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(54) **Title:** POLYPROPYLENE FOAM

(57) **Abstract:** The present invention relates to a foam comprising a polypropylene, wherein said polypropylene is produced in the presence of a metallocene catalyst, and the foam and/or the polypropylene has (have) a) a branching index g' of less than 1.00 and b) a strain hardening index (SHI@1s^{-1}) of at least 0.30 measured by a deformation rate $d\varepsilon/dt$ of 1.00 s^{-1} at a temperature of 180 °C, wherein the strain hardening index (SHI) is defined as the slope of the logarithm to the basis 10 of the tensile stress growth function (lg (ηE^+)) as function of the logarithm to the basis 10 of the Hencky strain (lg (ε)) in the range of Hencky strains between 1 and 3.

Polypropylene foam

5   The present invention relates to a polypropylene foam having an even foam surface
and small cell size. It also relates to the use of multibranched polypropylene for the
preparation of foam.

Thermoplastic foams possess a cellular structure generated by the expansion of a
10   blowing agent. The cellular structure provides unique properties that enable the
foamed plastics to be used for various industrial applications. Due to its outstanding
functional characteristics and low material cost, polypropylene foams have been
considered as a substitute for other thermoplastic foams in industrial applications. In
particular, they have higher rigidity compared to other polyolefins, offer higher
15   strength than polyethylene and better impact strength than polystyrene. Furthermore,
they provide a higher service temperature range and good temperature stability.

However, polypropylene is suffering from some serious drawbacks, limiting its use
for the preparation of foams. In particular, many polypropylene materials have low
20   melt strength and/or low melt extensibility.

Polypropylene foams are made in a foam extrusion process wherein a gas-laden melt
is suddenly expanded through pressure drop after the extrusion die. Such an
expansion induces extensional flow to the polymer melt and sets certain requirements
25   to the extensional rheology of the melt. In particular, high melt strength and/or high
melt extensibility are required. If these conditions are not met, bubble film rupture is
more likely to occur and the average foam cell size will decrease due to bubble
coalescence. Increasing bubble size results in a decrease of impact strength of the
foam.

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At present, two polypropylene-based systems are used in the industry for the
preparation of foams:

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1.   Linear, bimodal high molecular weight polypropylene obtained either from
      copolymerisation of propylene with comonomers such as ethylene or from
      reacting a coupling agent with polypropylene. EP-A-0887379 discloses the
      preparation of linear bimodal polypropylene in a multi-step process using at
5   least one slurry reactor and at least one gas phase reactor. WO 00/78858
      discloses a coupled propylene copolymer prepared by reacting a coupling
      agent such as polysulfonyl azide with a propylene copolymer.
      Due to the high molecular weight, these polymers have a high zero shear
      viscosity. However, they have reduced output from the extruder because a
10   high pressure is built up in the extrusion line.

2.   Y/H-shaped polypropylenes from post-reactor processes such as irradiation or
      peroxide treatment or from copolymerisation of propylene with dienes in the
      presence of a metallocene catalyst. WO 2005/044877 discloses a foamed
15   article comprising a propylene/α-ω diene copolymer. EP-A-0879830
      discloses Y/H-shaped polypropylene from peroxide treatment.

      However, Y/H-shaped polypropylenes are inherently inhomogeneous, contain
      gels and show a low number of cells, thereby adversely affecting foam
20   surface quality.

Considering the problems outlined above, it is an object of the present invention to
provide a polypropylene foam having improved foam surface properties such as high
surface evenness, and a small cell size. Furthermore, the preparation of such a foam
25 should be possible with high output at the foaming line without adversely affecting
surface properties and cell size. Thus, the present invention intends to provide an
improved balance between processibility and final foam properties.

In a first aspect of the present invention, the object is solved by providing a foam
30 comprising a polypropylene, wherein

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said polypropylene is produced in the presence of a metallocene catalyst, preferably in the presence of a metallocene catalyst as further defined below, and said foam and/or said polypropylene has (have)

a.   a branching index g' of less than 1.00 and

5   b.   a strain hardening index (SHI@1s^{-1}) of at least 0.30 measured by a deformation rate $d\varepsilon/dt$ of 1.00 s^{-1} at a temperature of 180 °C, wherein the strain hardening index (SHI) is defined as the slope of the logarithm to the basis 10 of the tensile stress growth function (lg (η_E^+)) as function of the logarithm to the basis 10 of the Hencky strain (lg (ε)) in

10   the range of Hencky strains between 1 and 3.

Preferably the foam is free of polyethylene, even more preferred the foam comprises a polypropylene as defined above and further defined below as the only polymer component.

15

The present invention is based on the finding that an improved balance between processibility and final foam properties can be achieved by using a polypropylene which has a specific branching structure.

20   The foam of the present invention comprises a polypropylene which is characterized in particular by extensional melt flow properties. The extensional flow, or deformation that involves the stretching of a viscous material, is the dominant type of deformation in converging and squeezing flows that occur in typical polymer processing operations. Extensional melt flow measurements are particularly useful in

25   polymer characterization because they are very sensitive to the molecular structure of the polymeric system being tested. When the true strain rate of extension, also referred to as the Hencky strain rate, is constant, simple extension is said to be a "strong flow" in the sense that it can generate a much higher degree of molecular orientation and stretching than flows in simple shear. As a consequence, extensional

30   flows are very sensitive to crystallinity and macro-structural effects, such as long-

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chain branching, and as such can be far more descriptive with regard to polymer characterization than other types of bulk rheological measurement which apply shear flow.

5   The first requirement according to the present invention is that the foam and/or the polypropylene present within said foam has/have a branching index g' of less than 1.00, more preferably less than 0.90, still more preferably less than 0.80. In the preferred embodiment, the branching index g' shall be less than 0.75. On the other hand it is preferred that the branching index g' is

10   more than 0.6, still more preferably 0.7 or more. Thus it is preferred that the branching index g' of the polypropylene is in the range of 0.6 to below 1.0, more preferred in the range of more than 0.65 to 0.95, still more preferred in the range of 0.7 to 0.95. The branching index g' defines the degree of branching and correlates with the amount of branches of a polymer. The

15   branching index g' is defined as $g'=[IV]_{br}/[IV]_{lin}$ in which g' is the branching index of the foam or the polypropylene component, $[IV_{br}]$ is the intrinsic viscosity of either the foam comprising the branched polypropylene if g' of the foam shall be determined or of the branched polypropylene if g' of the polypropylene shall be determined, and $[IV]_{lin}$ is the intrinsic viscosity of

20   either the foam comprising a linear polypropylene having the same weight average molecular weight (within a range of ±10 %) as the branched polypropylene if g' of the foam shall be determined or of a linear polypropylene having the same weight average molecular weight (within a range of ±10 %) as the branched polypropylene if g' of the branched

25   polypropylene shall be determined. Thereby, a low g'-value is an indicator for a highly branched polymer. In other words, if the g'-value decreases, the branching of the polypropylene increases. Reference is made in this context to B.H. Zimm and W.H. Stockmeyer, J. Chem. Phys. 17,1301 (1949). This document is herewith included by reference.

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The intrinsic viscosity needed for determining the branching index g' is measured according to DIN ISO 1628/1, October 1999 (in Decalin at 135 °C).

A further requirement is that the strain hardening index (SHI@1s^{-1}) of the
5   foam and/or the polypropylene present within said foam shall be at least 0.30, more preferred of at least 0.40, still more preferred of at least 0.50. In a preferred embodiment the strain hardening index (SHI@1s^{-1}) is at least 0.55.

The strain hardening index is a measure for the strain hardening behavior of
10   the melted foam or the polypropylene melt. In the present invention, the strain hardening index (SHI@1s^{-1}) has been measured by a deformation rate $d\varepsilon/dt$ of 1.00 s^{-1} at a temperature of 180 °C for determining the strain hardening behavior, wherein the strain hardening index (SHI) is defined as the slope of the tensile stress growth function η_E^+ as a function of the Hencky strain ε on a
15   logarithmic scale between 1.00 and 3.00 (see Figure 1). Thereby the Hencky strain ε is defined by the formula $\varepsilon = \dot{\varepsilon}_H \cdot t$, wherein

the Hencky strain rate $\dot{\varepsilon}_H$ is defined by the formula

$$\dot{\varepsilon}_H = \frac{2 \cdot \Omega \cdot R}{L_0} \ [\text{s}^{-1}]$$

with
20   "L_0" is the fixed, unsupported length of the specimen sample being stretched which is equal to the centerline distance between the master and slave drums
"R" is the radius of the equi-dimensional windup drums, and
"Ω" is a constant drive shaft rotation rate.

25   In turn the tensile stress growth function η_E^+ is defined by the formula

$$\eta_E^+(\varepsilon) = \frac{F(\varepsilon)}{\dot{\varepsilon}_H \cdot A(\varepsilon)} \ \text{with}$$

$$T(\varepsilon) = 2 \cdot R \cdot F(\varepsilon) \ \text{and}$$

$$A(\varepsilon) = A_0 \cdot \left(\frac{d_S}{d_M}\right)^{2/3} \cdot \exp(-\varepsilon) \quad \text{wherein}$$

the Hencky strain rate $\dot{\varepsilon}_H$ is defined as for the Hencky strain ε

"F" is the tangential stretching force

"R" is the radius of the equi-dimensional windup drums

5   "T" is the measured torque signal, related to the tangential stretching force"F"

"A" is the instantaneous cross-sectional area of a stretched molten specimen

"A_0" is the cross-sectional area of the specimen in the solid state (i.e. prior to melting),

"d_s" is the solid state density and

10   "d_M" the melt density of the polymer.

Preferably, the polypropylene used for the preparation of the foam is not crosslinked.

15   In a preferred embodiment of the first aspect of the present invention, the foam and/or the polypropylene has/have a multi-branching index (MBI) of at least 0.15, wherein the multi-branching index (MBI) is defined as the slope of strain hardening index (SHI) as function of the logarithm to the basis 10 of the Hencky strain rate (lg ($d\varepsilon/dt$)). Multi-branching index (MBI) will be explained

20   in further detail below.

It is preferred that the polypropylene used for the preparation of the foam of the present invention shows strain rate thickening which means that the strain hardening increases with extension rates. Similar to the measurement of

25   SHI@1s^{-1}, a strain hardening index (SHI) can be determined at different strain rates. A strain hardening index (SHI) is defined as the slope of the logarithm to the basis 10 of the tensile stress growth function η_E^+, lg(η_E^+), as function of the logarithm to the basis 10 of the Hencky strain ε, lg(ε), between Hencky

strains 1.00 and 3.00 at a at a temperature of 180 °C, where a SHI@0.1 s^{-1} is

determined with a deformation rate $\dot{\varepsilon}_H$ of 0.10 s^{-1}, a SHI@0.3 s^{-1} is

determined with a deformation rate $\dot{\varepsilon}_H$ of 0.30 s^{-1}, a SHI@3 s^{-1} is determined

with a deformation rate $\dot{\varepsilon}_H$ of 3.00 s^{-1}, and a SHI@10 s^{-1} is determined with a

5   deformation rate $\dot{\varepsilon}_H$ of 10.0 s^{-1}. In comparing the strain hardening index (SHI)

at those five strain rates $\dot{\varepsilon}_H$ of 0.10, 0.30, 1.00, 3.00 and 10.0 s^{-1}, the slope of

the strain hardening index (SHI) as function of the logarithm to the basis 10 of

$\dot{\varepsilon}_H$ (lg ($\dot{\varepsilon}_H$)) is a characteristic measure for multi-branching. Therefore, a

multi-branching index (MBI) is defined as the slope of SHI as a function of

10   lg ($\dot{\varepsilon}_H$), i.e. the slope of a linear fitting curve of the strain hardening

index (SHI) versus lg ($\dot{\varepsilon}_H$) applying the least square method, preferably the

strain hardening index (SHI) is defined at deformation rates $\dot{\varepsilon}_H$ between

0.05 s^{-1} and 20.00 s^{-1}, more preferably between 0.10 s^{-1} and 10.0 s^{-1}, still more

preferably at the deformations rates 0.10, 0.30, 1.00, 3.00 and 10.0 s^{-1}. Yet

15   more preferably the SHI-values determined by the deformations rates 0.10,

0.30, 1.00, 3.00 and 10.0 s^{-1} are used for the linear fit according to the least

square method when establishing the multi-branching index (MBI).

It is in particular preferred that the foam of the present invention and/or the

20   polypropylene present within said foam has/have a branching index g' of less

than 1.00, a strain hardening index (SHI@1s^{-1}) of at least 0.30 and multi-

branching index (MBI) of at least 0.15. Still more preferred the foam and/or its

polypropylene component has/have a branching index g' of less than 0.80, a

strain hardening index (SHI@1s^{-1}) of at least 0.40 and multi-branching

25   index (MBI) of at least 0.15. In another preferred embodiment, the foam

and/or its polypropylene component has/have a branching index g' of less than

1.00, a strain hardening index (SHI@1s^{-1}) of at least 0.30 and multi-branching

index (MBI) of at least 0.20. In still another preferred embodiment, the foam

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and/or its polypropylene component has/have a branching index g' of less than 0.80, a strain hardening index $(SHI@1s^{-1})$ of at least 0.40 and multi-branching index (MBI) of at least 0.20. In yet another preferred embodiment, the foam and/or its polypropylene component has/have a branching index g' of less than

5   0.80, a strain hardening index $(SHI@1s^{-1})$ of at least 0.50 and multi-branching index (MBI) of at least 0.30.

As discussed above, the foam of the present invention comprises a polypropylene having a specific branching structure, i.e. multi-branched

10   polypropylene. Such multi-branched polypropylene is characterized by the fact that its strain hardening index (SHI) increases with the deformation rate $\dot{\varepsilon}_H$, i.e. a phenomenon which is not observed in other polypropylenes. Single branched polymer types (so called Y polymers having a backbone with a single long side-chain and an architecture which resembles a "Y") or H-

15   branched polymer types (two polymer chains coupled with a bridging group and a architecture which resemble an "H") as well as linear or short chain branched polymers do not show such a relationship, i.e. the strain hardening index (SHI) is not influenced by the deformation rate (see Figures 2 and 3). Accordingly, the strain hardening index (SHI) of known polymers, in

20   particular known polypropylenes and polyethylenes, does not increase or increases only negligible with increase of the deformation rate $(d\varepsilon/dt)$. Industrial conversion processes which imply elongational flow operate at very fast extension rates. Hence the advantage of a material which shows more pronounced strain hardening (measured by the strain hardening index SHI) at

25   high strain rates becomes obvious. The faster the material is stretched, the higher the strain hardening index (SHI) and hence the more stable the material will be in conversion. Especially in the fast extrusion process, the melt of the multi-branched polypropylenes has a high stability.

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For further information concerning the measuring methods applied to obtain the relevant data for the branching index g', the tensile stress growth function η_E^+, the Hencky strain rate $\dot{\varepsilon}_H$, the Hencky strain ε and the multi-branching index (MBI) it is referred to the example section.

5

As explained above, the multi-branching index MBI is also a parameter which is very sensitive to the branching structure of a polymeric material and can be used to characterize the foam of the present invention. Thus, in a second aspect of the present invention, there is provided a foam comprising a polypropylene, wherein

10   the foam and/or the polypropylene has (have) a multi-branching index (MBI) of at least 0.15, wherein the multi-branching index (MBI) is defined as the slope of strain hardening index (SHI) as function of the logarithm to the basis 10 of the Hencky strain rate (lg ($d\varepsilon/dt$)), wherein

$d\varepsilon/dt$ is the deformation rate,

15   ε is the Hencky strain, and

the strain hardening index (SHI) is measured at 180 °C, wherein the strain hardening index (SHI) is defined as the slope of the logarithm to the basis 10 of the tensile stress growth function (lg (η_E^+)) as function of the logarithm to the basis 10 of the Hencky strain (lg (ε)) in the range of Hencky strains

20   between 1 and 3.

Preferably, the multi-branching index (MBI) is at least 0.20, and still more preferred at least 0.25. In a still more preferred embodiment the multi-branching index (MBI) is at least 0.28.

25

Preferably the foam is free of polyethylene, even more preferred the foam comprises a polypropylene as defined above and further defined below as the only polymer component.

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Preferably said polypropylene is produced in the presence of a metallocene catalyst, more preferably in the presence of a metallocene catalyst as further defined below.

5 In a preferred embodiment, the foam and/or the polypropylene present within said foam has/have a branching index g' of less than 1.00, more preferably less than 0.90, still more preferably less than 0.80. In the preferred embodiment, the branching index g' shall be less than 0.75. On the other hand it is preferred that the branching index g' is more than 0.6, still more preferably 0.7 or more.

10 Thus it is preferred that the branching index g' of the polypropylene is in the range of 0.6 to below 1.0, more preferred in the range of more than 0.65 to 0.95, still more preferred in the range of 0.7 to 0.95.

Preferably, the strain hardening index $(SHI@1s^{-1})$ shall be at least 0.30, more

15 preferred at least 0.40, still more preferred at least 0.50. In a preferred embodiment the strain hardening index $(SHI@1s^{-1})$ is at least 0.55.

The following statements apply to both aspects of the present invention as defined above.

20

Preferably, the polypropylene comprised by the foam of the present invention is not crosslinked.

Moreover it is preferred, that the foam is further characterized in that the foam

25 has a smooth surface, i.e. the surface does not show many defects. An indication, that the foam is rather defect free, is when the material used for the foam shows only few gels when converted into a film. Thus it is preferred that the foam material converted into a film has only gels with a diameter of equal or less than 500 μm, i.e. no gels with a diameter of more than 500 μm are

30 present in said film (converted foam), and wherein said gels are not more than

100 gels per square meter (sqm), more preferably not more than 80 gels per square meter (sqm), and yet more preferably not more than 60 gels per square meter (sqm). In yet another preferred embodiment the converted foam material has only gels with a diameter of equal or less than 400 μm, i.e. no gels with a diameter of more than 500 μm are present in said film (converted foam), and wherein said gels are not more than 100 gels per square meter (sqm), more preferably not more than 80 gels per square meter (sqm), and yet more preferably not more than 60 gels per square meter (sqm). In still yet another preferred embodiment the converted foam material has only gels with a diameter of equal or less than 300 μm, i.e. no gels with a diameter of more than 500 μm are present in said said film (converted foam), and wherein said gels are not more than 100 gels per square meter (sqm), more preferably not more than 80 gels per square meter (sqm), and yet more preferably not more than 60 gels per square meter (sqm).

Preferably, the polypropylene comprised by the foam of the present invention has an amount of hot xylene insolubles of less than 0.10 wt%, more preferably less than 0.05 wt%. The amount of hot xylene insolubles is determined by dissolving xylene hot solubles from the polymer in a soxhlet apparatus with boiling xylene for 2 days and measuring the mass fraction of the polypropylene material insoluble in boiling xylene. The amount of hot xylene insolubles indicates the degree of crosslinking, i.e. the higher the degree of crosslinking the higher the amount of polymer which does not dissolve in hot xylene. Polymers having crosslinked areas are of lower homogeneity and contain gels, thereby reducing the number of foam cells and deteriorating the foam surface. Furthermore, crosslinking has a detrimental effect on recycling properties.

In a preferred embodiment of the present invention, the polypropylene component of the foam has xylene solubles (XS) of less than 2.0 wt.-%, more preferably less than 1.50 wt%, and even more preferably less than 1.00 wt%. Xylene solubles are the part

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of the polymer soluble in cold xylene determined by dissolution in boiling xylene and letting the insoluble part crystallize from the cooling solution (for the method see below in the experimental part). The xylene solubles fraction contains polymer chains of low stereo-regularity and is an indication for the amount of non-crystalline areas. High levels of xylene solubles are detrimental for some applications as they represent potential contamination risk.

Furthermore, it is preferred that the foam comprises a polypropylene having a melt flow rate (MFR) given in a specific range. The melt flow rate mainly depends on the average molecular weight. This is due to the fact that long molecules render the material a lower flow tendency than short molecules. An increase in molecular weight means a decrease in the MFR-value. The melt flow rate (MFR) is measured in g/10 min of the polymer discharged through a defined dye under specified temperature and pressure conditions and the measure of viscosity of the polymer which, in turn, for each type of polymer is mainly influenced by its molecular weight but also by its degree of branching. The melt flow rate measured under a load of 2.16 kg at 230 °C (ISO 1133) is denoted as MFR_2. Accordingly, it is preferred that in the present invention the polypropylene has an MFR_2 in a range of 0.01 to 1000 g/10 min, more preferably of 0.01 to 100 g/10 min, still more preferred of 0.05 to 50 g/10 min. In a preferred embodiment, the MFR is in a range of 1.00 to 11.00 g/10 min. In another preferred embodiment, the MFR is in a range of 3.00 to 11.00 g/10 min.

The number average molecular weight (Mn) is an average molecular weight of a polymer expressed as the first moment of a plot of the number of molecules in each molecular weight range against the molecular weight. In effect, this is the total molecular weight of all molecules divided by the number of molecules. In turn, the weight average molecular weight (Mw) is the first moment of a plot of the weight of polymer in each molecular weight range against molecular weight.

The number average molecular weight (Mn) and the weight average molecular
weight (Mw) as well as the molecular weight distribution are determined by size
exclusion chromatography (SEC) using Waters Alliance GPCV 2000 instrument with

5   online viscometer. The oven temperature is 140 °C. Trichlorobenzene is used as a
solvent.

It is preferred that the polypropylene present within the foam has a weight
average molecular weight (Mw) from 10,000 to 2,000,000 g/mol, more

10   preferably from 20,000 to 1,500,000 g/mol.

More preferably, the polypropylene of the instant invention is isotactic. Thus
the foam of the present invention comprises a polypropylene having a rather
high pentad concentration, i.e. higher than 90 %, more preferably higher than

15   92 % and most preferably higher than 93 %. In another preferred embodiment
the pentad concentration is higher than 95 %. The pentad concentration is an
indicator for the narrowness in the stereo-regularity distribution of the
polypropylene.

20   In addition, it is preferred that the polypropylene has a melting temperature
Tm of higher than 120 °C. It is in particular preferred that the melting
temperature is higher than 120 °C if the polypropylene is a polypropylene
copolymer as defined below. In turn, in case the polypropylene is a
polypropylene homopolymer as defined below, it is preferred, that

25   polypropylene has a melting temperature of higher than 150 °C, more
preferred higher than 155 °C.

Not only the polypropylene itself but also the foam shall preferably comply
with specific melting temperature requirements. Hence in case the

30   polypropylene as defined above is a propylene homopolymer, it is preferred

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that the foam has a melting temperature Tm of higher than 145 °C. It is in particular preferred that the melting temperature of the foam comprising the propylene homopolymer is higher than 150 °C, more preferred higher than 155 °C. In case the polypropylene as defined above is a propylene copolymer,

5   it is preferred that the foam has a melting temperature Tm of higher than 120 °C. It is in particular preferred that the melting temperature of the foam comprising the propylene copolymer is higher than 135 °C, more preferred higher than 140 °C.

10   In a preferred embodiment the polypropylene as defined above (and further defined below) is preferably unimodal. In another preferred embodiment the polypropylene as defined above (and further defined below) is preferably multimodal, more preferably bimodal.

15   "Multimodal" or "multimodal distribution" describes a frequency distribution that has several relative maxima. In particular, the expression "modality of a polymer" refers to the form of its molecular weight distribution (MWD) curve, i.e. the appearance of the graph of the polymer weight fraction as a function of its molecular weight. If the polymer is produced in the sequential step process,

20   i.e. by utilizing reactors coupled in series, and using different conditions in each reactor, the different polymer fractions produced in the different reactors each have their own molecular weight distribution which may considerably differ from one another. The molecular weight distribution curve of the resulting final polymer can be seen at a super-imposing of the molecular

25   weight distribution curves of the polymer fraction which will, accordingly, show a more distinct maxima, or at least be distinctively broadened compared with the curves for individual fractions.

A polymer showing such molecular weight distribution curve is called bimodal

30   or multimodal, respectively.

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In case the polypropylene of the foam is not unimodal it is preferably bimodal.

The polypropylene used for the preparation of the foam can be a homopolymer
or a copolymer. Accordingly, the homopolymer as well as the copolymer can
be a multimodal polymer composition.

The expression homopolymer used herein relates to a polypropylene that
consists substantially, i.e. of at least 97 wt%, preferably of at least 99 wt%,
and most preferably of at least 99.8 wt% of propylene units. In a preferred
embodiment only propylene units in the polypropylene homopolymer are
detectable. The comonomer content can be determined with FT infrared
spectroscopy, as described below in the examples.

In case the polypropylene used for the preparation of the foam is a propylene
copolymer, it is preferred that the comonomer is ethylene. However, also other
comonomers known in the art are suitable. Preferably, the total amount of
comonomer, more preferably ethylene, in the propylene copolymer is up to 10
mol%, more preferably up to 8 mol%, and even more preferably up to 6 mol%.

In a preferred embodiment, the polypropylene is a propylene copolymer
comprising a polypropylene matrix and an ethylene-propylene rubber (EPR).

The polypropylene matrix can be a homopolymer or a copolymer, more
preferably multimodal, i.e. bimodal, homopolymer or a multimodal, i.e.
bimodal, copolymer. In case the polypropylene matrix is a propylene
copolymer, then it is preferred that the comonomer is ethylene or butene.
However, also other comonomers known in the art are suitable. The preferred
amount of comonomer, more preferably ethylene, in the polypropylene matrix
is up to 8.00 mol%. In case the propylene copolymer matrix has ethylene as

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the comonomer component, it is in particular preferred that the amount of ethylene in the matrix is up to 8.00 mol%, more preferably less than 6.00 mol%. In case the propylene copolymer matrix has butene as the comonomer component, it is in particular preferred that the amount of butene in the matrix is up to 6.00 Mol%, more preferably less than 4.00 mol%.

Preferably, the ethylene-propylene rubber (EPR) in the total propylene copolymer is 50 wt% or less, more preferably 40 wt% or less. More preferably the amount of ethylene-propylene rubber (EPR) in the total propylene copolymer is in the range of 10 to 50 wt%, still more preferably in the range of 10 to 40 wt%.

In addition, it is preferred that the polypropylene component of the foam as defined above is produced in the presence of a specific catalyst. Furthermore, for the production of the polypropylene of the inventive foam, the process as stated below is preferably used.

The polypropylene component of the inventive foam is obtainable by a new catalyst system. This new catalyst system comprises an asymmetric catalyst, whereby the catalyst system has a porosity of less than 1.40 ml/g, more preferably less than 1.30 ml/g and most preferably less than 1.00 ml/g. The porosity has been measured according to DIN 66135 (N_2). In another preferred embodiment the porosity is not detectable when determined with the method applied according to DIN 66135 (N_2).

An asymmetric catalyst according to this invention is a metallocene compound comprising at least two organic ligands which differ in their chemical structure. More preferably the asymmetric catalyst according to this invention is a metallocene compound comprising at least two organic ligands which differ in their chemical structure and the metallocene compound is free of C_2-

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symmetry and/or any higher symmetry. Preferably the asymmetric metallocene compound comprises only two different organic ligands, still more preferably comprises only two organic ligands which are different and linked via a bridge.

5

Said asymmetric catalyst is preferably a single site catalyst (SSC).

Due to the use of the catalyst system with a very low porosity comprising an asymmetric catalyst the manufacture of the above defined multi-branched

10   polypropylene is possible.

Furthermore it is preferred, that the catalyst system has a surface area of less than 25 m²/g, yet more preferred less than 20 m²/g, still more preferred less than 15 m²/g, yet still less than 10 m²/g and most preferred less than 5 m²/g.

15   The surface area according to this invention is measured according to ISO 9277 (N_2).

It is in particular preferred that the catalytic system according to this invention comprises an asymmetric catalyst, i.e. a catalyst as defined below, and has

20   porosity not detectable when applying the method according to DIN 66135 (N_2) and has a surface area measured according to ISO 9277 (N_2) less than 5 m²/g.

Preferably the asymmetric catalyst compound, i.e. the asymmetric metallocene,

25   has the formula (I):

$$(Cp)_2R_zMX_2 \qquad (I)$$
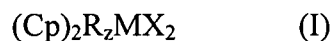
wherein

z is 0 or 1,

M is Zr, Hf or Ti, more preferably Zr, and

30   X is independently a monovalent anionic ligand, such as σ-ligand,

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R is a bridging group linking the two Cp ligands,

Cp is an organic ligand selected from the group consisting of unsubstituted cyclopenadienyl, unsubstituted indenyl, unsubstituted tetrahydroindenyl, unsubstituted fluorenyl, substituted cyclopenadienyl, substituted indenyl,

5   substituted tetrahydroindenyl, and substituted fluorenyl,

with the proviso that both Cp-ligands are selected from the above stated group and both Cp-ligands have a different chemical structure.

The term "σ-ligand" is understood in the whole description in a known manner, i.e. a group bonded to the metal at one or more places via a sigma bond. A preferred

10   monovalent anionic ligand is halogen, in particular chlorine (Cl).

Preferably, the asymmetric catalyst is of formula (I) indicated above, wherein

M is Zr and

15   each X is Cl.

Preferably both Cp-ligands are substituted.

Preferably both Cp-ligands have different residues to obtain an asymmetric structure.

20

Preferably, both Cp-ligands are selected from the group consisting of substituted cyclopenadienyl-ring, substituted indenyl-ring, substituted tetrahydroindenyl-ring, and substituted fluorenyl-ring wherein the Cp-ligands differ in the substituents bonded to the rings.

25

The optional one or more substituent(s) bonded to cyclopenadienyl, indenyl, tetrahydroindenyl, or fluorenyl may be independently selected from a group including halogen, hydrocarbyl (e.g. C_1-C_{20}-alkyl, C_2-C_{20}-alkenyl, C_2-C_{20}-alkynyl, C_3-C_{12}-cycloalkyl, C_6-C_{20}-aryl or C_7-C_{20}-arylalkyl), C_3-C_{12}-cycloalkyl

30   which contains 1, 2, 3 or 4 heteroatom(s) in the ring moiety, C_6-C_{20}-

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heteroaryl, C_1-C_{20}-haloalkyl, -SiR''$_3$, -OSiR''$_3$, -SR'', -PR''$_2$ and -NR''$_2$, wherein each R'' is independently a hydrogen or hydrocarbyl, e.g. C_1-C_{20}-alkyl, C_2-C_{20}-alkenyl, C_2-C_{20}-alkynyl, C_3-C_{12}-cycloalkyl or C_6-C_{20}-aryl.

5   More preferably both Cp-ligands are indenyl moieties wherein each indenyl moiety bears one or two substituents as defined above. More preferably each Cp-ligand is an indenyl moiety bearing two substituents as defined above, with the proviso that the substituents are chosen in such a manner that both Cp-ligands are of different chemical structure, i.e both Cp-ligands differ at least in

10   one substituent bonded to the indenyl moiety, in particular differ in the substituent bonded to the five membered ring of the indenyl moiety.

Still more preferably both Cp are indenyl moieties wherein the indenyl moieties comprise at least at the five membered ring of the indenyl moiety,

15   more preferably at 2-position, a substituent selected from the group consisting of alkyl, such as C_1-C_6 alkyl, e.g. methyl, ethyl, isopropyl, and trialkyloxysiloxy, wherein each alkyl is independently selected from C_1-C_6 alkyl, such as methyl or ethyl, with proviso that the indenyl moieties of both Cp must chemically differ from each other, i.e. the indenyl moieties of both

20   Cp comprise different substituents.

Still more preferred both Cp are indenyl moieties wherein the indenyl moieties comprise at least at the six membered ring of the indenyl moiety, more preferably at 4-position, a substituent selected from the group consisting of a

25   C_6-C_{20} aromatic ring moiety, such as phenyl or naphthyl, preferably phenyl, which is optionally substituted with one or more substitutents, such as C_1-C_6 alkyl, and a heteroaromatic ring moiety, with the proviso that the indenyl moieties of both Cp must chemically differ from each other, i.e. the indenyl moieties of both Cp comprise different substituents.

30

Yet more preferably both Cp are indenyl moieties wherein the indenyl moieties comprise at the five membered ring of the indenyl moiety, more preferably at 2-position, a substituent and at the six membered ring of the indenyl moiety, more preferably at 4-position, a further substituent, wherein

5   the substituent of the five membered ring is selected from the group consisting of alkyl, such as C_1-C_6 alkyl, e.g. methyl, ethyl, isopropyl, and trialkyloxysiloxy, wherein each alkyl is independently selected from C_1-C_6 alkyl, such as methyl or ethyl, and the further substituent of the six membered ring is selected from the group consisting of a C_6-C_{20} aromatic ring moiety,

10   such as phenyl or naphthyl, preferably phenyl, which is optionally substituted with one or more substituents, such as C_1-C_6 alkyl, and a heteroaromatic ring moiety, with proviso that the indenyl moieties of both Cp must chemically differ from each other, i.e. the indenyl moieties of both Cp comprise different substituents. It is in particular preferred that both Cp are idenyl rings

15   comprising two substituentes each and differ in the substituents bonded to the five membered ring of the idenyl rings.

Concerning the moiety "R" it is preferred that "R" has the formula (II)

$$-Y(R')_2- \qquad (II)$$

20   wherein

Y is C, Si or Ge, and

R' is C_1 to C_{20} alkyl, C_6-C_{12} aryl, or C_7-C_{12} arylalkyl or trimethylsilyl.

In case both Cp-ligands of the asymmetric catalyst as defined above, in

25   particular case of two indenyl moieties, are linked with a bridge member R, the bridge member R is typically placed at 1-position. The bridge member R may contain one or more bridge atoms selected from e.g. C, Si and/or Ge, preferably from C and/or Si. One preferable bridge R is $-Si(R')_2-$, wherein R' is selected independently from one or more of e.g. trimethylsilyl,C_1-C_{10} alkyl,

30   C_1-C_{20} alkyl, such as C_6-C_{12} aryl, or C_7-C_{40}, such as C_7-C_{12} arylalkyl, wherein

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alkyl as such or as part of arylalkyl is preferably C_1-C_6 alkyl, such as ethyl or methyl, preferably methyl, and aryl is preferably phenyl. The bridge $-Si(R')_2-$ is preferably e.g. $-Si(C_1-C_6 \text{ alkyl})_2-$, $-Si(\text{phenyl})_2-$ or $-Si(C_1-C_6 \text{ alkyl})(\text{phenyl})-$, such as $-Si(Me)_2-$.

5

In a preferred embodiment the asymmetric catalyst, i.e. the asymmetric metallocene, is defined by the formula (III)

$$(Cp)_2R_1ZrCl_2 \qquad (III)$$
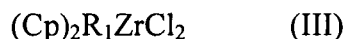
wherein

10   both Cp coordinate to M and are selected from the group consisting of unsubstituted cyclopenadienyl, unsubstituted indenyl, unsubstituted tetrahydroindenyl, unsubstituted fluorenyl, substituted cyclopenadienyl, substituted indenyl, substituted tetrahydroindenyl, and substituted fluorenyl, with the proviso that both Cp-ligands are of different chemical structure, and

15   R is a bridging group linking two ligands Cp,
       wherein R is defined by the formula (II)

$$-Y(R')_2- \qquad (II)$$

wherein

Y is C, Si or Ge, and

20   R' is C_1 to C_{20} alkyl, C_6-C_{12} aryl, or C_7-C_{12} arylalkyl.

More preferably the asymmetric catalyst is defined by the formula (III), wherein both Cp are selected from the group consisting of substituted cyclopenadienyl, substituted indenyl, substituted tetrahydroindenyl, and

25   substituted fluorenyl.

Yet more preferably the asymmetric catalyst is defined by the formula (III), wherein both Cp are selected from the group consisting of substituted cyclopenadienyl, substituted indenyl, substituted tetrahydroindenyl, and

30   substituted fluorenyl

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with the proviso that both Cp-ligands differ in the substituents, i.e. the subtituents as defined above, bonded to cyclopenadienyl, indenyl, tetrahydroindenyl, or fluorenyl.

5   Still more preferably the asymmetric catalyst is defined by the formula (III), wherein both Cp are indenyl and both indenyl differ in one substituent, i.e. in a substiuent as defined above bonded to the five member ring of indenyl.

It is in particular preferred that the asymmetric catalyst is a non-silica
10   supported catalyst as defined above, in particular a metallocene catalyst as defined above.

In a preferred embodiment the asymmetric catalyst is dimethylsilyl [(2-methyl-(4'-tert.butyl)-4-phenyl-indenyl)(2-isopropyl-(4'-tert.butyl)-4-phenyl-
15   indenyl)]zirconium dichloride (IUPAC: dimethylsilandiyl [(2-methyl-(4'-tert.butyl)-4-phenyl-indenyl)(2-isopropyl-(4'-tert.butyl)-4-phenyl-indenyl)]zirkonium dichloride). More preferred said asymmetric catalyst is not silica supported.

The above described asymmetric catalyst components are prepared according
20   to the methods described in WO 01/48034.

It is in particular preferred that the asymmetric catalyst system is obtained by the emulsion solidification technology as described in WO 03/051934. This document is herewith included in its entirety by reference. Hence the
25   asymmetric catalyst is preferably in the form of solid catalyst particles, obtainable by a process comprising the steps of

   a) preparing a solution of one or more asymmetric catalyst
      components;

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    b)   dispersing said solution in a solvent immiscible therewith to form an emulsion in which said one or more catalyst components are present in the droplets of the dispersed phase,

    c)   solidifying said dispersed phase to convert said droplets to solid particles and optionally recovering said particles to obtain said catalyst.

Preferably a solvent, more preferably an organic solvent, is used to form said solution. Still more preferably the organic solvent is selected from the group consisting of a linear alkane, cyclic alkane, linear alkene, cyclic alkene, aromatic hydrocarbon and halogen-containing hydrocarbon.

Moreover the immiscible solvent forming the continuous phase is an inert solvent, more preferably the immiscible solvent comprises a fluorinated organic solvent and/or a functionalized derivative thereof, still more preferably the immiscible solvent comprises a semi-, highly- or perfluorinated hydrocarbon and/or a functionalized derivative thereof. It is in particular preferred, that said immiscible solvent comprises a perfluorohydrocarbon or a functionalized derivative thereof, preferably C_3-C_{30} perfluoroalkanes, -alkenes or - cycloalkanes, more preferred C_4-C_{10} perfluoro-alkanes, -alkenes or -cycloalkanes, particularly preferred perfluorohexane, perfluoroheptane, perfluorooctane or perfluoro (methylcyclohexane) or a mixture thereof.

Furthermore it is preferred that the emulsion comprising said continuous phase and said dispersed phase is a bi-or multiphasic system as known in the art. An emulsifier may be used for forming the emulsion. After the formation of the emulsion system, said catalyst is formed in situ from catalyst components in said solution.

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In principle, the emulsifying agent may be any suitable agent which contributes to the formation and/or stabilization of the emulsion and which does not have any adverse effect on the catalytic activity of the catalyst. The emulsifying agent may e.g. be a surfactant based on hydrocarbons optionally interrupted with (a) heteroatom(s), preferably halogenated hydrocarbons optionally having a functional group, preferably semi-, highly- or perfluorinated hydrocarbons as known in the art. Alternatively, the emulsifying agent may be prepared during the emulsion preparation, e.g. by reacting a surfactant precursor with a compound of the catalyst solution. Said surfactant precursor may be a halogenated hydrocarbon with at least one functional group, e.g. a highly fluorinated C_1 to C_{30} alcohol, which reacts e.g. with a cocatalyst component, such as aluminoxane.

In principle any solidification method can be used for forming the solid particles from the dispersed droplets. According to one preferable embodiment the solidification is effected by a temperature change treatment. Hence the emulsion subjected to gradual temperature change of up to 10 °C/min, preferably 0.5 to 6 °C/min and more preferably 1 to 5 °C/min. Even more preferred the emulsion is subjected to a temperature change of more than 40 °C, preferably more than 50 °C within less than 10 seconds, preferably less than 6 seconds.

The recovered particles have preferably an average size range of 5 to 200 μm, more preferably 10 to 100 μm.

Moreover, the form of solidified particles have preferably a spherical shape, a predetermined particles size distribution and a surface area as mentioned above of preferably less than 25 m²/g, still more preferably less than 20 m²/g, yet more preferably less than 15 m²/g, yet still more preferably less than 10 m²/g and most preferably less than 5 m²/g, wherein said particles are obtained by the process as described above.

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For further details, embodiments and examples of the continuous and dispersed
phase system, emulsion formation method, emulsifying agent and solidification
methods reference is made e.g. to the above cited international patent application
5   WO 03/051934.

As mentioned above the catalyst system may further comprise an activator as a
cocatalyst, as described in WO 03/051934, which is enclosed herein with
reference.

10

Preferred as cocatalysts for metallocenes and non-metallocenes, if desired, are the
aluminoxanes, in particular the C_1-C_{10}-alkylaluminoxanes, most particularly
methylaluminoxane (MAO). Such aluminoxanes can be used as the sole cocatalyst or
together with other cocatalyst(s). Thus besides or in addition to aluminoxanes, other
15   cation complex forming catalysts activators can be used. Said activators are
commercially available or can be prepared according to the prior art literature.

Further aluminoxane cocatalysts are described e.g. in WO 94/28034 which is
incorporated herein by reference. These are linear or cyclic oligomers of
20   having up to 40, preferably 3 to 20, -(Al(R''')O)- repeat units (wherein R''' is
hydrogen, C_1-C_{10}-alkyl (preferably methyl) or C_6-C_{18}-aryl or mixtures thereof).

The use and amounts of such activators are within the skills of an expert in the
field. As an example, with the boron activators, 5:1 to 1:5, preferably 2:1 to
25   1:2, such as 1:1, ratio of the transition metal to boron activator may be used.
In case of preferred aluminoxanes, such as methylaluminumoxane (MAO), the
amount of Al, provided by aluminoxane, can be chosen to provide a molar
ratio of Al:transition metal e.g. in the range of 1 to 10 000, suitably 5 to 8000,
preferably 10 to 7000, e.g. 100 to 4000, such as 1000 to 3000. Typically in
30   case of solid (heterogeneous) catalyst the ratio is preferably below 500.

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The quantity of cocatalyst to be employed in the catalyst of the invention is thus variable, and depends on the conditions and the particular transition metal compound chosen in a manner well known to a person skilled in the art.

5

Any additional components to be contained in the solution comprising the organotransition compound may be added to said solution before or, alternatively, after the dispersing step.

10   Furthermore, it is preferred that the process temperature is higher than 60 °C. Preferably, the process is a multi-stage process to obtain multimodal polypropylene as defined above.

Multistage processes include also bulk/gas phase reactors known as multizone
15   gas phase reactors for producing multimodal propylene polymer.

A preferred multistage process is a "loop-gas phase"-process, such as developed by Borealis A/S, Denmark (known as BORSTAR® technology) described e.g. in patent literature, such as in EP 0 887 379 or in WO 92/12182.

20

Multimodal polymers can be produced according to several processes which are described, e.g. in WO 92/12182, EP 0 887 379 and WO 97/22633.

A multimodal polypropylene used for the preparation of the inventive foam is
25   preferably produced in a multi-stage process as described in WO 92/12182. The content of this document is included herein by reference.

It has previously been known to produce multimodal, in particular bimodal, polypropylene in two or more reactors connected in series, i.e. in different
30   steps (a) and (b).

According to the present invention, the main polymerization stages are preferably carried out as a combination of a bulk polymerization/gas phase polymerization.

The bulk polymerizations are preferably performed in a so-called loop reactor.

In order to produce the multimodal polypropylene component of the foam according to this invention, a flexible mode is preferred. For this reason, it is preferred that the composition be produced in two main polymerization stages in combination of loop reactor/gas phase reactor.

Optionally, and preferably, the process may also comprise a prepolymerization step in a manner known in the field and which may precede the polymerization step (a).

If desired, a further elastomeric comonomer component, so called ethylene-propylene rubber (EPR) component as defined in this invention, may be incorporated into the obtained propylene polymer to form a propylene copolymer as defined above. The ethylene-propylene rubber (EPR) component may preferably be produced after the gas phase polymerization step (b) in a subsequent second or further gas phase polymerizations using one or more gas phase reactors.

The process is preferably a continuous process.

Preferably, in the process for producing the propylene polymer as defined above the conditions for the bulk reactor of step (a) may be as follows:

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-    the temperature is within the range of 40 °C to 110 °C, preferably between 60 °C and 100 °C, 70 to 90 °C,

-    the pressure is within the range of 20 bar to 80 bar, preferably between 30 bar to 60 bar,

5   -   hydrogen can be added for controlling the molar mass in a manner known per se.

Subsequently, the reaction mixture from the bulk (bulk) reactor (step a) is transferred to the gas phase reactor, i.e. to step (b), whereby the conditions in step (b) are

10   preferably as follows:

-    the temperature is within the range of 50 °C to 130 °C, preferably between 60 °C and 100 °C,

-    the pressure is within the range of 5 bar to 50 bar, preferably between

15   15 bar to 35 bar,

-    hydrogen can be added for controlling the molar mass in a manner known per se.

The residence time can vary in both reactor zones. In one embodiment of the

20   process for producing the propylene polymer the residence time in bulk reactor, e.g. loop is in the range 0.5 to 5 hours, e.g. 0.5 to 2 hours and the residence time in gas phase reactor will generally be 1 to 8 hours.

If desired, the polymerization may be effected in a known manner under

25   supercritical conditions in the bulk, preferably loop reactor, and/or as a condensed mode in the gas phase reactor.

The process of the invention or any embodiments thereof above enable highly feasible means for producing and further tailoring the propylene polymer

30   composition within the invention, e.g. the properties of the polymer

composition can be adjusted or controlled in a known manner e.g. with one or more of the following process parameters: temperature, hydrogen feed, comonomer feed, propylene feed e.g. in the gas phase reactor, catalyst, the type and amount of an external donor (if used), split between components.

5

The above process enables very feasible means for obtaining the reactor-made propylene polymer as defined above.

Furthermore, the present invention also relates to a process for the preparation of the

10   foam as defined above, wherein a multi-branched polypropylene as defined above is subjected to foaming. In such process, a melt of the multi-branched polypropylene comprising a gaseous foaming agent such as butane, HFC or CO_2 is suddenly expanded through pressure drop.

15   Continuous foaming processes as well as discontinuous process may be applied.

In a continuous foaming process, the polymer is melted and laden with gas in an extruder under pressures typically above 20bar before extruded through a die where the pressure drop causes the formation of a foam. The mechanism of foaming

20   polypropylene in foam extrusion is explained, for example, in H. E. Naguib, C. B. Park, N. Reichelt, Fundamental foaming mechanisms governing the volume expansion of extruded polypropylene foams, Journal of Applied Polymer Science, 91, 2661-2668 (2004). Processes for foaming are outlined in S. T. Lee, Foam Extrusion, Technomic Publishing (2000).

25

In a discontinuous foaming process, the polymer (micro-)pellets are laden with foaming agent under pressure and heated below melting temperature before the pressure in the autoclave is suddenly relaxed. The dissolved foaming agent forms bubbles and creates a foam structure. Such preparation of discontinuously foamed

30   beads is described for example in DE 3 539 352.

- 30 -

The present invention also relates to the use of the multi-branched polypropylene as defined above for the preparation of foams.

5   The present invention will now be described in further detail by the following examples.

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Examples

1.   Definitions/Measuring Methods

5   The following definitions of terms and determination methods apply for the above general description of the invention as well as to the below examples unless otherwise defined.

A.   Pentad Concentration

10

For the meso pentad concentration analysis, also referred herein as pentad concentration analysis, the assignment analysis is undertaken according to T Hayashi, Pentad concentration, R. Chujo and T. Asakura, Polymer 29 138-43 (1988) and Chujo R, et al., Polymer 35 339 (1994)

15

B.   Multi-branching Index

1.   Acquiring the experimental data

20   Polymer is melted at T=180 °C and stretched with the SER Universal Testing Platform as described below at deformation rates of $d\varepsilon/dt$=0.1 0.3 1.0 3.0 and 10 s^{-1} in subsequent experiments. The method to acquire the raw data is described in Sentmanat et al., J. Rheol. 2005, Measuring the Transient Elongational Rheology of Polyethylene Melts Using the SER Universal

25   Testing Platform.

Experimental Setup

A Paar Physica MCR300, equipped with a TC30 temperature control unit and an oven CTT600 (convection and radiation heating) and a SERVP01-025 extensional device with temperature sensor and a software RHEOPLUS/32 v2.66 is used.

Sample Preparation

Stabilized Pellets are compression moulded at 220°C (gel time 3min, pressure time 3 min, total moulding time 3+3=6min) in a mould at a pressure sufficient to avoid bubbles in the specimen, cooled to room temperature. From such prepared plate of 0.7mm thickness, stripes of a width of 10mm and a length of 18mm are cut.

Check of the SER Device

Because of the low forces acting on samples stretched to thin thicknesses, any essential friction of the device would deteriorate the precision of the results and has to be avoided.

In order to make sure that the friction of the device less than a threshold of 5×10^{-3} mNm (Milli-Newtonmeter) which is required for precise and correct measurements, following check procedure is performed prior to each measurement:

- The device is set to test temperature (180°C) for minimum 20minutes without sample in presence of the clamps
- A standard test with 0.3s-1 is performed with the device on test temperature (180°C)
- The torque (measured in mNm) is recorded and plotted against time

- The torque must not exceed a value of 5×10^{-3} mNm to make sure that the friction of the device is in an acceptably low range

Conducting the experiment

5

The device is heated for min. 20min to the test temperature (180°C measured with the thermocouple attached to the SER device) with clamps but without sample. Subsequently, the sample (0.7x10x18mm), prepared as described above, is clamped into the hot device. The sample is allowed to melt for 2 minutes +/- 20 seconds

10   before the experiment is started.

During the stretching experiment under inert atmosphere (nitrogen) at constant Hencky strain rate, the torque is recorded as function of time at isothermal conditions (measured and controlled with the thermocouple attached to the SER device).

15

After stretching, the device is opened and the stretched film (which is winded on the drums) is inspected. Homogenous extension is required. It can be judged visually from the shape of the stretched film on the drums if the sample stretching has been homogenous or not. The tape must me wound up symmetrically on both drums, but

20   also symmetrically in the upper and lower half of the specimen.

If symmetrical stretching is confirmed hereby, the transient elongational viscosity calculates from the recorded torque as outlined below.

25   **2.   Evaluation**

For each of the different strain rates dε/dt applied, the resulting tensile stress growth function η_E^+ (dε/dt, t) is plotted against the total Hencky strain ε to determine the strain hardening behaviour of the melt, see Figure 1.

30

In the range of Hencky strains between 1.0 and 3.0, the tensile stress growth function η_E^+ can be well fitted with a function

$$\eta_E^+(\dot{\varepsilon},\varepsilon) = c_1 \cdot \varepsilon^{c_2}$$

5

where c_1 and c_2 are fitting variables. Such derived c_2 is a measure for the strain hardening behavior of the melt and called Strain Hardening Index *SHI*.

Dependent on the polymer architecture, *SHI* can

10

- be independent of the strain rate (linear materials, Y- or H-structures)
- increase with strain rate (short chain-, hyper- or multi-branched structures).

15   This is illustrated in Figure 2.

For polyethylene, linear (HDPE), short-chain branched (LLDPE) and hyperbranched structures (LDPE) are well known and hence they are used to illustrate the structural analytics based on the results on extensional viscosity. 20   They are compared with a polypropylene with Y and H-structures with regard to their change of the strain-hardening behavior as function of strain rate, see Figure 2 and Table 1.

To illustrate the determination of *SHI* at different strain rates as well as the 25   multi-branching index (*MBI*) four polymers of known chain architecture are examined with the analytical procedure described above.

The first polymer is a H- and Y-shaped polypropylene homopolymer made according to EP 879 830 ("A") example 1 through adjusting the MFR with the

amount of butadiene. It has a MFR 230/2.16 of 2.0 g/10min, a tensile modulus of 1950 MPa and a branching index g' of 0.7.

The second polymer is a commercial hyperbranched LDPE, Borealis "B", made in a high pressure process known in the art. It has a MFR 190/2.16 of 4.5 and a density of 923 kg/m³.

The third polymer is a short chain branched LLDPE, Borealis "C", made in a low pressure process known in the art. It has a MFR 190/2.16 of 1.2 and a density of 919 kg/m³.

The fourth polymer is a linear HDPE, Borealis "D", made in a low pressure process known in the art. It has a MFR 190/2.16 of 4.0 and a density of 954 kg/m³.

The four materials of known chain architecture are investigated by means of measurement of the transient elongational viscosity at 180 °C at strain rates of 0.10, 0.30, 1.0, 3.0 and 10s^{-1}. Obtained data (transient elongational viscosity versus Hencky strain) is fitted with a function

$$\eta_E^+ = c_1 * \varepsilon^{c_2}$$

for each of the mentioned strain rates. The parameters c1 and c2 are found through plotting the logarithm of the transient elongational viscosity against the logarithm of the Hencky strain and performing a linear fit of this data applying the least square method. The parameter c1 calculates from the intercept of the linear fit of the data $lg(\eta_E^+)$ versus $lg(\varepsilon)$ from

$$c_1 = 10^{\text{Intercept}}$$

and c_2 is the strain hardening index (*SHI*) at the particular strain rate.

This procedure is done for all five strain rates and hence, SHI@0.1s^{-1},
SHI@0.3s^{-1}, SHI@1.0s^{-1}, SHI@3.0s^{-1}, SHI@10s^{-1} are determined, see Figure
1.

Table 1:   SHI-values

dε/dt	lg (dε/dt)	Property	Y and H branched PP	Hyper-branched LDPE	short-chain branched LLDPE	Linear HDPE
			A	**B**	**C**	**D**
0,1	-1,0	SHI@0.1s^{-1}	2,05	-	0,03	0,03
0,3	-0,5	SHI@0.3s^{-1}	-	1,36	0,08	0,03
1	0,0	SHI@1.0s^{-1}	2,19	1,65	0,12	0,11
3	0,5	SHI@3.0s^{-1}	-	1,82	0,18	0,01
10	1,0	SHI@10s^{-1}	2,14	2,06	-	-

From the strain hardening behaviour measured by the values of the SHI@1s^{-1}
one can already clearly distinguish between two groups of polymers: Linear
and short-chain branched have a SHI@1s^{-1} significantly smaller than 0.30. In
contrast, the Y and H-branched as well as hyper-branched materials have a
SHI@1s^{-1} significantly larger than 0.30.

In comparing the strain hardening index at those five strain rates $\dot{\varepsilon}_H$ of 0.10,
0.30, 1.0, 3.0 and 10s^{-1}, the slope of SHI as function of the logarithm of $\dot{\varepsilon}_H$,
lg($\dot{\varepsilon}_H$) is a characteristic measure for multi -branching. Therefore, a multi-

branching index (MBI) is calculated from the slope of a linear fitting curve of SHI versus $\lg(\dot{\varepsilon}_H)$:

$$SHI(\dot{\varepsilon}_H) = c3 + MBI * \lg(\dot{\varepsilon}_H)$$

5

The parameters c3 and MBI are found through plotting the SHI against the logarithm of the Hencky strain rate $\lg(\dot{\varepsilon}_H)$ and performing a linear fit of this data applying the least square method. Please confer to Figure 2.

10   **Table 2:**   Multi-branched-index (MBI)

Property	Y and H branched PP	Hyper-branched LDPE	short-chain branched LLDPE	Linear HDPE
	A	B	C	D
MBI	0,04	0,45	0,10	0,01

The multi-branching index MBI allows now to distinguish between Y or H-branched polymers which show a MBI smaller than 0.05 and hyper-branched

15   polymers which show a MBI larger than 0.15. Further, it allows to distinguish between short-chain branched polymers with MBI larger than 0.10 and linear materials which have a MBI smaller than 0.10.

Similar results can be observed when comparing different polypropylenes, i.e.

20   polypropylenes with rather high branched structures have higher SHI and MBI-values, respectively, compared to their linear counterparts. Similar to the hyper-branched polyethylenes the new developed polypropylenes show a high degree of branching. However the polypropylenes according to the instant invention are clearly distinguished in the SHI and MBI-values when compared

to known hyper-branched polyethylenes. Without being bound on this theory, it is believed, that the different SHI and MBI-values are the result of a different branching architecture. For this reason the new found branched polypropylenes according to this invention are designated as multi-branched.

Combining both, strain hardening index (SHI) and multi-branching index (MBI), the chain architecture can be assessed as indicated in Table 3:

Table 3: SHI and MBI

Property	Y and H branched	Hyper-branched / Multi-branched	short-chain branched	linear
SHI@1.0s^{-1}	>0.30	>0.30	≤0.30	≤0.30
MBI	≤0.10	>0.10	≤0.10	0.10

C.   Further Measuring Methods

Particle size distribution: Particle size distribution is measured via Coulter Counter LS 200 at room temperature with n-heptane as medium.

NMR

NMR-spectroscopy measurements:

The ^{13}C-NMR spectra of polypropylenes were recorded on Bruker 400MHz spectrometer at 130 °C from samples dissolved in 1,2,4-trichlorobenzene/benzene-d6 (90/10 w/w). For the pentad analysis the assignment is done according to the

methods described in literature: (T. Hayashi, Y. Inoue, R. Chüjö, and T. Asakura, Polymer 29 138-43 (1988).and Chujo R, et al,Polymer 35 339 (1994).

The NMR-measurement was used for determining the mmmm pentad concentration
5   in a manner well known in the art.

Number average molecular weight (M_n), weight average molecular weight (M_w) and molecular weight distribution (MWD) are determined by size exclusion chromatography (SEC) using Waters Alliance GPCV 2000 instrument with online
10   viscometer. The oven temperature is 140 °C. Trichlorobenzene is used as a solvent (ISO 16014).

In detail: The number average molecular weight (M_n), the weight average molecular weight (M_w) and the molecular weight distribution (MWD) are measured by a method based on ISO 16014-1:2003 and ISO 16014-4:2003. A Waters Alliance
15   GPCV 2000 instrument, equipped with refractive index detector and online viscosimeter was used with 3 x TSK-gel columns (GMHXL-HT) from TosoHaas and 1,2,4-trichlorobenzene (TCB, stabilized with 200 mg/L 2,6-Di tert butyl-4-methyl-phenol) as solvent at 145 °C and at a constant flow rate of 1 mL/min. 216.5 µL of sample solution were injected per analysis. The column set was calibrated using
20   relative calibration with 19 narrow MWD polystyrene (PS) standards in the range of 0.5 kg/mol to 11 500 kg/mol and a set of well characterized broad polypropylene standards. All samples were prepared by dissolving 5 - 10 mg of polymer in 10 mL (at 160 °C) of stabilized TCB (same as mobile phase) and keeping for 3 hours with continuous shaking prior sampling in into the GPC instrument.
25

The xylene solubles (XS, wt.-%): Analysis according to the known method: 2.0 g of polymer is dissolved in 250 ml p-xylene at 135°C under agitation. After 30±2 minutes the solution is allowed to cool for 15 minutes at ambient temperature and then allowed to settle for 30 minutes at 25±0.5°C. The solution is filtered and

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evaporated in nitrogen flow and the residue dried under vacuum at 90 °C until constant weight is reached.

$XS\% = (100 \times m_1 \times v_0) / (m_0 \times v_1)$, wherein

5   m_0 = initial polymer amount (g)

m_1 = weight of residue (g)

v_0 = initial volume (ml)

V_1 = volume of analyzed sample (ml)

10   **Hot xylene insolubles (wt%):**

Circa 2 g of the polymer (m_p) are weighted and put in a mesh of metal which is weighted (m_{p+m}). The polymer in the mesh is extracted in a soxhlet apparatus with boiling xylene for two days. Subsequently, the mesh is dried and weighted again

15   (m_{XHU+m}). The mass of the xylene hot unsolubles $m_m-m_{XHU+m}=m_{XHU}$ is put in relation to the weight of the polymer to obtain the fraction of xylene insolubles m_{XHU}/m_p.

Melting temperature Tm, crystallization temperature Tc, and the degree of crystallinity: measured with Mettler TA820 differential scanning calorimetry (DSC)

20   on 5-10 mg samples. Both crystallization and melting curves were obtained during 10 °C/min cooling and heating scans between 30 °C and 225 °C. Melting and crystallization temperatures were taken as the peaks of endotherms and exotherms.

Also the melt- and crystallization enthalpy (**Hm and Hc**) were measured by the DSC

25   method according to ISO 11357-3.

Stiffness Film TD (transversal direction), Stiffness Film MD (machine direction), Elongation at break TD and Elongation at break MD: these are determined according to ISO527-3 (cross head speed: 1 mm/min).

30

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Melt strength and melt extensibility by Rheotens measurement:

The strain hardening behaviour of polymers is analysed by Rheotens apparatus (product of Göttfert, Siemensstr. 2, 74711 Buchen, Germany) in which a melt strand is elongated by drawing down with a defined acceleration. The haul-off force F in dependence of draw-down velocity v is recorded.

The test procedure is performed in a standard climatised room with controlled room temperature of T = 23 °C. The Rheotens apparatus is combined with an extruder/melt pump for continuous feeding of the melt strand. The extrusion temperature is 200 °C; a capillary die with a diameter of 2 mm and a length of 6 mm is used and the acceleration of the melt strand drawn down is 120 mm/s^2. The maximum points (F_{max}; v_{max}) at failure of the strand are characteristic for the strength and the drawability of the melt.

Haze and transparency: are determined according to ASTM D1003-92 (haze).

Intrinsic viscosity: is measured according to DIN ISO 1628/1, October 1999 (in Decalin at 135 °C).

Porosity: is measured according to DIN 66135

Surface area: is measured according to ISO 9277

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3.   **Examples**

Example 1

5

A support-free catalyst has been prepared as described in example 5 of WO 03/051934 whilst using an asymmetric metallocene dimethylsilyl [(2-methyl-(4'-tert.butyl)-4-phenyl-indenyl)(2-isopropyl-(4'-tert.butyl)-4-phenyl-indenyl)]zirkonium dichloride.

10

Such catalyst has been used to polymerise a polypropylene copolymer with 4mol% ethylene in the Borstar process, known in the art.

The material properties of the polymer are shown in Table 4.

15

Comparative Example 1 (linear bimodal)

A bimodal polypropylene copolymer has been prepared using a Z/N catalyst and the Borstar process.

20

Comparative Example 2 (Y/H-shaped polymer)

A Y/H shaped polymer has been prepared according to EP 0 887 379 to obtain a polypropylene copolymer of $MFR_{230/2.16}$ 2.2 g/10min and a branching index g' of 0.8.

25

The properties of the polymers are summarized in Table 4.

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Table 4:   Material Properties of the polypropylenes

	Unit	Method	E1 (MC)	CE1 (ZN)	CE2 (Y/H)
MFR$_{230/2.1}$	g/10min	MFR	4	1,9	2.2
g'	-	IV	0.7	1.0	0.8
SHI@0.1	-	SER	0,75	-	1,77
SHI@0.3	-	SER	0,85	-	1,60
SHI@1.0	-	SER	1,00	-	1,90
SHI@3.0	-	SER	0,96	-	1,96
SHI@10	-	SER	-	-	1,79
MBI	-	SER	0,16	-	0,08
Structure	-	SER	mb	lin	Y/H
C2	mol%	IR	4	6,5	6,0
XS	wt%	XS	0,7	7,8	6,9
Hot xylene insolubles	wt%		<0.05	<0.05	0.38
Mw	kg/mol	GPC	319	539	427
Mn	kg/mol	GPC	124	125	100
F30	cN	Rheotens	10	12	27
v30	mm/s	Rheotens	180	125	197
Tm1	°C	DSC	130,8	138,0	128,7
Hm1	J/g	DSC	60,3	75,3	1,1
Tm2	°C	DSC	140,8	-	144,7
Hm2	J/g	DSC	30,2	-	76,8
Tc	°C	DSC	106,2	92,7	110,3
Hc	J/g	DSC	81,8	71,7	75,2
Tensile Modulus	MPa	ISO527-2	1146,7	756,2	873,1
Tensile Stress At Yield	MPa	ISO527-2	30,6	23,8	26,8
Tensile Strain At Yield	%	ISO527-2	9,9	13,5	13,8
Tensile Strength	MPa	ISO527-2	33,5	27,2	31,7
Tensile Strain At Tensile Strength	%	ISO527-2	488,48	459,81	582,51
Tensile Stress At Break	MPa	ISO527-2	33,1	26,7	31,6
Tensile Strain At Break	%	ISO527-2	493,21	462,82	586,58

5   All materials have been pelletized together with additives, i.e. 1000ppm of a commercial stabilizer Irganox B215 (supplied by Ciba), using an extruder at melt temperature of 240 °C.

The pelletized samples have been used for foam extrusion.

10

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In a corotating 25 mm twin screw extruder (Berstorff ZE25, L/D 39.5), following
temperature settings are adjusted (Table 5):

In the second zone the pellets are melted before the foaming agent CO_2 is dosed into
5   the melt (zone 3) with a constant feed of 54g/hr through a feeder Bronkhorst F-
201AC-FB-22-V at a pressure of 20bar.

Such gas laden melt is homogenized and cooled before it exits the flat die attached to
the extruder. Immediately after the die, the foam expands and it is collected with a
10   standard cast-film windup equipment.

Foamed sheets are cut from the film and investigated for its mechanical properties.

The foaming process parameters and the foam properties are summarized in Table 5.
15

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Table 5:   Preparation and characterization of the foam

	Unit	Example 1	Comp. Ex. 1	Comp. Ex. 2
Type of polypropylene		Multi-branched	linear	Y/H-shaped
Throughput	kg/hr	10	10	10
Temperature Settings	°C	30°C/210°C/210°C/160°C/160°C/160°C/160°C/ 150°C/150°C/150°C/150°C/150°C/170°C/170°C		
Screw Speed	rpm	175	175	175
Melt temp.	°C	170	170	170
Melt pressure	bar	61	103	76
Foaming agent	% CO_2	0.54	0.54	0.54
Foam Density	Kg/m^3	480	690	360
Cell size	μm	320	1230	530
Foam surface	+ : high quality - : low quality	+	+	-
Tensile modulus (MD/TD)	MPa	329/186	648/500	295/148
Elongation at break (MD/TD)	%	39.7/28.9	16.8/8.1	14.0/10.4

5   The results of Table 5 indicate that the use of a multi-branched polypropylene as

defined above enables extrusion at lower melt pressure and results in a foam of high

surface quality and small cell size. Furthermore, if compared to the linear bimodal

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(Comp. Ex. 1) and the Y/H-shaped (Comp. Ex. 2) polypropylene, the elongation at break could be increased due to an improved homogeneity of the foam material.

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CLAIMS

1.   A foam comprising a polypropylene,

wherein said polypropylene is produced in the presence of

a metallocene catalyst, and

the foam and/or the polypropylene has (have)

a.   a branching index g' of less than 1.00 and

b.   a strain hardening index (SHI@1s^{-1}) of at least

0.30 measured by a deformation rate $d\varepsilon/dt$ of

1.00 s^{-1} at a temperature of 180 °C, wherein the

strain hardening index (SHI) is defined as the

slope of the logarithm to the basis 10 of the tensile

stress growth function (lg (η_E^+)) as function of the

logarithm to the basis 10 of the Hencky

strain (lg (ε)) in the range of Hencky strains

between 1 and 3.

2.   The foam according to claim 1, wherein the foam and/or the

polypropylene has (have) a multi-branching index (MBI) of at least

0.15, wherein the multi-branching index (MBI) is defined as the

slope of strain hardening index (SHI) as function of the logarithm to

the basis 10 of the Hencky strain rate (lg ($d\varepsilon/dt$)).

3.   A foam comprising a polypropylene, wherein the foam and/or the

polypropylene has (have) a multi-branching index (MBI) of at least

0.15, wherein the multi-branching index (MBI) is defined as the

slope of strain hardening index (SHI) as function of the logarithm to

the basis 10 of the Hencky strain rate (lg ($d\varepsilon/dt$)), wherein

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$d\varepsilon/dt$ is the deformation rate,

ε is the Hencky strain, and

the strain hardening index (SHI) is measured at 180 °C, wherein the

5   strain hardening index (SHI) is defined as the slope of the logarithm

to the basis 10 of the tensile stress growth function (lg (η_E^+)) as

function of the logarithm to the basis 10 of the Hencky

strain (lg (ε)) in the range of Hencky strains between 1 and 3.

10   4.   The foam according to claim 3, wherein the foam and/or the

polypropylene has (have)

a. a branching index g' of less than 1.00 and/or

b. a strain hardening index (SHI@1s^{-1}) of at least 0.30 measured by

a deformation rate $(d\varepsilon/dt)$ of 1.00 s^{-1} at a temperature of 180 °C.

15

5.   The foam according to one of the preceding claims, wherein the

polypropylene has an amount of hot xylene insolubles of less than

0.10 wt%.

20   6.   The foam according to one of the preceding claims, wherein the

polypropylene has an amount of xylene solubles (XS) of less than

2.0 wt%.

7.   The foam according to one of the preceding claims, wherein the

25   polypropylene has melt flow rate MFR$_2$ measured at 230 °C in the

range of 0.01 to 1000.00 g/10min.

8.   The foam according to one of the preceding claims, wherein the polypropylene has mmmm pentad concentration of higher than 90 %.

9.   The foam according to one of the preceding claims, wherein the polypropylene has a melting point Tm of at least 120 °C.

10.   The foam according to one of the preceding claims, wherein the polypropylene is multimodal.

11.   The foam according to one of the preceding claims, wherein the polypropylene is a propylene homopolymer.

12.   The foam according to one of the preceding claims, wherein the polypropylene is a propylene copolymer.

13.   The foam according to claim 12, wherein the comonomer is ethylene which is present in an amount of 8 mol% or less.

14.   The foam according to one of the preceding claims, wherein the polypropylene has been produced in the presence of a catalyst system comprising an asymmetric catalyst, wherein the catalyst system has a porosity of less than 1.40 ml/g.

15.   The foam according to claim 14, wherein the asymmetric catalyst is dimethylsilyl [(2-methyl-(4'-tert. butyl)-4-phenyl-indenyl)(2-isopropyl-(4'-tert. butyl)-4-phenyl-indenyl)]zirconium dichloride.

16.   A process for the preparation of the foam according to one of the claims 1 to 15, wherein the polypropylene as defined in one of the

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claims 1 to 15 is extruded through a die in the presence of a foaming agent to form a foam.

17.   Use of the polypropylene as defined in one of the claims 1 to 15 for the preparation of foam.
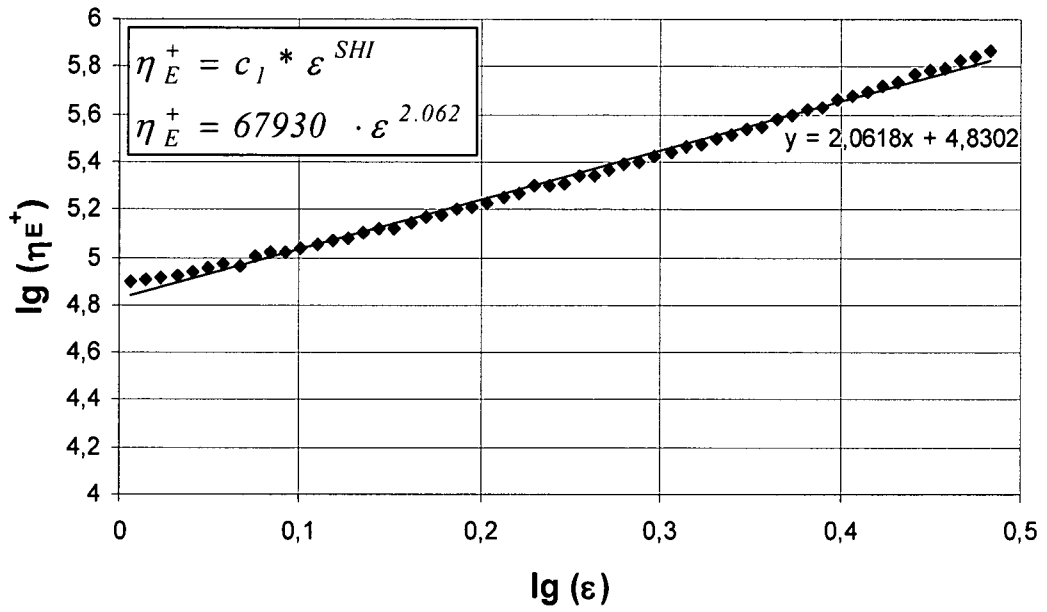
5

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The figure shows a plot of $lg(\eta E^+)$ versus $lg(\varepsilon)$ with the equations:

$$\eta_E^+ = c_1 * \varepsilon^{SHI}$$

$$\eta_E^+ = 67930 \cdot \varepsilon^{2.062}$$

and the linear fit:

$$y = 2.0618x + 4.8302$$

Figure 1   Determination of the SHI of Y/H-shaped polypropylene sample "A" at a strain rate of $0.1 s^{-1}$ ($SHI@0.1 s^{-1}$ is determined to be 2.06)
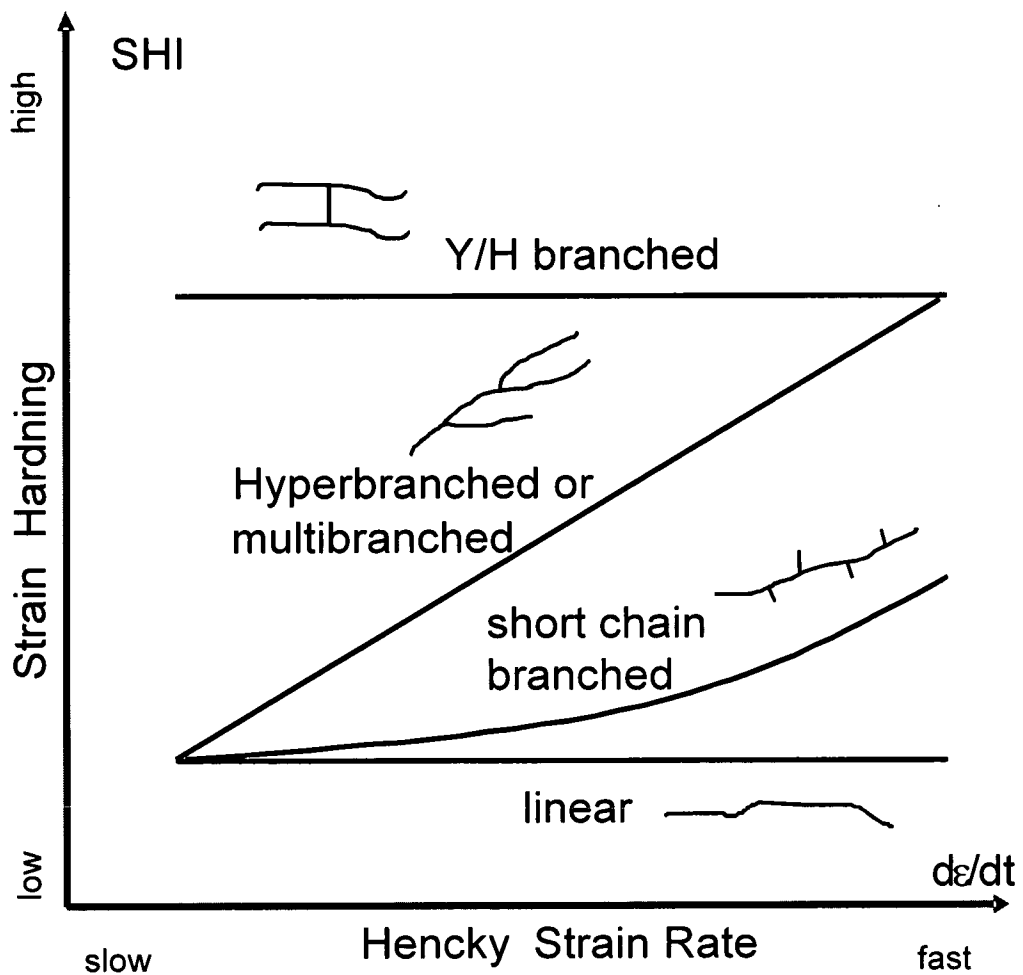
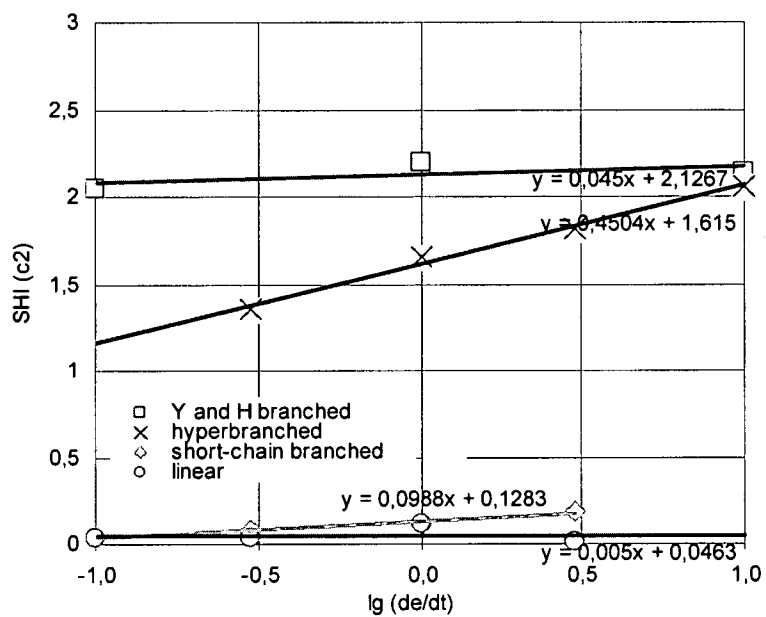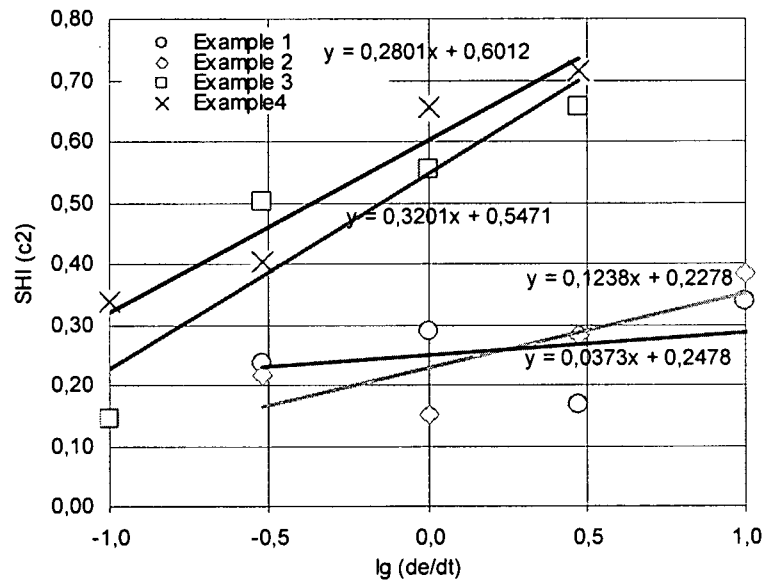Figure 2   Deformation Rate versus Strain Hardening

Figure 3

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Figure 4

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08F297/08 C08J9/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C08F C08J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2003 147110 A (MITSUI CHEMICALS INC) 21 May 2003 (2003-05-21) abstract	1-17
A	US 2005/090571 A1 (MEHTA ASPY K [US] ET AL) 28 April 2005 (2005-04-28) cited in the application paragraphs [0002] - [0005], [0030] - [0032] claims 4,9-11,17,18	1-17
A	WO 00/73369 A (BOREALIS TECH OY [FI]; CAMPBELL NEIL [GB]; BORVE KJETIL LARSEN [NO]; B) 7 December 2000 (2000-12-07) the whole document	1-17

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 October 2007	18/10/2007

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Lippert, Sigrid

Form PCT/ISA/210 (second sheet) (April 2005)

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