Daploy™ HMS Polypropylene for Foam Extrusion

BOREALIS

Borealis Film and Fibre

Borealis is a leading provider of plastics solutions. Its technology shapes daily life products and forms the basis of next generation innovation and creative product development in plastics.

The total Western European polyolefins film and fibre market exceeds 10 million tonnes per annum, with an annual growth rate of approximately 4%.

The Film and Fibre Business Unit supplies products to major converters in the application areas of film, fibre, coating, thermoforming and foam applications. Within these areas Borealis has a leading position in several key segments.

Six production sites at Beringen (Belgium), Burghausen (Germany), Kallo (Belgium), Porvoo (Finland), Rønningen (Norway), Schwechat (Austria) ensure that customers receive rapid and reliable deliveries.

Innovation centres for PP & PE are located in Linz (Austria) and Rønningen (Norway) respectively. Additional technical support activities are provided from Beringen (Belgium) and Porvoo (Finland).

Your success is our motivation

Borealis aims to provide added value beyond the customer expectations. Through interaction with our customers, and other key players in the value chain, Borealis understands the needs and future trends in the film and fibre industry.

Our products in the film and fibre area are carefully designed to meet our customers' demanding requirements, and we constantly focus on improving our products' performance in order to fulfill the needs of the whole supply chain.

This brochure profiles how we view the film and fibre market, its challenges and what we can do to help our customers' businesses become even more successful. If you have questions or require further information, please contact our sales representative in your area. See www.borealisgroup.com for contact details.

Polypropylene foam

Polymeric foams consume around 3.5 million tonnes of plastics materials annually and account for about 10% of all polymer usage in Europe. Foamed polymers are used in a wide number of application areas, which range from construction, automotive and household products to food and protective packaging. Among the many benefits of foamed materials are their good mechanical rigidity at low specific gravity, thermal and acoustic insulation, cushioning against mechanical shock and a significant contribution to source reduction in raw material usage.

The foam market is dominated by the amorphous polymers, such PS, PU and PVC, which have been industrially foamed for over 50 years.

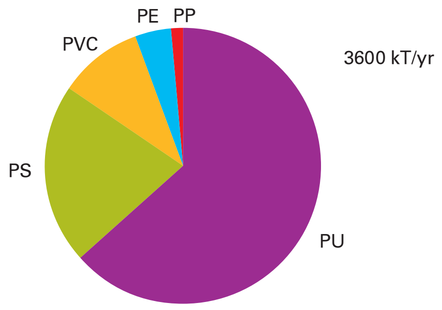


Figure 1

The low density polymeric foam market - Europe 2003

Polypropylene (PP) foams are a relative latecomer to this market. The reasons for this lie at the molecular level – standard PP's are semi-crystalline materials with a linear molecular structure. They lack the required extensional rheological properties in the melt phase for the production of extruded low density foams with a fine and controlled cell structure. This limitation is resolved in the Borealis Daploy range of high melt strength (HMS) PP products. These are long chain branched materials, which combine both high melt strength and extensibility in the melt phase. They open up the possibility of bringing the many well-known property benefits of PP into the world of low density polymeric foams. These benefits include a wide mechanical property range, high heat stability, good chemical resistance and no monomer issues. PP also brings its good environmental credentials to this market.

From a fairly recent and small beginning, the global PP foam market is growing rapidly (> 20%/year). Current PP foam applications include automotive, insulation and food and protective packaging. In Europe, the dominant PP foam applications are in the food packaging and automotive areas.

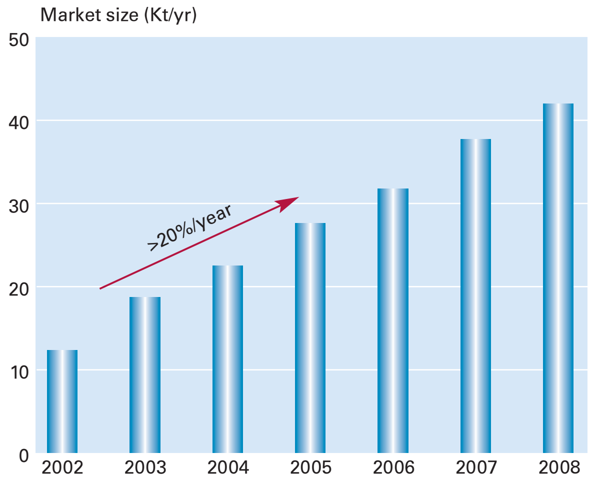


Figure 2

Actual and predicted global market growth for extruded low density PP foam

In the case of food packaging, PP foam offers a lightweight packaging solution with excellent grease/fat resistance (no stress cracking) and with no issues surrounding its monomer. Its high heat stability means products are microwaveable, with the good thermal insulation giving a "cool touch" during removal.

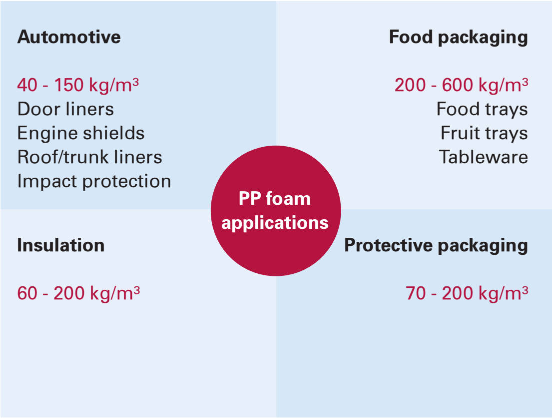


Figure 3

Some current applications for extruded PP foams

In automotive applications, lightweight foam solutions are helping to improve vehicle performance and fuel efficiency. With the increasing pressure for end-of-life vehicle recycling, mono-material solutions are being sought and, with PP becoming a preferred polymer, recyclable foamed PP solutions are a logical next step. PP foams have an excellent moisture barrier and chemical resistance which are important for durability and functionality in the presence of hot oil, grease or fuel and its high heat stability opens up the possibility for under the bonnet applications. PP foams also have very good cushioning properties, thereby contributing to improved driver and passenger safety.

As a leading PP supplier, Borealis is committed to support the development of the extruded PP foam market through its Daploy HMS PP products and by offering PP foam solutions.

Daploy HMS-PP

The basic extensional rheological properties of the long branched Daploy HMS-PP products are shown in figure 4, in comparison to those of standard linear PP's. The window in the high melt strength and extensibility area of this graph defines the requirements for a high performance foaming grade. With such long chain branched polymers, it is possible to produce very low density (20 - 50 kg/m³) extruded PP foams, which possess a fine and controlled closed cell structure. This is not possible with standard linear PP's or modified materials which fall outside the critical high performance foaming window.

The Daploy HMS-PP products can be blended with the full range of standard PP extrusion grades and other polyolefinic products. This offers the opportunity to widely tailor the foam properties to meet the particular demands of the end use application. Furthermore, the Daploy HMS-PP products are specifically designed to be suitable for processing on most types of existing industrial foaming equipment.

The Daploy HMS-PP products and their blends are not crosslinked. This means that extruded PP foams produced from them are fully recyclable. This is becoming an increasingly important environmental demand within the polymer industry.

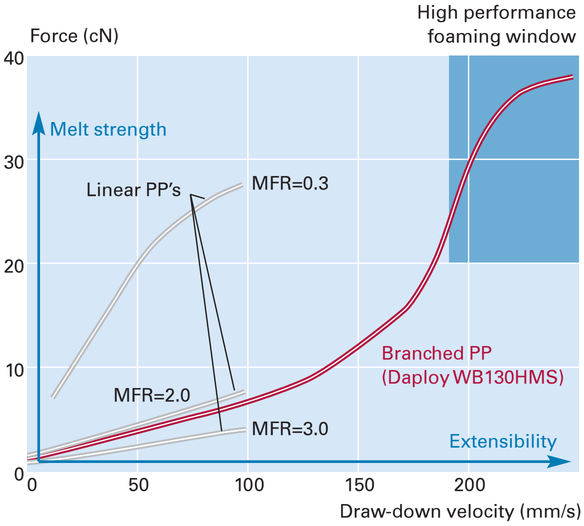


Figure 4

Extensional rheology curves for linear PP's and Daploy HMS

Foam extrusion process

The first steps in the foaming process (polymer feeding and melting) are common to all extrusion processes. However, three later stages are specific and critical to the process, as illustrated in figure 5.

These three specific steps in the foam extrusion process comprise (a) dissolving of a blowing agent gas in the polymer melt, (b) cell nucleation and (c) cell growth and stabilization. In order to perform these additional steps, foaming extruders are longer than standard types, typically with an overall L/D ratio > 40, in either a single or tandem extruder configuration.

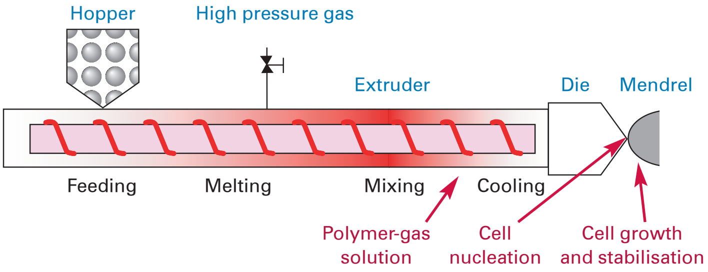


Figure 5

Schematic illustration of processing steps in foam extrusion – direct gas injection/annular die

Polymer-gas solution

A blowing agent is introduced into the polymer melt either by direct gas injection (physical foaming) or by decomposition of an added chemical blowing agent (chemical foaming).
In both cases, a key requirement for a uniform and controlled cell structure is a homogenous polymer-gas solution. This is controlled by two factors: the solubility of the blowing agent gas in the polymer and the sorption kinetics. The solubility itself is not the limiting factor for foaming with the more commonly used industrial foaming agents: butane and carbon dioxide. With the gas concentrations typically used in foam extrusion, these can be quantitatively dissolved with standard extrusion pressures up to 10 MPa (100 bar).
Figure 6 shows the equilibrium solubility curves for the more common blowing agent gases in PP.

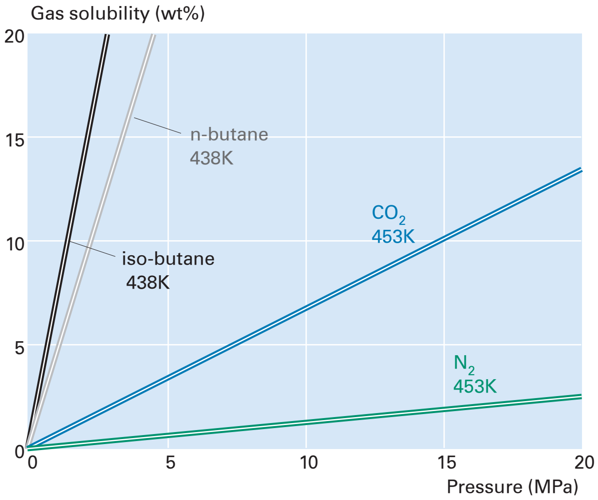


Figure 6

Solubility of common blowing agent gases in PP

The achievement of equilibrium solubility is determined by the sorption kinetics and this is therefore a time dependent process. This process can be accelerated by raising the melt temperature and using screw designs which promote good mixing of the polymer melt and injected gas.

Cell nucleation

Control of cell nucleation is crucial to obtaining the desired fine and uniform cell structure of the final foam. It is a complex area with several, often interrelated, factors playing a role.
The three main factors which influence the cell nucleation are the pressure drop in the die, the concentration of the blowing agent and the concentration of the external cell nucleating agent.

The rate of pressure drop at the die is determined by the die geometry. Higher rates of pressure drop at the die significantly increase the cell density, irrespective of the concentration of blowing agent gas or external nucleator. High shear rates are also believed to play a role in promoting cell nucleation.

It has also been established that higher concentrations of blowing agent gas lead to increased cell density. Addition of external nucleating agents is the most commonly used method of controlling cell nucleation in the foaming process. These are basically finely divided and dispersed solid particles (eg. talc), which provide sites for cell nucleation. Figure 7 shows an example of the influence of these two factors on cell density in the case of PP foamed with butane and talc as the nucleator.

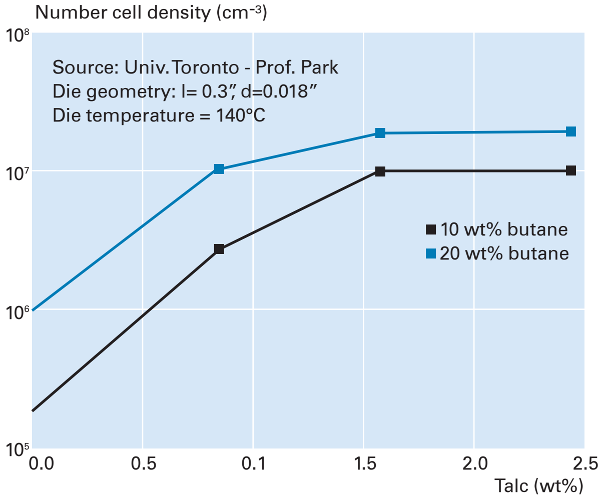


Figure 7

The effects on cell density of blowing agent and nucleating agent concentrations

Cell growth and stabilization

Melt temperature is one of the most important process parameters in foam extrusion. In the case of PP foam, depending on the type and concentration of the foaming agent used, the optimum in melt temperature may vary from approximately 130°C to 180°C.

When the melt temperature is too low, foaming is limited because the material solidifies before the cells have the possibility to fully expand.
When the temperature is too high, the foam first expands, then collapses again due to lack of stabilization of the structure. There is an optimum melt temperature window for foaming in which lowest densities are achieved; this temperature is lower than the standard PP melt temperatures (210°C to 240°C). The latter part of the foam extruder is dedicated to the melt cooling and intimate mixing of the polymer-gas system.

It is during this part of the process that the Daploy HMS-PP plays its crucial role. Its high melt strength and extensibility help to control the cell growth. By a "strain hardening" mechanism, it prevents rupture of the cell walls and coalescence, which would otherwise lead to a polymer containing a few rather large holes in it – far removed from the desired fine and closed cell structure.

The foam is finally stabilised by a cooling stage before winding. This is either by means of a calibrating mandrel in the case of an annular die or by a conventional roll stack when a flat die is used.

Daploy HMS-PP blends and foamability

In order to modify the final foam properties, Daploy HMS-PP’s can be blended with standard extrusion grade PP’s, as will be described in more detail in the next section.

An important consideration, however, is the foamability of such blends. When a long chain branched PP is mixed with a standard PP, it is evident that this will have a “diluting” effect on the melt strength and extensibility of the blend compared with that of the pure HMS-PP. This effect is shown in figure 8.

It can be seen, however, that quite high levels (ca. 60%) of blend partner may be added before the extensional rheological properties of the blend begin to fall outside the critical high performance foaming window.

This is further verified in figure 9, where the minimum achievable foam density is shown as function of the HMS-PP content in the blend.
There exists a wide range of blend compositions where it is possible to produce low density (<100 kg/m^3) PP foams.

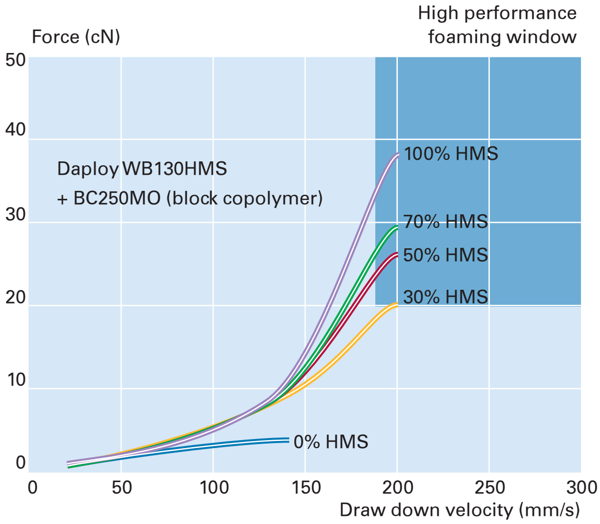


Figure 8

Extensional rheology curves for HMS-PP/block copolymer blends

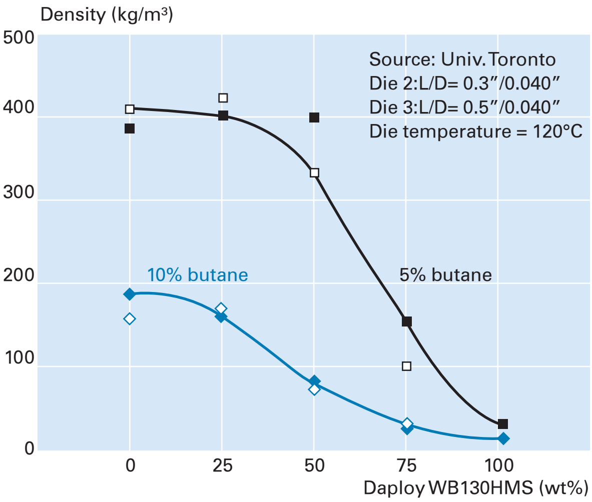


Figure 9

Minimum achievable foam density as a function of Daploy HMS-PP content of the blend

Providing PP foam solutions

The modification of foam properties is a crucial requirement in order to be able to produce PP foams with properties that meet the technical performance demands of particular end-use applications. Figure 10 shows, in a schematic way, how the balance between two properties (impact strength and stiffness) can be modified by the appropriate choice of blend partner.

The Daploy HMS-PP's are homopolymer based and, if used in their pure form or blended with standard homopolymers, provide foams with very high stiffness and heat stability. Enhancements in impact strength and toughness of the foam can be achieved by using random or heterophasic (block) copolymers as blend partners. In the case of random copolymers, the impact performance is improved at temperatures above approx. 0°C, but if good impact performance is required at low temperatures (< 0°C) then heterophasic copolymers should be used.

Further interesting property modifications are available by using the Borealis Borsoft™ random heterophasic copolymers as blend partners. These are soft PP's (tensile modulus around 400 MPa). These provide the opportunity to produce soft PP foams, which also combine good impact strength and toughness at low temperatures. Even softer foams can be obtained by blending Daploy HMS-PP's with various plastomeric materials, such metallocene LLDPE's, TPO's and EVA's.

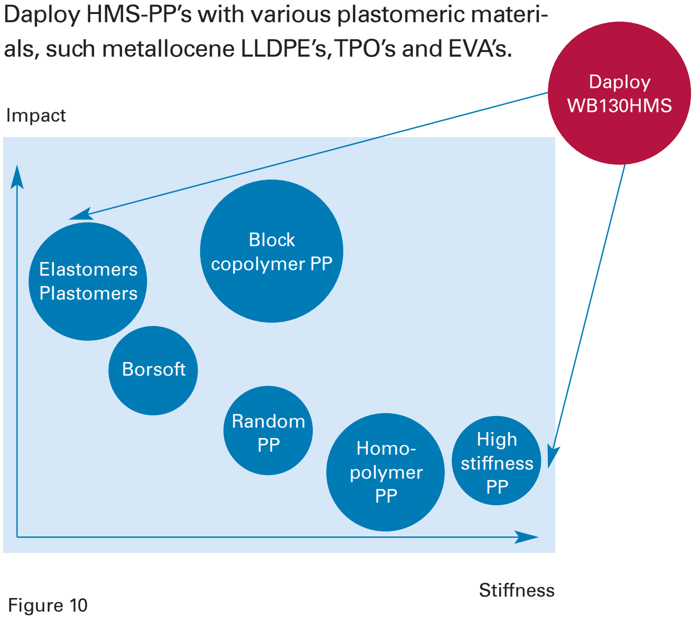


Figure 10

Schematic influence of different blend partner types on the stiffness/impact balance

Blend partner	Foam property modifications	Recommended* Borealis grades
Homopolymers	High stiffness Poor impact	HB671TF, HC600TF, HC205TF
Block copolymers	Low temperature impact Reduced stiffness Improved toughness	BC250MO, BC240TF, BC245MO
Random copolymers	Softer foams Improved toughness	RB501BF, RA130E, RB206MO
Borsoft PP's	Soft foams Low temperature impact	Borsoft SA233CF
m-PE's, TPO's, EVA's	Very soft foams Low temperature impact	

Figure 11

Blend partner types and their influence on foam properties

* Go to www.borealisgroup.com for more information and technical data sheets

The above general description of HMS blends can be further refined to provide more quantitative predictions of PP foam properties. This makes use of various theoretical models for describing foam properties. One of the more important foam properties is the tensile modulus and this is determined by three basic parameters:

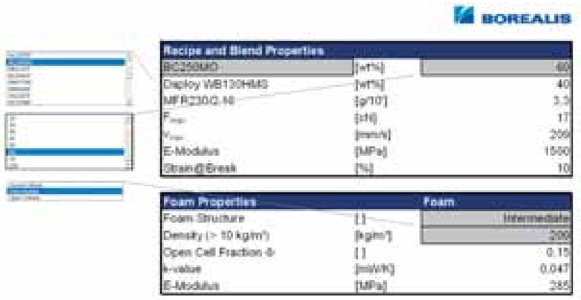
- Tensile modulus of the compact material
- Foam density
- Foam structure

The tensile modulus of the starting (compact) material is determined by the chosen blend partner and the composition – typically this modulus will be in the range of 750 to 2000 MPa. The tensile modulus of the foamed material will decrease as the density decreases. The third parameter is the foam structure and this relates to factors such as the relative proportions of open and closed cells and the cell size.

Figure 13 shows experimental data for tensile modulus as a function of foam density, for different Borealis blend partners. The agreement with the theoretical predictions is good and this provides confidence in the ability to use this as a quantitative tool.

Similar predictions can be made for other foam properties, for instance, in the of case thermal insulation. Figure 14 shows the variation of thermal conductivity with foam density. It can be seen that at low densities (ca. 100 kg/m^3) the thermal conductivity is reduced by a factor of about ten, when compared to compact PP.

Borealis has brought together this predictive information in the form of its "Daploy foam solution software". We are able to sit with customers and, in the space of few minutes, work through many blend options with the software – see figure 12. With this tool we are able to rapidly offer blend proposals for foam solutions to best meet the needs of the customers and end-users.



Recipe and Blend Properties		
BC250MO	[wt%]	60
Daploy WB130HMS	[wt%]	40
MFR230/2.16	[g/10']	3.3
F_{max}	[cN]	17
v_{max}	[mm/s]	200
E-Modulus	[MPa]	1500
Strain@Break	[%]	10

Foam Properties		Foam
Foam Structure	[ ]	Intermediate
Density (> 10 kg/m³)	[kg/m³]	200
Open Cell Fraction Φ	[ ]	0.15
k-value	[mW/K]	0.047
E-Modulus	[MPa]	285

Figure 12

Demonstration of "Daploy Foam Solution Software"

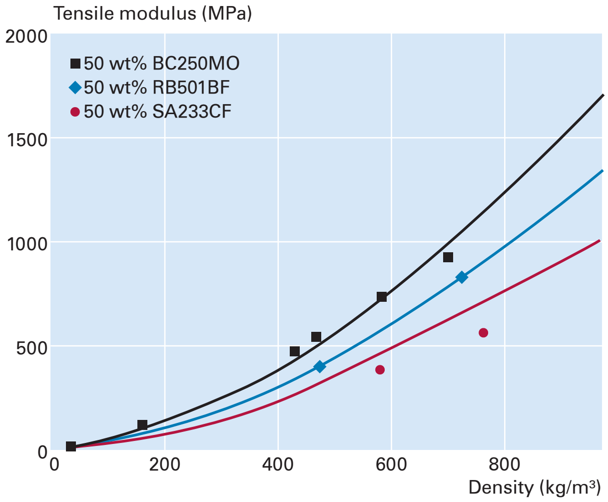


Figure 13

Experimental data for the tensile modulus of various Daploy HMS-PP blends and theoretical curves

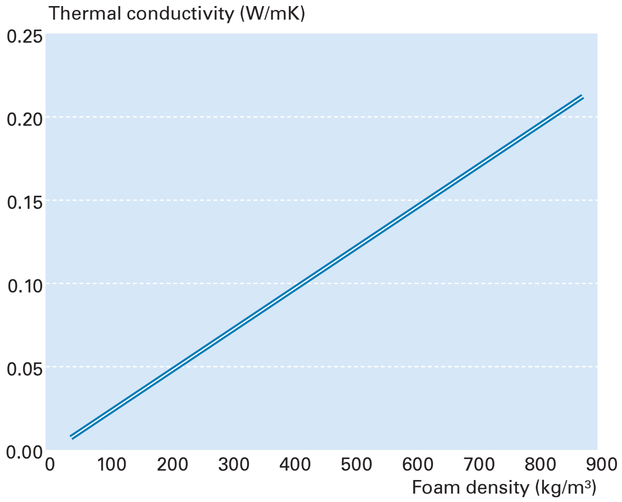


Figure 14

Thermal conductivity as a function of density for PP foam

Basic material data for Daploy HMS-PP's

Property	Unit	WB130HMS	WB135HMS	Standard
MFR 230/2.16	g/10 min	2.1	2.4	ISO 1133
Melt strength	cN	34	31	Borealis test method
Melting temperature	°C	165	165	ISO 11357
Crystallisation temperature	°C	128	128	ISO 11357
Thermal conductivity	W/mK	0.20 - 0.23	0.20 - 0.23	Borealis test method
Flexural modulus	MPa	1900	1850	ISO 178
Tensile modulus	MPa	2000	1950	ISO 527-2
Stress at yield	MPa	40	40	ISO 527-2
Strain at yield	%	6	6	ISO 527-2
Stress at break	MPa	30	30	ISO 527-2
Strain at break	%	12	15	ISO 527-2
Heat deflection temp. A	°C	60	60	ISO 75-2
Heat deflection temp. B	°C	110	110	ISO 75-2
Vicat A	°C	155	155	ISO 306
Vicat B	°C	100	100	ISO 306
Charpy impact str. notched +23°C	kJ/m²	3	3	ISO 179/1eA
Charpy impact str. unnotched +23°C	kJ/m²	100	100	ISO 179/1eU

Basic data of Daploy WB130HMS and WB135HMS (typical values)

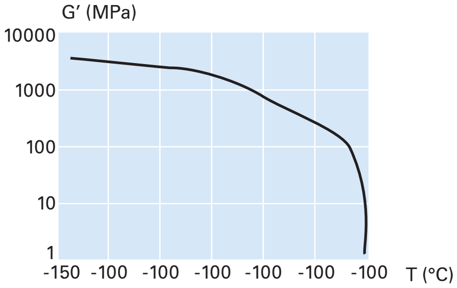


Figure 15

DMTA (ISO 6721-2A)

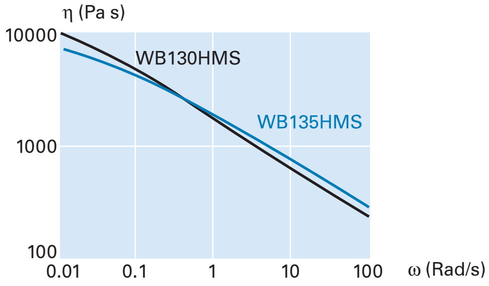


Figure 16

Shear rheology at 230°C (ISO6721-1)

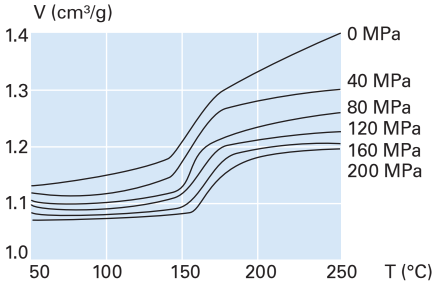


Figure 17

PVT diagram

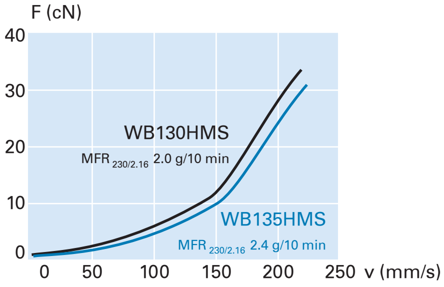


Figure 18

Rheotens curves at 200°C

Processing guidelines

Daploy HMS-PP's and their blends with standard polypropylenes can be processed on all types of conventional foam extrusion equipment.

The final foam density and quality will depend not only on the polymer, blowing agent, processing aids or masterbatches, but also on design and process settings of the machine.

The following tables offer some general process setting guidelines for foaming with Daploy HMS-PP, in the cases of chemical foaming with CO_2 and physical foaming with CO_2 and butane.

Chemical foaming of Daploy WB130HMS with CO_2

Parameter	Range	Unit
Mass flow	3 - 5	kg/h
Foaming agent*	0.5 - 2.5	%
Nucleating agent**	0 - 2	%
Extruder temperatures:		
■ zone 1	240	°C
■ zone 2	220	°C
■ zone 3	180 - 200	°C
■ zone 4	180 - 200	°C
■ zone 5	180	°C
■ zone 6	180	°C
■ zone 7	180	°C
■ die	175 - 180	°C
Melt temperature	180 - 190	°C
Melt pressures:		
■ die	40 - 200	bar
Screw speed	30 - 60	rpm
Take off speed	2.5 - 5	m/min
Foam density	250 - 600	kg/m³

Example for single screw 30 mm, flat die
*Hydrocerol® CF40E , **Hydrocerol® CT516

Physical foaming of Daploy WB130HMS with CO_2

Parameter	Range	Unit
Mass flow	15 - 25	kg/h
CO_2	0.4 - 1.2	%
Nucleating agent*	0.15 - 0.30	%
Extruder temperatures:		
■ zone 1	160 - 170	°C
■ zone 2	180 - 190	°C
■ zone 3	220 - 220	°C
■ zone 4	220 - 240	°C
■ zone 5	220 - 240	°C
■ zone 6	220 - 240	°C
■ zone 7	180	°C
■ cooling extension	175 - 180	°C
■ mixer	175	°C
■ adapter	175 - 180	°C
■ die	165 - 170	°C
Melt temperature	165 -170	°C
Melt pressures:		
■ extruder (injection)	50 - 80	bar
■ mixer	40 - 65	bar
■ die	30 - 50	bar
Screw speed	15 - 25	rpm
Take off speed	2.5 - 4	m/min
Foam density	120 - 400	kg/m³

Example for single screw 60 mm, annular die
*Hydrocerol® CF20E

Physical foaming of Daploy WB130HMS with butane

Parameter	Range	Unit
Mass flow	80 - 100	kg/h
Butane	4 - 8	%
Nucleating agent*	0.4 - 1.0	%
Extruder temperatures:		
■ zone 1	190 - 220	°C
■ zone 2	220 - 240	°C
■ zone 3	175 - 200	°C
■ zone 4	175 - 180	°C
■ zone 5	140 - 160	°C
■ zone 6	140 - 150	°C
■ zone 7	140 - 150	°C
■ cooling extension	140 - 150	°C
■ die	140 - 150	°C
Melt temperature	140 - 150	°C
Melt pressures:		
■ extruder (gas injection)	40 - 100	bar
■ die	40 - 100	bar
Screw speed	30 - 50	rpm
Take off speed	3 - 5	m/min
Foam density	30 - 120	kg/m³

Example for twin screw 60 mm, annular die
* Hydrocerol® CT516

Borealis - a leading, innovative plastics provider

Borealis is a leading provider of plastics solutions. Its technology shapes daily life products and forms the basis of next generation innovation and creative product development in plastics.

With EUR 4 billion revenue in sales and 5,000 employees, Borealis has more than 40 years of experience as a reliable supplier of polyethylene (PE) and polypropylene (PP) products. Borealis today is a partner to its customers manufacturing and developing products such as food packaging, diapers, appliances, automotive parts, distribution pipes for water, gas and sewage, power cables, sporting equipment and medical devices.

Borealis is headquartered in Copenhagen, Denmark with innovation centres, customer service centres, and main production sites in Europe and the Middle East. Borealis has representative offices and operations in Asia, North and South America.

At its heart, the company's four values of Responsibility, Respect, Exceed and Nimblicity™, define its way of doing business. For Borealis, success is driven by innovation, responsiveness, and operational excellence.

Borstar is the proprietary process technology supporting differentiated PE and PP products and is a registered trademark of Borealis A/S, Denmark.

To learn more about Borealis visit
www.borealisgroup.com

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