

Pressurized Gas Foaming of Thermin Tube “SN-UGA”

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ABSTRACT Thermin tube SN-UGA is a copper tube covered with polymer foam that has been developed as a part of air conditioning systems for large datacenters. As a main cover material, polypropylene (PP) was used because it shows superior heat resistance and high thermal insulation. In the past, foaming of the PP covering of SN-UGA has been carried out by a chemical method using azodicarbonamide (ADCA) as a foaming agent. But this method has a disadvantage in that the ammonia generated as a by-product of ADCA decomposition causes tarnishing of the copper tube. In this paper, we have investigated PP foaming with CO₂. CO₂ has the effect of decreasing the melt viscosity and promoting coalescence of cells, but this was successfully overcome by using a tandem extrusion system and adding rubber component with the PP. As a result, 5-fold expansion of PP foam was obtained.

1. INTRODUCTION

In the information-oriented society of today, the importance of electronic devices including integrated circuits is rapidly increasing, and they are required to operate on a large scale and at high speed. As a consequence, in large datacenters, electronic devices such as computers are generating more heat than ever, making it difficult to cool the devices sufficiently using existing air conditioners.

Thermin tube SN-UGA is a copper tube covered with polymer foam that has been developed as a part of air conditioning systems for large datacenters. Figure 1 shows a cross-section of SN-UGA and Figure 2 shows a rooftop installation. Since SN-UGA is supposed to be used for cooling very important computers, it has been developed with special concern for security and fire prevention. For example, to increase heat resistance and decrease heat conductivity, polypropylene (PP) foam is used as a raw material for the foam, and highly flame retardant polyolefin with non-halogen material is used as the raw material for the sheath. Tables 1 and 2 show the

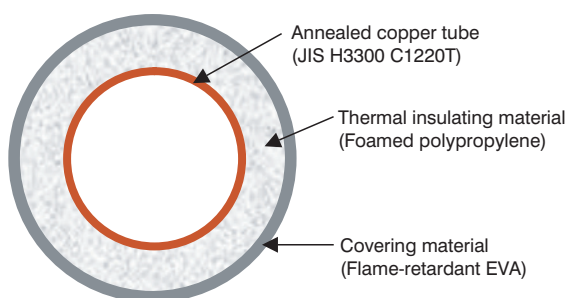


Figure 1 Cross-section of thermin tube SN-UGA.

flame retardance and heat resistance properties of SN-UGA. In this paper, we discuss the issues of existing SN-UGA and the way to increase the expansion ratio of the foam.

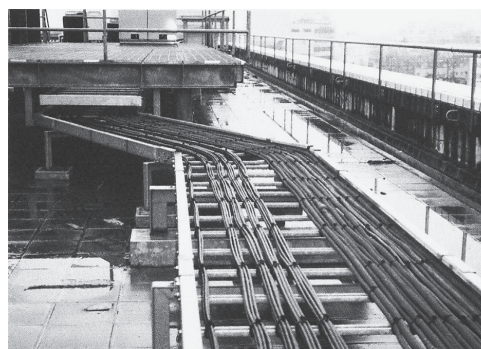


Figure 2 Rooftop installation of thermin tube SN-UGA.

Table 1 Flame retardance properties of SN-UGA.

Oxygen index (JIS K7201)	
Product name	Oxygen index
Covering material of SN-UGA made of flame retardant polyolefin	42
Covering material of existing product	30
Thermal insulating material made of highly expanded polyethylene (for reference)	18

Incline burning test (JIS C3005)

Product name		Burning time (sec)	Burned length (mm)	Burned droppings
SN-UGA4		0	55	Exist
Reference	Existing product	2	60	Exist
	Tube covered with highly expanded polyethylene	—	300 (Entire length)	Exist

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Table 2 Heat resistance properties of SN-UGA.

Heating condition	Shrinkage ratio of thermal insulating material (%)	Shrinkage ratio of covering material (%)
120°C, 24 h	0	0
130°C, 24 h	0	0

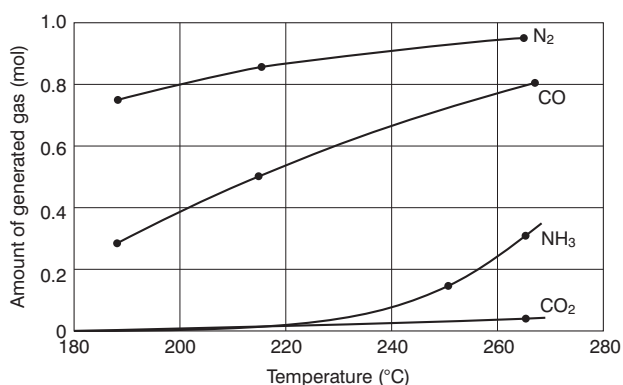
* The shrinkages were measured after annealing at 120°C and 130°C for 24 hrs.

2 BACKGROUND

2.1 Foaming Method

2.1.1 Chemical Foaming

In the past, SN-UGA has been produced by a chemical foaming method using azodicarbonamide (ADCA) as a foaming agent. In this method, ADCA is thermally decomposed in an extruder, generating nitrogen gas to foam the polymer. This method has the advantage that there is no need to attach expensive devices to inject gas into the extruder, but it has a disadvantage in that the ammonia generated as a by-product of ADCA decomposition causes tarnishing of copper tube. (See Figure 3)

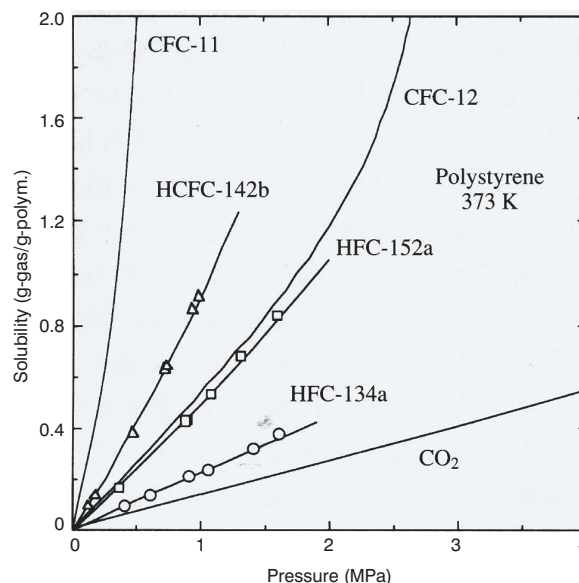

Figure 3 Changes in gas composition of ADCA.

2.1.2 Physical Foaming

There is another foaming method called physical foaming, in which some kind of gas is injected directly into the extruder instead of being generated by thermal decomposition. This method requires special devices such as a high pressure pump and gas injecting port, but has the advantage that no harmful by-products are generated. There are many gases that can be used for physical foaming.

2.1.3 Foaming Agents for Physical Foaming

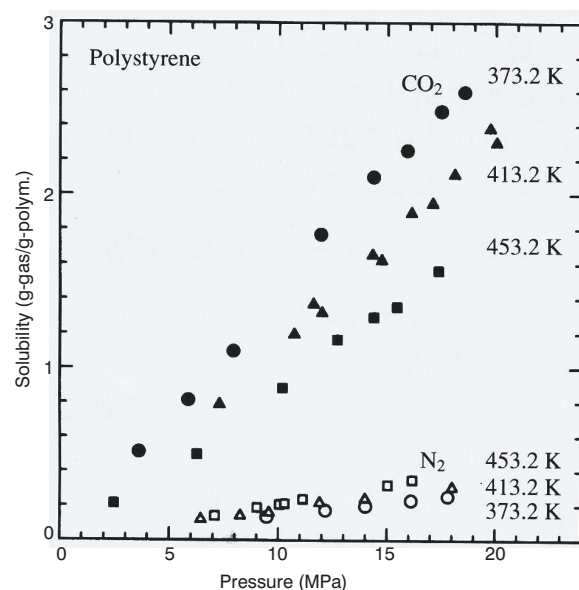
In the 1980s, chlorofluorocarbons (CFCs) were used as the foaming agent for physical foaming because they offer remarkably high performance, such as dissolving into polymer in large amounts, decreasing in temperature when they vaporize, and so on. But as CFCs came to be eliminated because of their effect of depleting the ozone layer, their replacement with CFC substitute or hydrocarbons such as isobutane has been accelerated. Recently, replacement with non-toxic gases such as carbon dioxide or nitrogen has been moving forward.


Figure 4 Comparison of gas solubility in polystyrene at 373 K.

2.1.4 Carbon Dioxide as a Foaming Agent

Carbon dioxide (CO₂) is expected to be very useful for physical foaming because it is non-toxic, non-flammable, low in critical temperature, easy to get, and low in cost. But as seen in Figure 4, CO₂ has significantly lower solubility than CFCs. This means that it is difficult to obtain a high expansion ratio with CO₂, and special measures must be taken to increase it.

Compared with nitrogen (N₂), the solubility of CO₂ is higher (Figure 5). This means that it is easier to obtain a high expansion ratio with CO₂ than with N₂. On the other hand, N₂ has the advantage that it produces finer cells than CO₂. Nowadays, N₂ is used mainly for injection foam molding, while CO₂ is used for extrusion foaming. In this paper, CO₂ is used to increase the expansion ratio as much as possible, and to avoid tarnishing of the copper tube.


Figure 5 Solubility of nitrogen and carbon dioxide in polystyrene melt.

2.2 Foaming of Polypropylene

Since polypropylene (PP) has a higher melting temperature than other general-purpose polymers like polyethylene or polystyrene, it shows greater thermal stability and mechanical strength. These advantages have attracted attention, especially in the field of food packings. But it has been difficult to increase the expansion ratio of PP because its viscosity changes dramatically around the melting temperature. In other words, the process window for PP foaming is very narrow. In this paper, an effort has been made to widen the process window by adding another polymer with PP.

3. POLYPROPYLENE FOAM MADE WITH CO₂

3.1 Improving Foaming Characteristics of PP

When CO₂ is dissolved into a polymer, it has an interesting effect to it: as CO₂ content increases, the viscosity of the polymer decreases due to its plasticizing effect. This characteristic is useful in injection molding because it can facilitate the extrusion of hard-to-extrude polymers. In extrusion foaming, however, this is not always an advantage because lowered viscosity promotes coalescence of cells, resulting in ugly large cells in the foam. Furthermore, too large an amount of CO₂ accelerates the dispersion of CO₂ to the air, resulting in lower expansion ratios.

One of the ways to overcome these problems is to decrease the melt temperature uniformly, because a lower melt temperature results in higher melt strength, which avoids cell coalescence and the dispersion of the gas to the air. In this research, a tandem extrusion system is used to decrease the melt temperature. A schematic view of the tandem system is seen in Figure 7. The first-stage extruder has the role of completely mixing the gas with the polymer, and the second-stage extruder has the role of decreasing melt temperature. To suppress heat dissipation, the screw rotation rate of the second-stage extruder should be low. Blowing air or water just after the die

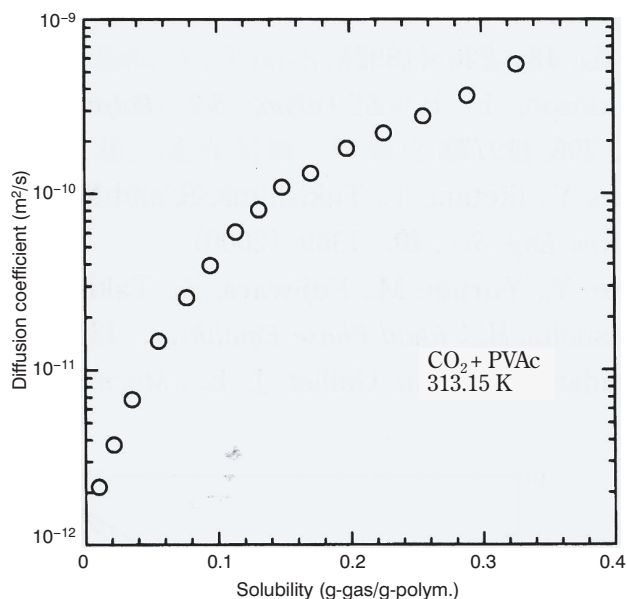


Figure 6 Diffusivity of carbon dioxide in polyvinyl acetate.

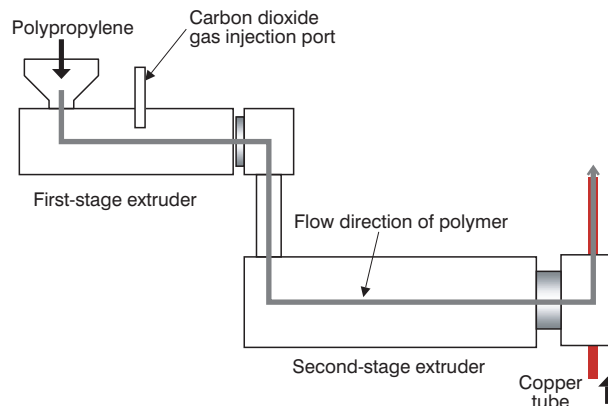


Figure 7 Schematic of tandem extrusion system.

outlet were also considered as alternative methods of cooling the melt, but these methods affected only the surface part of the melt.

3.2 Addition of Rubber Component

A rubber component was added to PP to provide three advantages, as described below.

3.2.1 Widening Process Window

As mentioned before, the viscosity of PP changes dramatically around the melting temperature, so that the process window for PP foaming is very narrow.

The process window can be widened by adding a rubber component to the PP because it makes the viscosity curve of PP more gradual. Figure 8 shows the viscosity curves of PP before and after the adding of the rubber component.

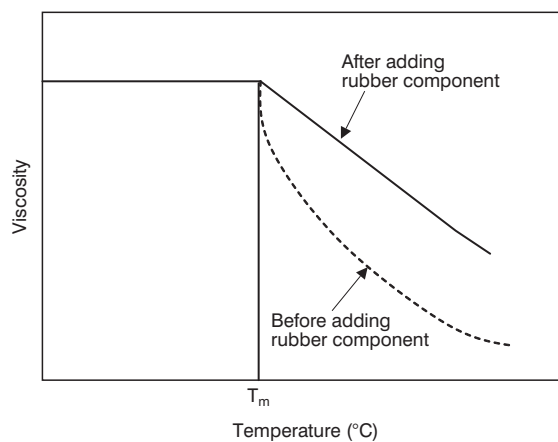


Figure 8 Dependence of viscosity on temperature before and after adding rubber component.

3.2.2 Lowering of Flexural Modulus

It is desirable for thermally insulated copper tube to have a low flexural modulus to facilitate handling in construction. PP has excellent properties in terms of thermal resistance, but it has a high flexural modulus as well. Adding a rubber component serves not only to widen the process window, but also to lower the flexural modulus. The flexural modulus before and after adding rubber component is shown in Table 3.

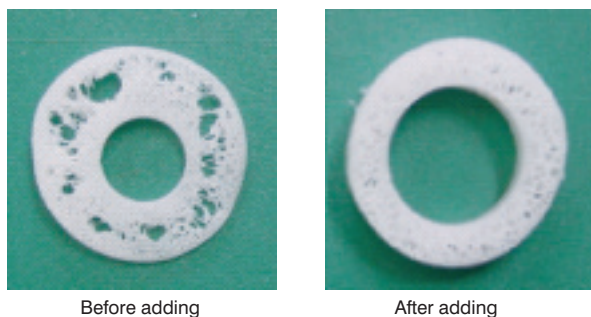
Table 3 Flexural modulus of polypropylene before and after adding rubber component.

Conditions	Before adding (MPa)	After adding (MPa)
0.1 MPa, 25°C	1200	650

These values were measured in unfoamed conditions.

3.2.3 Avoiding Large Cells

When PP is foamed by itself, non-uniform large cells sometimes emerge in the foam. The reason is that the melt tension of PP is too low to keep the cells closed. Adding a rubber component also has the effect of suppressing cell coalescence. Figure 9 compares the cross-section of foams before and after adding rubber component, and demonstrates that the number of large cells decreases by the adding of a rubber component. Table 1 shows the properties of the SN-UGA expanded with CO₂ obtained as a result of this work.

**Figure 9 Comparison of foamed PP before and after adding rubber component.****Table 4 Properties of SN-UGA expanded with CO₂.**

Property	Performance
Expansion ratio	5-fold
Upper temperature limit	130°C
Thermal conductivity	0.058 W/(m·K)

4. APPLICATION TO OTHER POLYMERS

The foaming method described above was also applied to the production of polyethylene (PE) foam. Since PE is a polymer easier to highly expand than PP, it was problem-free to extend the application of this method to PE. The properties of foamed PE are shown in Table 5. Since PE has less thermal stability than PP, it should be used for insulated copper tubes for general-water supply and hot-water supply systems.

Table 5 Properties of foamed polyethylene expanded with CO₂.

Property	Performance
Expansion ratio	5-fold
Upper temperature limit	90°C
Thermal conductivity	0.058 W/(m·K)

5. CONCLUSIONS

Currently, the expansion ratio of foam for SN-UGA that has been expanded with CO₂ is not more than 5 times, but a higher ratio is desirable because it contributes to light weight, low material cost and improved thermal insulation properties. The simplest concept for increasing the expansion ratio is simultaneously to satisfy two demands — to supply more gas and to suppress gas dispersion to the air. Supplying large amount of gas can be achieved by increasing gas pressure, but suppressing gas dispersion is not easy. One of the ways to keep the gas inside the foam is to cool the foam surface just after extrusion from the die, but this sometimes results in large cells and consequently a rough surface. This shows that simply lowering the temperature is not enough to assure a good product. Therefore much is expected of high melt strength PP (HMS) polypropylene, which offers high melt strength even at high temperatures.

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