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(54) Title: POLYETHYLENE COPOLYMER FOR A FILM LAYER

(57) Abstract: The present invention relates to a specific metallocene-catalysed multimodal medium density polyethylene (mMDPE), use of the multimodal medium density polyethylene (mMDPE) in film applications and a film comprising the mMDPE of the invention.



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POLYETHYLENE COPOLYMER FOR A FILM LAYER

The present invention relates to a metallocene-catalysed multimodal medium density polyethylene (mMDPE), to the use of the multimodal medium density polyethylene (mMDPE) in film applications and to a film comprising the mMDPE of the invention.

5

State of the art mLLDPE (metallocene catalysed linear low density polyethylene) is widely used everywhere in daily life, like packaging, due to its excellent cost / performance ratios.

Unimodal mLLDPEs are usually used for film application. Unimodal LLDPEs have for instance good optical properties, like low haze, but for instance, the melt processing of such polymers is not satisfactory in production point of view and may cause quality problems of the final product as well. Multimodal mLLDPEs with two or more different polymer components are better to process, but e.g. melt homogenisation of the multimodal PE may be problematic resulting to inhomogeneous final product evidenced e.g. with high gel content of the final product.

10

Multimodal mLLDPEs are known in the art.

WO 2021009189, WO 2021009190 and WO 2021009191 of Borealis disclose a process for preparing multimodal PE polymers in two loop reactors and one gas phase reactor in the presence of a silica supported metallocene catalyst based on the metallocene complex bis(1-methyl-3-n-butylcyclopentadienyl) zirconium (IV) dichloride.

20

Film properties, like tensile modulus (TM) and impact strength (dart drop impact, DDI) are not mentioned at all.

Also WO 2021009192 discloses such a process.

25

Film properties, like tensile modulus (TM) and impact strength (dart drop impact, DDI) are again not mentioned at all.

WO2008089978 discloses a multimodal medium density polyethylene polymer being composed of A) a lower molecular weight (LMW) polyethylene homopolymer component and (B) a higher molecular weight (HMW) polyethylene copolymer component, which is a copolymer of ethylene and at least one C3-12-alphaolefin, preferably 1-hexene.

30

The multimodal medium density polyethylene polymer of the inventive Example is produced in a loop reactor and a subsequent Gas phase reactor in the presence of a silica supported bis(n-butyl cyclopentadienyl)hafnium dibenzyl catalyst and has a density of 930 kg/m³, a comonomer content of 2.13 mol% and has an Mw/Mn of 3.4. Films made of the multimodal medium density polyethylene polymer have quite high haze values of ~ 52% measured on a 40 µm film.

35

There is a continuous need to find multimodal PE polymers with different property balances for providing tailored solutions to meet the increasing demands of the end application producers e.g. for reducing the production costs while maintaining or even improving the end product properties. Tailored polymer solutions are also needed to meet the requirements of continuously developing equipment technology in the end application field.

Therefore, there is a need in the art for providing a material that provides good mechanical properties, especially tensile modulus and/or dart drop (impact strength), without deteriorating the sealing performance and still have acceptable optical properties, i.e. a haze of below 35% (for a 40 μm film).

The inventors have now found, that a metallocene catalysed medium density polyethylene (mMDPE) made with a specific metallocene catalyst and having a specific polymer design yields films having improved mechanical properties, especially tensile modulus and dart drop (impact strength) and additionally an attractive balance of mechanical and sealing properties. Furthermore such films show improved hot tack force and optical properties, especially haze.

Description of the invention

The present invention is therefore directed to a metallocene catalysed multimodal medium density polyethylene (mMDPE) which consists of

- (i) 35.0 to 50.0 wt%, based on the mMDPE, of a polyethylene component (A), and
- (ii) 50.0 to 65.0 wt%, based on the mMDPE, of a polyethylene component (B),

whereby the polyethylene polymer component (A) has

- a density (ISO 1183) in the range of from 950 to 975 kg/m^3 ,
- a MFR_2 (190°C, 2.16 kg, ISO 1133) in the range of from 3.0 to 50.0 g/10 min;

the polyethylene component (B) has

- a density (ISO 1183) in the range of from 900 to 925 kg/m^3 ,
- a MFR_2 (190°C, 2.16 kg, ISO 1133) in the range of from 0.001 to 1.0 g/10 min;

whereby the metallocene catalysed medium density polyethylene (mMDPE) has

- a density (ISO 1183) in the range of from 920 to 945 kg/m^3 ,
- a MFR_2 (190°C, 2.16 kg, ISO 1133) in the range of 0.1 to 5.0 g/10 min and
- a ratio of the MFR_{21} (190°C, 21.6 kg, ISO 1133) to MFR_2 (190°C, 2.16 kg, ISO 1133), $\text{MFR}_{21}/\text{MFR}_2$, in the range of from 27 to 40 and
- a molecular weight distribution (MWD), Mw/Mn , in the range of 4.2 to 10.0.

Unexpectedly such a mMDPE provides films with improved mechanical properties, especially tensile modulus and/or dart drop (impact strength), still having acceptable optical properties,

i.e. a haze of below 35% (for a 40 µm film) and additionally an attractive balance of mechanical and sealing properties.

5 The invention is therefore further directed to a film comprising at least one layer comprising the above described mMDPE.

Definitions

10 Where the term "comprising" is used in the present description and claims, it does not exclude other non-specified elements of major or minor functional importance. For the purposes of the present invention, the term "consisting of" is considered to be a preferred embodiment of the term "comprising of". If hereinafter a group is defined to comprise at least a certain number of embodiments, this is also to be understood to disclose a group, which preferably consists only of these embodiments.

15 Whenever the terms "including" or "having" are used, these terms are meant to be equivalent to "comprising" as defined above.

Where an indefinite or definite article is used when referring to a singular noun, e.g. "a", "an" or "the", this includes a plural of that noun unless something else is specifically stated.

20 Metallocene catalysed medium density polyethylene (mMDPE) is defined in this invention as medium density polyethylene, which has been produced in the presence of a metallocene catalyst.

25 For the purpose of the present invention "medium density polyethylene (MDPE) which comprises polyethylene component (A) and polyethylene component (B)" means that the MDPE is produced in an at least 2-stage sequential polymerization process, wherein first component (A) is produced and component (B) is then produced in the presence of component (A) in a subsequent polymerization step, yielding the MDPE or vice versa, i.e. first component (B) is produced and component (A) is then produced in the presence of component (B) in a subsequent polymerization step, yielding the MDPE.

30 MDPEs produced in a multistage process are also designated as "in-situ" or "reactor" blends. The resulting end-product consists of an intimate mixture of the polymers from the two or more reactors, the different molecular-weight-distribution curves of these polymers together forming a molecular-weight-distribution curve having a broad maximum or two or more maxima, i.e. 35 the end product is a multimodal polymer mixture.

Term “multimodal” in context of medium density polyethylene (MDPE) means herein multimodality with respect to melt flow rate (MFR) of the at least two polyethylene components, i.e. the two polyethylene components, have different MFR values. The multimodal medium density polyethylene can have in addition or alternatively multimodality between the two polyethylene components with respect to one or more further properties, like density, comonomer type and/or comonomer content, as will be described later below.

Detailed Description of Invention

Ad metallocene catalysed multimodal medium density polyethylene (mMDPE)

10 The metallocene catalysed multimodal mMDPE according to the present invention has a density (ISO 1183) in the range of 920 to 945 kg/m³, preferably 922 to 940 kg/m³ and more preferably 923 to 935 kg/m³.

The MFR₂ (190°C, 2.16 kg, ISO 1133) of the metallocene catalysed mMDPE is in the range of 0.1 to 5.0 g/10 min, preferably 0.2 to 3.0 g/10 min, more preferably 0.3 to 2.5 g/10 min and even more preferably 0.4 to 2.0 g/10 min.

15 The MFR₂₁ (190°C, 21.6 kg, ISO 1133) of the metallocene catalysed mMDPE may be in the range of 8.0 to 60.0 g/10 min, preferably in a range of 10.0 to 55.0 g/10min, more preferably in the range of 12.0 to 50.0 g/10 min and most preferably 15.0 to 45.0 g/10 min.

The metallocene catalysed mMDPE according to the present invention furthermore has a Flow Rate Ratio (FRR) of the MFR₂₁/MFR₂ in the range of 27.0 to 40.0, preferably of 28.0 to 38.0 and more preferably of 29.0 to 35.0.

In an embodiment of the invention the mMDPE has one or two or all of:

a density (ISO1183) in the range of 922 to 940 kg/m³, preferably 923 to 935 kg/m³,

25 a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 0.2 to 3.0 g/10 min, preferably 0.3 to 2.5 g/10 min and more preferably 0.4 to 2.0 g/10 min,

a MFR₂₁ (190°C, 21.6 kg, ISO 1133) in the range of 10.0 to 55.0 g/10 min, preferably in a range of 12.0 to 50.0 g/10min and more preferably in the range of 15.0 to 45.0 g/10 min and/or a Flow Rate Ratio (FRR), MFR₂₁/MFR₂ in the range of 28.0 to 38.0, preferably of 29.0 to 35.0.

30 Additionally, the metallocene catalysed mMDPE has a molecular weight distribution (MWD), Mw/Mn, in the range of 4.2 to 10.0, preferably 4.5 to 8.0, and more preferably 4.8 to 6.5.

In addition, the metallocene catalysed mMDPE according to the present invention may have

a weight average molecular weight, M_w , of at least 60000 g/mol, preferably in the range of from 70000 to 130000 g/mol, more preferably from 75000 to 125000 g/mol, still more preferably from 80000 to 120000 g/mol.

- 5 The metallocene catalysed mMDPE according to the present invention may have a melting temperature T_m (measured with DSC) of at least 125°C, preferably in the range of 125 to 135°C.

The metallocene catalysed mMDPE consists of

- 10 (i) 35.0 to 50.0 wt%, preferably 38.0 to 48.0 wt%, relative to the total weight of the mMDPE, of a polyethylene component (A) with a density in the range of 950 to 975 kg/m³ and a MFR₂ (190°C, 2.16 kg, ISO 1133) of 3.0 to 50 g/10 min; and
(ii) 50.0 to 65.0 wt%, preferably 52.0 to 62.0 wt%, relative to the total weight of the mMDPE, of a polyethylene component (B) with a density in the range of 900 to 925 kg/m³ and a MFR₂
15 (190°C, 2.16 kg, ISO 1133) of 0.001 to 1.0 g/10 min.

The amounts of components (A) and (B) sum up to 100 wt%.

According to the present invention, the polyethylene component (A) is a polyethylene homopolymer.

- 20 In view of the present invention by polyethylene homopolymer a polymer is meant, which comprising at least 99.0 wt%, especially at least 99.5 wt% ethylene monomer units. Thus, the polyethylene homopolymer may comprise up to 1.0 wt% comonomer units, but preferably comprises only up to 0.5 wt%, like up to 0.2 wt% or even up to 0.1 wt% only.

- In an embodiment of the present invention, the amount of comonomer in the polyethylene
25 homopolymer component is not detectable with ¹³C-NMR.

Polyethylene component (B) is a copolymer of ethylene and a C4 to C8 comonomer, preferably C4 to C6 comonomer and more preferably a copolymer of ethylene and 1-hexene.

- Preferably, polyethylene component (B) consists of a single ethylene copolymer and
30 polyethylene component (A) may consist of a single ethylene homopolymer or alternatively, polyethylene component (A) may be an ethylene homopolymer mixture comprising (e.g. consisting of) a first ethylene polymer fraction (A-1) and a second ethylene polymer fraction (A-2), whereby both fractions are a homopolymer. Polyethylene component (A) may be unimodal or multimodal.

- 35 In an embodiment of the invention polyethylene component (A) preferably is unimodal and consists of a single ethylene homopolymer.

The total amount of comonomer, i.e. C4 to C8 comonomer, preferably C4 to C6 and more preferably 1-hexene, in the metallocene catalysed mMDPE preferably is in the range of 1.5 to 5.0 mol%, more preferably 1.6 to 4.0 mol %, even more preferably 1.7 to 3.5 mol% and yet more preferably 1.8 to 3.0 mol%.

5 The total amount of of comonomer, i.e. C4 to C8 comonomer, preferably C4 to C6 and more preferably 1-hexene, in the polyethylene component (B) is preferably in the range of 2.0 to 8.0 mol%, more preferably 2.5 to 7.0 mol %, even more preferably 3.0 to 6.0 mol% and yet more preferably 3.2 to 5.5 mol%.

10 The polyethylene component (A) preferably has a MFR₂ in the range of 4.0 to 30.0 g/10min, more preferably 5.0 to 20.0 g/10min, even more preferably 6.0 to 15.0 g/10min and most preferably 6.5 to 12.0 g/10 min, like 7.0 to 10.0 g/10 min.

The density of polyethylene component (A) preferably is in the range of 955 to 972 kg/m³, more preferably 960 to 970 kg/m³ and even more preferably 962 to 968 kg/m³.

15

It another embodiment polyethylene component (A) consists of two fractions, i.e. a first ethylene polymer fraction (A-1) and a second ethylene polymer fraction (A-2), preferably a first ethylene homopolymer fraction (A-1) and a second ethylene homopolymer fraction (A-2).

It is possible that fraction (A-1) is produced first and then fraction (A-2) is produced in the presence of fraction (A-1) in a subsequent reactor or vice versa, i.e. fraction (A-2) is produced first and then fraction (A-1) is produced in the presence of fraction (A-2) in a subsequent reactor. Preferably, fraction (A-1) is produced first.

20 The MFR₂ and/or the density of fractions (A-1) and (A-2) may be the same or may be different from each other.

25

The polyethylene component (B) preferably has a MFR₂ in the range of 0.005 to 0.8 g/10min, more preferably 0.01 to 0.6 g/10min, and even more preferably 0.05 to 0.5 g/10min.

The density of the polyethylene component (B) preferably is in the range of 903 to 920 kg/m³, more preferably 905 to 915 kg/m³ and even more preferably 905 to 912 kg/m³.

30

The metallocene catalysed mMDPE may be produced by polymerization using conditions which create a multimodal (e.g. bimodal) polymer product using a metallocene catalyst system.

Thus, the metallocene catalysed mMDPE can be produced in a 2-stage process, preferably comprising a slurry reactor (e.g. loop reactor), whereby the slurry (e.g. loop) reactor is connected in series to a gas phase reactor (GPR), whereby either polyethylene component (A) or polyethylene component (B) is produced in the slurry reactor and the other ethylene

polymer component is then produced in GPR in the presence of the first produced ethylene polymer component to produce the metallocene catalysed mMDPE, preferably the polyethylene component (A) is produced in the slurry reactor and the polyethylene component (B) is produced in GPR in the presence of the polyethylene component (A) to produce the metallocene catalysed mMDPE.

In case that the polyethylene component (A) of the metallocene catalysed mMDPE consists of ethylene polymer fractions (A-1) and (A-2), the metallocene catalysed mMDPE can be produced with a 3-stage process, preferably comprising a first slurry reactor (loop reactor 1), whereby the first slurry (loop) reactor is connected in series with another slurry reactor (loop reactor 2), so that the first ethylene polymer fraction (A-1) produced in the slurry reactor 1 is fed to the slurry reactor 2, wherein the second ethylene polymer fraction (A-2) is produced in the presence of the first fraction (A-1). It is possible that fraction (A-1) is produced first and then fraction (A-2) is produced in the presence of fraction (A-1) in a subsequent reactor or vice versa, i.e. fraction (A-2) is produced first and then fraction (A-1) is produced in the presence of fraction (A-2) in a subsequent reactor. Preferably, fraction (A-1) is produced first.

It is within the scope of the invention, that the first and the second ethylene polymer fraction (A-1 and A-2) of the polyethylene component (A) are present in a weight ratio of 4:1 up to 1:4, such as 3:1 to 1:3, or 2:1 to 1:2, or 1:1, based on the total weight of the polyethylene component (A).

The first and the optional second polymerization stages are preferably slurry polymerization steps.

The slurry polymerization usually takes place in an inert diluent, typically a hydrocarbon diluent such as methane, ethane, propane, n-butane, isobutane, pentanes, hexanes, heptanes, octanes etc., or their mixtures. Preferably, the diluent is a low-boiling hydrocarbon having from 1 to 4 carbon atoms or a mixture of such hydrocarbons. An especially preferred diluent is propane, possibly containing minor amount of methane, ethane and/or butane.

The temperature in each of the first and the optional second polymerization stages is typically from 60 to 100°C, preferably from 70 to 90°C. An excessively high temperature should be avoided to prevent partial dissolution of the polymer into the diluent and the fouling of the reactor. The pressure is from 1 to 150 bar, preferably from 40 to 80 bar.

The slurry polymerization may be conducted in any known reactor used for slurry polymerization. Such reactors include a continuous stirred tank or autoclave reactor and a loop reactor. In an embodiment it is especially preferred to conduct the slurry polymerization in a loop reactor. In such reactors the slurry is circulated with a high velocity along a closed pipe by using a circulation pump. Loop reactors are generally known in the art and examples

are given, for instance, in US-A-4582816, US-A-3405109, US-A-3324093, EP-A-479186 and US-A-5391654. It is thus preferred to conduct the first and second polymerization stages as slurry polymerizations in two consecutive loop reactors.

5 The slurry may be withdrawn from each reactor either continuously or intermittently. A preferred way of intermittent withdrawal is the use of settling legs where slurry is allowed to concentrate before withdrawing a batch of the concentrated slurry from the reactor. The use of settling legs is disclosed, among others, in US-A-3374211, US-A-3242150 and EP-A-1310295. Continuous withdrawal is disclosed, among others, in EP-A-891990, EP-A-1415999, EP-A-1591460 and WO-A-2007/025640. The continuous withdrawal is advantageously
10 combined with a suitable concentration method, as disclosed in EP-A-1310295 and EP-A-1591460. In an embodiment it is preferred to withdraw the slurry from each of the first and optional second polymerization stages continuously.

Hydrogen is typically introduced into the first and optional second polymerization stage for controlling the MFR₂ of the ethylene polymers. The amount of hydrogen needed to reach the
15 desired MFR depends on the catalyst used and the polymerization conditions.

The slurry reactor is preferably connected in series to a gas phase reactor (GPR), so that the polyethylene component (A) leaving the slurry reactor is fed to the GPR to produce a multimodal polyethylene copolymer.

20 The last polymerization stage is a gas phase polymerization step, i.e. carried out in a gas-phase reactor. Any suitable gas phase reactor known in the art may be used, such as a fluidised bed gas phase reactor.

For gas phase reactors, the reaction temperature used will generally be in the range 60 to 115°C (e.g. 70 to 110°C), the reactor pressure will generally be in the range 10 to 25 bar, and the residence time will generally be 1 to 8 hours. The gas used will commonly be a non-
25 reactive gas such as nitrogen or low boiling point hydrocarbons such as propane together with monomer (e.g. ethylene).

A chain transfer agent (e.g. hydrogen) is typically added to this polymerization stage.

Such a process is described inter alia in WO 2016/198273, WO 2021009189, WO 2021009190, WO 2021009191 and WO 2021009192. Full details of how to prepare suitable
30 multimodal polymers can be found in these references.

A suitable process is the Borstar PE process or the Borstar PE 3G process.

The metallocene catalysed mMDPE according to the present invention is therefore preferably produced in a slurry-gas-phase cascade or slurry-slurry-gas-phase cascade. Such polymerization steps may be preceded by a prepolymerization step.

5 The purpose of the prepolymerization is to polymerize a small amount of polymer onto the catalyst at a low temperature and/or a low monomer concentration. By prepolymerization it is possible to improve the performance of the catalyst in slurry and/or modify the properties of the final polymer. The prepolymerization step is preferably conducted in slurry. Thus, the prepolymerization step may be conducted in a loop reactor.

10 The prepolymerization is then preferably conducted in an inert diluent, typically a hydrocarbon diluent such as methane, ethane, propane, n-butane, isobutane, pentanes, hexanes, heptanes, octanes etc., or their mixtures. Preferably, the diluent is a low-boiling hydrocarbon having from 1 to 4 carbon atoms or a mixture of such hydrocarbons.

The temperature in the prepolymerization step is typically from 0 to 90°C, preferably from 20 to 80°C and more preferably from 45 to 75°C.

15 The pressure is not critical and is typically from 1 to 150 bar, preferably from 40 to 80 bar.

The amount of monomer is typically such that from 0.1 to 1000 grams of monomer per one gram of solid catalyst component is polymerized in the prepolymerization step. As the person skilled in the art knows, the catalyst particles recovered from a continuous prepolymerization reactor do not all contain the same amount of prepolymer. Instead, each particle has its own
20 characteristic amount, which depends on the residence time of that particle in the prepolymerization reactor. As some particles remain in the reactor for a relatively long time and some for a relatively short time, then also the amount of prepolymer on different particles is different and some individual particles may contain an amount of prepolymer which is outside the above limits. However, the average amount of prepolymer on the catalyst typically
25 is within the limits specified above.

The molecular weight of the prepolymer may be controlled by hydrogen as it is known in the art. Further, antistatic additives may be used to prevent the particles from adhering to each other or the walls of the reactor, as disclosed in WO-A-96/19503 and WO-A-96/32420.

30 The catalyst components are preferably all introduced to the prepolymerization step when a prepolymerization step is present. However, where the solid catalyst component and the cocatalyst can be fed separately it is possible that only a part of the cocatalyst is introduced into the prepolymerization stage and the remaining part into subsequent polymerization stages. Also in such cases it is necessary to introduce so much cocatalyst into the
35 prepolymerization stage that a sufficient polymerization reaction is obtained therein.

It is understood within the scope of the invention, that the amount of polymer produced in the prepolymerization lies within 1.0 to 5.0 wt% in respect to the final metallocene catalysed mMDPE. This can be counted as part of the first polyethylene component (A).

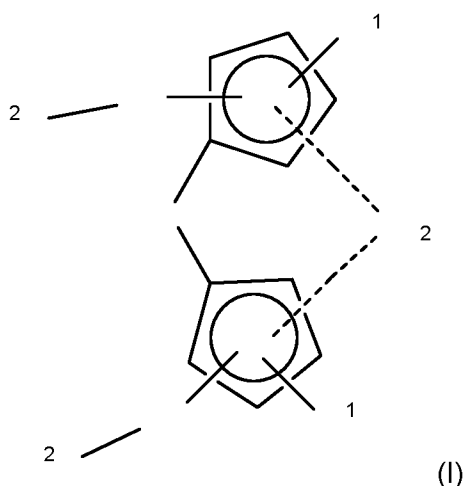
5 Catalyst

The metallocene catalysed mMDPE of the invention is one made using a metallocene catalyst. A metallocene catalyst comprises a metallocene complex and a cocatalyst. The metallocene compound or complex is referred herein also as organometallic compound (C).

10 The organometallic compound (C) comprises a transition metal (M) of Group 3 to 10 of the Periodic Table (IUPAC 2007) or of an actinide or lanthanide.

The term "an organometallic compound (C)" in accordance with the present invention includes any metallocene or non-metallocene compound of a transition metal, which bears at least one organic (coordination) ligand and exhibits the catalytic activity alone or together with a cocatalyst. The transition metal compounds are well known in the art and the present invention
 15 covers compounds of metals from Group 3 to 10, e.g. Group 3 to 7, or 3 to 6, such as Group 4 to 6 of the Periodic Table, (IUPAC 2007), as well as lanthanides or actinides.

In an embodiment, the organometallic compound (C) has the following formula (I):



20 wherein each X is independently a halogen atom, a C₁₋₆-alkyl group, C₁₋₆-alkoxy group, phenyl or benzyl group;

each Het is independently a monocyclic heteroaromatic group containing at least one heteroatom selected from O or S;

L is -R'₂Si-, wherein each R' is independently C₁₋₂₀-hydrocarbyl or C₁₋₁₀-alkyl substituted with
 25 alkoxy having 1 to 10 carbon atoms;

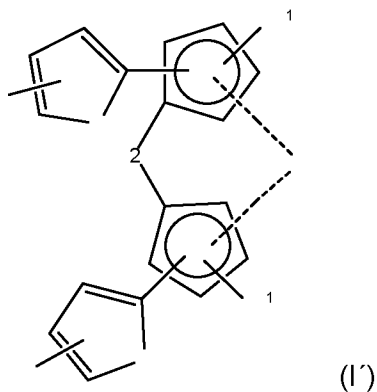
M is Ti, Zr or Hf;

each R¹ is the same or different and is a C₁₋₆-alkyl group or C₁₋₆-alkoxy group;

each n is 1 to 2;

each R^2 is the same or different and is a C_{1-6} -alkyl group, C_{1-6} -alkoxy group or $-\text{Si}(\text{R})_3$ group;
 each R is C_{1-10} -alkyl or phenyl group optionally substituted by 1 to 3 C_{1-6} -alkyl groups; and
 each p is 0 to 1.

5 Preferably, the compound of formula (I) has the structure



wherein each X is independently a halogen atom, a C_{1-6} -alkyl group, C_{1-6} -alkoxy group, phenyl or benzyl group;

L is a $\text{Me}_2\text{Si}-$;

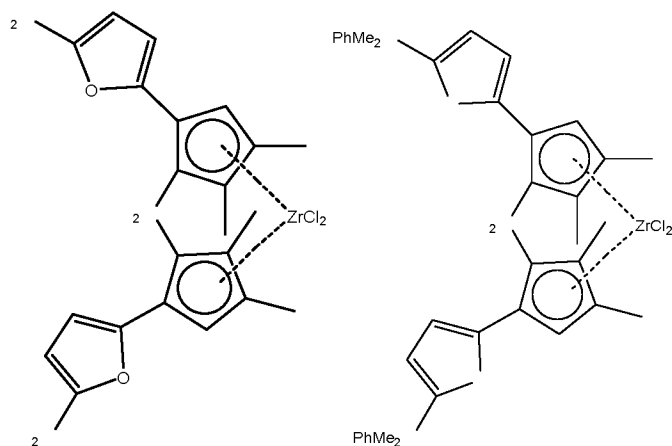
10 each R^1 is the same or different and is a C_{1-6} -alkyl group, e.g. methyl or t-Bu;

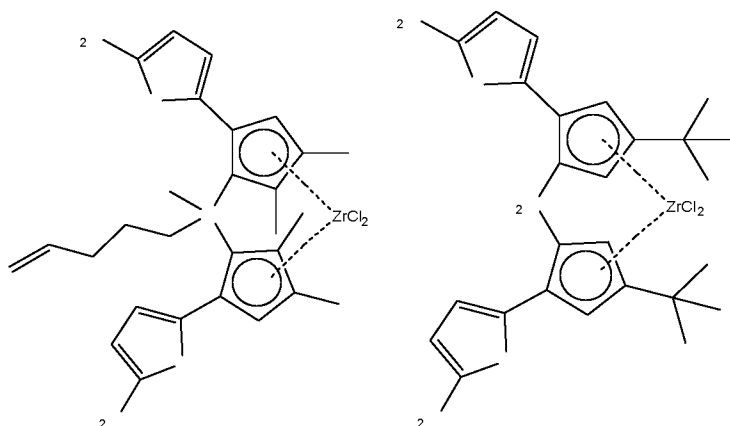
each n is 1 to 2;

R^2 is a $-\text{Si}(\text{R})_3$ alkyl group; each p is 1;

each R is C_{1-6} -alkyl or phenyl group.

15 Highly preferred complexes of formula (I) are





Most preferably the complex dimethylsilanediylbis[2-(5-trimethylsilylfuran-2-yl)-4,5-dimethylcyclopentadien-1-yl] zirconium dichloride is used.

- 5 More preferably the polyethylene components (A) and (B) of the metallocene catalysed mMDPE are produced using, i.e. in the presence of, the same metallocene catalyst.

To form a catalyst, a cocatalyst, also known as an activator, is used, as is well known in the art. Cocatalysts comprising Al or B are well known and can be used here. The use of
10 aluminoxanes (e.g. MAO) or boron based cocatalysts (such as borates) is preferred.

Polyethylene copolymers made using single site catalysis, as opposed to Ziegler Natta catalysis, have characteristic features that allow them to be distinguished from Ziegler Natta materials. In particular, the comonomer distribution is more homogeneous. This can be shown using TREF or Crystaf techniques. Catalyst residues may also indicate the catalyst used.
15 Ziegler Natta catalysts would not contain a Zr or Hf group (IV) metal for example.

The metallocene catalysed mMDPE may contain additives and/or fillers.

The optional additives and fillers and the used amounts thereof are conventional in the field of film applications. Examples of such additives are, among others, antioxidants, process
20 stabilizers, UV-stabilizers, pigments, fillers, antistatic additives, antiblock agents, nucleating agents, acid scavengers as well as polymer processing agent (PPA).

As mentioned above, the metallocene catalysed mMDPE according to the present invention provides improved mechanical properties, especially tensile modulus and dart drop (impact
25 strength) and additionally an attractive balance of mechanical and sealing properties.

The invention is therefore further directed to a film comprising at least one layer comprising the above described metallocene catalysed mMDPE.

Film

The film of the invention comprises at least one layer comprising the above defined metallocene catalysed mMDPE. The film can be a monolayer film comprising the above defined polyethylene composition or a multilayer film, wherein at least one layer comprises the above defined polyethylene composition. The terms "monolayer film" and multilayer film" have well known meanings in the art.

Preferably, the at least one layer of the invention comprises at least 50 wt%, more preferably at least 60 wt%, even more preferably at least 70 wt%, yet more preferably at least 80 wt%, based on the total weight of the film, of the metallocene catalysed mMDPE of the invention. Most preferably said at least one layer of the film of invention consists of the metallocene catalysed mMDPE.

The films are preferably produced by any conventional film extrusion procedure known in the art including cast film and blown film extrusion. Most preferably, the film is a blown or cast film, especially a blown film. E.g. the blown film is produced by extrusion through an annular die and blowing into a tubular film by forming a bubble which is collapsed between nip rollers after solidification. This film can then be slit, cut or converted (e.g. gusseted) as desired. Conventional film production techniques may be used in this regard. If the preferable blown or cast film is a multilayer film then the various layers are typically coextruded. The skilled man will be aware of suitable extrusion conditions.

Films according to the present invention may be subjected to post-treatment processes, e.g. surface modifications, lamination or orientation processes or the like. Such orientation processes can be mono-axially (MDO) or bi-axially orientation, wherein mono-axial orientation is preferred.

In another preferred embodiment, the films are unoriented.

Preferred films according to the invention are monolayer blown films.

The monolayer film of the invention may have a thickness of 20 to 120 μm , preferably 30 to 100 μm and more preferably 35 to 80 μm .

Films based on the above defined metallocene catalysed mMDPE result in improved mechanical performance (higher stiffness at the same dart-drop impact strength (DDI) or higher dart-drop impact strength (DDI) at the same stiffness as comparative examples) without deteriorating the sealing performance and still having acceptable optical properties, especially haze.

Thus, in one embodiment the films according to the present invention have

a) a tensile modulus (measured on a 40 µm monolayer test blown film according to ISO 527-3) in machine (MD) direction in the range of 350 MPa to 800 MPa, preferably of 380 MPa to 500 MPa and in transverse (TD) direction in the range of 400 MPa to 800 MPa, preferably of 420 MPa to 550 MPa and

5 b) a dart-drop impact strength (DDI) determined according to ISO 7765-1:1988 on a 40 µm monolayer test blown film of at least 150 g up to 500 g, preferably 200 g up to 450 g and more preferably 220 g up to 400 g and

c) a relation between mechanical properties and sealing properties according to formula (I):

$$\frac{\text{Tensile Modulus (MD)[MPa]} * \text{DDI(g)}}{\text{SIT [}^{\circ}\text{C]}} > 650$$

10 determined on 40 µm test blown film, wherein the Tensile Modulus in machine direction is measured according to ISO 527-3 at 23°C on 40 µm test blown films, DDI is the dart-drop impact strength determined according to ISO 7765-1:1988 on a 40 µm test blown film and SIT is the sealing initiation temperature measured as described in the experimental part on a 40 µm test blown film.

15 Preferably TM(MD)*DDI/SIT for this embodiment is > 700, and more preferably > 750.

A suitable upper limit for TM(MD)*DDI/SIT for this embodiment is 1500, preferably 1000, and more preferably 900.

In another embodiment the films according to the present invention have

20 a) a tensile modulus (measured on a 40 µm monolayer test blown film according to ISO 527-3) in machine (MD) direction in the range of 200 MPa to 600 MPa, preferably of 250 MPa to 400 MPa and in transverse (TD) direction in the range of 250 MPa to 600 MPa, preferably of 300 MPa to 500 MPa and

25 b) a dart-drop impact strength (DDI) determined according to ISO 7765-1:1988 on a 40 µm monolayer test blown film of at least 700 g up to 2000 g, preferably 800 g up to 1600 g and more preferably 900 g up to 1400 g and

c) a relation between mechanical properties and sealing properties according to formula (I):

$$\frac{\text{Tensile Modulus (MD)[MPa]} * \text{DDI(g)}}{\text{SIT [}^{\circ}\text{C]}} > 1000$$

30 determined on 40 µm test blown film, wherein the Tensile Modulus in machine direction is measured according to ISO 527-3 at 23°C on 40 µm test blown films, DDI is the dart-drop impact strength determined according to ISO 7765-1:1988 on a 40 µm test blown film and SIT is the sealing initiation temperature measured as described in the experimental part on a 40 µm test blown film.

Preferably TM(MD)*DDI/SIT for this embodiment is > 2000, and more preferably > 2500.

A suitable upper limit for $TM(MD)*DDI/SIT$ for this embodiment is 5000, preferably 4500, and more preferably 4000.

5 The haze measured on 40 μm test blown films according ASTM D1003 for both embodiments is below 35%, preferably in the range of 5 to 32% more preferably of 10 to 30%, like in the range of 10 to 20% or 21 to 30%.

10 Films of both embodiments according to the present invention may have a relative Elmendorf tear resistance measured according to ISO 6383/2 on a blown film with a film thickness of 40 μm in machine direction (MD) of at least 60 N/mm up to 300 N/mm, preferably 70 N/mm up to 250 N/mm and more preferably 80 N/mm up to 220 N/mm and in transversal direction (TD) of at least 140 N/mm up to 350 N/mm, preferably 150 N/mm up to 300 N/mm and more preferably 170 N/mm up to 250 N/mm.

15 The films according to the present invention are highly useful for being used in various packaging applications.

Furthermore the films according to the present invention may be used as a layer in multilayer polyethylene based blown film, preferably as core layer in multilayer polyethylene based blown films.

20

The invention will be further described with reference to the following non-limiting examples.

Determination methods

Unless otherwise stated in the description or in the experimental part, the following methods were used for the property determinations of the polymers (including its fractions and components) and/or any sample preparations thereof as specified in the text or experimental part.

Melt Flow Rate

The melt flow rate (MFR) was determined according to ISO 1133 and is indicated in g/10 min. The MFR is an indication of the flowability, and hence the processability, of the polymer. The MFR is determined at 190 °C for polyethylene. MFR may be determined at different loadings such as 2.16 kg (MFR₂), 5 kg (MFR₅) or 21.6 kg (MFR₂₁).

Calculation of MFR₂ of Component B

$$\log A = x \cdot \log B + (1 - x) \cdot \log C$$

$$C = 10^{\frac{(\log A - x \cdot \log B)}{(1-x)}}$$

15 *For Component B:*

B = MFR₂ of Component (A)

C = MFR₂ of Component (B)

A = final MFR₂ (mixture) of multimodal mMDPE

X = weight fraction of Component (A).

20

Density

Density of the polymer was measured according to ISO 1183 and ISO1872-2 for sample preparation and is given in kg/m³.

25 GPC

Molecular weight averages (Mz, Mw and Mn), Molecular weight distribution (MWD) and its broadness, described by polydispersity index, PDI= Mw/Mn (wherein Mn is the number average molecular weight and Mw is the weight average molecular weight) were determined by Gel Permeation Chromatography (GPC) using the following formulas:

30

$$M_n = \frac{\sum_{i=1}^N A_i}{\sum_{i=1}^N (A_i/M_i)} \quad (1)$$

$$M_w = \frac{\sum_{i=1}^N (A_i \times M_i)}{\sum_{i=1}^N A_i} \quad (2)$$

$$M_z = \frac{\sum_{i=1}^N (A_i \times M_i^2)}{\sum_{i=1}^N (A_i \times M_i)} \quad (3)$$

For a constant elution volume interval ΔV_i , where A_i , and M_i are the chromatographic peak slice area and polyolefin molecular weight (MW), respectively associated with the elution volume, V_i , where N is equal to the number of data points obtained from the chromatogram
 5 between the integration limits.

A high temperature GPC instrument, equipped with either infrared (IR) detector (IR4 or IR5 from PolymerChar (Valencia, Spain), equipped with 3 x Agilent-PLgel Olexis and 1x Agilent-PLgel Olexis Guard columns was used. As the solvent and mobile phase 1,2,4-trichlorobenzene (TCB) stabilized with 250 mg/L 2,6-Di tert butyl-4-methyl-phenol) was used.
 10 The chromatographic system was operated at 160 °C and at a constant flow rate of 1 mL/min. 200 μ L of sample solution was injected per analysis. Data collection was performed using either Agilent Cirrus software version 3.3 or PolymerChar GPC-IR control software.

The column set was calibrated using universal calibration (according to ISO 16014-2:2003) with 19 narrow MWD polystyrene (PS) standards in the range of 0,5 kg/mol to 11 500 kg/mol.
 15 The PS standards were dissolved at room temperature over several hours. The conversion of the polystyrene peak molecular weight to polyolefin molecular weights is accomplished by using the Mark Houwink equation and the following Mark Houwink constants:

$$K_{PS} = 19 \times 10^{-3} \text{ mL/g}, \quad \alpha_{PS} = 0.655$$

$$K_{PE} = 39 \times 10^{-3} \text{ mL/g}, \quad \alpha_{PE} = 0.725$$

$$20 \quad K_{PP} = 19 \times 10^{-3} \text{ mL/g}, \quad \alpha_{PP} = 0.725$$

A third order polynomial fit was used to fit the calibration data.

All samples were prepared in the concentration range of 0,5 -1 mg/ml and dissolved at 160 °C for 2.5 hours for PP or 3 hours for PE under continuous gentle shaking.

To exclude the influence of additives like irganox 1010, irgafos 168 or some other low
 25 molecular weight oligomers, the low molecular weight integration limit was set in the valley between the antioxidant peak and the polymer peak ($\sim \log M$ of 2.8 (PE equivalent) for the analysed samples).

Comonomer contents:

30 Quantification of microstructure by NMR spectroscopy

Quantitative nuclear-magnetic resonance (NMR) spectroscopy was used to quantify the comonomer content of the polymers.

Quantitative $^{13}\text{C}\{^1\text{H}\}$ NMR spectra recorded in the molten-state using a Bruker Avance III 500 NMR spectrometer operating at 500.13 and 125.76 MHz for ^1H and ^{13}C respectively. All spectra were recorded using a ^{13}C optimized 7 mm magic-angle spinning (MAS) probehead at 150°C using nitrogen gas for all pneumatics. Approximately 200 mg of material was packed into a 7 mm outer diameter zirconia MAS rotor and spun at 4 kHz. This setup was chosen primarily for the high sensitivity needed for rapid identification and accurate quantification {klimke06, parkinson07, castignolles09}. Standard single-pulse excitation was employed utilizing the NOE at short recycle delays of 3 s {pollard04, klimke06} and the RS-HEPT decoupling scheme {fillip05, griffin07}. A total of 1024 (1k) transients were acquired per spectra.

Quantitative $^{13}\text{C}\{^1\text{H}\}$ NMR spectra were processed, integrated and relevant quantitative properties determined from the integrals. All chemical shifts are internally referenced to the bulk methylene signal ($\delta+$) at 30.00 ppm.

The amount of ethylene was quantified using the integral of the methylene ($\delta+$) sites at 30.00 ppm accounting for the number of reporting sites per monomer:

$$E = I_{\delta+} / 2$$

the presence of isolated comonomer units is corrected for based on the number of isolated comonomer units present:

$$E_{\text{total}} = E + (3*B + 2*H) / 2$$

where B and H are defined for their respective comonomers. Correction for consecutive and non-consecutive comonomer incorporation, when present, is undertaken in a similar way.

Characteristic signals corresponding to the incorporation of 1-butene were observed and the comonomer fraction calculated as the fraction of 1-butene in the polymer with respect to all monomer in the polymer:

$$f_{\text{Btotal}} = B_{\text{total}} / (E_{\text{total}} + B_{\text{total}} + H_{\text{total}})$$

The amount isolated 1-butene incorporated in EEBEE sequences was quantified using the integral of the αB_2 sites at 39.8 ppm accounting for the number of reporting sites per comonomer:

$$B = I_{\alpha\text{B}_2}$$

If present the amount consecutively incorporated 1-butene in EEBBEE sequences was quantified using the integral of the $\alpha\alpha\text{B}_2\text{B}_2$ site at 39.4 ppm accounting for the number of reporting sites per comonomer:

$$BB = 2 * I_{\alpha\alpha\text{B}_2\text{B}_2}$$

If present the amount non consecutively incorporated 1-butene in EEBEBEE sequences was quantified using the integral of the $\beta\beta\text{B}_2\text{B}_2$ site at 24.6 ppm accounting for the number of reporting sites per comonomer:

$$\text{BEB} = 2 * I_{\beta\beta\text{B}_2\text{B}_2}$$

Due to the overlap of the α B2 and β B2B2 sites of isolated (EEBEE) and non-consecutively incorporated (EEBEBEE) 1-butene respectively the total amount of isolated 1-butene incorporation is corrected based on the amount of non-consecutive 1-butene present:

$$B = I_{\alpha B2} - 2 * I_{\beta B2B2}$$

- 5 Sequences of BBB were not observed. The total 1-butene content was calculated based on the sum of isolated, consecutive and non consecutively incorporated 1-butene:

$$B_{total} = B + BB + BEB$$

The total mole fraction of 1-butene in the polymer was then calculated as:

$$fB = B_{total} / (E_{total} + B_{total} + H_{total})$$

- 10 Characteristic signals corresponding to the incorporation of 1-hexene were observed and the comonomer fraction calculated as the fraction of 1-hexene in the polymer with respect to all monomer in the polymer:

$$fH_{total} = H_{total} / (E_{total} + B_{total} + H_{total})$$

- The amount isolated 1-hexene incorporated in EEHEE sequences was quantified using the integral of the α B4 sites at 38.3 ppm accounting for the number of reporting sites per comonomer:

$$H = I_{\alpha B4}$$

- If present the amount consecutively incorporated 1-hexene in EEHHEE sequences was quantified using the integral of the $\alpha\alpha$ B4B4 site at 40.5 ppm accounting for the number of reporting sites per comonomer:

$$HH = 2 * I_{\alpha\alpha B4B4}$$

If present the amount non consecutively incorporated 1-hexene in EEHEHEE sequences was quantified using the integral of the $\beta\beta$ B4B4 site at 24.7 ppm accounting for the number of reporting sites per comonomer:

- 25 $HEH = 2 * I_{\beta\beta B4B4}$

Sequences of HHH were not observed. The total 1-hexene content was calculated based on the sum of isolated, consecutive and non consecutively incorporated 1-hexene:

$$H_{total} = H + HH + HEH$$

The total mole fraction of 1-hexene in the polymer was then calculated as:

- 30 $fH = H_{total} / (E_{total} + B_{total} + H_{total})$

The mole percent comonomer incorporation is calculated from the mole fraction:

$$B \text{ [mol\%]} = 100 * fB$$

$$H \text{ [mol\%]} = 100 * fH$$

The weight percent comonomer incorporation is calculated from the mole fraction:

- 35 $B \text{ [wt\%]} = 100 * (fB * 56.11) / ((fB * 56.11) + (fH * 84.16) + ((1-(fB + fH)) * 28.05))$

$$H \text{ [wt\%]} = 100 * (fH * 84.16) / ((fB * 56.11) + (fH * 84.16) + ((1-(fB + fH)) * 28.05))$$

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20 DSC analysis, melting (T_m)

Data was measured with a TA Instrument Q2000 differential scanning calorimetry (DSC) on 5 to 7 mg samples. DSC was run according to ISO 11357 / part 3 /method C2 in a heat / cool / heat cycle with a scan rate of 10 °C/min in the temperature range of -30 to +225°C.

- Crystallization temperature (T_c) and crystallization enthalpy (H_c) were determined from the
- 25 cooling step, while melting temperature (T_m) and melting enthalpy (H_m) are determined from the second heating step.

Dart drop strength (DDI): Impact resistance by free-falling dart method

- The DDI was measured according to ISO 7765-1:1988 / Method A from the films (non-oriented
- 30 films and laminates) as produced indicated below. This test method covers the determination of the energy that causes films to fail under specified conditions of impact of a free-falling dart from a specified height that would result in failure of 50 % of the specimens tested (Staircase method A). A uniform missile mass increment is employed during the test and the missile weight is decreased or increased by the uniform increment after test of each specimen,
- 35 depending upon the result (failure or no failure) observed for the specimen.

Standard conditions:

Conditioning time: > 96 h at 50 \pm 2 °C \pm 10 %rh

Test temperature: 23 °C

Dart head material: phenolic

5 Dart diameter: 38 mm

Drop height: 660 mm

Results:

Impact failure weight - 50% [g]

10 Tensile modulus

The tensile test was conducted according to ISO 527-3, moreover the modulus of elasticity (secant modulus between 0.05 % and 0.25 % elongation) is also determined. Type 2 (parallel-sided specimens) specimens were used.

15 During testing a specimen is extended along its major axis for determination of tensile properties at constant testspeed (speed of crosshead) until the specimen fracture. During this procedure the load sustained by the specimen and the elongation, which is measured by the crosshead, are measured.

Standard conditions:

20 Conditioning time: > 96 h at 50 \pm 2 °C \pm 10 %rh

Test temperature: 23 °C

Gripping distance: 100 mm

Gauge length: 100 mm

Secant modulus: 0,05 % - 0,25 %

25 Testspeed modulus: 1 mm/min

Testspeed: 200 mm/min

Haze

30 The haze was measured according ASTM D1003 test method (Method A - Hazemeter). The method covers the evaluation of specific light-transmitting and scattering properties of planar sections of materials such as essentially transparent plastic.

A light beam strikes the specimen and enters an integrating sphere. The sphere's interior is coated uniformly with a matte white material to allow diffusion. A detector in the sphere measures total transmittance, haze and clarity (not part of ASTM D1003).

35 The incident light will be diffusely transmitted changing the appearance quality of the product. This can be a result of scattering at surface structures (roughness) or internal scattering at

particles like e.g. air enclosures, poorly dispersed pigments, dust enclosures or crystallisation. With increasing roughness haze is increasing and transmittance of plastics is decreasing.

Standard conditions:

5

Conditioning time: > 96 h

Temperature: 23 °C

Test procedure: A - Hazemeter

10 **Tear resistance** (determined as Elmendorf tear (N) in machine (MD) and transverse (TD) direction:

The tear resistance was measured according to the ISO 6383-2 method. The force required to propagate tearing across a film sample was measured using a pendulum device and a constant-radius test specimen was used. The pendulum swings under gravity through an arc, tearing the specimen from pre-cut slit. The specimen was fixed on one side by the pendulum and on the other side by a stationary clamp.

15

The tear resistance is the force required to tear the specimen. The relative tear resistance (N/mm) was then calculated by dividing the tear resistance by the thickness of the film.

20 **Sealing initiation temperature (SIT); sealing end temperature (SET), sealing range**

The method determines the sealing temperature range (sealing range) of polyethylene films, in particular blown films or cast films. The sealing temperature range is the temperature range, in which the films can be sealed according to conditions given below.

25

The lower limit (heat sealing initiation temperature (SIT)) is the sealing temperature at which a sealing strength of 5 N is achieved. The upper limit (sealing end temperature (SET)) is reached, when the films stick to the sealing device.

The measurement was done according to the slightly modified ASTM F1921 – 12, where the test parameters sealing pressure, cooling time and test speed have been modified. The determination of the force/temperature curve was continued until thermal failure of the film.

30

The sealing range was determined on a J&B Universal Sealing Machine Type 4000 with a monolayer test blown film of 40 µm thickness with the following further parameters:

Conditioning time: > 96 h

Specimen width: 25 mm

Sealing pressure: 0.4 N/mm² (PE)

35

Sealing time: 1 sec

Delay time: 30 sec

Sealing jaws dimension: 50x5 mm

Sealing jaws shape: flat

Sealing jaws coating: Niptef

Sealing temperature: ambient - 240°C

5 Sealing temperature interval: 5°C

Start temperature: 50°C Grip separation rate: 42 mm/sec

Film sample preparation

10 The film samples have been produced on a small-scale laboratory blown film line from company COLLIN Lab & Pilot Solutions GmbH.

The line consists of an extruder with a Ø 25 mm screw with an L/D ratio of 30. The extruder temperature has been set at 200°C, the melt temperature was 202 - 204°C and has been recorded after 45 min of process stabilization. The extruder is followed by a blow head which is equipped with a Ø 50 mm annular die with a die gap of 1.5 mm. The line has been run at a
15 constant throughput of 6.5 kg/h and a line speed of 7,4 m/min. The blow up ratio (BUR) of the film bubble was 2.5:1 resulting in a laid flat width of the film of 196 mm. The film was produced with a thickness of 40 µm.

The films produced were used for the following mechanical testing.

20 Examples:

Cat.Example: Catalyst preparation for CAT1:

Loading of SiO₂:

10 10 kg of silica (PQ Corporation ES757, calcined 600°C) was added from a feeding drum and inertized in the reactor until O₂ level below 2 ppm was reached.

Preparation of MAO/tol/MC:

30 30 wt% MAO in toluene (14.1 kg) was added into another reactor from a balance followed by toluene (4.0 kg) at 25°C (oil circulation temp) and stirring 95 rpm. Stirring speed was increased 95 rpm -> 200 rpm after toluene addition, stirring time 30 min. Metallocene Rac-dimethylsilanediybis{2-(5-(trimethylsilyl)furan-2-yl)-4,5-dimethylcyclopentadien-1-yl}zirconium dichloride 477 g was added from a metal cylinder followed by flushing with 4 kg toluene (total toluene amount 8.0 kg). Reactor stirring speed was changed to 95 rpm for MC feeding and returned back to 200 rpm for 3 h reaction time. After reaction time MAO/tol/MC solution was transferred into a feeding vessel.

Preparation of catalyst:

35 Reactor temperature was set to 10°C (oil circulation temp) and stirring was turned to 40 rpm during MAO/tol/MC addition. MAO/tol/MC solution (22.2 kg) was added within 205 min followed by 60 min stirring time (oil circulation temp was set to 25°C). After stirring "dry mixture"

was stabilised for 12 h at 25°C (oil circulation temp), stirring 0 rpm. Reactor was turned 20° (back and forth) and stirring was turned on 5 rpm for few rounds once an hour.

After stabilisation the catalyst was dried at 60°C (oil circulation temp) for 2 h under nitrogen flow 2 kg/h, followed by 13 h under vacuum (same nitrogen flow with stirring 5 rpm). Dried catalyst was sampled and HC content was measured in the glove box with Sartorius Moisture Analyser, (Model MA45) using thermogravimetric method. Target HC level was < 2% (actual 1.3 %).

Polymerization:

10 The polymerizations were done in a stirred autoclave with a volume of 20.9 L. The polymerization procedure is described in the following:

The evacuated autoclave was filled with 3600 g propane. 0.5 mmol triethylaluminium (0.62 mol/l solution in heptane) were added using a stream of additional 200 g propane. The required batch amounts of ethylene and hydrogen were fed and the reactor was heated up to the desired prepolymerization temperature of 60 °C.

400 - 600 mg of catalyst were weighted into a steel vial inside a glove box and suspended in 3 ml heptane. Then the vial was attached to the polymerization autoclave and the suspension was flushed into the reactor with 200 g propane.

20 For prepolymerization, the reactor was stirred 30 - 45 min at 60 °C. The pressure was kept constant at 21.1 barg by feeding ethylene with a flow meter. Then the temperature was increased to 85 °C. The required batches of hydrogen and 1-butene were fed to the reactor. In parallel, ethylene was fed until the desired slurry polymerization pressure was reached.

25 For slurry polymerization, the reactor was stirred at 85 °C. The pressure was kept constant by feeding ethylene, 1-butene and hydrogen in fixed ratios. After consumption of the desired quantity of ethylene, the reaction was stopped by venting and evacuating the reactor.

For the gas phase polymerization, the reactor temperature was set to 75 °C. It was refilled with propane until the required inert gas pressure for gas phase polymerization was reached.

30 Then hydrogen and 1-hexene batches were fed to the reactor. In parallel, ethylene was fed until the reactor pressure reached 20 barg. During polymerization, the pressure was kept constant by feeding ethylene, 1-hexene and hydrogen in fixed ratios. After consuming the desired quantity of ethylene, the reaction was stopped by venting the reactor.

Detailed polymerization settings are listed in Table 1 below:

TABLE 1: polymerization settings

5

Example	CE1	CE2	IE1	IE2
Catalyst	CAT1	CAT1	CAT1	CAT1
Catalyst quantity [mg]	600	600	400	400
Prepolymerization hydrogen batch [g]	0.005	0.005	0.030	0.030
Prepolymerization ethene batch [g]	64	64	52	52
Prepolymerization time [min]	45	45	45	30
Slurry hydrogen batch [g]	0.12	0.12	0.14	0.14
Slurry 1-butene batch [g]	14	14	0	0
Slurry pressure [barg]	39.8	39.8	39.9	39.9
Slurry hydrogen/ethene feed ratio [g/g]	0.000076	0.000076	0.000068	0.000068
Slurry 1-butene/ethene feed ratio [g/g]	0.008	0.008	0	0
Slurry ethene consumption feed [g]	1000	950	700	550
Gas phase inert gas pressure [barg]	13	13	14.5	14.5
Gas phase hydrogen batch [g]	0.017	0.028	0.022	0.025
Gas phase 1-hexene batch [g]	9	9	40	25
Gas phase hydrogen/ethene feed ratio [g/g]	0.000043	0.000041	0.000036	0.000057
Gas phase 1-hexene/ethene feed ratio [g/g]	0.066	0.066	0.156	0.112
Gas phase ethene consumption feed [g]	1345	1279	912	762

10 The polymers were mixed with 0.027 wt% FX 5922 (3M Dynamar Polymer Processing Additive) and 0.24 wt% Irganox B 561 (BASF), where wt% are relative to total weight of composition (the sum of mMDPE powder + additive = 100%) compounded and extruded on a ZSK 18 twin screw extruder. The melt temperature was ~195°C production rate was 2kg/h for both IEs and 4 kg/h for CE1/2.

15 As Comparative Example 3 (CE3) the polymer of WO2008089978, Example 1 is used. Polymerization conditions are given in Table 1 of WO2008089978.

Table 2: Material properties of CE1 to CE3, IE1 and IE2

Material	CE1	CE2	IE1	IE2	CE3
MFR ₂ (g/10 min) (final)	0.44	0.72	0.52	1.38	0.84
MFR ₂₁ (g/10 min)	13.0	20.0	19.0	41.0	n.d.
MFR ₂₁ /MFR ₂ (FRR)	26.0	25.0	31.7	29.3	n.d.
MFR ₂ (g/10 min) Component (A)	2.3	2.3	7.6	7.6	15
Density (kg/m ³) Component (A)	943.4	943.4	946.9	966.5	homopolymer
Split GPR (%)	57	57	58	58	61
MFR ₂ (g/10 min) Component (B)	0.13	0.30	0.07	0.40	0.13
Density (kg/m ³) Component (B)	917	919	910	906	n.d.
Density (kg/m ³)	928.5	929.5	925.7	931.2	930
Mw (kg/mol)	119	107	114	88.65	148
Mn (kg/mol)	28.7	27.1	20.15	17.6	43.4
Mw/Mn (MWD)	4.15	3.95	5.66	5.04	3.4
C4 (mol%)	0.2	0.2	0	0	0
C6 (mol%)	1.0	1.0	2.9	2.1	2.13
C6 in GPR (mol%)	1.8	1.8	5.0	3.6	n.d.
Tm (°C)	123.3	123.5	128.7	129.8	126.4

n.d. not determined

Monolayer blown films

5 **Table 3:** Properties of blown films

	IE1	IE2	CE1	CE2	CE3
TM/MD (MPa)	313	403	315	344	n.d.
TM/TD (MPa)	364	452	363	371	n.d.
DDI (g)	1050	230	225	195	1010
Rel. tear resistance MD (N/mm)	198	92	59	54	n.d.
Rel. tear resistance TD (N/mm)	179	215	172	164	n.d.
SIT (°C)	110	119	115	116	n.d.
TM(MD)*DDI/SIT	2988	780	616	577	n.d.
Haze (%)	15.7	28.1	9.2	9.7	51.7

As can be seen from the above Table 3 the films based on the metallocene catalysed mMDPEs according to the present invention have an improved mechanical performance

(higher stiffness at the same dart-drop impact strength (DDI) or higher dart-drop impact strength (DDI) at the same stiffness) without deteriorating the sealing performance and still having acceptable optical properties, especially haze.

The inventive films show the best balance between stiffness, impact and sealing properties.

- 5 In addition, the films based on the mMDPEs according to the present invention have an improved relative tear resistance.

Claims

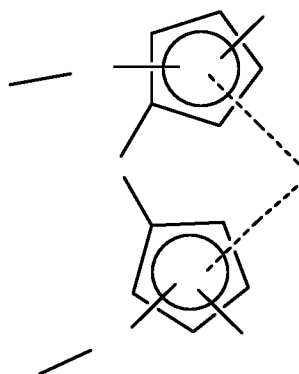
1. A metallocene catalysed multimodal medium density polyethylene (mMDPE), which consists of
- (i) 35.0 to 50.0 wt%, based on the mMDPE, of a polyethylene component (A), and
- 5 (ii) 50.0 to 65.0 wt%, based on the mMDPE, of a polyethylene component (B), whereby the polyethylene polymer component (A) has
- a density (ISO 1183) in the range of 950 to 975 kg/m³,
- a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 3.0 to 50.0 g/10 min;
- the polyethylene component (B) has
- 10 a density (ISO 1183) in the range of 900 to 925 kg/m³,
- a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 0.001 to 1.0 g/10 min;
- whereby the metallocene catalysed medium density polyethylene (mMDPE) has
- a density (ISO 1183) in the range of 920 to 945 kg/m³,
- a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 0.1 to 5.0 g/10 min and
- 15 a ratio of the MFR₂₁ (190°C, 21.6 kg, ISO 1133) to MFR₂ (190°C, 2.16 kg, ISO 1133), MFR₂₁/MFR₂, in the range of 27 to 40 and
- a molecular weight distribution (MWD), Mw/Mn, (measured with GPC) in the range of 4.2 to 10.0.
- 20 2. The metallocene catalysed multimodal medium density polyethylene (mMDPE), according to claim 1, wherein the mMDPE has one or two or all of:
- a density (ISO1183) in the range of 922 to 940 kg/m³, preferably 923 to 935 kg/m³,
- a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 0.2 to 3.0 g/10 min, preferably 0.3 to 2.5 g/10 min and more preferably 0.4 to 2.0 g/10 min,
- 25 a MFR₂₁ (190°C, 21.6 kg, ISO 1133) in the range of 10.0 to 55.0 g/10 min, preferably in a range of 12.0 to 50.0 g/10min and more preferably in the range of 15.0 to 45.0 g/10 min and/or a Flow Rate Ratio (FRR), MFR₂₁/MFR₂ in the range of 28.0 to 38.0, preferably of 29.0 to 35.0.
3. The metallocene catalysed multimodal medium density polyethylene (mMDPE) according to claim 1 or 2, wherein the mMDPE has
- 30 a molecular weight distribution (MWD), Mw/Mn, in the range of 4.5 to 8.0, preferably 4.8 to 6.5 and a weight average molecular weight, Mw, (measured with GPC) of at least 60000 g/mol, preferably in the range of 70000 to 130000 g/mol, more preferably 75000 to 125000 g/mol, still more preferably 80000 to 120000 g/mol.
- 35 4. The metallocene catalysed multimodal medium density polyethylene (mMDPE) according to any of the preceding claims 1 to 3, wherein in the mMDPE, the polyethylene component (A)

is a polyethylene homopolymer and polyethylene component (B) is a copolymer of ethylene and a C4 to C8 comonomer, preferably C4 to C6 comonomer and more preferably a copolymer of ethylene and 1-hexene.

- 5 5. The metallocene catalysed multimodal medium density polyethylene (mMDPE) according to any of the preceding claims 1 to 4, wherein in the mMDPE, the polyethylene component (A) has a density (ISO 1183) in the range in the range of 955 to 972 kg/m³, preferably 960 to 970 kg/m³ and more preferably 962 to 968 kg/m³ and a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 4.0 to 30.0 g/10min, preferably 5.0 to 20.0 g/10min
10 and more preferably 6.0 to 15 g/10min, and the polyethylene component (B) has a density (ISO 1183) in the range of 903 to 920 kg/m³, preferably 905 to 915 kg/m³ and more preferably 905 to 912 kg/m³ and a MFR₂ (190°C, 2.16 kg, ISO 1133) in the range of 0.005 to 0.8 g/10min, preferably 0.01 to 0.6 g/10min and more preferably 0.05 to 0.5 g/10min.

- 15 6. The metallocene catalysed multimodal medium density polyethylene (mMDPE) according to any of the preceding claims 1 to 5, wherein the mMDPE has a total amount of C4 to C8 comonomer, preferably C4 to C6 comonomer and more preferably 1-hexene, in the range of 1.5 to 5.0 mol%, preferably 1.6 to 4.0 mol%, more preferably 1.7 to 3.5 mol% and yet more
20 preferably 1.8 to 3.0 mol%, based on the mMDPE and a total amount of C4 to C8 comonomer, preferably C4 to C6 comonomer and more preferably 1-hexene, in the polyethylene component (B) preferably in the range of 2.0 to 8.0 mol%, more preferably 2.5 to 7.0 mol %, even more preferably 3.0 to 6.0 mol% and yet more preferably 3.2 to 5.5 mol%, based on component (B).

- 25 7. The metallocene catalysed multimodal medium density polyethylene (mMDPE) according to anyone of the preceding claims, wherein the mMDPE is produced in the presence of a metallocene complex of formula (I):



(I)

wherein each X is independently a halogen atom, a C₁₋₆-alkyl group, C₁₋₆-alkoxy group, phenyl or benzyl group;

each Het is independently a monocyclic heteroaromatic group containing at least one heteroatom selected from O or S;

5 L is -R'₂Si-, wherein each R' is independently C₁₋₂₀-hydrocarbyl or C₁₋₁₀-alkyl substituted with alkoxy having 1 to 10 carbon atoms;

M is Ti, Zr or Hf;

each R₁ is the same or different and is a C₁₋₆-alkyl group or C₁₋₆-alkoxy group;

each n is 1 to 2;

10 each R₂ is the same or different and is a C₁₋₆-alkyl group, C₁₋₆-alkoxy group or -Si(R)₃ group;

each R is C₁₋₁₀-alkyl or phenyl group optionally substituted by 1 to 3 C₁₋₆-alkyl groups; and

each p is 0 to 1.

8. A film comprising the metallocene catalysed multimodal medium density polyethylene
15 (mMDPE) according to any of the preceding claims 1 to 7.

9. The film according to claim 8, wherein the film comprises at least 50 wt%, more preferably at least 60 wt%, even more preferably at least 70 wt%, yet more preferably at least 80 wt%, based on the total weight of the film of the metallocene catalysed mMDPE according to any of
20 the preceding claims 1 to 7, an most preferably said film consists of the metallocene catalysed mMDPE.

10. The film according to claim 8 or 9, wherein the film has

a) a tensile modulus (measured on a 40 μm monolayer test blown film according to ISO 527-
25 3) in machine (MD) direction in the range of 350 MPa to 800 MPa, preferably of 380 MPa to 500 MPa and in transverse (TD) direction in the range of 400 MPa to 800 MPa, preferably of 420 MPa to 550 MPa and

b) a dart-drop impact strength (DDI) determined according to ISO 7765-1:1988 on a 40 μm monolayer test blown film of at least 150 g up to 500 g, preferably 200 g up to 450 g and more
30 preferably 220 g up to 400 g and

c) a relation between mechanical properties and sealing properties according to formula (I):

$$\frac{\text{Tensile Modulus (MD)[MPa]} * \text{DDI(g)}}{\text{SIT [}^{\circ}\text{C]}} > 650$$

determined on 40 μm test blown film, wherein the Tensile Modulus in machine direction is measured according to ISO 527-3 at 23°C on 40 μm test blown films, DDI is the dart-drop
35 impact strength determined according to ISO 7765-1:1988 on a 40 μm test blown film and SIT

is the sealing initiation temperature measured as described in the experimental part on a 40 µm test blown film.

11. The film according to claim 8 or 9, wherein the film has

- 5 a) a tensile modulus (measured on a 40 µm monolayer test blown film according to ISO 527-3) in machine (MD) direction in the range of 200 MPa to 600 MPa, preferably of 250 MPa to 400 MPa and in transverse (TD) direction in the range of 250 MPa to 600 MPa, preferably of 300 MPa to 500 MPa and
- 10 b) a dart-drop impact strength (DDI) determined according to ISO 7765-1:1988 on a 40 µm monolayer test blown film of at least 700 g up to 2000 g, preferably 800 g up to 1600 g and more preferably 900 g up to 1400 g and
- c) a relation between mechanical properties and sealing properties according to formula (I):

$$\frac{\text{Tensile Modulus (MD)[MPa]} * \text{DDI(g)}}{\text{SIT [}^{\circ}\text{C]}} > 1000$$

- 15 determined on 40 µm test blown film, wherein the Tensile Modulus in machine direction is measured according to ISO 527-3 at 23°C on 40 µm test blown films, DDI is the dart-drop impact strength determined according to ISO 7765-1:1988 on a 40 µm test blown film and SIT is the sealing initiation temperature measured as described in the experimental part on a 40 µm test blown film.

- 20 12. The film according to any of the preceding claims 8 to 11, wherein the film has a haze measured on 40 µm test blown films according ASTM D1003 of below 35%, preferably in the range of 5 to 32% more preferably of 10 to 30%, even more preferably in the range of 10 to 20% or 21 to 30%.

- 25 13. The film according to any of the preceding claims 8 to 12, wherein the film has a relative Elmendorf tear resistance measured according to ISO 6383/2 on a blown film with a film thickness of 40 µm in machine direction (MD) of at least 60 N/mm up to 300 N/mm, preferably 70 N/mm up to 250 N/mm and more preferably 80 N/mm up to 220 N/mm and in transversal direction (TD) of at least 140 N/mm up to 350 N/mm, preferably 150 N/mm up
- 30 to 300 N/mm and more preferably 170 N/mm up to 250 N/mm.

14. Use of the film according to any of the preceding claims 8 to 13 in packaging applications or as a layer in multilayer polyethylene based blown film, preferably as core layer in multilayer polyethylene based blown films.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/066544

A. CLASSIFICATION OF SUBJECT MATTER

INV. C08F210/16 B32B27/32 C08J5/18 C08L23/08
ADD. C08F4/659

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)

C08J B32B C08F C08L

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 practicable, 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	WO 2021/191019 A1 (BOREALIS AG [AT])	1-14
	30 September 2021 (2021-09-30)	
Y	page 9; claims 1, 2, 8, 12-15; examples	1-14
	IE1-4; tables 1, 2	

X	WO 2021/009192 A1 (BOREALIS AG [AT])	1-14
	21 January 2021 (2021-01-21)	
Y	claims 1, 12, 15; example IE1; table 1	1-14

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/066544

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		EP 4126994 A1	08-02-2023
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		WO 2021009192 A1	21-01-2021
