



Applications and advantages of β -crystalline polypropylene

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A β -nucleation additive makes it possible to obtain novel materials such as microporous films, as well as improve the properties and lower the cost of injection-molded and thermoformed parts.

Polypropylene (PP) is a semi-crystalline polymer widely used in many applications, thanks to its low cost and excellent balance of properties. The characteristics of PP depend greatly on the level of crystallinity achieved when the polymer crystallizes from the melt, and on the structure and morphology of those crystals. Such factors can be controlled through a class of additives known as crystal nucleating agents, which speed up and encourage crystallization by providing nucleation sites around which crystals can develop.

Although PP can crystallize in more than one crystal form,^{1,2} the one most commonly found in nearly all commercial PP products is the α or monoclinic form, which melts at $\sim 165^\circ\text{C}$. However, a less common form—known as the β or hexagonal form—generally accounts for $<5\%$ of the crystals. These β crystals have a melting point that is typically $12\text{--}14^\circ\text{C}$ below that of the α form, and other physical properties that are desirable for many applications. Thus, obtaining PP with a high proportion of β crystals is of interest, and this can be done by incorporating specific additives, β nucleants, into the resin.^{3,4} The resultant β -crystalline PP has certain unique characteristics that can enhance a variety of products, including rigid thermoformed food packaging, injection molded parts, and oriented films.

A first important benefit conferred by β nucleation is impact enhancement. β -Crystalline PP has a higher impact strength than α -crystalline PP.⁵ This difference is illustrated in Table 1, which compares the physical properties of a β -nucleated PP homopolymer (prepared using the proprietary MPM 2000 β -nucleant masterbatch additive)⁶ to those of the corresponding non-nucleated PP resin. We can see from this data that, although the flexural modulus is virtually unchanged, the notched Izod impact strength increases by a factor of 4 in the β form. The tensile yield strength also drops by $>10\%$. Typically a small decrease in flexural modulus occurs when β crystals are present, but this decrease is generally not $>10\%$. A detailed description of these property changes has been published previously.⁷

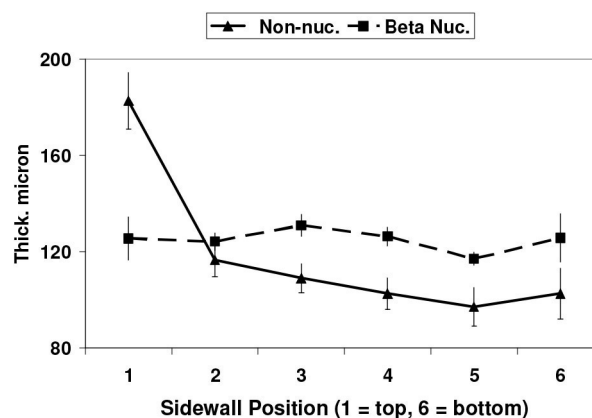


Figure 1. Thermoformed cups made from β -nucleated (Beta Nuc.) PP have a more uniform sidewall thickness distribution (Thick.) than those made from non-nucleated (Non-nuc.) PP.

A second benefit relates to thermoforming processability. PP is widely used to thermoform food packaging containers because of its low cost, low density, and good physical and organoleptic properties. Typically, an extruded PP sheet is heated very close to its melting point to form it into the final container. The processing temperature window is very narrow owing to the sharp melting point of the PP and the low melt strength of the molten polymer. However, β nucleation dramatically broadens⁸ the processing window for PP, since thermoforming can now take place between the melting points of the two crystal phases, which are almost 15°C apart. Also, the more ductile nature of the β -crystal phase permits thermoforming in the solid state below the melting point of the β -crystal phase if there is a high level of β crystallinity present in the sheet.

We found that when a β -nucleated sheet is thermoformed, uniform drawing takes place during the forming process, and the sidewalls of the final container are highly uniform in thickness.⁷ Since the rigidity and top-load crush strength of a thermoformed container are very sensitive to the minimum sidewall thickness, an even thickness distribution across the part results in containers with high strength and

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Table 1. Properties of a non-nucleated polypropylene (PP) homopolymer compared with those of β -nucleated PP containing 0.3% by weight of the proprietary MPM 2000 β -nucleant masterbatch.

Property	β -nucleated	Non-nucleated
Melt flow rate (g/10 min)	3.2	3.3
Yield strength (MPa)	30.0	34.3
Yield elongation (%)	11.0	8.9
Flexural modulus (MPa)	1,470	1,460
Notched Izod @ 23°C (J/m)	172	42

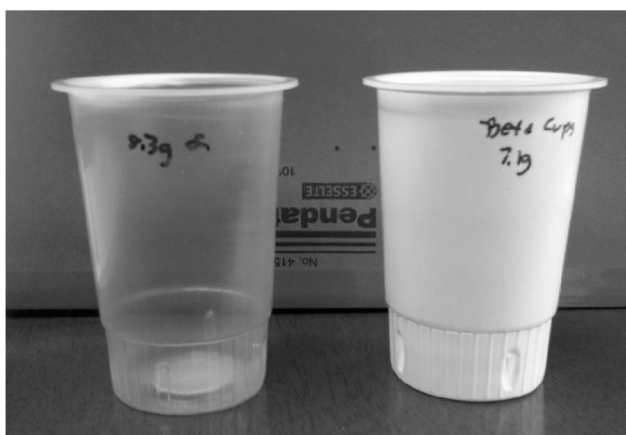


Figure 2. The non-nucleated PP cup (left) weighs 8.3g, whereas the β -nucleated PP cup (right) weighs 7.1g and has a white appearance despite the absence of pigments.

rigidity, that can, therefore, be down-weighted to save cost. Figure 1 shows the improvement in thickness uniformity for a six-ounce drinking cup made from β -nucleated PP, as compared with one made from non-nucleated PP.

Another unique characteristic of β -crystalline PP is that, when an extruded sheet is stretched below the melting point of the β -crystal phase, microvoids develop and the density of the stretched sheet is reduced. These microvoids cause the sheet to turn white because of light scattering from the voids. Consequently, when solid-state thermoforming β -crystalline PP, the finished containers take on a very white appearance without the need for pigments, which in turn enables dramatic reductions in the amount of titanium dioxide (TiO₂) pigment needed, translating into significant cost savings and better recyclability. Figure 2 shows two solid-state thermoformed cups, one made from non-nucleated PP and the other from PP with the MPM 2000 masterbatch additive, where no TiO₂ was added to obtain the white cup. The β -nucleated cup could be down-weighted by ~15% and still maintain its critical rigidity and top-load crush strength.

The microvoiding effect can also be used to produce microporous oriented PP films from β -nucleated PP. In mono-oriented PP film, achieving density reductions is possible in the range of 10–20%, depending on processing conditions. In biaxially oriented PP film (BOPP), density reductions as high as 70% have been achieved. These highly porous films are also breathable, as the pores are interconnected and, therefore, enable high rates of vapor transmission through the film. Such microporous BOPP films are being used for the production of protective clothing, roofing membranes,⁹ and lithium-ion battery separator membranes.¹⁰

In summary, β nucleation is useful for improving the properties of PP in molded applications that require high impact strength without a significant sacrifice of stiffness. β nucleation also dramatically broadens the processing window for producing thermoformed containers and improves material distribution, leading to higher rigidity, higher top-load crush strength, and the ability to down-weight by up to 15%. When the thermoforming occurs at low temperatures, the cups take on a white appearance that dramatically lowers the amount of white pigment that is required. β nucleation also facilitates the production of low density oriented microporous films without the need for a cavitating filler to obtain the void cavities. Moving forward, we are continuing to work on broadening the applications of β -nucleated polypropylene, and improving the effectiveness of our β -nucleant masterbatches.

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Philip Jacoby is vice president of technology at Mayzo, where he has been for 10 years. Prior to that he worked at Amoco for 26 years in PP product development. He has commercialized the use of β nucleation in several PP products, including microporous films, geogrids for road reinforcement, and thermoformed containers. He is a past president of the Southern Section of SPE, and has served on the Thermoforming Division Board of Directors.

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