can be thought of as effectively controlling the selective expansion and deformation in the direction of thickness.

The molding method that efficiently gives products with a high foaming ratio and thickness is technology that can provide solutions for both of the problems of decreasing weight and increasing rigidity in automotive parts. Here we would like to consider the rigidity of FEM molded products using Sumiceller® in a model of a 2.3mm thick solid molded product made of a polypropylene block copolymer, envisioned for typical interior parts for automobile.

A solid molded product with a thickness of 2.3mm is approximately 2,070g/m^2. In contrast to this, a 3.0× expansion of Sumiceller® with a thickness of 2.5mm is approximately 750g/m^2. **Fig. 10** shows the flexural rigidity on the vertical axis and the expansion ratio on the horizontal axis, that is, the expansion ratio and the extent to which the thickness and foaming ratio increase with Sumiceller® using FEM technology. First of all, the flexural rigidity of the solid molded product is 119N·cm^2, and in contrast to this, the flexural rigidity of the 2.5mm thick Sumiceller® is approximately 45N·cm^2. If, based on this, we move towards an increased expansion ratio and greater thickness using FEM technology on Sumiceller®, it would appear that the flexural rigidity would increase at a fixed rate.

We can see that at a thickness of 4.2mm after FEM (and foaming ratio of approximately 5) the flexural

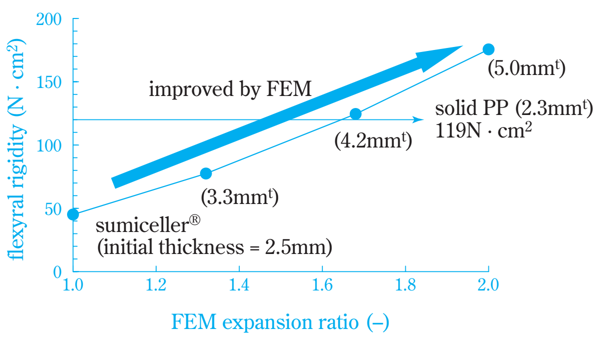

Fig. 10 Improvement of flexural rigidity by FEM technology

rigidity (124N·cm^2) is somewhat higher than that of the solid molded product. If we go further to a thickness of 5mm (foaming ratio of 6), the flexural rigidity reaches 175N·cm^2. A simple interpretation of these results is that in the FEM molded product (expansion doubled) with a foaming ratio of 6 and a thickness of 5mm, we have achieved both a weight reduction of approximately 64% over the solid molded product (thickness of 2.3mm) and approximately the same flexural rigidity.

The concept of the reduced weight and higher rigidity developed with FEM technology is as described above, but in the development of actual products, there are problems such as (i) the design side at least having to be covered with a covering material and (ii) consideration having to be given to trimming of the end parts (periphery of the part) for applications of foam sheets in automotive parts. These cannot simply replace solid molded products. Conversely, if products are developed making use of the characteristics of FEM technology, the replacement targets are highly rigid and highly heat resistant parts that make use of non-polypropylene materials. At present, we are progressing with the development of highly functional interior parts for automobiles by combining Sumiceller® material design and FEM technology with the goal of making replacements for non-polypropylene materials.

3. In-line foam expansive molding (FEM) technology

If we obtain high foaming ratio and high thickness Sumiceller® using conventional technology, there are drops in cell quality and quality of appearance such as cell breakdown and sheet deformation, so there is a limit to the foaming ratio and thickness.

The concept of FEM technology is first forming a foam sheet with a superior surface appearance, and by selectively expanding in the direction of thickness in the next process, making it possible to obtain high foaming ratio, high thickness and high independent bubble ratio products without losing the surface smoothness or precision in the thickness. Therefore, FEM technology is technology for obtaining a high foaming ratio and high thickness foam sheet using a vacuum chamber if it is not necessary to have partial molding of the shape using vacuum forming.

The authors have incorporated FEM processes in the later stages of the Sumiceller® extrusion foaming process and have proposed the concept of in-line FEM technology that continuously manufacturers high foaming ratio, high thickness Sumiceller®. As an investigation of industrialization for this process, we examined expansion forming in the direction of thickness using a small vacuum chamber and keeping the planar shape of the Sumiceller® the same in a batch system.

To confirm whether it was possible to control foaming ratio and the thickness of the final product using the vacuum chamber clearance in this process, we inquired into the changes in the atmospheric pressure and internal pressure in the bubbles in the various processes. The preconditions for the inquiry are given in **Table 2**.

Table 2 Preconditions of FEM simulation

	process of FEM in vacuum chamber			
	heating	vacuum	cooling	discharge
$P_{atm.}$	0.1 MPa	0 MPa	0 MPa	0.1 MPa
$P_{in\ cell}$	0.1 MPa + ΔP	0.1 MPa – ΔP	0.1 MPa – ΔP	0.1 MPa – ΔP
$T_{cellwall}$	165°C	165°C	r.t. (23°C)	

The atmosphere for the heating process was at atmospheric pressure, and as the temperature increased the internal cell pressure was 0.1MPa + ΔP. The cell walls increased up to heating temperature. When the sheet in this condition was placed in the vacuum chamber and placed under a vacuum, adiabatic expansion occurred because of the difference between the pressure in the atmosphere and the pressure inside the cells, and it expanded to the extent of the clearance in the vacuum chamber. Furthermore, it was cooled to room temperature while maintaining the vacuum state, and the foaming ratio and thickness were fixed. Moreover, with the reduction in pressure and cooling, the internal pressure in the cells was reduced and became 0.1MPa – ΔP. If the sheet is removed and placed under atmospheric pressure after cooling is completed, there is a possibility that it will shrink because of the difference in pressure with the internal pressure of the cells, which were in a reduced pressure state.

To clarify this point, we carried out a simulation of how the sheet changed because of this difference in pressure while referring to resource[9] in the References list. An overview of the simulation is shown in **Fig. 11**.

Presupposing a sheet model with a thickness L where bubbles of the same shape are arranged in one

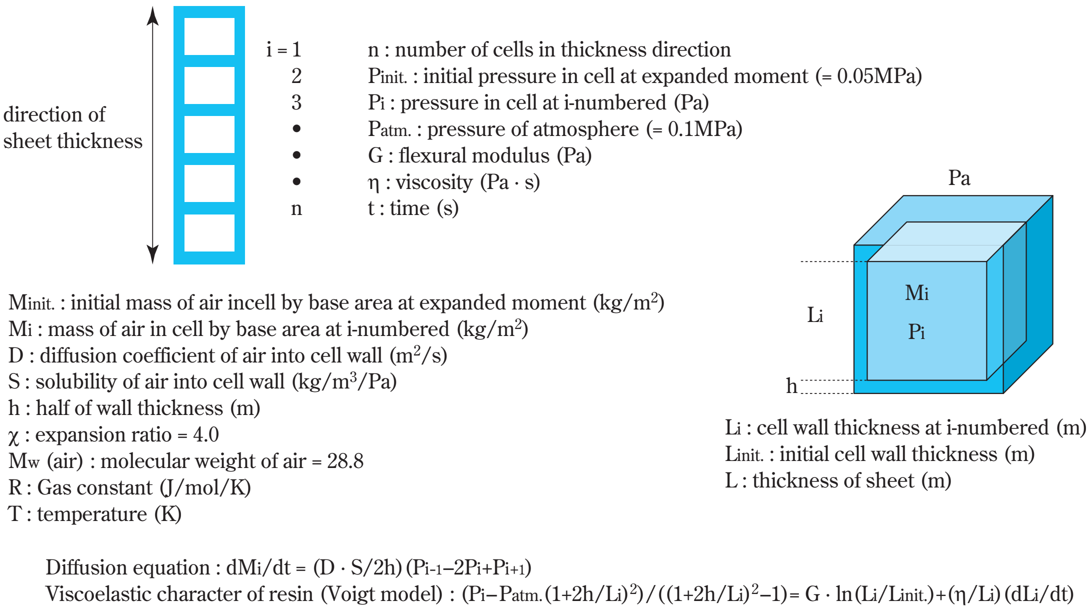

Fig. 11 Simulation of FEM process in vacuum chamber

dimension, we carried out calculations simultaneously on a diffusion equation expressing the diffusion and dissolution of the air within the cell walls and a Voigt model expressing the viscoelasticity of the resin. Moreover, envisioning the molding of a product with a foaming ratio of 2.0× and a thickness of 2.0mm into a product with a foaming ratio of 4.0× and a thickness of 4.0mm, we decided on a pressure of 0.1MPa for the atmosphere directly after pressure release and an internal cell pressure of 0.05MPa directly after applying the vacuum.

The simulation results are shown in **Fig. 12**. The horizontal axis is the time after pressure release (h) and the vertical axis is the sheet thickness L (μm). The thickness of the sheet directly after pressure release was 4,400μm, and while the compressed thickness was reduced with the generation of ΔP, the amount only came out to be 3μm. From these results, we determined that it was possible to control the foaming ratio and thickness of the final product using the clearance of a vacuum chamber.

On the other hand, from the results of this investigation, we can see that there is a recovery of 1μm in the thickness after a passage of approximately 15 hours following the release of the pressure. This is interpreted as shown in **Fig. 13**. The number of bubbles in the direction of thickness is plotted on the horizontal axis and the internal cell pressure on the vertical axis, and we set the critical conditions at bubble numbers of 0 and 41. Comparing the initial pressure in the cells and the pressure in the cells after 30 days, we found that

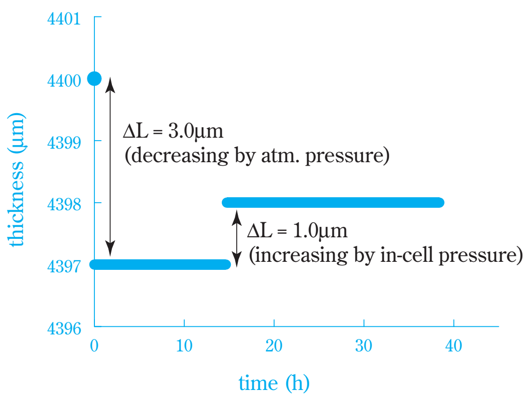

Fig. 12 Simulation of FEM process (fluctuation in thickness direction)

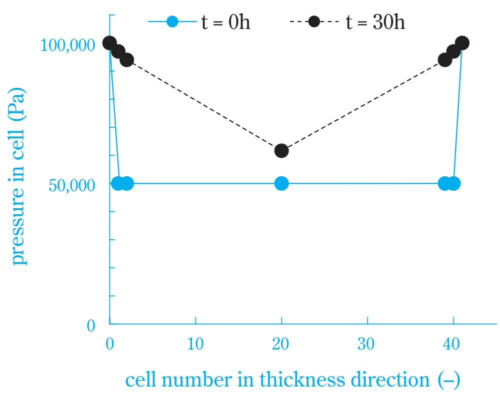

Fig. 13 Simulation of FEM process (restoration of in-cell pressure in thickness direction)

mitigation of the pressure in the cells to the atmosphere required an extremely long time. We interpret this to mean that the thickness recovery above is a phenomenon that accompanies the mitigation of the pressure in the cells to the atmosphere. Moreover, it was found that the mitigation of the pressure in the cells in the center of the sheet required a longer time than that at the periphery.

Going forward, we want to move forward with device design and prototypical examinations of large products to increase the scale while moving forward with examinations into the optimization of the heating conditions and pressure control conditions for maintaining of the independent bubble ratio and improving the surface smoothness.

Vision for the Future of Automotive Parts

1. Reduction of weight in automotive parts

The goal of reducing the weight of automobiles (parts) is improving specific fuel consumption (fuel economy: km/liter) and reducing the amount of carbon dioxide emissions. Moreover, a 22.8% improvement by FY 2010 has been set as a goal for the improvement of fuel economy. This means an approximately 3.4km/liter improvement for a passenger car with a fuel economy of 15km/liter and an increased driving distance of 200km if we think in terms of a 60 L full tank of gasoline.

Naturally, automotive makers are proposing a stepwise and continuous weight reduction of 5 to 10% in new vehicle development for this goal, and not only materials and parts, but also vehicle designs themselves are being reassessed.

In addition, while this severe weight reduction goal has been set, development aimed at supplying safer automobiles with comfortable spaces is moving forward and is following a one-way road toward increases in the average vehicle weight of passenger cars. In other words, our untiring attempts at reducing the weight of automotive parts are an attempt to conform to environmental regulations while increasing the safety of automobiles and level of satisfaction with comfort.

Moreover, we digress, but while vehicle weight (net weight of the empty vehicle) is a basic indicator, the setting of the target standards for fuel economy is a setting based on equivalent inertial weight (weight viewed for each category divided into classes for test vehicle weight with the weight of two passengers, 110kg, added), so there are cases where even if a vehicle is classified into one lower equivalent inertial weight category by only becoming 1kg lighter in vehicle weight, it is seen as achieving a weight reduction of 250kg.

2. Automotive parts and foaming molding technology

Fig. 14 shows the positioning of Sumitomo Chemical's foaming technology in automotive parts. The horizontal axis shows the permissible cost, or put another way, the degree of added value that is defined by design characteristics or functionalities as required. In addition, the vertical axis is the rate of weight reduction that can be achieved, in other words, the foaming ratio. Sumitomo Chemical has a double-sided strategy to develop injection foaming technology and extrusion foaming technology for automotive parts, and to meet the demands of customers.

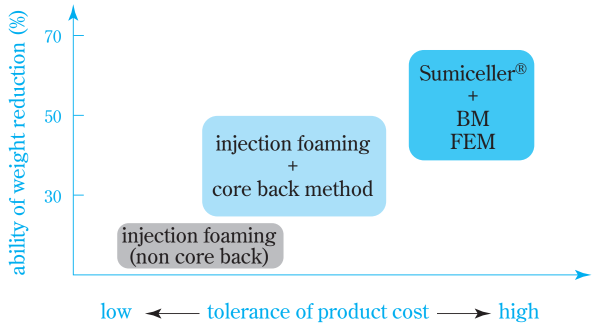

Fig. 14 Positioning of expansion foaming molding technologies

At this stage of our pioneering reduced pressure molding technology using the SPM technology we have developed, we are challenging how we can fascinate customers with performance at present, after having obtained a new weapon in BM/FEM technology.

The authors have achieved a reduction in the burden on the environment by adding a new molding process technology using Sumiceller® to one of the proposed technologies and materials unique to the Sumitomo Chemical Group, and we would like to contribute to the continuing possibilities for growth in our company.

3. Future outlook for needs in automotive parts

Since Toyota Motor Company started selling the world's first hybrid vehicle (Prius) in 1997, the popularity has rapidly expanded, and at present it is sold in 44 countries around the world. In addition, with a sudden jump in the price of gasoline last year, there is a force driving consumers toward hybrid vehicles. In addition, it is said that fuel cell vehicles will make their appearance around 2010.

The societal needs of responding to the environment with reduced use of resources and lower fuel consumption within this trend are predicted to increase even further. Polypropylene extruded foam sheets can be thought of as an effective material proposal for being able to precisely respond to needs of this sort. To keep up continued growth by moving with the times of environmental responsiveness in the future, it is necessary to discover the attractiveness (characteristics) of the foaming technology and products that lead to reduced weight.

In addition, there is also the intelligent vehicle in what is being thought of as the near future of automotive technology. This is something that automates driving control and automatically avoids collisions between cars and with obstacles. If the concept of intelligent vehicles is realized, it is predicted that the priority of protecting drivers in damaging accidents will be reduced, and a closer look will be taken at priorities for protecting pedestrians. If so, there will be a large changeover in design concepts for vehicle materials, and there is a possibility that conversion of vehicle materials, including the materials for outside panels to resins will be accelerated.

Conclusion

In this paper we have discussed plastic foaming products, Sumiceller®, and new molding technology (BM/FEM) using Sumiceller®.

Foaming technology is effective for decreasing the weight of automotive parts, and it is desirable to make progress in the diligent application of injection foaming technology and extrusion foaming technology in order to make a fine tuned response to the needs of customers and society. Based on the long-term outlook for automotive materials in which there is predicted to be a large paradigm shift, we would like to continue to grind away at preparing and completing the elemental technologies and technology that integrates these at a high level to be able to propose new process technology and products.

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