Optimizing performance in microwave-only packaging with PPO/HIPS resins

Kristine Nieman and Adriaan Boon van Ostade

The heat performance of a microwave-only package can be tailored for a specific food product by adjusting the ratio of PPO resin.

The microwave oven became a common household appliance during the 1980s. Food processors have responded to this market opportunity by increasing the number and variety of microwaveable food products. According to a survey*, the number of microwaveable products introduced by food companies grew from 278 in 1986 to over 918 in 1989. The market has grown to the point that food companies are formulating their foods specifically for reconstitution in microwave ovens. This, in turn, has created a market for microwave-only packaging. Designers of food containers are no longer restricted to the use of dual-ovenable materials such as crystallized polyethylene (CPET) and coated paperboard. The heat requirements for microwave packaging are lower than those for conventional ovens, and this has led to a growing demand for polypropylene (PP) as well as polyphenylene oxide (PPO)/high-impact polystyrene (HIPS).

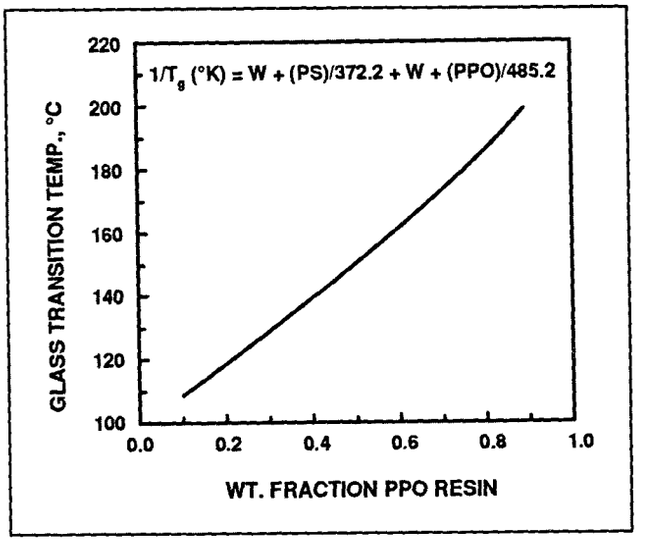
Although PPO/HIPS resin is a newcomer in the food packaging market, it has been used commercially since 1966. The resin is a blend of polyphenylene ether (PPE) and high-impact polystyrene. PPE is commonly referred to by its trademark, polyphenylene oxide, which connotes the oxidative coupling reaction of 2,6-xylenol to the polymer.

The unique characteristic of PPO/HIPS resin is that the two component resins are completely miscible and can be blended in any ratio to obtain a range of glass transition temperatures (T_g). **Figure 1** depicts T_g over the full range of PPO/HIPS resin blends.

Stiffness at temperature

PPO/HIPS blends retain their mechanical properties at cold and hot temperatures. The PPO component adds heat performance to the PPO/HIPS blend, with the T_g of the material increasing with the proportion of PPO, as seen in Fig. 1. The flexural modulus (stiffness) of a polymer decreases severely at temperatures near the T_g. Thus a material with a higher T_g will retain its stiffness at higher temperatures.

1. Glass transition temperature of PPO/HIPS resin as a function of blend ratio



Flexural modulus data obtained from dynamic mechanical analysis (DMA) indicate that trays of 25% PPO/75% HIPS will retain their stiffness better at elevated temperature than trays of PP or CPET. **Table I** lists the flexural modulus of the materials at -29°C, 22°C (room temperature), 104°C, and 116°C. The initial flexural modulus (room temperature) of the PP and CPET samples was 40% and 11% lower, respectively, than the PPO/HIPS blend. At 104°C, the modulus of the PP is 7.3 times lower than that of the PPO/HIPS, while at 116°C it is 8.5 times lower. Similarly, the modulus of the CPET is 6.3 times lower than that of PPO/HIPS at 104°C and 6.5 times lower at 116°C.

Nieman is an application development engineer and van Ostade is a programs marketing specialist. Both are affiliated with GE Plastics, One Plastics Ave., Pittsfield, Mass. 01201.

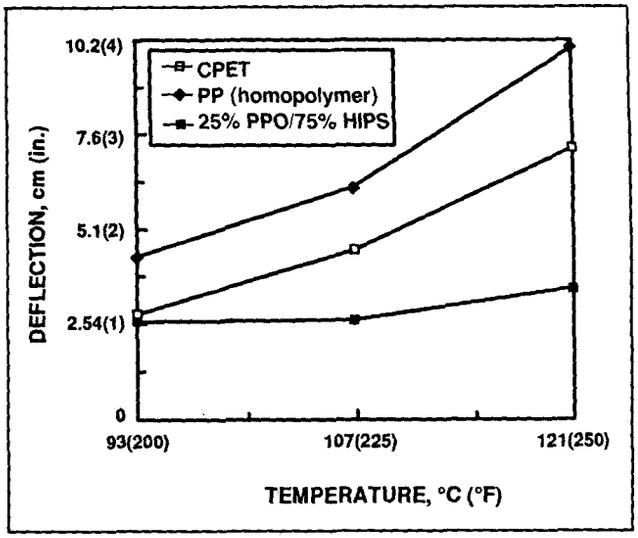
*Microwave Foods 1989, Gorman's New Product News, Chicago, Ill., 1989.

1. Flexural modulus of three polymers*

Temp., °C	25% PPO/75% HIPS Flexural modulus lb/in.²	25% PPO/75% HIPS Flexural modulus kg·s/cm²	Homopolymer polypropylene Flexural modulus lb/in.²	Homopolymer polypropylene Flexural modulus kg·s/cm²	Crystallized PET Flexural modulus lb/in.²	Crystallized PET Flexural modulus kg·s/cm²
-29	362,200	25,500	452,100	31,800	323,600	22,800
22	337,000	23,700	200,600	14,100	298,400	21,000
104	265,500	18,700	35,890	2,500	42,430	3,000
116	204,100	14,400	23,940	1,700	31,570	2,200

*Flexural modulus determined from dynamic mechanical analysis of samples from test trays.

2. Tray stiffness as a function of temperature for three different tray materials. The 0.762-mm-thick trays were all of the same design and contained 200 g of food.



Such differences in flexural modulus should be readily apparent in the stiffness of the trays at elevated temperatures. A test was conducted to measure the stiffness of the three materials at temperatures likely to be encountered during normal microwave heating.

PP and CPET trays were compared with 25% PPO/75% HIPS trays for stiffness at elevated temperature. Identical tray designs were used for each material, and all trays were thermoformed from 0.76-mm sheets. Trays were filled with the specified product weight (200 g) and held in a device that gripped a flange on one end of the tray. Benchmark measurements of tray deflection were made at room temperature. The trays were then heated to target temperatures of 93°C, 107°C, and 121°C, with tray deflection measured at each temperature. The difference between deflection at room temperature and at elevated temperatures was reported, and the results are illustrated in **Fig. 2**. As implied by the DMA data, CPET and PP trays had a higher loss of stiffness at elevated temperatures and showed greater deflection than PPO/HIPS at all temperatures tested.

At 93°C, PP and CPET deflected slightly more than PPO/HIPS. At 107°C and 121°C, however, the PP trays sagged two to three times as much as PPO/HIPS. The CPET trays sagged about 1.7 times more than the PPO/HIPS trays at 107°C and more than twice as much at 121°C.

Tray stiffness at elevated temperatures is an important quality parameter. A stiff tray reduces the potential for hazards when hot food is removed from the oven. A stiffer tray also can enhance product image and consumer confidence.

Stiffness and tray design

A material with high stiffness and the ability to retain that stiffness at high temperatures provides greater freedom in designing a microwaveable tray. Larger, deeper trays of more intricate shape can be fabricated. Greater stiffness also can allow the manufacturer to "downgauge" the product (reduce the thickness) and thus decrease the amount of raw materials used in each tray.

The deflection of a plate (y) is equal to a constant (C) divided by the flexural modulus (E) and the thickness (t) to the third power:

$$y = C/Et^3 \quad (1)$$

The overall stiffness of a tray is determined by both the flexural modulus of the material used to fabricate the tray as well as tray thickness (Et^3). These two variables can be manipulated to achieve the desired tray rigidity.

Using data from Table I in conjunction with the formula in Eq. 1, it is possible to predict (a) the stiffness for equivalent trays of CPET or PP vs. PPO/HIPS and (b) the magnitude of differences in stiffness for trays of the same thickness.

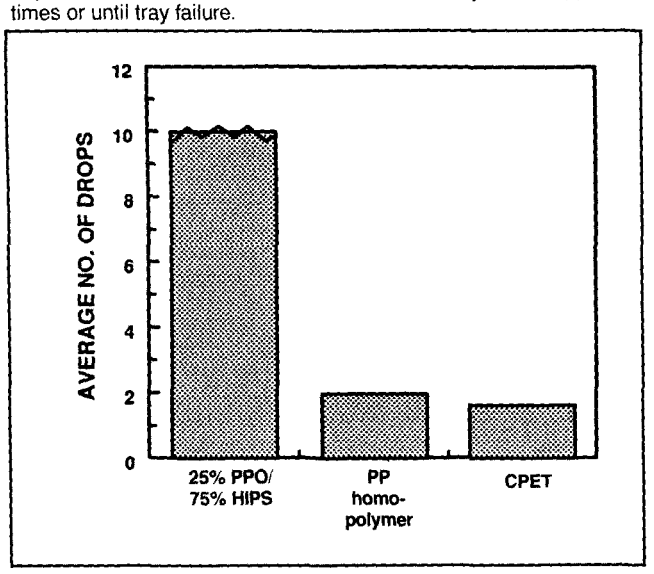
If room temperature data are used for comparison, a 5-17% reduction in tray wall thickness is calculated for trays of PPO/HIPS vs. CPET or PP. Real benefits are seen at elevated temperatures. CPET and PP lose modulus more quickly than PPO/HIPS, so trays made of these materials must be produced at thicker gauges to maintain stiffness at elevated temperatures.

Based on the modulus data at 104°C and the formula in Eq. 1, a 0.43-mm tray of PPO/HIPS will be equivalent in stiffness to a 0.76-mm PP or CPET tray. This represents more than a 40% reduction in gauge to obtain equivalent stiffness. Practically, it is common to reduce the PPO/HIPS tray thickness 20-25% vs. PP or CPET trays of the same design.

Performance at freezer temperatures

The majority of microwaveable foods in trays are refrigerated or frozen prior to use. Trays are stored, distributed, and sometimes filled at low temperatures.

3. Results of cold-temperature (-29°C) drop-impact tests (drop height = 3 ft). The 0.762-mm-thick trays were all of the same design. Ten trays were tested for each material, and each tray was dropped ten times or until tray failure.



This is when a tray is most likely to break upon impact, since polymers become brittle at low temperatures. Flexural modulus, an indicator of a material's elasticity, increases as temperature decreases.

PPO/HIPS, CPET, and PP trays, all 0.76-mm thick and of the same design, were tested for cold-temperature drop impact. Trays were filled with chili and stored in a freezer conditioned to -29°C. They were then dropped from a height of 0.92 m (3 ft) onto a concrete surface. Tray orientation for the drop was such that the tray opening was flush with the wall and perpendicular to the drop surface. The tray was dropped repetitively until failure or until ten successful drops were completed.

Tray performance during drop-impact testing is greatly influenced by tray design. Excessively large and/or sharp flanges will affect any material's performance when impacted at cold temperatures. Special efforts were made during our drop-impact trials to test material performance rather than tray design. The results in **Fig. 3** show that all of the PPO/HIPS trays passed 10 drops without breaking. The PP trays failed after an average of two drops. Performance of CPET trays was even lower, with failure occurring after less than two drops per tray.

Performance at microwave temperatures

The heat performance of PPO/HIPS trays is directly related to the percent of PPO resin blended with the HIPS. The correlation between PPO content and T_g is given in Fig. 1. Under normal microwave conditions, 25% PPO/75% HIPS will perform in the microwave to temperatures of 107°C.

PP trays and 25% PPO/75% HIPS trays were subjected to a battery of cooking tests. Tests were conducted in a 750-W microwave oven, with the trays placed in the predetermined hottest location within the oven. Temperatures of the tray and food were measured using Luxtron equipment. Trays were monitored visually during heating, with observers watching for blisters, bumps, wrinkles, pitting, crazing/cracking, dimensional change, buckling, rupture/holes, melting, and browning/charring. Results of the cooking tests are given in **Table II.**

PPO/HIPS trays passed (no visual effect) all the cooking tests in which the food did not exceed the recommended temperature (107°C) for blends of 25% PPO resin in HIPS. In two cases (lasagna and pizza), the foods reached temperatures higher than 107°C without affecting the PPO/HIPS tray. Bacon reached 148°C after 4 min, which distorted the tray. Similarly, the PP trays were not affected, with the exception of bacon cooked for 4 min. Temperatures during these tests ranged from 84°C to 148°C.

FDA requirements

PPO resin complies with FDA (Food and Drug Administration) requirements as outlined in 21 CFR 177.2460. Polystyrene complies with FDA requirements as outlined in 21 CFR 177.1640. Physical blends of these materials are in compliance with FDA requirements subject to both of these applicable regulations.

Additional tests were conducted simulating room-temperature storage and microwave cooking of food in containers made from PPO/HIPS resin. The extraction data from these tests demonstrate that containers made from PPO/HIPS resin are in compliance with FDA requirements under these conditions of use.

Trays made from PPO/HIPS resin have an upper temperature range. Under normal microwaving, a 25% PPO/75%HIPS tray will function well up to 107°C. Above 113°C, the tray will first soften and, much later, char. PPO/HIPS resin has been tested for potential migration of hazardous materials under intended conditions of use and has been found to have no migration of species of hazardous or regulatory concern.

Odor and taste

Our company has invested more than US$ 4 million in plant and equipment over the last three years to remove potential taste- and odor-causing species from the PPO/HIPS food-grade materials. Testing done at the Sensory Analysis Center at Kansas State University compared PPO/HIPS and commercial PP and CPET containers with glass for sensory effect with several different food groups. The taste panel judged PPO/HIPS to be similar to the PP and CPET in terms of sensory effect. All were recognizably different from glass when tested with very pure water and with buttered rice, a fairly bland food. There was no significant difference from glass when tested with a high-fat-content food like cheese sauce.

Environmental

A key environmental attribute of PPO/HIPS resin is the potential to downgauge. A PPO/HIPS tray retains its stiffness at microwave temperatures, so such trays can be manufactured at thinner gauges than comparable trays made of PP or CPET. Thus, food companies can reduce solid-waste generation and perhaps avoid consumer perceptions that the product is overpackaged.

II. Cooking performance of PPO/HIPS and PP trays*

Food	Food weight, g	Cook time, min	25% PPO/75% HIPS Max. temp., °C	25% PPO/75% HIPS Result	Homopolymer polypropylene Max. temp., °C	Homopolymer polypropylene Result
Broccoli & cheese	180	5	126	Pass	127	Pass
		4	108	Pass	108	Pass
Bacon	110	4	148	Blisters and dimensional change	138	Dimensional change and discoloration (turned white)
		3	127	Pass	131	Pass
		2	127	Pass	114	Pass
Chicken nuggets	138	3	98	Pass	84	Pass
		2	100	Pass	98	Pass
Lasagna	300	6	121	Pass	121	Pass
Chili	210	3	104	Pass	108	Pass
		2.5	107	Pass	113	Pass
Pizza	72	2	138	Pass	126	Pass
		2.5	132	Pass	143	Pass
Broccoli	150	5	99	Pass	99	Pass

*Pass indicates no physical change in tray after microwave heating.

The total miscibility of PPO resin in styrene makes a PPO/HIPS tray compatible in the styrene recycle stream. Extrusion and regrind tests showed that the addition of up to 25% PPO in styrene had a minor effect on extrusion conditions. Material properties were enhanced by the presence of PPO.

Processing

For most microwave applications, a blend of 25% PPO/75% HIPS is sufficient. To achieve this mixture, a 50% PPO/50% HIPS concentrate is diluted by half with HIPS. The converter does this in-house. A quality sheet is easily manufactured by following simple processing steps.

PPO/HIPS resins can be processed using typical styrene-extrusion equipment. The PPO/HIPS concentrate should be predried for 2–4 h at 104–116°C. This will ensure no moisture blemishes on the sheet and prevent material buildup on the die. It is very important to have the proper screw so that good mixing of the 50% PPO/50% HIPS resin and HIPS occurs during extrusion. Higher-shear barrier screws with a Maddox-type mixing section are ideal. Conventional screws with a 3.0–3.8:1 compression ratio with Maddox-type mixing section also have been used successfully. Extrusion rates should be nearly identical to standard HIPS rates.

PPO/HIPS sheets are inherently amorphous, so thermoforming is much easier than with CPET and PP. Although forming temperatures must be increased, forming speeds should be similar to HIPS. Again, like HIPS, tight tray tolerances and design flexibility (e.g., rolled lips, fluted sides, embossing, etc.) are possible. In fact, the shrinkage for PPO/HIPS is identical to straight HIPS, so existing molds can be used with no modifications.

The low capital investment in equipment and molds and the high output rates make PPO/HIPS structures cost-competitive with PP and lower in cost than CPET.

Market growth

The number of applications for PPO/HIPS trays will continue to grow with the expanding market for microwaveable foods. The food-service industry is using PPO/HIPS resin-based microwaveable trays for deli takeout and vending machines. Major food companies are specifying and using PPO/HIPS for nonbarrier frozen foods. There also seems to be a strong interest in PPO-based barrier rollstock for aseptic "form, fill, and seal" applications. Typically, these utilize a coextruded structure of PP and EVOH for barrier properties and PPO/HIPS for temperature resistance and thermoformability.

Conclusion

Resins containing a blend of polyphenylene oxide (PPO) and high-impact polypropylene (HIPS) can be used to produce trays for microwave-only foods. Addition of PPO enhances tray performance at high temperatures. Because the PPO content can be adjusted from 0-50%, the package's performance can be optimized for a given food-reconstitution temperature.

Marketplace acceptance of PPO/HIPS containers is evidence that this resin meets the performance requirements of microwave-only packaging in a cost-effective manner. PPO/HIPS blends provide a range of benefits that make this material an attractive option for microwave-only packaging:

- Stiffness retention at microwave temperatures, enabling 20-25% downgauging compared with polypropylene (PP) and crystallized polyethylene (CPET)
- Repeatable cold-temperature impact
- Microwaveability for a wide variety of food products
- Full compliance with FDA requirements
- Organoleptic results similar to PP and CPET
- Recyclable with styrene
- Extrusion and forming processing similar to styrene
- Shrinkage similar to HIPS
- Costs comparable with PP and lower than CPET.□

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