PHB a Bioplast for High Impact and Compression Resistant Applications

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PHB, polyhydroxybutyrate, is a rather old thermoplast, much older than the first known invented here, namely Bakelite. Actually it has been around for some 3,5 billions years, but nobody realized its potential. It was only in 1973 during the first oil crisis when ICI, Chemie Linz, Solvay, Givaudan, and Grace Italia looked at PHB as possible bio-replacement for the oil derived thermoplast. Unfortunately, when the oil price dropped, the PHB projects also were dropped.

PHB has thermoplastic properties, but nature never intended PHB to become a thermoplast. Evolution optimized it to function inside the cells. However some of the biological functions are of interest to plastics processors. Being of renewable resource is one, being biodegradable another one, but by far not the most important ones.

PHB was optimized by evolution for 3,5 billions of years,
but only for biological needs, not plastics!
Nevertheless, unique properties:

- absolutely linear
  -> affects melt behavior
- made exclusively C4 monomers, absolutely stereoregular, absolutely isotactic, Tg below 0°C
  -> affects crystallization
- food reserve
  -> affects biodegradability

To function inside the cells the molecules need to be absolutely linear. This affect the melt behavior. To function inside the cells the polymer needs to be composed exclusively of C4-subunits, needs to be absolutely stereoregular (i.e. isotactic), and needs to have a Tg below 0°C. This strongly affects crystallization. As food reserve for soil bacteria it needs to be easily digested.

This affects biodegradability. I will dwell on just the first two of these properties, namely linearity and regularity.

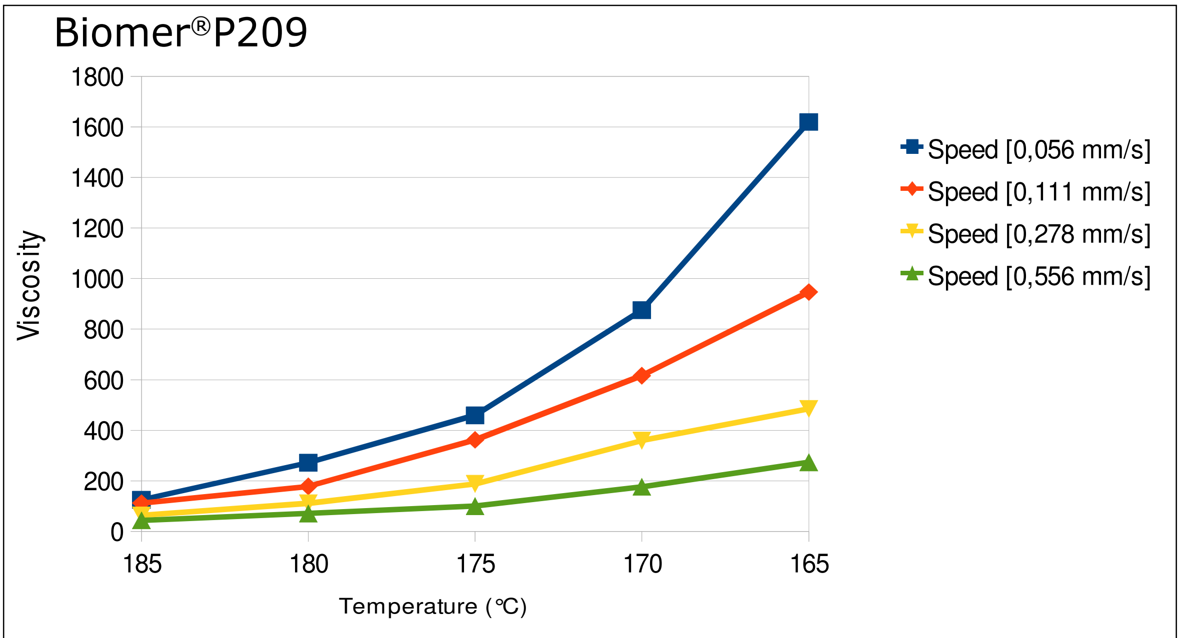
Absolute linearity means that the polymer chains have no chance whatsoever to entangle in the melt.

What means "absolutely linear" to plastics processors?

- Hot/cold spaghetti like behavior in the melt

-> viscosity adjustable directly on the machine

They behave exactly like spaghettis: flexible when hot, sticky when cooled. In other words: the melt viscosity can be changed at will, simply by changing temperatures. Mr. Borner, a student of the University of Applied Sciences in Fribourg, Switzerland measured the viscosity of Biomer®P209, one of our grades, as function of the temperature and speed. The results were not surprising. The viscosity that is almost as water at 185°C changes by a factor of 40 simply by lowering temperature to 165°C. For extrusion we even recommend 135°C we recommend even 135°C. Such a spread of the viscosity within narrow settings is not possible with any man-made thermoplast and is due to the linearity of the PHB chains.



Can plastics processors profit of the absolute linearity i.e. from the adjustable viscosity of PHB? The answer is "yes indeed".

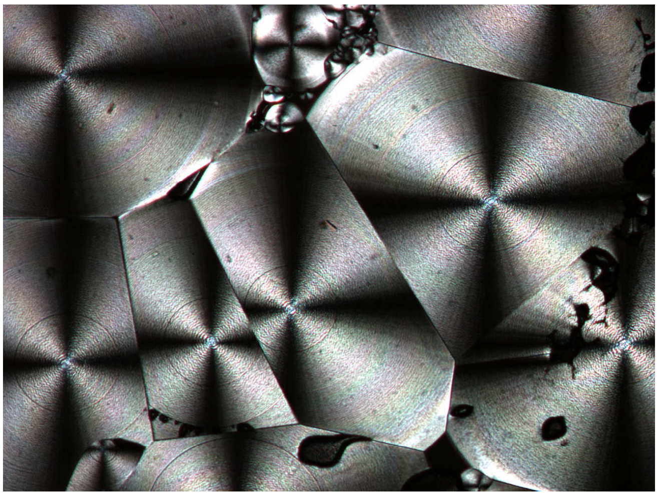
Can plastics processors profit from the adjustable viscosity of PHB?

- complex structures
- thin walls
- shiny surfaces
- visual effects (down to the sub-micron level)

-> a feast for designers!

The possibility to adjust the melt viscosity over a wide range allows molders to produce complex structures, thin walls, shiny surfaces, or unusual surface effects even on small machines with low clamping forces. There are almost no limits in the design of surface structures. We have seen structures well below 0,2 µ. In this sense PHB definitely is a real delight for designers, especially for those dealing with consumer product.

What means absolutely regular, absolutely isotactic, Tg below 0°C? It simply means that the polymer chains have no chance whatsoever but to crystallize. You are ending up with a crystallinity not know with other thermoplasts The crystals are hard and there is no free amorphous mass left. The result is a material that looks and acts like a metal.

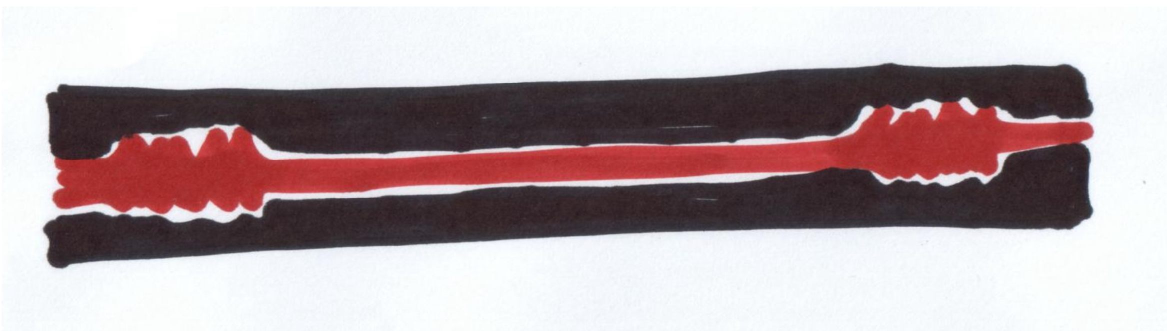


Can plastics processors profit of the extreme crystallinity? I will show two examples. The first one is a PHB natural fiber composite, the second one an injection molded part.

You all know that bridges made of concrete are excellent to support heavy loads. However, concrete is not very good in flexibility. That's concrete bridges need to be massive. Cable bridges are light and elegant, because they can flex on changing loads. However they are sensitive to shear stresses like lateral winds. So cable bridges are limited in length. It is possible to combine concrete with steel cables. The cables take up the tension and the stones resist the pressure. The two together, a composite of stones and steel, performs by far better than each one alone and allows to build long, elegant, torsion resistant bridges.

Now look again at the hard PHB crystals. Think of crystals as the stones and the fibers as the steel. You come up with a situation that resembles the steel reinforced concrete: the fibers take up the tension and the crystals the load. PHB offers an additional benefit with natural fibers. Natural fibers are not as uniform as glass or steel fibers. They have thicker parts (called meristems) where the leaves or branches were attached before harvesting the fibers.

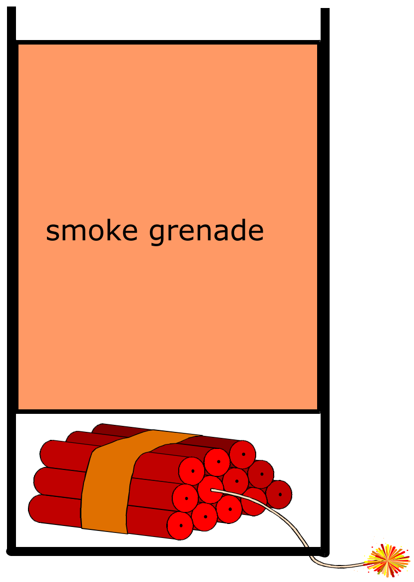
During crystallization the volume of PHB decreases. As the natural fibers have no affinity to PHB, the PHB mass retreats from the fibers and forms



tunnels in which the fibers are free to move

Yet at positions where the fibers are thicker they are entrapped by physical clamping and strongly held by the hard crystals like in a vise. If this composite is stressed by impact, then the fibers are free to stretch and to retract between the clamping sites. This results in an extreme high impact strength composite that can be thermoformed without loosing the strength. This is just one example how plastics processors can benefit the crystallinity of PHB.

Smoke grenades, the second example, are ejected into the air by exploding a charge in a mortar.



The grenade has to withstand huge accelerations or impact forces. This is the reason why they had to be tooled from metals. Now metal processing is costly. This all changed by the advent of PHB. PHB allows it to be molded. The dimensions of the pieces are shown on the slide: wall thickness: 1 mm, wall length: 90 mm, diameter: 70 mm, and bottom thickness: 6 mm. This piece with this thick bottom and such long and thin walls is molded in a single shot because, due to the absolute linearity of the PHB polymer chains, it is possible to adopt the viscosity to just this piece. Whenever plastics processors have to deal with similar problems, they may try PHB. The 6 mm thick bottom perfectly resists the explosion shock as it were made of metal. The resistance of the bottom to the accelerating shock is due to the extreme crystallinity.

With respect to crystallinity the inner pillar is even more interesting. Its function is to transmit the acceleration from the bottom to the heavy top. Its wall strength is just 1 mm. The thin wall does not yield upon the acceleration. It is not compressed. The pillar is connected to the bottom and the top by a screws design of the size of a M14 metal screw. The treats made of PHB behave exactly as those made of metal screws: they are not compressed and they do not yield upon the impact. Such a creep resistance is possible because of the crystallinity of PHB. It shows how plastics processors can use the crystalline (or should I say metal type behavior) of PHB.

Let me summarize the opportunities for plastics processors by using PHB:

- PHB is of renewable resources
- PHB is fully biodegradable in aerobic (garden, compost) as well as in anaerobic environments (sewage tanks, bottom of lakes, sea)
- PHB is absolutely linear meaning the melt viscosity is adjustable. This allows to mold thin walls, visual effects, complex structures, sharp edges, shiny surfaces, or agreeable touch.
- PHB is absolutely regular and Tg below 0°C forcing it to be extremely crystalline. This impairs creep resistance, allows to mold thin and thick parts in same shot, to prepare strong, thermoformable composites. It also impairs resistance to chemicals and allows shelf live 5 years (-40 to +60°C).

Nature never intended PHB to become a thermoplast. It optimized the polymer to perform inside the cells. Several properties are hard to find in manmade thermoplasts. It is the absolute regularity and the absolute linearity. Please don't hesitate to ask or call if you need specific details.

PHB:
- adjustable melt viscosity
- extreme crystallinity
For questions please call or write
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