Application of Synthetic Wood in Prototype Molds for Food Packaging

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Our eating habits have changed greatly in concurrence with increase in the number of double-income households, single-person households, and elderly married-couple households. Recent years have seen an increased demand for "ready-to-eat meals," comprising side dishes, lunches, and other types of meals, along with home delivery of food. Such meals are attractive because they reduce the burden of cooking, dishwashing, and food-material wastage. Moreover, they offer a high degree of convenience in terms of meal consumption times and locations when compared with eating out. Along with the development of various new products associated with such meals, there have been considerable developments in their packaging as well. One such technology that supports food packaging is the synthetic wood used in prototype packaging molds. This article introduces "SANMODUR," a synthetic wood material developed by our company.

Photo 1 Various types of food packaging

Food packaging

Several packaging designs are proposed for packaging foods like lunches or side dishes. Food-packaging design considers both aesthetics (for e.g., "appearing delicious") and practical functionalities, such as heat resistance and sealing properties. The final design is determined after fabricating various prototypes and confirming that the above criteria are fulfilled. The packaging mold for mass production is manufactured only after the final design is determined. While food packaging is usually produced by the vacuum molding of a thermoplastic resin (**Photo 1, Fig. 1**), a lightweight and easy-to-process resin model is used in the trial production phase.

Synthetic wood

As the term "wooden model" indicates, wood was traditionally used as the mold material. However, today, synthetic wood, which is easier to cut and has higher dimensional stability and strength than wood, is used in resin molds. Among the various resins available, urethane resin has become the standard because it is easy to process and allows for diverse designs.
Urethane is formed by the reaction between a polyol and an isocyanate (**Reaction formula 1**). When a small amount of water

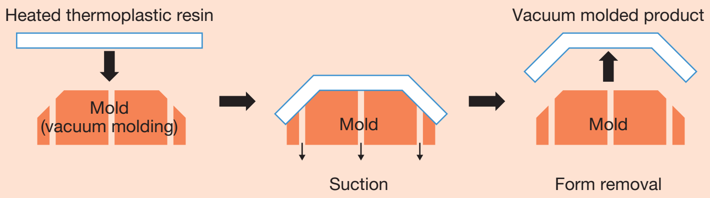


Fig. 1 Vacuum-forming process

$$\text{—CH}_2\text{CH}_2\text{OH} + \text{—CH}_2\text{NCO} \rightarrow \text{—CH}_2\text{CH}_2\text{O—NHCOCH}_2\text{—}$$

Polyol + Isocyanate → Urethane

Reaction formula 1 Urethane formation reaction

$$2\ \text{—CH}_2\text{NCO} + \text{H}_2\text{0} \rightarrow \text{—CH}_2\text{NHCONHCH}_2\text{—} + \text{CO}_2\uparrow$$

Isocyanate + Water → Urea compound + Carbon dioxide gas

Reaction formula 2 Generation of carbon dioxide in the presence of water is added, some of the water and isocyanate react to form a urea compound along with carbon dioxide **(Reaction formula 2)**. The water-foaming method, which uses these carbon dioxide bubbles to tune the foam density, is a common manufacturing method for preparing hard urethane foam. While synthetic wood, which is made of hard urethane foam, is mainly used for prototyping automotive engines and components, its adoption for preparing food-packaging prototype molds has also increased.

“SANMODUR” and the mechanical froth method

Our company’s product, “SANMODUR,” adopts a foaming method called the mechanical froth method to forcibly form fine homogeneous cells in the solution mixture by blowing air or nitrogen and stirring vigorously when mixing liquid polyol and isocyanate components. The solution mixture hardens in the urethane formation reaction and forms a urethane resin with fine air bubbles ranging in size from a few to several tens of micrometers **(Fig. 2)**. The foam density can be finely controlled by the amount of gas injected, and this process differentiates the physical properties of “SANMODUR” from those of other competing products **(Photo 2)**.
Although the characteristics of the tooling material vary depending on the specific polyol, isocyanate, and filler used, the most significant factor affecting the physical properties of it is its density. While holding uniform and fine cells, 'SANMODUR' have densities ranging from 0.27 g/cm^3 to 1.45 g/cm^3.

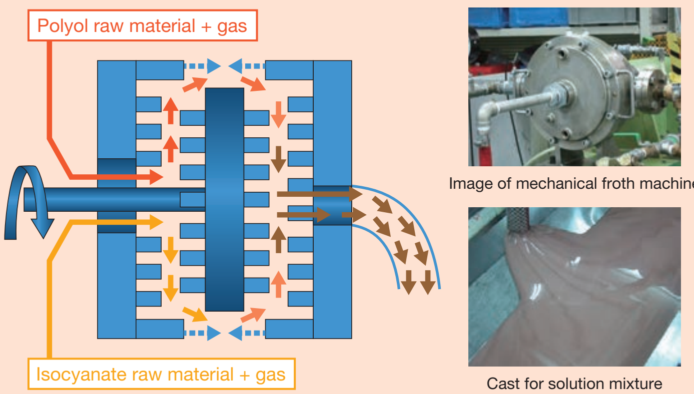
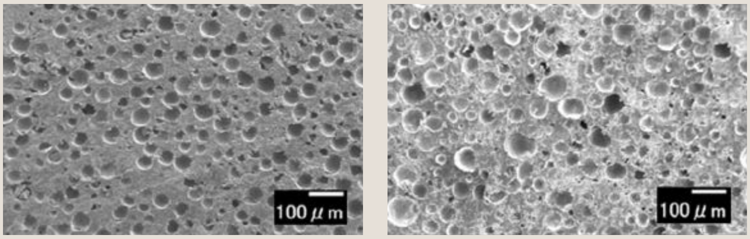


Image of mechanical froth machine
Cast for solution mixture

Fig. 2 **Mechanical froth method**



Our company product
Density: 0.75 g/cm^3 (25 °C), mean cell size: 47 μm

Comparison example (competing product)
Density: 0.72 g/cm^3 (25 °C), mean cell size: 71 μm

Photo 2 **Photos of cut surfaces of our company product and a competing product after water foaming**

Essential functionalities of synthetic wood used for food packaging

What are the essential functionalities of the synthetic wood used for the prototype molds applied for food packaging? These are summarized below.

●Machinability

Food packaging comes in a large variety of types. A large number of packaging prototypes must be manufactured in very short time periods considering the short life cycle available to meet the seasonality requirements of food materials and current fads. Therefore, synthetic wood must exhibit high machinability. In general, synthetic wood is cut with a computer-controlled cutting machine called the CNC machine. The cutting speed must be reduced if the material is too hard. On the other hand, the physical properties of tooling material as a mold become undesirable if it is too soft. The primary factor that affects the machinability of tooling material is the density. **Fig. 3** shows the relationship between the cutting resistance (resistance force experienced by the blade during cutting). The cutting resistance should be as low as possible; the appropriate density range corresponds to 0.6-0.8 g/cm^3 considering other physical properties, such as texture, heat resistance, and strength.

●Fineness

The lid of the food packaging must be transparent to ensure that the contents are visible, and parts of the lid and the main body must fit into their corresponding mating structures to ensure that the lid “locks” onto the container. The texture of the mold surface needs to be extremely fine and uniform to afford increased transparency or to provide for small mating structures. The desired surface roughness is expressed by the average surface roughness (Ra), which is usually 5 μm or smaller.

This fineness cannot be achieved using normal water-foaming methods.

In addition to adopting the mechanical froth method to easily obtain fine and uniform cells, our company's researchers have tuned the molecular weights and viscosity levels of polyol and isocyanate and carefully selected the foaming-agent type and inorganic filler. This approach prevents the increase in air-bubble size due to the fusion of fine air bubbles during the time between gas dispersion and curing.

Fig. 4 shows the relationship between the density and surface roughness for "SANMODUR". Since "SANMODUR" has a smaller Ra value than other competing products, processes like sandpaper application and base treatment before coating for the prototype mold are less time-consuming, which greatly contributes to the shortening of the overall work period.

● Heat resistance and strength

The prototype mold acts as a bridge toward full production (which uses a metal mold). This mold need not have the thermal resistance and strength of metal molds, with which tens of thousands of pieces are vacuum molded. The mold material must facilitate quick machining, endure several rounds of vacuum molding, and conform to the required formability and design properties. Since popular food packaging materials, such as polypropylene (PP) and polyethylene terephthalate (PET) sheets, have thermal softening points of 100-140 °C, the heat resistance of the prototype mold must at least lie in this range. Although "SANMODUR" is composed of a thermosetting resin that does not melt upon heating, it softens at higher temperatures. From the viewpoint of heat resistance, if the thermal deformation temperature is approximately 85 °C or higher, the shape can be transferred without deformation of the mold in the few seconds during which the heated sheet contacts it.

Because only the surface layer of the mold is heated during these few seconds, the mold material can suitably withstand successive vacuum moldings to fabricate a small quantity of molded articles. Because the thermal deformation temperature is also correlated with the density, the density is adjusted to realize a thermal deformation temperature of approximately 85 °C or higher **(Fig. 5)**. In addition, because a compression force of 0.1 MPa is applied to the mold during vacuum molding, the mold must also withstand this force. "SANMODUR" affords sufficient strength in this regard, with the minimum compressive yield strength being 4 MPa; however, long thin ribs and pin shapes may not be able to withstand such pressures.

● Dimensional stability

Most materials, whether metal or plastic, swell when heated and shrink when cooled. It is obvious that the mold dimensions must not change drastically with changes in the surrounding temperature or during vacuum molding. The linear expansion coefficient is used to express the degree of this type of thermal expansion (contraction). For example, a material with a linear expansion coefficient of 50×10^{-6}/°C and length of 100 mm will expand or shrink by 0.05 mm under a temperature change of 10 °C. This means that the dimensional stability under temperature changes is better when the linear expansion coefficient is smaller.

Two methods are available for reducing the linear expansion coefficients of resin materials. One approach is to blend raw materials such as inorganic fillers that have smaller linear expansion coefficients. However, because these materials are

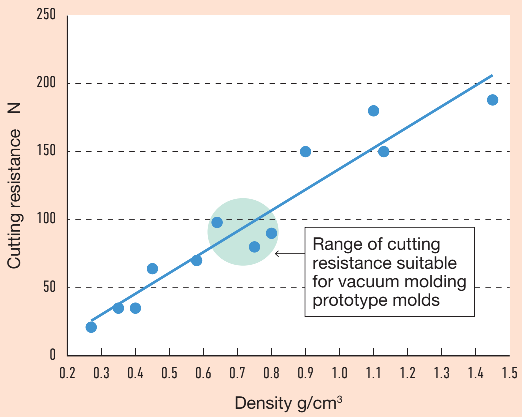
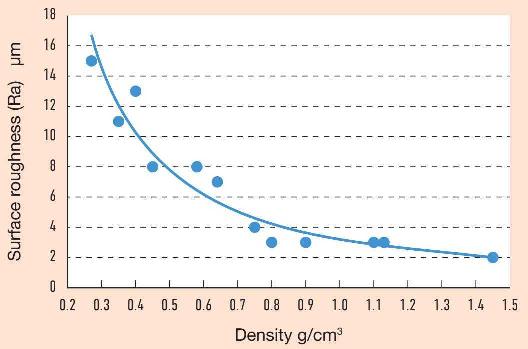


Fig. 3 Density and cutting resistance of "SANMODUR"



*Surface roughness: The cut surface was measured with a non-contact three-dimensional surface roughness tester, and the absolute values of the unevenness of the sample surface were averaged.

Fig. 4 Density and surface roughness (Ra) of "SANMODUR"

generally harder than resins, the cutting blade is likely to wear faster during cutting. In addition, the vacuum-molded prototypes require holes to create vacuum conditions, and these holes are made with a thin drill of approximately 1 mm in diameter under high rotation speeds. If friction occurs between the drill blade and the wall surface in making the hole, the cutting powder may soften and carbonize to clog the hole or drill blade. Some inorganic fillers also cause problems like the rapid wear of the drill blade and the generation of frictional heat. To overcome such issues, the “SANMODUR” TW-E product of our company uses talc, which is the softest filler that also has lubricant properties.
The second method involves mixing a gas with the material. Although the linear expansion coefficient of gases itself is larger than that of solids, its expansion pressure is small, and thus, the gas negligibly contributes to the expansion or contraction of the entire material. Because the linear expansion coefficient of the entire material is expressed as the sum of the products linear expansion coefficients comprising the material and their volume occupancies, the overall linear expansion coefficient reduces as the material density decreases. A uniform bubble size is also desirable to ensure that there is no variation in the linear expansion coefficient. In this regard, as “SANMODUR” is prepared using the mechanical froth method to ensure the uniform and fine dispersion of gas, its linear expansion coefficient is generally small; this translates into higher product quality.
As described above, the “SANMODUR” composition design matches the user needs from the viewpoints of fineness, heat resistance, strength, dimensional stability, and blade wearability. This makes “SANMODUR” highly suitable for fabricating prototype molds for the vacuum molding of food packaging **(Table 1)**.

Summary

Our line of “SANMODUR” products, prepared using various techniques, are designed to best suit different user conditions. The market for highly convenient ready-to-eat meals is expected to continually grow, and our company will continue to work on solving related issues and further improve the performance of our products.

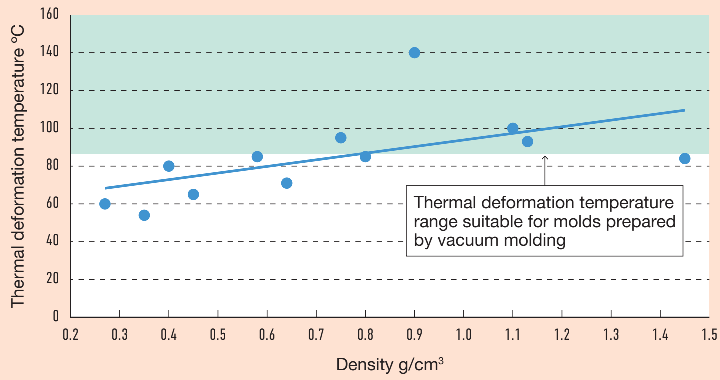


Fig. 5 Density and thermal deformation temperature of “SANMODUR”

[Contact (about the product)]

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Table 1 Representative physical properties of “SANMODUR” suited to fabricating prototype molds for the vacuum molding of food packaging

Name of product	Density (25 °C) g/cm³	Hardness Shore D	Bending strength MPa	Linear expansion coefficient × 10^{-6}/°C	Thermal deformation temperature °C	Surface roughness µm	Blade wearability mm
	JIS K 7222	ASTM D 2240	JIS K 6911	TMA method	JIS K 6911	Our company’s method*1	Our company’s method*2
“SANMODUR TW-E”	0.75	64	25.0	47	95	4	1.0
“SANMODUR VM”	0.80	64	25.0	50	85	3	1.0

*1 The cut surface was measured using a non-contact three-dimensional surface roughness tester, and the averaged absolute value of the unevenness of the sample surface was calculated.
*2 Wear at the blade edge was measured with a stereoscopic microscope (50x magnification) after continuous cutting for 10 m using a 10 mm-diameter, high-speed steel straight blade operating at a rotation speed of 10,000 rpm, feeding speed of 100 mm/min, and cutting depth of 3 mm.

Please contact our company’s sales representative when handling our company’s products. It is also necessary to read the “Safety Data Sheet” (SDS) before use. It is the responsibility of the user to determine the suitability and safety of the product for the application they choose.