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Superior sealing performance polyethylene films

The present invention relates to a polyethylene sealant film comprising an outer layer O, a core layer C and an inner layer I, wherein the inner layer comprises a composition with optimized sealing performance comprising a linear low density ethylene polymer and an ethylene-based plastomer. Furthermore, the invention relates to a laminate and article comprising the film, and to the use of said laminate or film; and the use of the respective composition in a sealant film.

Polyethylene-based laminates are usually prepared from a flexible film structure comprising a polyethylene sealant film adhered to a substrate film, which is commonly made of polyester (PET), biaxially oriented polypropylene (BOPP), or biaxially oriented polyamide (BOPA). Laminates are generally employed to match multi-functional requirements: sealant film is used for sufficient toughness-related properties and to ensure package seal integrity; whereas substrate film is used for stiffness and barrier-related properties to ensure improved shelf life of packed goods and to enable good handling operations during packaging on Form, Fill & Seal (FFS) machines. Coextruded blown films are widely used in a variety of packaging applications and film properties are often subject to the combined effect of the co-extrusion process conditions and polymer compositions selected for the different layers.

Nowadays, there is a trend to provide "100% PE" solutions, i.e. laminates consisting of a polyethylene substrate film laminated to a polyethylene sealant film, since such laminates – being based on a single class of resin - can be easily recycled. This brings huge challenges to the flexible packaging industry, as replacing high performance substrates like BOPET and BOPA by polyethylene substrates, which can run smoothly on the existing high-speed FFS packaging machines, is very challenging. For example, MDO PE substrates often contained in "pure" polyethylene laminates usually have lower heat resistance compared to other PET, BOPP, BOPA substrates and, thus, always tend to have a limited process window on the FFS packaging machines. The suitable selection of a sealant film for combination with a substrate film can overcome the above challenges and fulfil the requirements on high-speed packaging applications.

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Several approaches have been made to provide such "100% PE" solutions. For example, WO 2019/005930 discloses polyethylene laminates for use in flexible packaging materials, wherein the sealant film comprises a particular ethylene interpolymers in the lamination layer and at least one of the layers comprises a composition comprising at least one ethylene based polymer having a Molecular Weighted Comonomer Distribution Index (MWCDI) value greater than 0.9, and a melt index ratio (I_{10}/I_2) that meets the following equation: $I_{10}/I_2 \geq 7.0 - 1.2 \times \log(I_2)$. The substrate (print) film comprises an HDPE in the middle layer.

Although numerous efforts have been made to explore alternative film designs with well-balanced laminate performance, yet room for improvement remains with respect to the overall laminate design and sealing performance to run on high-speed FFS machines. Thus, there is a steady need to further improve properties of polyethylene laminates and sealant films and to provide film formulations with superior sealing behavior, in addition to the general requirements on the packaging performance of the films such as optical properties, stiffness and other mechanical properties, and in particular to match the performance on FFS packing machines.

Therefore, it is an object of the present invention to provide sealant films and respective laminated films, based on polyethylene polymers, with the above-described properties.

This object is achieved by the present invention, which provides a polyethylene sealant film comprising an outer layer O, a core layer C and an inner layer I, wherein the inner layer I is made of an inner layer composition comprising:

- a) a component AI, which is a linear low density ethylene polymer having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133,
- b) a component BI, which is an ethylene-based plastomer, preferably is a copolymer of ethylene and a C3 to C10 alpha-olefin, preferably 1-octene, and which has an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133, and a density of from 880 to 912 kg/m³, in an amount of 30 to 80 wt.%, based on the total weight of the inner layer composition, and
- c) a slip agent.

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The present invention is based on the finding that such polyethylene sealant films, which can be used in packaging materials, may be provided by a film comprising an inner (sealing) layer, wherein the inner layer composition comprises a combination of particularly selected linear low density ethylene polymer and ethylene-based plastomer, and a slip agent.

The composition of the inner layer I of the polyethylene sealant films according to the present invention solves the above objects.

Generally, the films according to the present invention are polyethylene-based films, which may easily be recycled. They are characterized by all the physical properties required for packaging applications.

The films have excellent sealing properties, displayed in low seal initiation and hot tack temperatures, and are further characterized by a low coefficient of friction. Accordingly, the films according to the present invention may be run on conventional packaging lines at high-speed conditions.

In the present invention, the polyethylene sealant film comprises, or consists of, an outer layer O, a core layer C and an inner layer I, wherein the core layer C is located between the inner layer I and the outer layer O.

Inner Layer I

The inner layer I, which is the sealing layer of the sealant film, is an external layer of the film, and it is made of an inner layer composition comprising components, which particularly contribute to heat and sealing properties.

Component A1

The inner layer I is made of an inner layer composition comprising a component A1, which is a linear low density ethylene polymer (LLDPE) having a density of from 910 to 925 kg/m³, determined according to ISO 1183, and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133.

LLDPEs are well known in the art and are produced in polymerization processes using a catalyst.

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In one embodiment, the LLDPE of component AI is an ethylene copolymer, preferably a multimodal ethylene copolymer, preferably having a density of from 910 kg/m³ to 925 kg/m³ and/or an MFR₂ of from 0.5 to 2.0 g/10 min.

5 Preferably, the ethylene copolymer has a ratio MFR₂₁/MFR₂ of from 13 to 30 and/or an MWD of 6 or less.

Preferably, the ethylene copolymer comprises, or consists of, a multimodal polymer of ethylene with one or more comonomers selected from alpha-olefins having from 4 to 10 carbon atoms, which has a ratio MFR₂₁/MFR₂ of from 13 to 30 and an MWD of 6 or less.

10 Such multimodal ethylene copolymers are disclosed, for example, in WO2016/083208.

The multimodal ethylene copolymer preferably has an MFR₂ of from 0.6 to 2.0 g/10 min, and particularly preferred from 1.2 to 1.8 g/10 min.

15 Preferably, the multimodal ethylene copolymer has a density of from 910 to 925 kg/m³, more preferably of from 913 to 922 kg/m³, and particularly preferred of from 916 to 920 kg/m³.

The multimodal ethylene copolymer preferably has a ratio MFR₂₁/MFR₂ of from 13 to 30, more preferably from 15 to 25.

20 The multimodal ethylene copolymer preferably has an MWD of 6 or less and usually more than 1, more preferably of from 3 to 5.

The alpha-olefin comonomers having from 4 to 10 carbon atoms of the multimodal ethylene copolymer are preferably 1-butene and/or 1-hexene.

25 Preferably, the total amount of comonomers present in the multimodal ethylene copolymer is from 0.5 to 10 mol%, preferably from 1 to 8 mol%, more preferably from 1 to 5 mol%, still more preferably from 1.5 to 5 mol% and most preferably from 2.5 to 4 mol%.

30 In a preferred embodiment, the multimodal ethylene copolymer is a bimodal copolymer, i.e. it comprises a low molecular weight and a high molecular weight component, and has an MFR₂ of from 1.2 to 1.8 g/10 min, and/or an MFR₅ of from 3.0 to 5.0 g/10 min, and/or an MFR₂₁ of from 20 to 40 g/10 min, and/or a

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density of from 916 to 920 kg/m³, and/or a molecular weight distribution (MWD) of from 3 to 5, and/or an M_n of from 15 to 25 kg/mol, and/or an M_w of from 80 to 115 kg/mol, and/or an MFR_{21}/MFR_2 ratio ($FRR_{21/2}$) of from 15 to 25, and/or an MFR_{21}/MFR_5 ratio ($FRR_{21/5}$) of from 6 to 9.

- 5 In a further preferred embodiment, the ethylene copolymer of component A1 comprises, or consists of, an ethylene terpolymer, more preferably a multimodal ethylene terpolymer (I).

Preferably, the multimodal ethylene terpolymer (I) is an ethylene terpolymer having a density of from 910 kg/m³ to 925 kg/m³ and an MFR_2 of from 0.5 to 2.0 g/10 min.

The multimodal ethylene terpolymer (I) preferably comprises, or consists of, a multimodal polymer of ethylene with at least two different comonomers selected from alpha-olefins having from 4 to 10 carbon atoms, which has a ratio MFR_{21}/MFR_2 of from 13 to 30 and an MWD of 5 or less.

- 15 Such multimodal ethylene terpolymers are disclosed, for example, in WO2016/083208. As far as definitions (such as for the "modality" of a polymer) and production methods for these ethylene terpolymers are concerned, it is referred to WO2016/083208. Furthermore, all embodiments and preferred embodiments of such ethylene terpolymers as described in WO2016/083208, which
20 have a density in the range of from 910 to 925 kg/m³ are also preferred embodiments of the multimodal ethylene terpolymer (I) in the present disclosure, whether or not explicitly described herein.

The multimodal ethylene terpolymer (I) preferably has an MFR_2 of from 0.6 to 2.0 g/10 min, and particularly preferred from 1.2 to 1.8 g/10 min.

- 25 Preferably, the multimodal ethylene terpolymer (I) has a density of from 910 to 925 kg/m³, more preferably from 913 to 922 kg/m³, and particularly preferred from 916 to 920 kg/m³.

The multimodal ethylene terpolymer (I) preferably has a ratio MFR_{21}/MFR_2 of from 13 to 30, more preferably from 15 to 25.

- 30 The at least two alpha-olefin comonomers having from 4 to 10 carbon atoms of the multimodal ethylene terpolymer (I) are preferably 1-butene and 1-hexene.

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Preferably, the total amount of comonomers present in the multimodal ethylene terpolymer (I) is from 0.5 to 10 mol%, more preferably from 1 to 8 mol%, even more preferably from 1 to 5 mol%, still preferably from 1.5 to 5 mol% and most preferably from 2.5 to 4 mol%.

- 5 The multimodal ethylene terpolymer (I), which preferably is a bimodal terpolymer, preferably comprises, or consists of, an ethylene polymer component (A) and an ethylene polymer component (B), wherein the ethylene polymer component (A) has higher MFR₂ than the ethylene polymer component (B).

- 10 Preferably, the ethylene polymer component (A) has an MFR₂ of from 1 to 50 g/10 min, more preferably from 1 to 40 g/10 min, even more preferably from 1 to 30 g/10 min, still more preferably from 2 to 20 g/10 min, still more preferably from 2 to 15 g/10 min and most preferably from 2 to 10 g/10 min.

- 15 The ratio of the MFR₂ of ethylene polymer component (A) to the MFR₂ of the ethylene polymer component (B) is from 2 to 50, preferably from 5 to 40, more preferably from 10 to 30, even more preferably from 10 to 25 and most preferably from 11 to 25.

Preferably, the ethylene polymer component (A) comprises a different comonomer than the ethylene polymer component (B).

- 20 Preferably, the ethylene polymer component (A) has lower amount (mol%) of comonomer than the ethylene polymer component (B), more preferably, the ratio of [the amount (mol%) of the alpha-olefin comonomer having from 4 to 10 carbon atoms comonomer present in ethylene polymer component (A)] to [the amount (mol%) of at least two alpha-olefin comonomers having from 4 to 10 carbon atoms of the final multimodal ethylene terpolymer] is of from 0.10 to 0.60, preferably from 0.15 to 0.50.

Preferably, the alpha-olefin comonomer having from 4 to 10 carbon atoms of the ethylene polymer component (A) is 1-butene and the alpha-olefin comonomer having from 4 to 10 carbon atoms of the ethylene polymer component (B) is 1-hexene.

- 30 Preferably, the ethylene polymer component (A) has different, preferably higher, density than the density of the ethylene polymer component (B).

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The density of the ethylene polymer component (A) is preferably from 925 to 950 kg/m³, more preferably from 930 to 945 kg/m³.

- Preferably, the multimodal ethylene terpolymer (I) comprises the ethylene polymer component (A) in an amount of from 30 to 70 wt.%, more preferably from 40 to 60 wt.%, even more preferably from 35 to 50 wt.%, still more preferably from 40 to 50 wt.%; and the ethylene polymer component (B) in an amount of from 70 to 30 wt.%, more preferably from 60 to 40 wt.%, even more preferably from 50 to 65 wt.%, still more preferably from 50 to 60 wt.%, based on the total amount (100 wt.%) of the multimodal ethylene terpolymer (I).
- 10 Most preferably, the multimodal ethylene terpolymer (I) consists of the ethylene polymer components (A) and (B) as the sole polymer components. Accordingly, the split between the ethylene polymer component (A) to the ethylene polymer component (B) is (30 to 70):(70 to 30) preferably (40 to 60):(60 to 40), more preferably (35 to 50):(65 to 50), still more preferably (40 to 50):(50 to 60).
- 15 In a particularly preferred embodiment, the multimodal ethylene terpolymer (I) is a bimodal terpolymer, i.e. comprises a low molecular weight and a high molecular weight component, and has an MFR₂ of from 1.2 to 1.8 g/10 min, and/or an MFR₅ of from 3.0 to 5.0 g/10 min, and/or an MFR₂₁ of from 20 to 40 g/10 min, and/or a density of from 915 to 920 kg/m³, and/or a molecular weight distribution (MWD) of from 3.0 to 5.0, and/or an M_n of from 15 to 25 kg/mol, and/or an M_w of from 80 to 115 kg/mol, and/or an MFR₂₁/MFR₂ ratio (FRR_{21/2}) of from 15 to 25, and/or an MFR₂₁/MFR₅ ratio (FRR_{21/5}) of from 6 to 9.

Preferred as the multimodal ethylene terpolymers (I) are also commercially available products such as Anteo™ from Borealis or Borouge having the properties as required herein, especially Anteo™ FK1828 or Anteo™ FK1820.

Preferably, the component AI is present in an amount of from 10 to 70 wt.%, more preferably from 20 to 60 wt.%, in the inner layer composition, based on the total weigh of the inner layer composition.

Component BI

- 30 The inner layer composition further comprises a component BI, which is a an ethylene-based plastomer, preferably is a copolymer of ethylene and a C3 to C10 alpha-olefin, preferably 1-octene, and which has an MFR₂ of from 0.5 to 2.0

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g/10 min, determined according to ISO 1133, and a density of from 880 to 912 kg/m³. The component BI is present in the inner layer composition in an amount of 30 to 80 wt.%, based on the total weight of the inner layer composition.

5 It has been found that the presence of a plastomer in the inner (sealing) layer changes the softness of the sealing layer and enables lower sealing temperatures.

10 Preferably, the plastomer of component BI is a copolymer of ethylene and a C3 to C10 alpha-olefin, preferably a copolymer of ethylene and 1-butene, 1-hexene or 1-octene and most preferably a copolymer of ethylene and 1-octene. The content of the comonomer, such as 1-octene, in the plastomer may be 5.0 to 40.0 wt.%, such as 15.0 to 30.0 wt.%, based on the total weight of the plastomer.

The plastomer has an MFR₂ of from 0.5 to 2.0 g/10 min and preferably from 0.8 to 1.5 g/10 min, determined according to ISO 1133.

15 The plastomer has a density of from 880 to 912 kg/m³ and preferably from 890 to 910 kg/m³, determined according to ISO 1183.

Preferably, the plastomer has a molecular mass distribution Mw/Mn of below 4, such as 3.8 or below, but of at least 1.5. Preferably, the molecular mass distribution Mw/Mn is between 3.5 and 1.8.

20 As the ethylene-based plastomer of component BI, any copolymer of ethylene and propylene or ethylene and 1-butene, 1-hexene or 1-octene having the above defined properties may be used, which are commercial available, e.g. from Borealis under the tradename Queo (such as Queo 0201FX), from DOW Chemical Corp (USA) under the tradename Engage or Affinity, or from Mitsui Chemicals under the tradename Tafmer.

25 Alternatively, ethylene-based plastomers may be prepared by known processes, in a one stage or two stage polymerization process, comprising solution polymerization, slurry polymerization, gas phase polymerization or combinations therefrom, in the presence of suitable catalysts, like vanadium oxide catalysts or single-site catalysts, e.g. metallocene or constrained geometry catalysts, known to
30 the person skilled in the art.

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Preferably, the ethylene-based plastomers are prepared by a one stage or two stage solution polymerization process, especially by high temperature solution polymerization process at temperatures higher than 100 °C.

5 Such process is essentially based on polymerizing the monomer and a suitable comonomer in a liquid hydrocarbon solvent in which the resulting polymer is soluble. The polymerization is carried out at a temperature above the melting point of the polymer, as a result of which a polymer solution is obtained. This solution is flashed in order to separate the polymer from the unreacted monomer and the solvent. The solvent is then recovered and recycled in the process.

10 Preferably, the solution polymerization process is a high temperature solution polymerization process, using a polymerization temperature of higher than 100 °C. Preferably, the polymerization temperature is at least 110 °C, more preferably at least 150 °C. The polymerization temperature can be up to 250 °C.

15 The pressure in such a solution polymerization process is preferably in a range of 10 to 100 bar, preferably 15 to 100 bar and more preferably 20 to 100 bar. The liquid hydrocarbon solvent used is preferably a C5-C12 hydrocarbon which may be unsubstituted or substituted by C1-C4 alkyl group such as pentane, methyl pentane, hexane, heptane, octane, cyclohexane, methylcyclohexane and hydrogenated naphtha. More preferably, unsubstituted C6-C10 hydrocarbon sol-
20 vents are used.

Plastomers of the invention are ideally formed using metallocene-type catalysts.

A known solution technology suitable for the process according to the invention is the Borceed™ technology.

25 The component BI is present in an amount of from 30 to 80 wt.%, more preferably 40 to 80 wt.%, still more preferably 45 to 80 wt.% and most preferably from more than 45 to 80 wt.%, such as 50 to 70 wt.%, in the inner layer composition, based on the total weight of the inner layer composition.

In addition to the components AI and BI, the inner layer composition may comprise further components, which are different from the components AI and BI.

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Component CI

The inner layer composition may additionally comprise a component CI. Preferably, the component CI is a low density ethylene polymer (LDPE).

LDPEs are well known in the art and are produced in high pressure processes usually performed in a tubular reactor or an autoclave. LDPE and their production are, for example, described in WO2017/055174, page 9, line 29, to page 12, line 6, to which it is referred.

Preferably, the LDPE has a density of from 910 to 930 kg/m³ more preferably from 918 to 928 kg/m³ and most preferably from 920 to 925 kg/m³, determined according to ISO 1183.

Preferably, the LDPE has an MFR₂ of from 0.1 to 2.5 g/10 min, more preferably from 0.25 to 2.5 g/10 min, determined according to ISO 1133. In one embodiment, the LDPE has an MFR₂ of from 0.5 to 1 g/10 min; in another embodiment, the LDPE has an MFR₂ of from 1.5 to 2.5 g/10 min.

Preferably, the component CI is a low density ethylene polymer (LDPE) having a density of from 910 to 930 kg/m³ and an MFR₂ of from 0.1 to 2.5 g/10 min, more preferably a density of from 918 to 928 kg/m³ and an MFR₂ of from 0.25 to 2.3 g/10 min.

In one preferred embodiment, the LDPE of component CI has an MFR₂ of 1.6 to 2.40, and/or a density of 920 to 925 kg/m³, and/or an MWD of 5.5 to 9, and/or an M_n of 12 to 18 kg/mol, and/or an M_w of 80 to 130 kg/mol.

In another preferred embodiment, the LDPE of component CI has an MFR₂ of 0.5 to 1.0, and/or a density of 920 to 925 kg/m³, and/or an MWD of 5 to 8, and/or an M_n of 12 to 18 kg/mol, and/or an M_w of 85 to 130 kg/mol.

All molecular weight parameters of LDPE were measured by the GPC viscosity method as further described in detail below.

As the LDPE, resin FT6230 or FT6236 as produced by Borealis may be used. Alternatively, resin FT5230 or FT5236 as produced by Borealis may be used.

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Preferably, the component CI is present in an amount of from 5 to 20 wt.%, more preferably from 5 to 15 wt.%, in the inner layer composition, based on the total weight of the inner layer composition.

Additives

- 5 According to the invention, the inner layer composition comprises a slip agent. As per definition, a slip agent is an additive that changes the slip properties between films and between the film and converting equipment.

Preferably, the slip agent is present in the inner layer composition in an amount of from 50 to 5000 ppm, more preferably from 100 to 4000 ppm, even more preferably from 300 to 3000 ppm and most preferably from 400 to 2000 ppm, based on the total weight of the inner layer composition.

Preferably, the slip agent comprises a compound selected from the group consisting of fatty acid amides, such as erucamide, oleamide or stearamide, and combinations thereof.

- 15 In one embodiment, the inner layer comprises from 300 to 3000 ppm erucamide.

In one embodiment, the inner layer composition additionally comprises an anti-block agent. As per definition, an anti-block agent assists in minimizing surfaces from interacting with one another either through adhesion or other forces.

- 20 The anti-block agent may be present in the inner layer composition in an amount of from 50 to 5000 ppm, preferably from 100 to 4000 ppm, more preferably from 300 to 3000 ppm, based on the total weight of the inner layer composition.

- 25 Preferably, the anti-block agent comprises a compound selected from the group consisting of inorganic compounds such as talc, kaolin, cristobalite, natural silica and synthetic silica, diatomaceous earth, mica, calcium carbonate, calcium sulfate, magnesium carbonate, magnesium sulfate, and feldspars, and combinations thereof.

The slip agent and optionally anti-block agent may be added to the inner layer composition during preparation of the composition or may already be contained in any of the polymers used for the preparation of the inner layer.

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The slip agent and optionally anti-block agent may be added as pure compounds or as (e.g. commercially available) compositions including one or more of these agents, such as Polybatch FSU-105-E or Polybatch CE505E (provided by A. Schulman).

- 5 The inner layer composition may comprise further additives as described further below.

In one preferred embodiment, the inner layer composition comprises from 10 to 70 wt.%, preferably from 20 to 60 wt.%, of the component AI, from 30 to 80 wt.%, preferably from 40 to 80 wt.%, of the component BI, from 0 to 15 wt.% of the component CI and from 100 to 3000 ppm of the slip agent, each being based on
10 the total weight of the inner layer composition.

Core Layer C

The core layer C of the film is made of a core layer composition, which may comprise one or more components, which particularly contribute to stiffness of
15 the film necessary for film extrusion and lamination processes.

Component AC

The core layer composition may comprise a component AC. Preferably, the component AC is a linear low density ethylene polymer (LLDPE) having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0 g/10 min, determined
20 according to ISO 1133.

The component AC is preferably an LLDPE, as described for the component AI of the inner layer composition.

All embodiments described for the component AI are embodiments of the component AC. The component AC may be selected from anyone of these embodiments independently, and the selected embodiment may be the same or different
25 for AC and AI.

The component AC may be present in the core layer composition in an amount of from 10 to 30 wt.%, preferably 15 to 25 wt.%, based on the total weight of the core layer composition.

Component BC

The core layer composition may comprise a component BC. Preferably, the component BC is a linear low density ethylene polymer (LLDPE). LLDPEs are well known in the art and are usually produced in polymerization processes using a catalyst.

The LLDPE of component BC is preferably is a multimodal LLDPE, more preferably bimodal LLDPE. Such multimodal LLDPE and their production are, for example, described in WO 2004/000933 A1, p. 9 to 12 to which it is referred.

Preferably, the component BC has a density of from 915 to 930 kg/m³, preferably from 918 to 928 kg/m³, more preferably from 920 to 925 kg/m³.

Preferably, the component BC is an ethylene copolymer. The comonomer can be alpha-olefins having 4 to 12 carbon atoms, e.g. 1-butene, 4-methyl-1-pentene, 1-hexene, 1-octene, 1-decene. More preferably, the LLDPE is a copolymer of ethylene and 1-butene or 1-hexene, most preferred 1-butene.

Preferably, the total amount of comonomers present in the component BC is of 2.0 to 6.0 mol%, more preferably of 2.5 to 5.5 mol%, and most preferably 3.0 to 5.2 mol%.

Preferably, the component BC has an MFR₂ of from 0.10 to 0.45 g/10min, more preferably from 0.15 to 0.4 g/10min, and most preferably from 0.20 to 0.30 g/10min.

In a particularly preferred embodiment, the component BC has an MFR₂ of 0.20 to 0.30 g/10 min, and/or an MFR₅ of 0.80 to 1.2 g/10 min and/or an MFR₂₁ of 18 to 26 g/10 min, and/or a density of 920 to 925 kg/m³, and/or a molecular weight distribution (MWD) of 10 to 20, and/or an M_n of 10 to 15 kg/mol, and/or an M_w of 150 to 250 kg/mol, and/or an MFR₂₁/MFR₂ ratio (FRR_{21/2}) of 80 to 110 and/or an MFR₂₁/MFR₅ ratio (FRR_{21/5}) of 18 to 26.

As the component BC, resin Borstar FB2230 as produced by Borealis or Borouge may be used.

Preferably, the component BC is present in an amount of 70 to 90 wt.%, more preferably 75 to 85 wt.%, in the core layer composition, based on the total weight of the core layer composition.

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In one embodiment of the film, the core layer C is made of core layer composition comprising, or consisting of, the components AC and BC, selected from any of the embodiments as described above.

If both components are present in the core layer composition, the weight ratio of the components AC : BC is preferably from 10 : 90 to 30 : 70.

Preferably, the component AC is present in an amount of 10 to 30 wt.% and more preferably 15 to 25 wt.%, and the component BC is present in an amount of 70 to 80 wt.%, preferably 75 to 85 wt.%, in the core layer composition, based on the total weight of the core layer composition.

10 *Additives*

The core layer composition may comprise a slip agent and/or an anti-block agent. For the compounds, contents and further features of the additives, it is referred to the respective description of additives of the inner layer composition. The embodiments concerning the additives of the inner layer composition are also embodiments of the core layer composition.

In one embodiment, the core layer composition comprises a slip agent in an amount of from 50 to 5000 ppm and/or an anti-block agent in an amount of from 50 to 5000 ppm, each being based on the total weight of the core layer composition.

20 The core layer composition may comprise further additives as described further below.

Outer Layer O

The outer layer O is an external layer of the film, and it comprises components, which particularly contribute to heat resistance and optical properties of the film.

25 The outer layer O is preferably the layer used for lamination to a substrate.

The outer layer O is made of an outer layer composition, which may comprise one or more components.

Preferably, the outer layer composition is different from the inner layer composition and may be the same as or different from the core layer composition, for

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example may comprise the same polymer components as the core layer composition.

Component AO

5 The outer layer composition may comprise a component AO. Preferably, the component AO is a linear low density ethylene polymer (LLDPE) having a density of from 910 to 925 kg/m³, determined according to ISO 1183, and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133.

10 The component AO is preferably an LLDPE, as described for the component AI of the inner layer composition or the component AC of the core layer composition.

All embodiments described for the components AI and AC are embodiments of the component AO. The component AO may be selected from anyone of these embodiments independently, and the selected embodiment may be the same or different for AO and AI and/or AC.

15 Preferably, the component AO is present in an amount of from 10 to 30 wt.%, preferably 15 to 25 wt.%, in the outer layer composition, based on the total weight of the outer layer composition.

Component BO

20 The outer layer composition may comprise a component BO. Preferably, the component BO is a linear low density ethylene polymer (LLDPE).

The component BO is preferably an LLDPE, as described for the component BC of the core layer composition.

25 All embodiments described for the component BC are embodiments of the component BO. The component BO may be selected from anyone of these embodiments independently, and the selected embodiment may be the same or different for BO and BC.

Preferably, the component BO is present in an amount of from 70 to 90 wt.%, preferably 75 to 85 wt.%, in the outer layer composition, based on the total weight of the outer layer composition.

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If both components AO and BO are present in the outer layer composition, the weight ratio of AO : BO is preferably from 10 : 90 to 30 : 70.

Preferably, the component AO is present in an amount of 10 to 30 wt.% and more preferably 15 to 25 wt.%, and the component BO is present in an amount of 70 to 80 wt.%, preferably 75 to 85 wt.%, in the outer layer composition, based on the total weight of the outer layer composition.

In one embodiment, the components AO and BO of the inner layer composition are identical with the components AC and BC of the core layer composition, respectively.

10 The outer layer composition may comprise additives as described further below.

In one embodiment, the outer layer composition does not contain a slip agent and/or an anti-block agent.

Polyethylene Sealant Film

Structure

15 The polyethylene sealant film according to the present invention comprises, or consists of, several layers, and at least an inner layer I, an outer layer O and a core layer C, wherein the core layer is located between the inner layer I and the outer layer O.

In one embodiment, the film consists of an inner layer I, an outer layer O and a core layer C. In another embodiment, the film comprises one or more further intermediate (or sub-skin) layers X.

In a particular embodiment, the film further comprises one or more intermediate layer(s) X between the core layer C and the inner layer I, and the core layer C and the outer layer O, for example in a five layer film structure O/X1/C/X2/I.

25 Preferably, the film according to the invention comprises up to five layers.

If present, the intermediate layer(s) X preferably comprise(s), or consist(s) of, a composition similar to the composition of its neighboring layer, which may thus be a composition of the core layer C or either of a composition of the neighboring inner layer I or the neighboring outer layer O.

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Preferably, the polyethylene sealant film has a thickness of 40 to 80 μm , more preferably 45 to 75 μm and most preferably 50 to 70 μm .

In the polyethylene sealant film, the core layer C preferably has a thickness of 40 to 80 %, more preferably 45 to 75 % and most preferably 50 to 70 %, of the total film thickness.

The inner layer I and/or the outer layer O preferably each has/have a thickness of 5 to 30 %, preferably 10 to 30% and most preferably 15 to 25 %, of the total film thickness. In a five-layer film structure O/X1/C/X2/I, the inner layer I and/or the outer layer O preferably each has/have a thickness of 5 to 20 % of, more preferably of 7.5 to 15 %, of the total film thickness.

The expression "polyethylene (sealant) film" denotes a film that comprises, or consists of, at least one type of ethylene polymer, which may be a homopolymer or a copolymer of ethylene. Preferably, the polyolefin film comprises at least 90 wt.%, more preferably at least 95 wt.% and most preferably at least 98 wt.% of ethylene polymer, based on the total weight of the polyethylene film. Preferably, the polyethylene film comprises from 90 to 100 wt.%, more preferably from 95 to 100 wt.% and most preferably from 98 to 100 wt.% of ethylene polymer, based on the total weight of the polyethylene film. Most preferably, the polyethylene film consists of only ethylene polymer(s). Preferably, ethylene polymer comprises, or consists of, ethylene homopolymer and/or copolymer of ethylene with propylene and/or any of α -olefins having from 4 to 10 carbon atoms. Preferably, the polyethylene film does not contain non-polyolefin polymers, preferably does not contain non-polyethylene polymers. Use of polyethylene films enables the provision of fully recyclable and sustainable packaging structures.

The expression "sealant film" denotes a film that comprises a sealing layer, which is a layer that promotes bonding to another film, layer or article. The sealant film has an outer layer O, a core layer C, and an inner layer I, and optionally one or more sub-skin layer(s), wherein the inner layer is the sealing layer.

Generally, polyethylene films may be provided as oriented or non-oriented films. An oriented film is a film that has been "stretched" after its production. Oriented films are typically stretched by more than 300%, in the machine direction (MD) and/or longitudinal direction (TD), preferably by 500% and more. Films stretched in machine direction are often referred to as "MDO" films. Films stretched in two

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directions are referred to as "bi-axially oriented polyethylene" ("BOPE") films. A non-oriented film is a blown or cast film, which is not intentionally stretched after the film production (preferably, by more than 200%) by any suitable means i.e. subsequent heating and/or using the rollers during the film production.

- 5 Preferably, the polyethylene sealant film according to the present invention is a non-oriented film.

As is understood within the meaning of this disclosure, the polyethylene sealant film and its respective layer compositions for layer preparation may also comprise additives such as stabilizers, processing aids and/or pigments. Examples
10 of such additives are antioxidants, UV stabilizers, acid scavengers, nucleating agents, anti-block agents, slip agents etc. as well as polymer processing agents (PPA). The additives may be present in some or only in one layer of the polyethylene film, in the same or in different contents. The inner layer composition and optionally the core layer composition of the sealant comprise(s) a slip agent as
15 defined above. They may also comprise further additives.

Generally, each of the additives may be present in an amount of 0 to 5000 ppm, based on the total weight of the respective layer composition used for the preparation of the layers of the film. The additives are generally available from several suppliers and are contained in compositions as single additive or as ad-
20 mixtures of two or more additives. Such compositions may generally be present in an amount of 0 to 5 wt.% in the layer composition(s), based on the weight of the respective layer composition used for the preparation of the layers of the film.

Generally, the percentage (%) is to be understood as weight percentage (wt.%) within the meaning of this disclosure, unless otherwise indicated.

25 *Properties*

The film according to the invention has an excellent coefficient of friction (CoF). The coefficient of friction is important for maintaining good packaging performance (on FFS machines), particularly for high-speed packaging.

Preferably, the film has a dynamic coefficient of friction after 4 days of up to 0.30,
30 more preferably up to 0.25. Preferably, the film has a dynamic coefficient of friction after 4 days of from 0.05 to 0.30. The dynamic coefficient of friction (CoF) is

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determined according to ASTM D1894 and may be measured on outer or inner layers of the film, preferably, it is measured on the inner layers of the film.

The film according to the invention has an improved seal initiation temperature (SIT).

- 5 Preferably, the film has a seal initiation temperature (5 N) of less than 90 °C, more preferably of less than 85 °C. Also preferably, the film has a seal initiation temperature (5 N) of more than 70 °C, more preferably more than 75 °C. The seal initiation temperature (SIT) is determined according to ASTM F 2029 and ASTM F 88, preferably at the sealing layer of the film.
- 10 The film according to the invention has an improved hot tack temperature.
- Preferably, the film has a hot tack temperature (1 N) of less than 85 °C, more preferably of less than 80 °C. Also preferably, the film has a hot tack temperature (1 N) of more than 65 °C, more preferably more than 70 °C. The hot tack temperature is determined according to ASTM F 1921, preferably at the sealing layer
- 15 of the film.

Preparation

The polyethylene sealant film according to the present invention is generally prepared by a conventional process, wherein the layers of the film are co-extruded.

- 20 The different polymer components in any of the layers of the film are typically intimately mixed prior to layer formation, for example using a twin screw extruder, preferably a counter-rotating extruder or a co-rotating extruder. Then, the blends are converted into a coextruded film.

Generally, the sealant film according to the present invention can be produced by a blown film or cast film process, preferably by a blown film process.

- 25 In order to manufacture such sealant films, for example at least two polymer melt streams are simultaneously extruded (i.e. coextruded) through a multi-channel tubular, annular or circular die to form a tube which is blown-up, inflated and/or cooled with air (or a combination of gases) to form a film. The manufacture of blown film is a well-known process.

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The blown (co-)extrusion can be effected at a temperature in the range 150 to 230 °C, more preferably 150 to 225 °C and cooled by blowing gas (generally air) at a temperature of 10 to 40 °C, more preferably 12 to 16 °C to provide a frost line height of 0.5 to 4 times, more preferably 1 to 2 times the diameter of the die.

- 5 The blow up ratio (BUR) should generally be in the range of 1.5 to 3.5, preferably 2.0 to 3.0, more preferably 2.1 to 2.8.

Laminate & Article

The invention further relates to a laminated polyethylene film comprising the polyolefin sealant film according to the present invention. The laminated polyethylene film is a polyethylene film as defined for the expression "polyethylene (sealant) film" above.

A laminated polyethylene film may be obtained by laminating the sealant film according to the present invention to another film, such as a substrate film. This may be effected in any conventional lamination device using conventional lamination methods, such as adhesive lamination, including both solvent-based and solvent-less adhesive lamination using any conventional, commercially available adhesive. Lamination may alternatively be carried out without any adhesive, as sandwich lamination with or without a melt web, which may be pressed between the substrates. Such melt web may be any conventional melt web material based on polyethylene, such as LDPE. Lamination may further be performed via extrusion coating technique. All these lamination methods are well known in the art and described in literature.

In one embodiment, the sealant film, preferably via its outer layer O, is laminated to a substrate film and, thus, the laminated polyethylene film comprises or preferably consists of the sealant film according to the present invention and a substrate film, and optionally an adhesive layer.

The expression "substrate film" denotes a film that is used to provide physical stability (such as stiffness) to another film, e.g. if laminated to this film such as a sealant film. The substrate film may be produced by a blown film or cast film process as described above for the sealant film. The substrate film may be an oriented or a non-oriented film, orientation of films being as defined above. Preferably, the substrate film is an oriented film, preferably a uniaxially oriented film, such as a machine direction-oriented (MDO) film.

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Preferably, the substrate film is also a polyethylene film as defined for the expression "polyethylene (sealant) film" above. Use of laminated polyethylene films with high contents of polyethylene enables the provision of fully recyclable and sustainable packaging structures.

- 5 Preferably, the laminated polyethylene film has a thickness of 70 to 100 μm and more preferably 80 to 90 μm .

- Preferably, the laminated polyethylene film has a dynamic coefficient of friction after 4 days of up to 0.30. Preferably, the film has a dynamic coefficient of friction after 4 days of from 0.05 to 0.30. The dynamic coefficient of friction (CoF) is
10 determined according to ASTM D1894 and may be measured on outer or inner layers of the film, preferably, it is measured on the inner layers of the film.

- Preferably, the laminated polyethylene film has a seal initiation temperature (5 N) of less than 90 $^{\circ}\text{C}$, more preferably of less than 85 $^{\circ}\text{C}$. Also preferably, the film has a seal initiation temperature (5 N) of more than 70 $^{\circ}\text{C}$, more preferably
15 more than 75 $^{\circ}\text{C}$. The seal initiation temperature (SIT) is determined according to ASTM F 2029 and ASTM F 88, preferably at the sealing layer of the laminated film.

- Preferably, the laminated polyethylene film has a hot tack temperature (1 N) of less than 85 $^{\circ}\text{C}$, more preferably of less than 80 $^{\circ}\text{C}$. Also preferably, the film has
20 a hot tack temperature (1 N) of more than 65 $^{\circ}\text{C}$, more preferably more than 70 $^{\circ}\text{C}$. The hot tack temperature is determined according to ASTM F 1921, preferably at the sealing layer of the laminated film.

- The invention further relates to an article comprising the polyethylene sealant film according to the present invention and/or the laminated polyethylene film
25 according to the present invention. Preferred articles are packaging articles such as pouches, like stand up pouches, sacks, bag, sachets, lamitubes etc.

Use

- The invention further relates to the use of the polyethylene sealant film according to the present invention and/or the laminated polyethylene film according to the
30 present invention for packaging of an article. Particularly, they may be used in form, fill and seal packaging technology or in the formation of pouches, such as stand up pouches, sacks, bags, sachets or lamitubes.

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- Still further, the invention relates to the use of a composition comprising a component AI, which is a linear low density ethylene polymer having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133, a component BI, which is an ethylene-based plastomer, preferably is a copolymer of ethylene and a C3 to C10 alpha-olefin, preferably 1-octene, and which has an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133, and a density of from 880 to 912 kg/m³, in an amount of 30 to 80 wt.%, based on the total weight of the composition, and a slip agent, in the sealing layer of a film for improving sealing performance of the film.
- 10 Any one of the embodiments of the invention described herein can be combined with one or more of these embodiments. Particularly, any embodiment described for the sealant film of the invention is applicable to the laminated film, the article and to the use of the composition, the sealant film or the laminated film.
- 15 In the following, the invention will be further illustrated by way of examples and figures, wherein
- Fig. 1 depicts the seal initiation temperature curves (at 5 N) of the sealant films;
- Fig. 2 depicts the hot tack curves (hot tack initiation temperature at 1 N) of the sealant films;
- 20 Fig. 3 depicts the seal initiation temperature curves (at 5 N) of the laminated films (at the sealing layer); and
- Fig. 4 depicts the hot tack curves (hot tack initiation temperature at 1 N) of the laminated films (at the sealing layer).

Measurement and Determination Methods

- 25 The following definitions of terms and measurement and determination methods apply to the above general description of the invention as well as to the below examples. Unless otherwise indicated, the measurements of film properties were performed on sealant films with a thickness of 60 µm and laminated films with a thickness of 80 to 90 µm.

a) Melt Flow Rate MFR

The melt flow rate (MFR) was determined according to ISO 1133 and was indicated in g/10 min. The higher the melt flow rate, the lower the viscosity of the polymer. The MFR is determined at 190 °C for polyethylene and at 230 °C for polypropylene, at a loading of 2.16 kg (MFR₂), 5.00 kg (MFR₅) or 21.6 kg (MFR₂₁).

The quantity FRR ((melt) flow rate ratio) is an indication of molecular weight distribution and denotes the ratio of flow rates at different loadings. Thus, FRR_{21/5} denotes the value of MFR₂₁/MFR₅ and FRR_{21/2} denotes the value of MFR₂₁/MFR₂.

b) Density

Density of the polymer was measured according to ISO 1183-1:2004 (method A) on compression molded specimen prepared according to EN ISO 1872-2 (Feb 2007) and is given in kg/m³.

15 c) GPC**(1) GPC conventional method**

Unless otherwise indicated, the GPC conventional method is used for the measurement of ethylene polymers – except for LDPE.

Molecular weight averages (M_z, M_w and M_n), molecular weight distribution (MWD) and its broadness, described by polydispersity index, PDI= M_w/M_n (wherein M_n is the number average molecular weight and M_w is the weight average molecular weight) were generally determined by Gel Permeation Chromatography (GPC) according to ISO 16014-1:2003, ISO 16014-2:2003, ISO 16014-4:2003 and ASTM D 6474-12 using the following formulas:

$$25 \quad M_n = \frac{\sum_{i=1}^N A_i}{\sum_{i=1}^N (A_i/M_i)} \quad (1)$$

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

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

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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 between the integration limits.

- 5 A high temperature GPC instrument, equipped with either infrared (IR) detector (IR4 or IR5 from PolymerChar (Valencia, Spain)) or differential refractometer ((RI) from Agilent Technologies, equipped with 3 x Agilent-PLgel Olexis and 1x Agilent-PLgel Olexis Guard columns) was used. As mobile phase 1,2,4-trichlorobenzene (TCB) stabilized with 250 mg/L 2,6-Di tert-butyl-4-methyl-phenol) was
- 10 used. The chromatographic system was operated at column temperature of 160 °C and detector at 160 °C and at a constant flow rate of 1 mL/min. 200 µL 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.
- 15 The column set was calibrated using 19 narrow MWD polystyrene (PS) standards in the range of from 0.5 kg/mol to 11 500 kg/mol. 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:
- 20 **$K_{PS} = 19 \times 10^{-3} \text{ mL/g}$, $\alpha_{PS} = 0.655$**
 $K_{PE} = 39 \times 10^{-3} \text{ mL/g}$, $\alpha_{PE} = 0.725$

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

- All samples were prepared in the concentration range of around 1 mg/ml and dissolved at 160 °C for 3 (three) hours for PE in fresh distilled TCB stabilized
- 25 with 250 ppm Irgafos168 under continuous gentle shaking.

(2) GPC viscosity method

- Molecular weight averages (M_z , M_w and M_n), molecular weight distribution (MWD) of LDPE is measured by GPC-viscosity method using universal calibration. Molecular weight averages (M_w , M_n), Molecular weight distribution (MWD) and its
- 30 broadness, described by polydispersity index, $PDI = M_w/M_n$ (wherein M_n is the number average molecular weight and M_w is the weight average molecular weight) were determined by Gel Permeation Chromatography (GPC) according to ISO 16014-4 2019. A PL 220 (Polymer Laboratories) GPC equipped with an

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IR4 infrared detector, an online four capillary bridge viscometer (PL-BV 400-HT) was used. 3x Olexis and 1x Olexis Guard columns from Polymer Laboratories as stationary phase and 1,2,4-trichlorobenzene (TCB, stabilized with 250 mg/L 2,6-Di tert butyl-4-methyl-phenol) as mobile phase at 160 °C and at a constant flow rate of 1 mL/min was applied. 200 µL of sample solution were injected per analysis. The corresponding detector constant of the viscometer as well as the inter-detector delay volumes were determined with a narrow PS standard (MWD = 1.01) with a molar mass of 132900 g/mol and an intrinsic viscosity of 0.4789 dl/g. The detector constant of the IR4 detector was determined using NIST1475a with dn/dc of 0.094 cm³/g.

The column set was calibrated using universal calibration (according to ISO 16014-2:2019) with at least 15 narrow MWD polystyrene (PS) standards in the range of 0.5 kg/mol to 11600 kg/mol. The corresponded intrinsic viscosities of the PS standards were calculated from their corresponding concentration (IR4), online viscometer signals, and determined detector constants for polystyrene. For low molecular weight PS with a molar mass below 3000 g/mol the initial weight out concentration is used, due to end group effects in the IR detector.

The molecular weight of the sample (M₂) at each chromatographic slice using the universal calibration approach can be calculated by following correlation:

$$\log M_1[\eta_1] = V_R = \log M_2[\eta_2]$$

with: M₁ Molar mass of PS
 η₁ intrinsic viscosity of the PS
 M₂ Molar mass of sample
 η₂ intrinsic viscosity of sample
 V_R Retention volume

All data processing and calculation was performed using the Cirrus Multi-Offline SEC-Software Version 3.2 (Polymer Laboratories a Varian inc. Company).

All samples were prepared by dissolving 5.0 – 9.0 mg of polymer in 8 mL (at 160 °C) of stabilized TCB (same as mobile phase) for 2.5 hours for PP or 3 hours for PE at max. 160 °C under continuous gentle shaking.

d) Comonomer Content

The comonomer content was determined as described in WO2019081611, pages 31 to 34.

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e) Coefficient of friction

The dynamic Coefficient of Friction (CoF) as a measure of the frictional behavior of the film was determined using a method according to ISO 8295:1995 and ASTM D1894-11. It may be measured on outer or inner layers of the film, preferably, it is measured on the inner layers of the film.

The apparatus was similar as shown in Figure 1(c) of ASTM D1894. Three samples of size 210x297 mm were cut in machine direction from the coated material and they were thermostated at 23 °C for at least 16 hours. The test was also conducted at this temperature. The sample was fastened to the table so that the machine direction of the sample coincides with the direction in which the sled moves during the test. An aluminum foil having a size of 65x140 mm was fastened to the sled. The foil was inspected to see that it was free of wrinkles. The weight of the sled (including the foil) was 200 grams $\pm$ 2 grams. The sled was connected to the load cell of Instron universal testing machine as shown in Figure 1(c) of ASTM D1894. The sled was then pulled with a constant speed (100 mm/min) along the table. The recording from the load cell was then collected over time. An average force that was required to keep the sled moving, i.e., the dynamic friction force F_f was then determined as described in paragraph 9.2 of ISO 8295:1995. The dynamic coefficient of friction was then calculated as described in ISO 8295:1995, i.e. $CoF = F_f / w \cdot g$, where F_f is the dynamic friction force in N, w is the weight of the sled in kg and g is the gravitational constant 9.81 m/s². Three replicate runs were conducted. If any information were missing from the abovementioned description then the information given in ISO 8295:1995 should be used for experimental conditions and ASTM D1894, Figure 1 and paragraph 5 for the apparatus.

f) Seal initiation temperature (SIT)

The seal initiation temperature (SIT) at 5 N force and the maximum seal force were determined according to ASTM F2029 and ASTM F88.

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. The lower limit (heat sealing initiation temperature (SIT)) is the sealing temperature at which a sealing strength of 5 $\pm$ 0.5 N is achieved. The upper limit (sealing end temperature (SET)) is reached, when the films stick

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to the sealing device. The sealing range was determined on a J&B Universal Sealing Machine Type 4000 with a 60 μm thickness film produced on a three-layer cast film co-extrusion line as described below with the following further parameters:

- 5 Conditioning time: > 96 h
 Sealing jaws dimension: 50x5 mm
 Sealing temperature: ambient – 240 °C
 Sealing temperature interval: 5 °C
 Sealing time: 1 sec
- 10 Delay time: 30 sec
 Sealing pressure: 0.4 N/mm² (PE);
 Grip separation rate: 42 mm/sec
 Sealing initiation force: 5 N
 Sample width: 25 mm
- 15 Specimen is sealed A to A at each sealbar temperature and seal strength (force) is determined at each step. The temperature is determined at which the seal strength reaches 5 +/- 0.5 N.

g) Hot Tack Temperature

- Hot tack temperature (1 N) was measured according to ASTM F1921-12 / method B on J&B model 4000 MB, flat, NIPTEF ® coated seal bar length of 50 mm, Seal bar width: 5 mm. Sealing time 1 s, cooling time 0.2 s, sealing pressure: 0.15 N/mm². Clamp separation rate: 200 mm/s, Sample width: 25 mm, Force range: 45 N;
- 20 Start of Energy calculation: 2 [%]
 - 25 End of Energy calculation: 2 [%]

h) Thickness

Thickness of the films was determined according to ASTM D6988.

i) Melting Point

- Data were 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. The melting temperature (T_m) was determined from the second heating step.
- 30

Examples**Sealant films**

Four comparative examples (CE1 to CE4) and two inventive examples (IE1 and IE2) have been prepared as sealant films with a thickness of 60 μm . The details of the films are summarized in Table 1, whereas the key properties of the polymers used are listed in Table 2. The external layers each make up 20 % and the core layer makes up 60 % of the total film thickness.

Table 1: Sealant film formulations (in wt. %).

Example	Outer Layer O (lamination layer)	Core Layer C	Inner Layer I (sealing layer)
Thickness / layer ratio	20%	60%	20%
CE1 (BB5)	80% FM1810 20% FT6230	80% FM1818 20% FT6230	80% FK1828 20% FT6236
CE2 (BB2)	80% FM1810 20% FT6230	80% FM1818 20% FT6230	80% Exceed 1012MK 20% FT6236
CE3 (BB3)	80% FM1810 20% FT6230	80% FM1818 20% FT6230	80% Dow Elite 5401G 20% FT6236
CE4 (BB9)	80% FB2230 20% FK1820	80% FB2230 20% FK1828	70% FK1828 20% Queo 0201FX 10% FT6236
IE1 (BR3)	80% FB2230 20% FK1820	80% FB2230 20% FK1828	60% FK1828 40% Queo 0201FX
IE2 (BB10)	80% FB2230 20% FK1820	80% FB2230 20% FK1828	20% FK1828 70% Queo 0201FX 10% FT6236

Table 2: Characteristics of the polymers used.

Resin name	Producer	Type	MFR ₂ (g/10min)	Density (kg/m ³)
Anteo FK1820 FK1828	Borouge	Bimodal 1-butene,1-hex-ene ethylene terpolymer	1.5	918
FM1810 FM1818	Borouge	Bimodal 1-butene ethylene copolymer	1.1	918
FT6230 FT6236	Borealis/ Borouge	tubular LDPE	2	923
Exceed 1012MK	ExxonMobil	Unimodal LLDPE: 1-hex-ene ethylene copolymer	1.0	912
Elite 5401G	Dow Chemical Company	Unimodal LLDPE: 1-octene ethylene copolymer	1.0	918
Queo 0201FX	Borealis	Ethylene-based octene-1 plastomer comprising 1000 - 1400 ppm erucamide and 2400 - 3600 ppm anti-block agent	1.1	902
Borstar FB2230	Borealis/ Borouge	Bimodal LLDPE	0.25	923

MFR₂ (190 °C/2.16 kg).

The 3-layer blown films were produced on a Polyrema (Reifenhauser blown film line with internal bubble cooling system) having an output of 150 kgs/hr and cooling air temperature were in between 12 to 16°C. The details as listed below in Table 3.

Table 3: Blown film line parameters.

Die diameters	300 mm
Die gap	1.8 mm
Blow up ratio (BUR)	2.2:1
Bubble cooling	internal bubble cooling (IBC)
Cooling air temperature	142 °C
Corona treatment	44 dyne/cm

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The temperature profiles of the blown film extruders line i.e., the temperatures used for different locations of the blown film lines were as follows in Table 4.

Table 4: Blown film extruders production temperatures in °C.

Layer	Extruder zone 1	Extruder zone 2	Extruder zone 3	Extruder zone 4	Extruder zone 5	Extruder zone 6	Post Extruder zone 7	Post Extruder zone 8
Outer layer (O)	155	170	180	190	190	190	200	200
Core layer (C)	155	170	180	190	190	190	200	200
Inner layer (I)	155	170	180	190	190	190	200	200
Die zone	195							

Properties of the sealant films

- 5 The films were evaluated for their properties and the results are summarized below.

Table 5: Sealing properties of the sealant films.

Example	Unit	CE1 (BB5)	CE2 (BB2)	CE3 (BB3)	CE4 (BB9)	IE1 (BR3)	IE2 (BB10)
Film thickness	μm	61	61	62	59	59	60
Seal initiation temperature (SIT at 5N)	°C	90.9	92.7	100.3	90.5	81.3	79.4
Hot tack temperature (at 1N)	°C	86.6	86.7	93.6	85.2	75.7	74.7

- 10 Excellent sealing behavior of inventive PE sealant film is demonstrated by the lower heat seal initiation temperature and lower hot tack temperature, which are critical parameters for the seal integrity and higher packaging speed while the films are in use for Vertical Form Fill Sealing (VFFS) packaging applications.

It can be seen from Table 5 that the inventive sealant films excelled the comparative examples for lower values in both SIT (heat seal initiation temperatures at 5 N) and hot tack initiation temperature at 1 N.

- 15 In Figure 1, the heat seal curves (SIT - heat seal initiation temperatures at 5 N) are shown and the plot indicates that the polyethylene blends used in the sealing layer of inventive examples IE1 (BR3) and IE2 (BB10) have a seal initiation temperatures at 5 N well below 90 °C, more specifically below 85 °C, in contrast to

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the comparative examples, which all have a seal initiation temperature at 5 N above 90 °C, and thus at least 9 °C higher than the inventive examples.

Lower seal initiation temperatures are beneficial for the overall performance profile of the (e.g. polyethylene) laminates, as lower seal initiation temperature of the sealing layer creates the difference of heat resistance in between sealant layer of sealant film and the top outermost layer of substrate film, and it has advantages during faster packaging operations on the FFS machines.

As visualized in Figure 2, the polyethylene blends used in the sealing layer of inventive examples IE1 (BR3) and IE2 (BB10) have lower hot tack temperatures at 1 N and hence exhibit superior sealing capabilities, significantly at lower temperature. The hot tack temperatures at 1N of the inventive films IE1 and IE2 are about 75 to 76 °C, which is significantly lower than of all comparative examples (i.e. about 10 °C and lower). This results in less energy input required to create the same seal strength.

Further, the higher values of hot tack strength and also the broader hot tack curve (in the wide range between 80 to 115 °C) of the inventive examples are significantly beneficial while using the same films and laminates on the FFS packaging line operations at packing speed of 55 to 89 pouches/min.

Table 6: Coefficient of friction of the sealant films after 4 days.

Example	CE1 (BB5)	CE2 (BB2)	CE3 (BB3)	CE4 (BB9)	IE1 (BR3)	IE2 (BB10)
dynamic CoF >96 h inside-inside	0.14	0.15	0.19	0.13	0.10	0.12
static CoF >96 h inside-inside	0.14	0.16	0.19	0.13	0.11	0.13
dynamic CoF >96 h outside-outside	0.22	0.25	0.24	0.15	0.18	0.21
static CoF >96 h outside-outside	0.25	0.28	0.28	0.17	0.20	0.23

Further, both inventive examples are characterized by low coefficients of friction (CoF), i.e. below 0.30, being an important feature for high-speed packaging.

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Moreover, the inventive examples have good mechanical and optical properties (not shown) and satisfy the requirements on packaging applications.

Laminated films

Preparation of laminated films

- 5 Laminated films are widely used for packaging applications, the examples were laminated to MDO PE substrates, to provide full-PE monomaterial laminates, which can be easily recyclable and suitable for sustainable packaging structure. The outer surface layer of MDO PE substrate film was laminated to the outer surface layer (corona treated film surface layer) of the sealant PE film examples.

10 MDO film details:

- During the MDO, the primary PE film from the blown-film line, the composition of which is shown in Table 7, is heated to an orientation temperature and the heating is preferably performed utilizing multiple heated rollers. The heated film is fed into a slow drawing roll with a nip roller, which has the same rolling speed as
15 the heated rollers. The film then enters a fast drawing roll and uniaxially stretched for 5 to 7 times faster than the slow draw roll, which effectively orients the film on a continuous basis. The oriented film is annealed by holding the film at an elevated temperature for a period of time to allow for stress relaxation.

- Stretching was carried out using a monodirectional stretching machine manufactured by Hosokawa Alpine AG in Augsburg/Germany. The unit consists of pre-heating, drawing, annealing, and cooling sections, with each set at specific temperatures to optimize the performance of the unit and produce films with the desired properties. The heating was at 105 °C, the stretching was done at 117 °C, annealing and cooling was done at 110 °C down to 40 °C. The primary film,
25 made of LLDPE FX1002 and HDPEs MB5568 or FB5600 (all polymers can be purchased from Borealis and/or Borouge) obtained from blown film extrusion was pulled into the orientation machine, then stretched between two sets of nip rollers, where the second pair runs at higher speed than the first pair, resulting in the desired draw ration. Stretching is carried out with the respective draw ratios
30 to reach the desired thickness of 21.5 microns.

Table 7: Composition of primary film (before stretching).

Film Layer distribution (wt.%)	15	10	50	10	15
FX1002	-	70	100	70	-
MB5568 or FB5600	100	30	-	30	100

For all extruders, zone 1-5 were heated at 180 °C, and the screen changer at 195 °C.

Basic properties of the primary MDO-PE film:

5 Film thickness: 140 µm

Draw ratio: 1:6.5

Final stretched film thickness: 21.5 µm

Lamination Process:

10 The MDO-PE films were laminated with different sealant films at Henkel Corporation using adhesive LA7102 and hardener LA6902 (both supplied by Henkel), mixed at a 2:1 ratio. Lamination was done on a solvent-less laminator at a running speed of 150 m/min with an adhesive content of 1.8 g/m². The corona treatment intensity on the carrier web was 2.5 kW.

15 Four comparative laminated films (Table 8, CE5 to CE8, wherein e.g. CE5 is a laminated film comprising the CE1 (BB5) sealant film etc.) and one inventive laminated film IE3 (comprising the IE2 (BB10) sealant film) with a thickness of about 80-90 µm were prepared. Properties of the laminates were evaluated and are depicted below.

Properties of the laminated films

20 **Table 8:** Sealing properties of the laminated films.

Example	Unit	CE5 (BB5)	CE6 (BB2)	CE7 (BB3)	CE8 (BB9)	IE3 (BB10)
Film thickness	µm	85	85	86	86	86
Seal initiation temperature (SIT at 5N)	°C	95.4	92.6	100.5	90.8	80.7

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Hot tack temperature (at 1N)	°C	89.6	90.7	95.0	85.9	74.0
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The excellent sealing properties of the sealant films are also reflected in the laminated film IE3 comprising the sealant film IE2, as shown in Table 8 and Figures 3 and 4.

5 The seal initiation temperature of the inventive example is about 80 °C, i.e. still below 85 °C and at least 10 °C lower than the seal initiation temperature of the comparative examples.

10 The same applies to the hot tack temperature, which is 74 °C, and thus more than 10 °C lower than the lowest hot tack temperature among the comparative examples. Further, the broader curve of hot tack strength between 80 and 110 °C temperature range of the inventive example excelled the other comparative examples.

15 The improved sealing properties of the inventive example can be correlated to the superior performance profile of the (polyethylene) laminated films, as lower SIT of the sealing layer helped to create the difference of SIT or heat resistance between the sealing layer versus the top substrate, and this provides advantages during the packaging operations on the FFS machine.

Table 9: Coefficient of friction of the laminated films after 4 days.

Example	CE5 (BB5)	CE6 (BB2)	CE7 (BB3)	CE8 (BB9)	IE3 (BB10)
dynamic CoF >96 h inside-inside	0.21	0.22	0.25	0.22	0.20
static CoF >96 h inside-inside	0.34	0.34	0.35	0.34	0.31
dynamic CoF >96 h outside-outside	0.16	0.16	0.17	0.26	0.22
static CoF >96 h outside-outside	0.20	0.19	0.22	0.27	0.28

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The coefficient of friction (CoF) of both external layers of the inventive example was below 0.30 when measured at dynamic conditions, hence the laminated film is most suitable for use in the subsequent steps of FFS packaging operations, even at higher packing speeds.

5 FFS packaging trials:

The Vertical Form Fill Sealing (VFFS) machine used for producing the flexible pouch was smartpacker SX400 machine from GEA. The sealing window of all laminated examples were checked by running 180 mm width x 250 mm height pouches (pillow pack) at different packing speed of 55 to 89 pouches/min. Sealing design “serrated 5-seal lines” and sealing pressure of 4000 N/m were used during VFFS trials. The summary of key observations is provided in Table 10 as follows.

Table 10: VFFS performance of laminated films.

	CE5 (BB5)	CE6 (BB2)	CE7 (BB3)	CE8 (BB9)	IE3 (BB10)
FFS packing speed & seal time	Sealing window (seal temperature range, °C)				
55 pouches/min 570 mili seconds	105-110 °C	100-110 °C	110-115 °C	105-115 °C	95-115 °C
85 pouches/min 220 mili seconds	No seal (bad seal at 130 °C)	No seal (bad seal at 125 °C)	No seal (bad seal at 125 °C)	~125 °C	120-125 °C
89 pouches/min 170 mili seconds	No seal (bad seal at 130 °C)	No seal (bad seal at 130 °C)	No seal (bad seal at 130 °C)	No seal (bad seal at 130 °C)	125 °C Good seal

Accordingly, at lower packaging speed of 55 pouches/min, the sealing window of the inventive laminate is significantly broader (20 °C) compared to other examples (5 to 10 °C). The broader range of the sealing window of inventive laminate may be useful for running the laminate on different types of VFFS packaging line. The broader curve of hot tack of the inventive laminate is correlated to the broader sealing window at 55 pouches/min.

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At a high packaging speed of 89 pouches/min (when seal time is less than 200 mili seconds), the inventive laminate has still good sealing performance and can be used to produce pouches, in contrast to the comparative laminates, which could not run at very high packing speed (≥ 85 pouches/min). Lower SIT
5 and hot tack temperatures of the inventive laminate is beneficial for high packing speed at 89 pouches/min (when seal time is significantly lower).

Moreover, the inventive example has good mechanical and optical properties (not shown) and satisfies all requirements on packaging applications.

The inventive laminates may be utilized for a broader seal window and high-
10 speed packaging efficiency, which can provide fully recyclable and sustainable packaging solutions for various flexible packaging applications.

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Claims

1. A polyethylene sealant film comprising an outer layer O, a core layer C and an inner layer I, wherein the inner layer I is made of an inner layer composition comprising:
 - 5 a) a component AI, which is a linear low density ethylene polymer having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133,
 - b) a component BI, which is an ethylene-based plastomer, preferably is a copolymer of ethylene and a C3 to C10 alpha-olefin, preferably 1-octene, and which has an MFR₂ of from 0.5 to 2.0 g/10 min, determined
10 according to ISO 1133, and a density of from 880 to 912 kg/m³, in an amount of 30 to 80 wt.%, based on the total weight of the inner layer composition, and
 - c) a slip agent.
- 15 2. The polyethylene sealant film according to claim 1, wherein the inner layer composition comprises the slip agent in an amount of from 50 to 5000 ppm, and optionally comprises an anti-block agent in an amount of from 50 to 5000 ppm, each being based on the total weight of the inner layer
20 composition.
3. The polyethylene sealant film according to any one of the preceding claims, wherein the core layer C is made of a core layer composition comprising a component AC, which is a linear low density ethylene polymer having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0
25 g/10 min, determined according to ISO 1133, and a component BC, which is a linear low density ethylene polymer having a density of from 915 to 930 kg/m³ and an MFR₂ of from 0.10 to 0.45 g/10 min, and optionally a slip agent and/or an anti-block agent, wherein the weight ratio of AC : BC is preferably from 10 : 90 to 30 : 70.
- 30 4. The polyethylene sealant film according to any one of the preceding claims, wherein the slip agent comprises a compound selected from the group consisting of fatty acid amides, such as erucamide, oleamide or

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- stearamide, and combinations thereof; and/or the anti-block agent comprises a compound selected from the group consisting of inorganic compounds such as talc, kaolin, cristobalite, natural silica and synthetic silica, diatomaceous earth, mica, calcium carbonate, calcium sulfate, magnesium carbonate, magnesium sulfate, and feldspars, and combinations thereof.
- 5
5. The polyethylene sealant film according to any one of the preceding claims, wherein the outer layer O is made of an outer layer composition comprising a component AO, which is a linear low density ethylene polymer having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133, and a component BO, which is a linear low density ethylene polymer having a density of from 915 to 930 kg/m³ and an MFR₂ of from 0.10 to 0.45 g/10 min, wherein the weight ratio of AO : BO is preferably from 10 : 90 to 30 : 70.
- 10
6. The polyethylene sealant film according to any one of the preceding claims, wherein the component AI and optionally any or both of the components AO and AC is/are an ethylene copolymer, preferably an ethylene terpolymer, more preferably a multimodal ethylene terpolymer, having a density of from 916 to 920 kg/m³ and an MFR₂ of from 1.2 to 1.8 g/10 min, determined according to ISO 1133.
- 15
7. The polyethylene sealant film according to any one of the preceding claims, wherein the inner layer composition further comprises a component CI, which is a low density ethylene polymer having a density of from 910 to 930 kg/m³ and an MFR₂ of from 0.1 to 2.5 g/10 min.
- 20
8. The polyethylene sealant film according to any one of the preceding claims, wherein the polyethylene sealant film is a non-oriented film.
- 25
9. The polyethylene sealant film according to any one of the preceding claims, wherein the polyethylene sealant film has a thickness of 40 to 80 μm, preferably 50 to 70 μm.
10. The polyethylene sealant film according to any one of claims 1 to 9, wherein the polyethylene sealant film has a dynamic coefficient of friction after 4 days of up to 0.30, determined according to ASTM D1894, and/or a seal initiation temperature (5 N) of less than 90 °C and preferably of more than
- 30

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70 °C, determined according to ASTM F 2029; ASTM F 88, and/or a hot tack temperature (1 N) of less than 85 °C and preferably of more than 65 °C, determined according to ASTM F 1921.

- 5 11. A laminated polyethylene film comprising the polyethylene sealant film according to any one of the preceding claims and a substrate film, preferably a machine direction-oriented polyethylene substrate film.
- 10 12. The laminated polyethylene film according to claim 11, wherein the laminated polyethylene film has a dynamic coefficient of friction after 4 days of up to 0.30, determined according to ASTM D1894, and/or a seal initiation temperature (5 N) of less than 90 °C and preferably of more than 70 °C, determined according to ASTM F 2029; ASTM F 88, and/or a hot tack temperature (1 N) of less than 85 °C and preferably of more than 65 °C, determined according to ASTM F 1921.
- 15 13. An article comprising the polyethylene sealant film according to any one of claims 1 to 10, or the laminated polyethylene film according to any one of claims 11 or 12.
14. Use of the polyethylene sealant film according to any one of claims 1 to 10, or the laminated polyethylene film according to any one of claims 11 or 12 for packaging of an article.
- 20 15. Use of a composition comprising a component AI, which is a linear low density ethylene polymer having a density of from 910 to 925 kg/m³ and an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133, a component BI, which is an ethylene-based plastomer, preferably is a copolymer of ethylene and a C3 to C10 alpha-olefin, preferably 1-octene, and which has an MFR₂ of from 0.5 to 2.0 g/10 min, determined according to ISO 1133, and a density of from 880 to 912 kg/m³, in an amount of 30 to 80 wt.%, based on the total weight of the composition, and a slip agent, 25 in the sealing layer of a film for improving sealing performance of the film.