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# Daploy™ High-Melt-Strength PP

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Foaming guide

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# Polypropylene foam

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 as PS, PU and PVC) which have been industrially foamed for more than 50 years.

Polypropylene (PP) foams are a relative late comer to this market. The reasons for this lie in the molecular structure – standard PP's are semi-crystalline materials with a linear molecular structure. They lack the required extensional rheological properties in the melt phase which are required for the production of extruded low density foams with a fine and controlled cell structure. This limitation is resolved by 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 numerous 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.

PP foams offer significant benefits versus other polymeric foam solutions in terms of sustainability:

- Low density/light weighting
- Non-cross-linked i.e no extra processing step
- Thermal and sound insulation
- Easy Recycling
- Various processing techniques: Extrusion, Thermoforming, Blow moulding
- Dimensional stability
- Printable

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 related to its monomer. Its high heat stability means products are microwaveable, with good thermal insulation giving them a 'cool touch' during use.

In automotive applications, lightweight foam solutions are helping to improve vehicle performance and fuel efficiency. With 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. Its high heat stability also opens the possibility for under the bonnet applications. PP foams also have very good cushioning properties, thereby contributing to improved driver and passenger safety.

In construction applications, PP Foams bring dimensional stability, low water absorption, heat resistance and insulation properties. Recyclability is also here one of the key benefits, supporting the aim of having a better sustainable future.

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

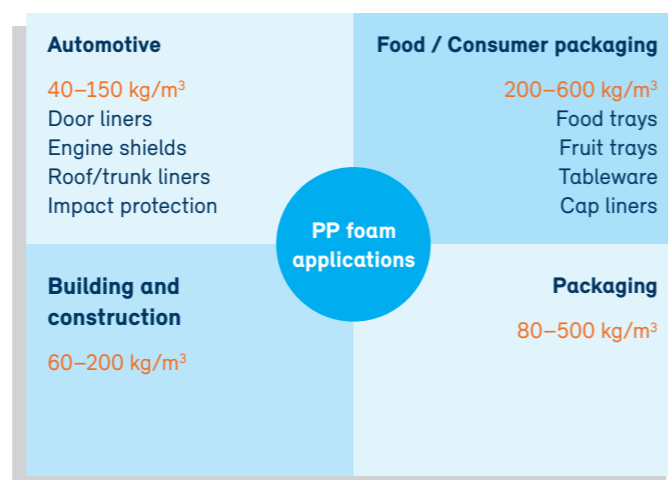


Figure 1: Some current applications for extruded PP foams

# Daploy™ HMS-PP

The basic extensional rheological properties of the long branched Daploy HMS-PP products are shown in figure 2, 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/m<sup>3</sup>) 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.

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, Daploy HMS-PP products are specifically designed to be suitable for processing on most types of existing industrial foaming equipment.

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

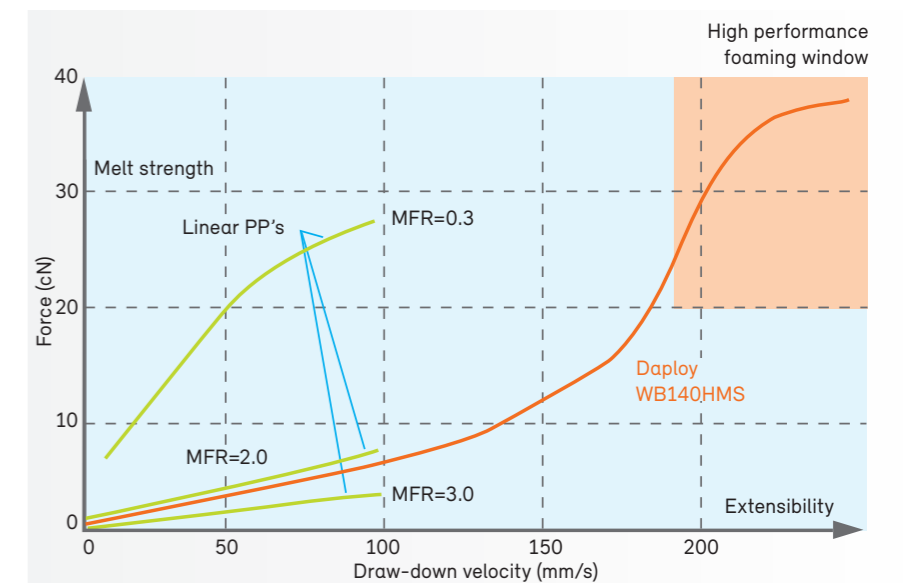


Figure 2: Extensional rheology curves for linear PP's and Daploy HMS



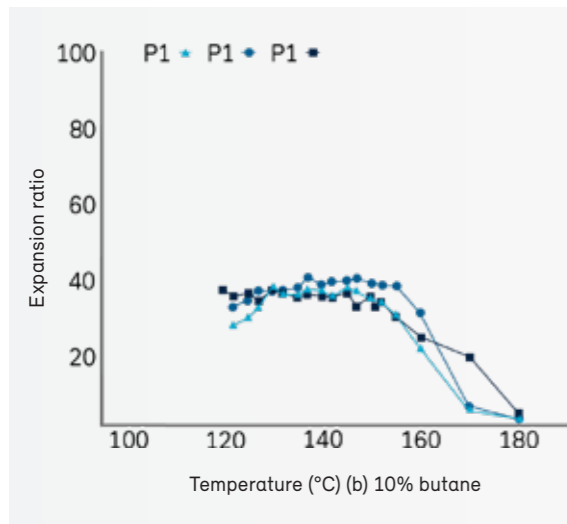


Figure 3: Expansion Ratio

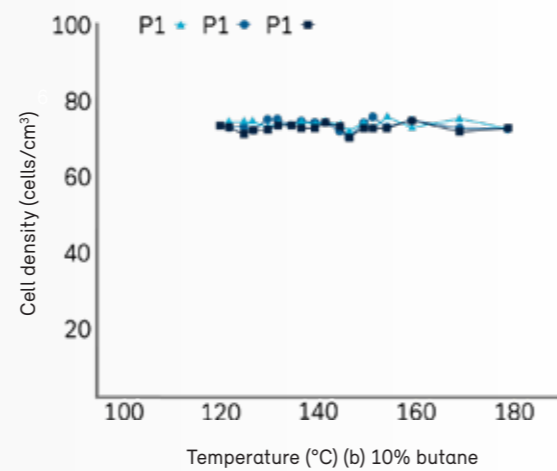


Figure 4: Cell Density (cells/cm<sup>3</sup>)

Foam based on Daploy™ HMS PP can be recycled, e.g. into low density foam\*

Samples	Description of samples	Melt Flow Index (230°C/2.16 kg) (g/10min)	Inherent viscosity (135°C, decline)
P1	Virgin sample	2.50	1.91
P2	One pass of extruder	4.66	1.91
P3	Two passes of extruder	8.19	1.91

\* Data published 2002 (C. Park & N. Reichelt; Blowing agents and foaming processes; Heidelberg)



## 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 3.

These three specific steps in the foam extrusion process comprise of

(a) dissolving of a blowing agent gas in the polymer melt

(b) cell nucleation

(c) cell growth and stabilisation

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.

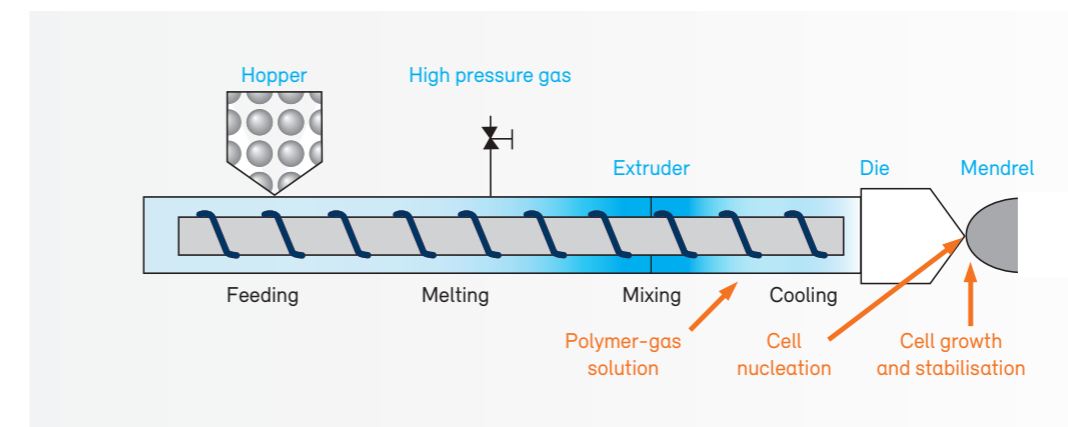


Figure 5: Schematic illustration of processing steps in foam extrusion – direct gas injection/annular die

### 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).

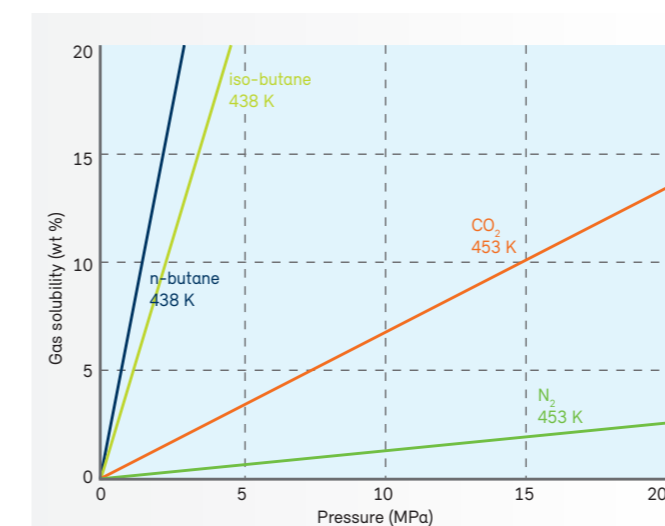


Figure 6: Solubility of commonly used blowing agents in PP

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 when using the more common 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 4 shows the equilibrium solubility curves for the commonly used 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.

The content of the blowing agent, as well as the one of the nucleating agent, has a direct impact on the cell density. Figure 5 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.

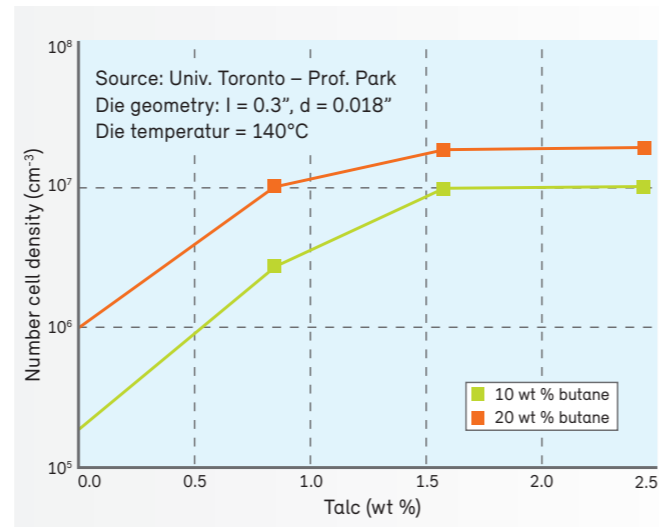


Figure 7: The effects on cell density of blowing agent and nucleating agent concentrations

### Cell growth and stabilisation

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  $130^{\circ}\text{C}$  to  $180^{\circ}\text{C}$ .

When the melt temperature is too low, foaming is limited because the material solidifies before the cells have the possibility to expand fully. When the temperature is too high, the foam first expands, then collapses again due to lack of stabilisation 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 ( $210^{\circ}\text{C}$  to  $240^{\circ}\text{C}$ ) – see also figure 6. 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 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 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.

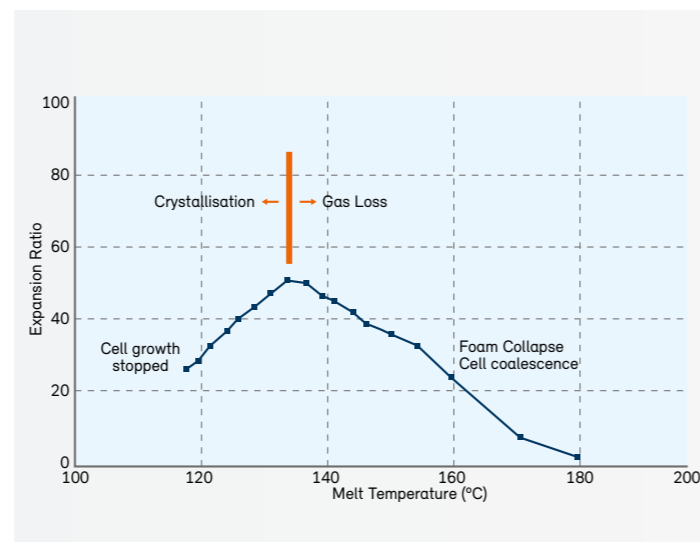


Figure 8: Temperature balance between insufficient cell growth and collapsing cells

## 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.

However, an important consideration 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 7.

**It can be seen, however, that quite high levels (approx. 60%) of blend partner can 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 8, where the minimum achievable foam density is shown as a function of the HMS-PP content in the blend. A wide range of blend compositions can be used in order to reach low density ( $<100 \text{ kg/m}^3$ ) PP foams or in order to adjust the extruded foam properties for the end application.

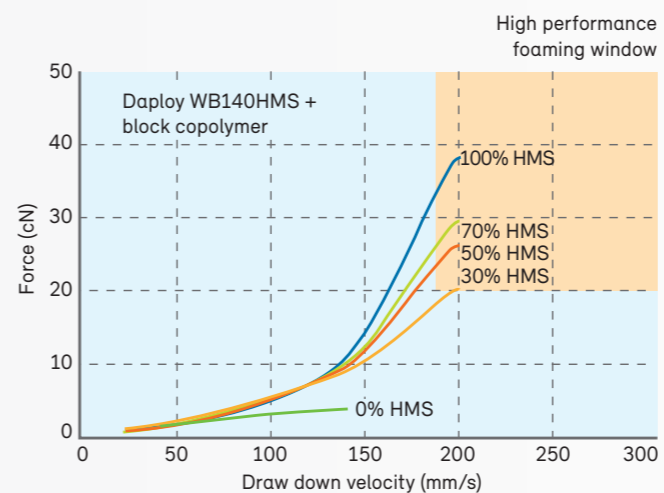


Figure 9: Extensional rheology curves for HMS-PP/block copolymer blends

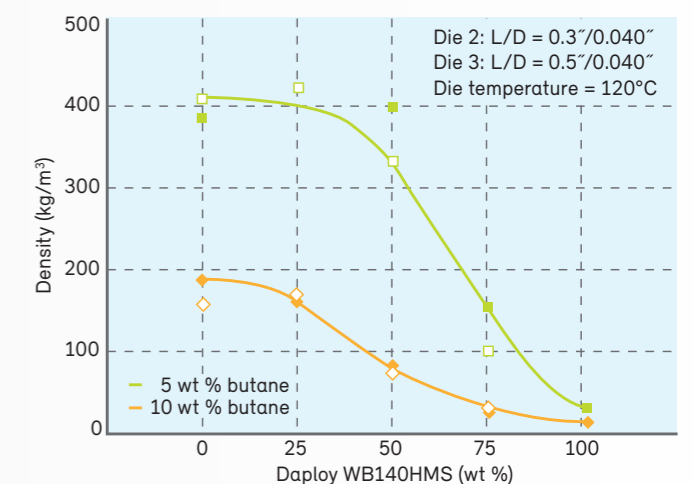


Figure 10: Minimum achievable foam density as a function of Daploy HMS-PP content of the blend

## 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.

The homopolymer based HMS-PP's can be used pure or in blends with standard homopolymers, providing foams with 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, impact performance is improved at temperatures above approximately 0°C. If good impact performance is required at low temperatures (<0°C), heterophasic copolymers should be used.

Further interesting property modifications can be made available by using Borealis random heterophasic copolymers as blend partners. These are soft PP's (tensile modulus ~400 MPa). The blend with these products provides the opportunity to produce soft PP foams with good impact strength and toughness at low temperatures. Even softer foams can be obtained by blending Daploy HMS-PP's with various polymeric materials such as metallocene LLDPE's, TPO's or EVA's.

Blend Partner	Foam property modifications
Homopolymers	<ul style="list-style-type: none"> <li>- High stiffness</li> <li>- Reduced impact</li> </ul>
Block copolymers	<ul style="list-style-type: none"> <li>- Low temperature impact</li> <li>- Reduced stiffness</li> <li>- Improved toughness</li> </ul>
Random copolymers	<ul style="list-style-type: none"> <li>- Softer foams</li> <li>- Improved toughness</li> </ul>
Random heterophasic copolymers	<ul style="list-style-type: none"> <li>- Soft foams</li> <li>- Low temperature impact</li> </ul>

\* For more information and technical data sheets please consult our webpage [www.borealisgroup.com](http://www.borealisgroup.com)

Table 1: Blend partner types and their influence on foam properties using a certain HMS PP product as base resin

The 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 which 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 2,000 MPa. The tensile modulus of the foamed material will decrease as the density decreases. The third parameter is foam structure and this relates to factors such as the relative proportions of open and closed cells and cell size.

Figure 9 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.

For the selection of the right polymer structure – density profile for your specific applications we will be able to provide support with experience of many years in the area of PP foam and a tool developed by Borealis to predict the final properties of a foam.

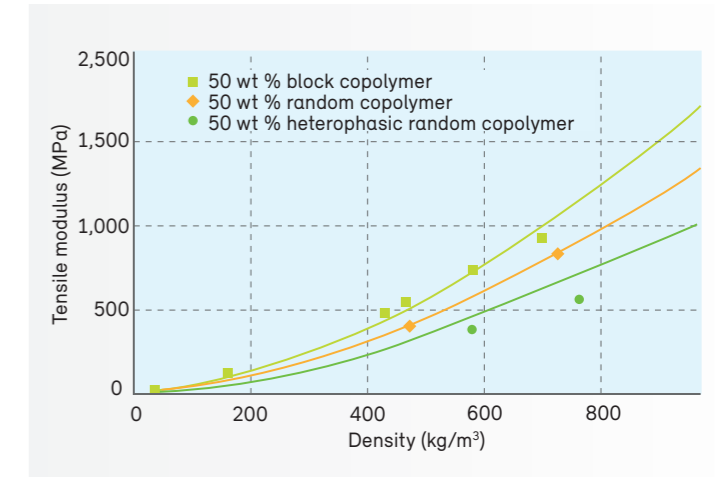


Figure 11: Experimental data for the tensile modulus of various Daploy HMS-PP blends and theoretical curves



## Basic material data for the Daploy™ HMS grades

Daploy WB135HMS and WB140HMS are PP-homo based materials where long chain branching was introduced using a post reactor step.

This treatment results in an enhanced melt strength, improved drawability and also high stiffness.

Property	Unit	WB135HMS	WB140HMS	Method
MFR 230/2.16	g/10 min	2.4	2.1	ISO 1133
Melt Strength	cN	32	36	Borealis test method
Melting Temperature	°C	163	163	ISO 11357
Crystallisation temperature	°C	128	127	ISO 11357
Flexural modulus	MPa	1,900	1,900	ISO 178
Tensile modulus	MPa	2,000	2,000	ISO 527-2
Elongation at break	%	10	10	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
Charpy impact str. notched +23°C	kJ/m <sup>2</sup>	4	3	ISO 179/1eA
Charpy impact str. notched -20°C	kJ/m <sup>2</sup>	1	1	ISO 179/1eA

Table 2: Comparison of Daploy foam grades

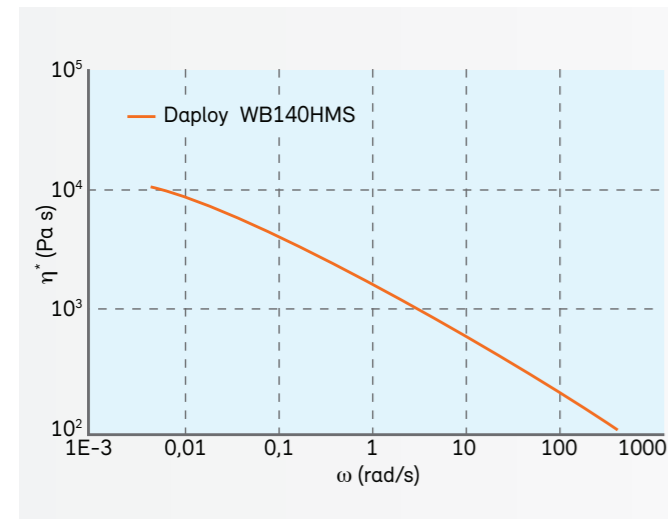


Figure 12: Shear rheology at 230°C (ISO67211)

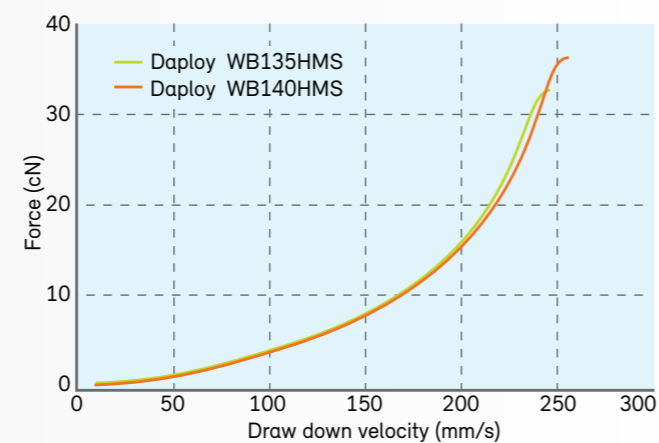


Figure 13: Rheotens curves at 200°C

## Processing guidelines for HMS-PP grades

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<sub>2</sub> and physical foaming with CO<sub>2</sub> or butane.

### Example for single screw 60 mm, annular die

\*Hydrocerol® CF20E

Parameter	WB140HMS/ WB135HMS	Unit
Mass flow	15 – 25	kg/h
CO <sub>2</sub>	0.4 – 1.2	%
Nucleating agent*	0.15 – 0.30	%
<b>Extruder temperatures:</b>		
– zone 1	160 – 170	°C
– zone 2	180 – 190	°C
– zone 3	200 – 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
<b>Melt pressures:</b>		
– extruder (injection)	50 – 80	bar
– mixer	40 – 65	bar
– die	30 – 50	bar
<b>Screw speed</b>	15 – 25	rpm
<b>Take off speed</b>	2.5 – 4	m/min
<b>Foam density</b>	120 – 400	kg/m <sup>3</sup>

Table 3: Physical foaming of Daploy WB135HMS/WB140HMS with CO<sub>2</sub>

#### Example for twin screw 60 mm, annular die

\*Hydrocerol® CT516

Parameter	Range	Unit
<b>Mass flow</b>	80 – 100	kg/h
<b>Butane</b>	4 – 8	%
<b>Nucleating agent*</b>	0.4 – 1.0	%
<b>Extruder temperatures:</b>		
– 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
<b>Melt temperature</b>	140 – 150	°C
<b>Melt pressures:</b>		
– extruder (gas injection)	40 – 100	bar
– die	40 – 100	bar
<b>Screw speed</b>	30 – 50	rpm
<b>Take off speed</b>	3 – 5	m/min
<b>Foam density</b>	30 – 120	kg/m <sup>3</sup>

Table 4: Physical foaming of Daploy WB140HMS with butane

#### Example for single screw 30 mm, flat die

\*Hydrocerol® CF40E, \*\*Hydrocerol® CT516

Parameter	Range	Unit
<b>Mass flow</b>	3 – 5	kg/h
<b>Foaming agent*</b>	0.5 – 2.5	%
<b>Nucleating agent**</b>	0 – 2	%
<b>Extruder temperatures:</b>		
– 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
<b>Melt temperature</b>	180 – 190	°C
<b>Melt pressures:</b>		
– die	40 – 200	bar
<b>Screw speed</b>	30 – 60	rpm
<b>Take off speed</b>	2.5 – 5	m/min
<b>Foam density</b>	250 – 600	kg/m <sup>3</sup>

Table 5: Chemical foaming of Daploy WB140HMS with CO<sub>2</sub>

Together we can | Date of issue: March 2019

**About Borealis** Borealis is a leading provider of innovative solutions in the fields of polyolefins, base chemicals and fertilizers. With its head office in Vienna, Austria, the company currently has around 6,800 employees and operates in over 120 countries. Borealis generated EUR 8.3 billion in sales revenue and a net profit of EUR 906 million in 2018. Mubadala, through its holding company, owns 64% of the company, with the remaining 36% belonging to Austria-based OMV, an integrated, international oil and gas company. Borealis provides services and products to customers around the world in collaboration with Borouge, a joint venture with the Abu Dhabi National Oil Company (ADNOC).

Borealis and Borouge aim to proactively benefit society by taking on real societal challenges and offering real solutions. Both companies are committed to the principles of Responsible Care®, an initiative to improve safety performance within the chemical industry, and work to solve the world's water and sanitation challenges through product innovation and their Water for the World programme.

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