BIMODAL ETHYLENE-BASED POLYMERS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 63/639,181 filed April 26, 2025, the contents of which are incorporated in their entirety herein.

BACKGROUND

Technical Field

[0002] Embodiments of the present disclosure generally relate to ethylene-based polymers, and more specifically to bimodal ethylene-based polymers.

Technical Background

[0003] Tear strength (as exemplified by machine direction tear or "MD tear") and dart impact strength are important mechanical properties of polyethylene films used for applications such as packaging, piping, and construction. MD tear refers to the resistance of a material to tear when a force is applied in the machine direction. Dart impact measures the impact strength of a polymer, representing the drop performance of a film in a final article (e.g., a package). The balance between MD tear and dart impact must be considered when designing polymer products. Typically, MD tear and dart impact strengths are inversely correlated. Thus, producers generally seek a balance between these properties to ensure that the material can meet all strength requirements for the intended application. In particular, low MD tear often remains an issue, especially if the resulting film is processed at high MD orientation.

[0004] Additionally, it is desirable to use at least some post-consumer resins (PCR) to meet environmental goals. However, the inclusion of PCR resins tends to decrease the ability of the resulting films to meet material property requirements, such as MD-tear and dart.

BRIEF SUMMARY

[0005] Embodiments of the present disclosure meet this need by providing a bimodal ethylene-based polymer having a high density fraction (HDF) from 12.0% to 35.0%, where the high density fraction has a molecular weight of at least 120,000 g/mol. Generally, a bimodal ethylene-based polymer having a high density fraction (HDF) from 12.0% to 35.0% and a molecular weight distribution skewed towards higher molecular weights, such as molecular weights of at least 120,000 g/mol, results in an improved balance of material properties. Further, reductions in material properties due to blending the bimodal ethylene-based polymer with PCR are reduced when a bimodal ethylene-based having a high density fraction (HDF) from 12.0% to 35.0%, where the high density fraction has a molecular weight of at least 120,000 g/mol is utilized, relative to conventional resins.

[0006] Embodiments of the present disclosure, include a bimodal ethylene-based polymer, the bimodal ethylene-based polymer being the polymerized reaction product of ethylene and one or more C_3-C_{14} olefinic comonomers. The bimodal ethylene-based polymer comprises: a high density fraction (HDF) from 12.0% to 35.0%, the HDF being defined as a ratio of the mass eluted at temperatures from 93 °C to 119 °C to the total mass eluted when measured using an improved comonomer content distribution (iCCD) curve of mass eluted versus temperature; an I_{10}/I_2 ratio from 5.5 to 7.0, wherein I_2 is the melt index when measured according to ASTM D 1238 at a load of 2.16 kg and temperature of 190° C. and I_{10} is the melt index when measured according to ASTM D 1238 at a load of 10 kg and temperature of 190° C; and the high density fraction has a weight averaged molecular weight (Mw) of at least 120,000 g/mol.

[0007] These and other embodiments are described in more detail in the Detailed Description. It is to be understood that both the foregoing general description and the following detailed description present embodiments of the presently disclosed technology, and are intended to provide an overview or framework for understanding the nature and character of the technology as it is claimed.

DETAILED DESCRIPTION

[0008] Definitions

[0009] The term "polymer" refers to a polymeric compound prepared by polymerizing monomers, whether of the same or a different type. The generic term polymer thus embraces the term "homopolymer," usually employed to refer to polymers prepared from only one type of monomer as well as "copolymer" which refers to polymers prepared from two or more different monomer types.

[0010] "Polyethylene" or "ethylene-based polymer" shall mean polymers comprising greater than 50% by weight of units that have been derived from ethylene monomer. This includes polyethylene homopolymers or copolymers (meaning units derived from two or more monomer types). Common forms of polyethylene known in the art include Low Density Polyethylene (LDPE); Linear Low Density Polyethylene (LLDPE); Ultra Low Density Polyethylene (ULDPE); Very Low Density Polyethylene (VLDPE); single-site catalyzed Linear Low Density Polyethylene, including both linear and substantially linear low density resins (m-LLDPE); Medium Density Polyethylene (MDPE); and High Density Polyethylene (HDPE).

[0011] The term "LDPE" may also be referred to as "high pressure ethylene polymer" or "highly branched polyethylene" and is defined to mean that the polymer is partly or entirely homopolymerized or copolymerized in autoclave or tubular reactors at pressures above 14,500 psi (100 MPa) with the use of free-radical initiators, such as peroxides (*see*, for example, U.S. Patent No. 4,599,392, which is hereby incorporated by reference in its entirety). LDPE resins typically have a density in the range of 0.916 g/cm^3 to 0.930 g/cm^3.

[0012] The term "LLDPE," includes resin made using Ziegler-Natta catalyst systems as well as resin made using single-site catalysts, including, but not limited to, bis-metallocene catalysts (sometimes referred to as "m-LLDPE"), phosphinimine, and constrained geometry catalysts, and resins made using post-metallocene, molecular catalysts, including, but not limited to, bis(biphenylphenoxy) catalysts (also referred to as polyvalent aryloxyether catalysts). LLDPE includes linear, substantially linear, or heterogeneous ethylene-based copolymers. LLDPEs contain less long chain branching than LDPEs and include the substantially linear ethylene polymers, which are further defined in U.S. Patent No. 5,272,236, U.S. Patent No. 5,278,272, U.S. Patent No. 5,582,923 and U.S. Patent No. 5,733,155 each of which are incorporated herein by reference in their entirety; the

homogeneously branched linear ethylene polymer compositions such as those in U.S. Patent No. 3,645,992 which is incorporated herein by reference in its entirety; the heterogeneously branched ethylene polymers such as those prepared according to the process disclosed in U.S. Patent No. 4,076,698 which is incorporated herein by reference in its entirety; and blends thereof such as those disclosed in U.S. Patent No. 3,914,342 and U.S. Patent No. 5,854,045 which are incorporated herein by reference in their entirety. The LLDPE resins can be made via gas-phase, solution-phase, or slurry polymerization or any combination thereof, using any type of reactor or reactor configuration known in the art.

[0013] "Blend," "polymer blend," and like terms mean a composition of two or more polymers. Such a blend may or may not be miscible. Such a blend may or may not be phase separated. Such a blend may or may not contain one or more domain configurations, as determined from transmission electron spectroscopy, light scattering, x-ray scattering, and any other method known in the art. Blends are not laminates, but one or more layers of a laminate may contain a blend. Such blends can be prepared as dry blends, formed in situ (*e.g.*, in a reactor), melt blends, or using other techniques known to those of skill in the art.

[0014] "Multilayer structure" or "multilayer film" means any structure having more than one layer. For example, the multilayer structure (for example, a film) may have two, three, four, five, six, seven, or more layers. A multilayer structure may be described as having the layers designated with letters. For example, a three-layer structure designated as A/B/C may have a core layer, (B), and two external layers, (A) and (C).

[0015] As used herein, "bimodal" refers to polymers produced from two polymer fractions, each polymer fraction being produced by a distinct catalyst in a distinct reaction environment.

[0016] The terms "comprising," "including," "having," and their derivatives, are not intended to exclude the presence of any additional component, step or procedure, whether or not the same is specifically disclosed. In order to avoid any doubt, all compositions claimed through use of the term "comprising" may include any additional additive, adjuvant, or compound, whether polymeric or otherwise, unless stated to the contrary. In contrast, the term, "consisting essentially of" excludes from the scope of any succeeding recitation any other component, step or procedure, excepting those that are not essential to operability. The

term "consisting of" excludes any component, step or procedure not specifically delineated or listed.

[0017] "Recycled polymer" refers to polymers, which were incorporated into products and subsequently re-melted to form a recycled polymer. The term "recycled polymer" refers to mechanically recycled polymers, where the polymer is melted and reincorporated into a new product. "Recycled polymer" does not include chemically recycled polymers, where the polymer is broken down into constituent monomers and incorporated into a new virgin polymer. Recycled polymers are defined in ISO 14021 7.8.1.1. The term "post-consumer recycled" (or "PCR"), as used herein, refers to a recycled polymeric material that includes materials previously used in a consumer or industry application (i.e., pre-consumer recycled polymer and post-industrial recycled polymer). PCR is typically collected from recycling programs and recycling plants. The PCR ethylene-based polymer may include one or more ethylene-based polymers, such as LDPE, LLDPE, HDPE, or polyethylene. The PCR may include one or more contaminants. The contaminants may be the result of the polymeric material's use prior to being repurposed for reuse. For example, contaminants may include paper, ink, food residue, or other recycled materials in addition to the polymer, which may result from the recycling process. PCR is distinct from virgin polymeric material. A virgin polymeric material (such as a virgin polyethylene resin) does not include materials previously used in a consumer or industry application. Virgin polymeric material has not undergone, or otherwise has not been subject to, a heat process or a molding process, after the initial polymer manufacturing process. The physical, chemical, and flow properties of PCR resins differ when compared to virgin polymeric resin, which in turn can present challenges to incorporating PCR into formulations for commercial use. Post-consumer resin is defined in ISO 14021 7.8.1.1.

[0018] Bimodal Ethylene-Based Polymers

[0019] Embodiments of the present disclosure relate to bimodal ethylene-based polymers. The bimodal ethylene-based polymer may be the polymerized reaction product of ethylene and one or more C_3-C_{14} olefinic comonomers.

[0020] Suitable C_3-C_{14} olefinic comonomers may include, by way of example but not limitation, propylene, 1-butene, 1-pentene, 1-hexene, 4-methyl-1-pentene, 1-heptene, 1-

decene and 1-octene, as well as other monomer types such as styrene, alkyl-substituted styrenes, vinyl benzocyclobutane, dienes such as 1,4-hexadiene, 1,7-octadiene, 1,9-decadiene, and ethylidene norbornene and cycloalkenes (e.g., cyclopentene, cyclohexene and cyclooctene). The bimodal ethylene-based polymer may comprise from 1 to 49 wt. % of the C_3-C_{14} olefinic comonomers, on the basis of the total polymer weight of the bimodal ethylene-based polymer. In embodiments, the bimodal ethylene-based polymer may comprise from 1 to 45 wt. %, from 1 to 35 wt. %, from 1 to 20 wt. %, from 1 to 5 wt. %, from 5 to 10 wt. %, from 10 to 15 wt. %, from 15 to 20 wt. %, from 20 to 25 wt. %, wt. %, from 25 to 30 wt. %, from 30 to 35 wt. %, from 35 to 40 wt. %, from 40 to 45 wt. %, from 45 to 49 wt. %, or any combination of two or more of these ranges of the C_3-C_{14} olefinic monomers, on the basis of the total weight of the bimodal ethylene-based polymer. Methods of producing the bimodal ethylene-based polymers are disclosed in PCT Patent Appln. Nos. WO2019241475A1, WO2019241518A1, and WO2019241518A, which are incorporated herein by reference in their entireties.

[0021] The bimodal ethylene-based polymer may have a high density fraction (HDF) from 12.0% to 35.0%. Generally, having an HDF from 12.0 % to 35.0% is believed to result in increased tear and dart performance. Generally, when the HDF is too low (e.g., less than 12.0 %), the resulting polymer has poor tear performance. Generally, when the HDF is too high (e.g., greater than 35.0 %), the resulting polymer has poor dart performance. In embodiments, the bimodal ethylene-based polymer may have a HDF from 12.0% to 30.0%, from 12.0% to 14.5%, from 14.5% to 17.5%, from 17.5% to 20.0%, from 20.0% to 22.5%, from 22.5% to 25.0%, from 25.0% to 27.5%, from 27.5% to 30.0%, from 30.0% to 32.5%, from 32.5% to 35%, or any combination of two or more of these ranges. The HDF is defined as a ratio of the mass eluted at temperatures from 93 °C to 119 °C to the total mass eluted when measured using an improved comonomer content distribution (iCCD) curve of mass eluted versus temperature.

[0022] The HDF of the bimodal ethylene-based polymer may have a weight averaged molecular weight (Mw) of at least 120,000 g/mol. Generally, greater Mw of the HDF is believed to correlate to improved MD-tear performance. However, without being limited by theory, when the Mw of the HDF is too high (e.g., greater than 200,000 g/mol), the Mw of the LDF will have to be reduced to achieve overall Mw targets. This reduction in the Mw of

the LDF is believed to result in poor dart performance. In embodiments, the HDF may have a molecular weight of at least 125,000 g/mol, at least 130,000 g/mol, at least 135,000 g/mol, at least 140,000 g/mol, at least 145,000 g/mol, at least 150,000 g/mol, at least 160,000 g/mol, from 120,000 g/mol to 130,000 g/mol, from 130,000 g/mol to 140,000 g/mol, from 140,000 g/mol to 150,000 g/mol, from 150,000 g/mol to 160,000/g/mol, from 160,000 g/mol to 190,000 g/mol, from 190,000 g/mol to 200,000 g/mol, or any combination of two or more of these ranges. The HDF is defined as a ratio of the mass eluted at temperatures from 93 °C to 119 °C to the total mass eluted when measured using an improved comonomer content distribution (iCCD) curve of mass eluted versus temperature.

[0023] The HDF may have a single peak in the temperature range of from 87 °C to 120 °C.. As used herein, a "single peak" refers to an iCCD wherein a particular fraction include only a single peak. That is, in some embodiments, the iCCD of the HDF and/or the LDF includes only an upward sloping region followed by a downward sloping region to form the single peak. In embodiments, the HDF may have a peak temperature of from 90 °C to 119 °C, from 90 °C to 92 °C, from 92 °C to 94 °C, from 94 °C to 96 °C, from 96 °C to 98 °C, from 98 °C to 100 °C, from 100 °C to 105 °C, from 105 °C to 110 °C, from 110 °C to 115 °C, from 115 °C to 119 °C, or any combination of two or more of these ranges. Generally, polymers having an HDF with a single peak in this range (e.g., from 87 °C to 120 °C) will produce films having a higher MD-tear, relative to other polymers.

[0024] The bimodal ethylene-based polymer may have a low density fraction (LDF) of from 65.0% to 88.0%. In embodiments, the bimodal ethylene-based polymer may have a low density fraction of from 65.0% to 68.0%, from 68.0% to 71.0%, from 71.0% to 74.0%, from 74.0% to 77.0%, from 77.0% to 80.0%, from 80.0% to 83.0%, from 83.0% to 86.0%, from 86.0% to 88.0%, or any combination of two or more of these ranges. The LDF being defined as a ratio of the mass eluted at temperatures from 30 °C to transition point X to the total mass eluted when measured using an improved comonomer content distribution (iCCD) curve of mass eluted versus temperature. Transition point X refers to the temperature at which the sample undergoes the transition from LDF to HDF. Transition point X is determined individually for each sample using the iCCD test as follows. Initially, predefined boundaries set the transition range from a minimum to a maximum value (75 °C to 96 °C, respectively). Then, the temperature is iterated, within the specified boundaries, incrementing by 0.1 °C. At

each temperature point, the first derivative of a fitted iCCD function with respect to temperature is calculated. The transition temperature X is the point where the first derivative changes sign from negative to positive.

[0025] The LDF may have a weight averaged molecular weight (Mw) of less than 120,000 g/mol. In embodiments, the LDF may have a Mw of less than 118,000 g/mol, less than 115,000 g/mol, less than 113,000 g/mol, from 90,000 g/mol to 115,000 g/mol, from 90,000 g/mol to 92,500 g/mol, from 92,500 g/mol to 95,000 g/mol, from 95,000 g/mol to 97,500 g/mol, from 97,500 g/mol to 100,000 g/mol, from 100,000 g/mol to 102,500 g/mol, from 102,500 g/mol to 105,000 g/mol, from 105,000 g/mol to 107,500 g/mol, from 107,500 g/mol to 110,000 g/mol, from 110,000 g/mol to 112,500 g/mol, from 112,500 g/mol to 115,000 g/mol, from 115,000 g/mol to 120,000 g/mol, or any combination of two or more of these ranges. Generally, when the Mw of the LDF is within this range (e.g., less than 120,000 g/mol), a film made from the polymer will have a greater MD tear, relative to other polymers.

[0026] The LDF may have a single peak in the temperature range of from 70 °C to 85 °C. In embodiments, the LDF may have a peak temperature of from 76 °C °C to 85 °C, from 70 °C to 72.5 °C, from 72.5 °C to 75 °C, from 75 °C to 76 °C, from 76 °C to 78 °C, from 78 °C to 80 °C, from 80 °C to 82.5 °C, from 82.5 °C to 85 °C, or any combination of two or more of these ranges. Generally, films made from polymers where the peak temperature of the LDF is within this range (e.g., from 70 °C to 85 °C) will have improved dart impact resistance, relative to other polymers.

[0027] In embodiments, the difference (Δ Mw) between the Mw of the HDF and the Mw of the LDF (e.g., $\Delta Mw = Mw_{HDF} - Mw_{LDF}$) may be at least 30,000 g/mol. Generally, it is believed that greater Δ Mw of the bimodal ethylene-based polymer results in greater tear resistance of the resulting film. In embodiments, Δ Mw may be at least 31,000 g/mol, at least 35,000 g/mol, at least 40,000 g/mol, at least 45,000 g/mol, at least 50,000 g/mol, or from 30,000 g/mol to 90,000 g/mol.

[0028] In embodiments, the difference (Δ T) between the peak temperature of the HDF and the peak temperature of the LDF (e.g., $\Delta T = T_{HDF} - T_{LDF}$) may be at least 15 °C. Generally, it is believed that greater Δ T of the bimodal ethylene-based polymer results in greater tear resistance of the resulting film. In embodiments, the Δ T may be at least 16 °C, at least 17

°C, at least 18 °C, from 15 °C to 30 °C, from 15 °C to 17.5 °C, from 17.5 °C to 20 °C, from 20 °C to 22.5 °C, from 22.5 °C to 25 °C, from 25 °C to 27.5 °C, from 27.5 °C to 30 °C, or any combination of two or more of these ranges.

[0029] The bimodal ethylene-based polymer may have a soluble fraction (SF) less than 2.0%. In embodiments, the bimodal ethylene-based polymer may have an SF less than 1.8%, less than 1.6%, less than 1.4%, less than 1.2%, less than 1.0%, less than 0.8%, less than 0.6%, or less than 0.4%. The SF is defined as a ratio of the mass eluted at temperatures less than 35 °C to the total mass eluted when measured according to iCCD.

[0030] The bimodal ethylene-based polymer may have a molecular weight Mn (conventional) of at least 40,000 g/mol. In embodiments, the bimodal ethylene-based polymer may have a Mn (conventional) of from 40,000 g/mol to 42,000 g/mol, from 42,000 g/mol to 44,000 g/mol, from 44,000 g/mol to 46,000 g/mol, from 46,000 g/mol to 48,000 g/mol, from 48,000 g/mol to 50,000 g/mol, from 50,000 g/mol to 52,000 g/mol, from 52,000 g/mol to 54,000 g/mol, or any combination of two or more of these ranges.

[0031] The bimodal ethylene-based polymer may have a density of from 0.900 g/cc to 0.925 g/cc. In embodiments, the bimodal ethylene-based polymer may have a density of from 0.900 g/cc to 0.905 g/cc, from 0.905 g/cc to 0.910 g/cc, from 0.910 g/cc to 0.915 g/cc, from 0.915 g/cc to 0.920 g/cc, from 0.920 g/cc to 0.925 g/cc, or any combination of two or more of these ranges.

[0032] The bimodal ethylene-based polymer may have a melt index (I_2) from 0.5 g/10 mins to 7.0 g/10 mins. In embodiments, the bimodal ethylene-based polymer may have an I_2 from 0.5 g/10 mins to 6.0 g/10 mins, from 0.5 g/10 mins to 5.0 g/10 mins, from 0.5 g/10 mins to 4.0 g/10 mins, from 0.5 g/10 mins to 3.0 g/10 mins, from 0.5 g/10 mins to 2.0 g/10 mins, from 0.5 g/10 mins to 1.5 g/10 mins, from 0.5 g/10 mins to 1.0 g/10 mins, from 0.5 g/10 mins to 0.95 g/10 mins, from 0.5 g/10 mins to 0.7 g/10 mins, from 0.7 g/10 mins to 0.9 g/10 mins, from 0.9 g/10 mins to 0.98 g/10 mins, from 0.98 g/10 mins to 2 g/10 g/10 mins, or any combination of two or more of these ranges.

[0033] The bimodal ethylene-based polymer may have an I_{10}/I_2 ratio from 5.5 to 7.0. In embodiments, the bimodal ethylene-based polymer may have an I_{10}/I_2 ratio from 5.5 to 6.7 or from 5.5 to 6.0.

[0034] The bimodal ethylene-based polymer may have a viscosity ratio ($V_{0.1}/V_{100}$) of from 2 to 4. In embodiments, the bimodal ethylene-based polymer may have a viscosity ratio ($V_{0.1}/V_{100}$) of from 2.5 to 4, from 2 to 2.2, from 2.2 to 2.4, from 2.4 to 2.6, from 2.6 to 2.8, from 2.8 to 3.0, from 3.0 to 3.2, from 3.2 to 3.4, from 3.4 to 3.6, from 3.6 to 3.8, from 3.8 to 4, or any combination of two or more of these ranges.

[0035] Polymer Blends

[0036] Embodiments of the present disclosure relate to polymer blends. The polymer blends generally comprise the bimodal ethylene-based polymer described hereinabove and post-consumer recycled (PCR) ethylene-based polymer. The bimodal ethylene-based polymer may be a virgin polymer. Generally, the incorporation of PCR ethylene-based polymers into a blend results in reduced material properties (e.g., reduced MD-Tear and/or dart), relative to a virgin polymer. Surprisingly, the bimodal ethylene-based polymers of the present disclosure do not experience the same reduction in material properties as conventional ethylene-based polymers, when blended with PCR ethylene-based polymer.

[0037] The PCR ethylene-based polymer may be an ethylene-based polymer having a density of 0.910 to 0.930 g/cc, such as from 0.910 to 0.915, from 0.915 to 0.920, from 0.920 to 0.925, from 0.925 to 0.930, or any combination of two or more of these ranges. The PCR ethylene-based polymer may be an ethylene-based polymer having a melt index (I_2) of 0.3 to 2 dg/min, such as from 0.3 to 0.5 dg/min, from 0.5 to 0.8 dg/min, from 0.8 to 1.1 dg/min, from 0.1 to 1.4 dg/min, from 1.4 to 1.7 dg/min, from 1.7 to 2.0 dg/min, or any combination of two or more of these ranges. The PCR ethylene-based polymer may comprise an LDPE, an HDPE, an LLDPE, or a blend thereof. In embodiments, the PCR ethylene-based polymer resin comprise at least 50 wt. %, at least 75 wt. %, at least 85 wt. %, at least 90 wt. %, at least 95 wt. %, or even at least 99 wt. % of an LDPE, an HDPE, an LLDPE, or a blend thereof, on the basis of the total weight of the PCR ethylene-based polymer. Suitable PCR ethylene-based polymers include AVANGARD™ NATURA PCR-LDPCR-100 ("AVANGARD™

100") and AVANGARD™ NATURA PCR-LDPCR-150 ("AVANGARD™ 150") (PCR commercially available from Avangard Innovative LP, Houston, Texas).

[0038] The polymer blend may comprise from 10 to 50 wt.% PCR ethylene-based polymer, such as from 10 to 15 wt. %, from 15 to 20 wt. %, from 20 to 25 wt. %, from 25 to 30 wt. %, from 30 to 35 wt. %, from 35 to 40 wt. %, from 40 to 45 wt. %, from 45 to 50 wt. %, or any combination of two or more of these ranges.

[0039] Additives

[0040] It should be understood that the above-described bimodal ethylene-based polymers, the polymer blends, or films produced therefrom may further include one or more additives as known to those of skill in the art such as, for example, plasticizers, stabilizers including viscosity stabilizers, hydrolytic stabilizers, primary and secondary antioxidants, ultraviolet light absorbers, anti-static agents, dyes, pigments or other coloring agents, inorganic fillers, fire-retardants, lubricants, reinforcing agents such as glass fiber and flakes, synthetic (for example, aramid) fiber or pulp, foaming or blowing agents, processing aids, slip additives, anti-block agents such as silica or talc, release agents, tackifying resins, or combinations of two or more thereof. Inorganic fillers, such as calcium carbonate, and the like can also be incorporated into the film. In embodiments, the bimodal ethylene-based polymers, the polymer blends, or films produced therefrom may comprise from 0 to 40 wt. %, such as from 0 to 30 wt. %, from 0 to 20 wt. %, from 0 to 10 wt. %, from 1 to 40 wt. %, from 1 to 30 wt. %, from 1 to 20 wt. %, or from 1 to 10 wt. % of additives.

[0041] Films

[0042] Additional embodiments of the present disclosure are directed to films. The films may include the bimodal ethylene-based polymers and/or polymer blends described herein. In embodiments, the films may comprise at least 80 wt. %, at least 90 wt. %, at least 95 wt. %, or at least 99 wt. % of the bimodal ethylene-based polymers and/or polymer blends described herein. In embodiments, the film is substantially free of any other polymeric component.

[0043] The film of may be a monolayer or multilayer film, such as a film having 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or 11 layers. One or more of the layers of a multilayer film may comprise

the bimodal ethylene-based polymers and/or polymer blends described herein. In embodiments, the layer or layers comprising the bimodal ethylene-based polymers and/or polymer blends may each comprise at least 80 wt. %, at least 90 wt. %, at least 95 wt. %, or at least 99 wt. % of the bimodal ethylene-based polymers and/or polymer blends described herein. The films of the present disclosure can have a variety of thicknesses. The thickness of the film may depend on a number of factors including, for example, the number of layers in the film, the composition of the layers in the multilayer film, the desired properties of the film, the desired end-use application of the film, the manufacturing process of the film, and others. In embodiments, the film may have a thickness of 0.5 to 5 mils, from 1 to 4 mils, from 1 to 3 mils, from 1.5 to 2.5 mils, from 1.7 to 2.3 mil, or about 2 mil.

[0044] The film may have a haze of less than 25%, such as less than 20%, less than 15%, or less than 10%. The film may have an MD-Tear of greater than 800 gf, such as greater than 825 gf, greater than 850 gf, or greater than 870 gf. The film may have a dart impact of at least 500 g, such as at least 525 g, at least 550 g, at least 575 g, at least 600 g, at least 650 g, at least 700 g, at least 750 g, at least 800 g, at least 850 g, at least 900 g, or at least 1000 g. Film properties are measured at a thickness of 2 mil.

[0045] Various methodologies are contemplated for producing the films of this disclosure. In one or more embodiments, the process of manufacturing the film may include cast film extrusion or blown film extrusion.

[0046] Articles

[0047] Embodiments of the present disclosure also relate to articles, such as packages, formed from the films of the present disclosure. The films of the present disclosure are particularly useful in articles where good tear strength and dart strength are desired. Examples of such articles can include flexible packages, pouches, stand-up pouches, and pre-made packages or pouches. Various methods of producing embodiments of articles from the films disclosed herein would be familiar to one of ordinary skill in the art.

TEST METHODS

[0048] Improved method for comonomer content analysis (iCCD)

[0049] Details of the ICCD method can be found in U.S. Patent Application Number 17/632598, which is incorporated by reference herein.

[0050] Density

[0051] Samples for density measurement are prepared according to ASTM D 1928. Polymer samples are pressed at 190 °C and 30,000 psi for three minutes, and then at 21 °C and 207 MPa for one minute. Measurements are made within one hour of sample pressing using ASTM D792, Method B.

[0052] Melt Index (I_2) and (I_{10})

[0053] Melt index, or I_2, (grams/10 minutes or dg/min) is measured in accordance with ASTM D 1238, Condition 190 °C/2.16 kg, Procedure B. Melt index, or I_{10}, (grams/10 minutes or dg/min) is measured in accordance with ASTM D 1238, Condition 190 °C/10 kg, Procedure B.

[0054] Haze

[0055] Haze is measured using a Byk Haze-Gard I. After thickness measurement, the film sample is hold against the lens at the integrating sphere end of the Haze-Gard I where it measures an Illuminant A value in accordance with ASTM D1003. This test is performed first, since it is non-destructive.

[0056] Instrumented Dart Impact (IDI)

[0057] IDI is measured according ASTM D7192. This standard requires a probe assembly of 12.70 ± 0.13 mm diameter with hemispherical end of the same diameter. The probe used has a 4500 N range with 1.1 mV/N sensitivity and is designed for dynamic measurements. The dart probe assembly is mounted atop a LinMot linear motor, which is an electromagnetic direct drive motor in tubular form. It has a maximum velocity of 5.4 m/s and maximum force of 1650 N.

[0058] MD Tear

[0059] MD Tear was tested according to ASTM D1922-15, covering the average force required to propagate tearing through a specified length of plastic film after the tear has been started using an Elmendorf type tearing tester.

[0060] Gel Permeation Chromatography (GPC)

[0061] Details of the GPC method can be found in U.S. Patent Application Number 17/632598, which is incorporated by reference herein.

EXAMPLES

[0062] The following examples illustrate features of the present disclosure but are not intended to limit the scope of the disclosure. The following experiments analyzed the performance of embodiments of the bimodal ethylene-based polymers described herein.

[0063] Production of Bimodal Ethylene-Based Polymers

[0064] All raw materials (monomer and comonomer) and the process solvent (a narrow boiling range high-purity paraffinic and cycloparaffinic solvent) were purified with molecular sieves before introduction into the reaction environment. High purity hydrogen was used to terminate the polymerization reaction. The reactor monomer feed stream was pressurized via a mechanical compressor to above reaction pressure. The solvent feed was pressurized via a pump to above reaction pressure. The comonomer feed was pressurized via a pump to above reaction pressure. The individual catalyst components were manually batch diluted to specified component concentrations with purified solvent and pressured to above reaction pressure. All reaction feed flows were measured with mass flow meters and independently controlled with metering pumps.

[0065] The reactor configuration used a liquid full, adiabatic, and continuously stirred tank reactor (CSTR) as the first reactor, followed by a plug flow reactor as the second reactor. Independent control of all solvent, monomer, comonomer, hydrogen, and catalyst component feeds was utilized. The total feed stream (solvent, monomer, comonomer, and hydrogen) was fed to the first reactor, and was temperature controlled by passing the feed stream through a heat exchanger. The catalyst components were injected into the first polymerization reactor separate from the other feeds, additional catalyst and co-catalyst components were injected

into the plug flow reactor as described in the tables. An agitator in the reactor was responsible for continuously mixing of the reactants in the CSTR. An oil bath was provided for fine tuning of the reactor temperature.

[0066] The final reactor effluent (second reactor effluent for dual series, the combined effluent for dual parallel, or the single reactor effluent) entered a zone where it was deactivated with the addition of, and reaction with, water. At this same reactor exit location other additives were added for polymer stabilization (Octadecyl 3,5-Di-Tert-Butyl-4-Hydroxyhydrocinnamate, Tetrakis (Methylene(3,5-Di-Tert-Butyl-4-Hydroxyhydrocinnamate))Methane, and Tris(2,4-Di-Tert-Butyl-Phenyl) Phosphite), as mentioned in the tables.

[0067] Following catalyst deactivation and any additive addition, the reactor effluent entered a devolatization system where the polymer was removed from the non-polymer stream. The non-polymer stream was removed from the system. The isolated polymer melt was pelletized and collected.

[0068] Reaction conditions are as disclosed in Table 1 and co-catalysts are disclosed in Table 2. For all reactions disclosed in Table 1, the monomer was ethylene and the comonomer was octene. In Table 1, Rxr 1 refers to the first reactor, Rxr 2 refers to the second reactor, and ASC refers to a tubular reactor downstream of the second reactor.

Table 1

Example	**C1**	**C2**	**C3**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**
Rxr 1 Feed Temperature (°C)	15	25	20	15	15	24	20	18	20	30.0
Rxr 1 Fresh Solvent Flow (kg/h)	24.65	25.71	26.64	24.57	25.86	25.29	25.79	26.91	27.01	28.1
Rxr 1 Total Solvent Flow (kg/h)	24.79	25.86	27.28	24.79	26.13	25.35	26.34	27.6	27.67	28.3
Rxr 1 Fresh Monomer Flow (kg/h)	4.93	4.97	5.4	4.94	4.95	4.89	5.22	5.21	5.21	5.4
Rxr 1 Fresh Comonomer Flow (kg/h)	2.92	2.84	3.06	3.09	1.8	1.28	3.07	1.95	1.85	1.0

Rxr 1 Feed Solvent/ Monomer Ratio	5.63	5.81	5.61	5.64	5.65	5.46	5.65	5.67	5.66	5.4
Rxr 1 Fresh Hydrogen Flow (Sml/min)	226	236	241	256	234	366	306	410	344	281.0
Rxr 1 Hydrogen Mole Percent (mol%)	0.34	0.36	0.33	0.39	0.36	0.56	0.44	0.59	0.50	0.4
Rxr 1 Feed Pressure (barg)	35.89	36.85	36.28	36.89	36.87	36.94	36.37	36.2	36.25	35.9
Rxr 2 Feed Temperature (°C)	31	34	0.0	34	33	32	0	0	0	23.6
Rxr 2 Fresh Solvent Flow (kg/h)	0.01	1.87	5.0	0.01	1.86	1.84	0	0	0	10
Rxr 2 Total Solvent Flow (kg/h)	0.38	1.97	5.0	0.02	1.85	1.85	0	0	0	10
Rxr 2 Fresh Monomer Flow (kg/h)	0	0	0	0	0	0	0	0	0	0
Rxr 2 Fresh Comonomer Flow (kg/h)	0	0	0	0	0	0	0	0	0	0
Rxr 2 Feed Solvent/Monomer Ratio	0	0	0	0	0	0	0	0	0	0
Rxr 2 Fresh Hydrogen Flow (Sml/min)	0	0	0	0	0	0	0	0	0	0
Rxr 2 Hydrogen Mole Percent (mol%)	0	0	0	0	0	0	0	0	0	0
Rxr 2 Feed Pressure (barg)	44.07	48.62	36.89	50.0	50.0	50.0	36.99	36.93	37.07	49.3

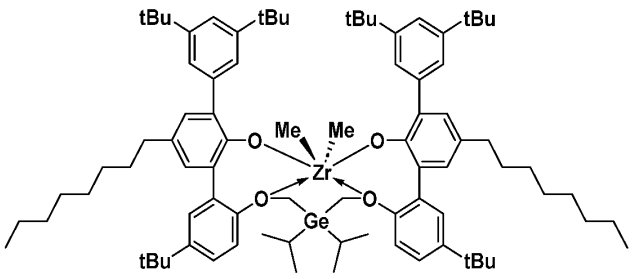
Table 1: Continued

Example	**C1**	**C2**	**C3**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**
Rxr 1 Catalyst-1 Type	D	A	A	A	A	B	A	B	B	B
Rxr 1 Catalyst-1 Flow (g/h)	41.1	45.55	143.8	65.2	57.1	20.3	115.7	161.0	146.2	72.2

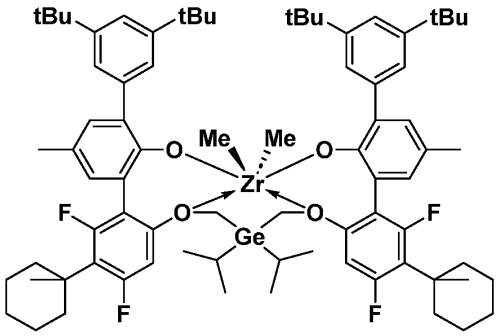
Rxr 1 Catalyst-1 Concentration (mmol/kg)	0.08	0.15	0.13	0.15	0.15	0.15	0.13	0.13	0.13	0.5
Rxr 1 Catalyst Efficiency (ton/g)	15.26	6.77	2.72	4.98	5.9	14.84	3.22	2.28	2.54	1.5
Rxr 1 Co-Catalyst-1 Molar Ratio	1.2	0.48	1.2	1.6	0	0	92.3	66.4	73.1	0.0
Rxr 1 Co-Catalyst-1 Type	1	1	1	1	None	None	4	4	4	None
Rxr 1 Co-Catalyst-1 Flow (g/h)	41.27	44.69	144.74	86.99	0	0	333.96	333.96	333.95	0.0
Rxr 1 Co-Catalyst-1 Concentration (mmol/kg)	0.09	0.18	0.15	0.18	0	0	4.0	4.0	4.0	0.0
Rxr 1 Co-Catalyst-2 Molar Ratio	48.86	149.82	76.59	27.56	75.16	75.3	1.2	1.2	1.2	66.5
Rxr 1 Co-Catalyst-2 Type	2	4	4	4	3	3	1	1	1	3
Rxr 1 Co-Catalyst-2 Flow (g/h)	50.14	222.85	344.18	59.93	245.27	43.39	116.58	162.13	147.21	120.0
Rxr 1 Co-Catalyst-2 Concentration (mmol/kg)	3.0	4.5	4.0	4.5	2.63	5.25	0.15	0.15	0.15	20.0
Rxr 1 Aluminium concentration in reactor (ppm)	0.12	3.38	1.04	0.94	0.52	0.19	1.08	1.07	1.08	1.9
ASC Catalyst-1 Type	F	F	F	C	C	C	C	E	C	E
ASC Catalyst-1 Flow (g/h)	227.73	230.0	300.29	12.69	11.54	10.77	11.19	138.8	7.81	61.1
ASC Catalyst-1	0.6	0.6	0.32	0.03	0.03	0.02	0.03	0.03	0.03	0.1

Concentration (mmol/kg)										
ASC Catalyst Efficiency (ton/g)	0.54	0.56	1.36	65.5	42.24	62.16	123.15	15.6	169.04	1.3
Rx2 Catalyst-2 Metal Mol% (mol%)	0	0	0	0	0	0	0	0	0	0.0
Rx2 Catalyst-2 Type	None	None	None	None	None	None	None	None	None	None
Rx2 Catalyst-2 Flow (g/h)	0	0	0	0	0	0	0	0	0	0.0
Rx2 Catalyst-2 Concentration (mmol/kg)	0	0	0	0	0	0	0	0	0	0.0
Rx2 Aluminium concentration in reactor (ppm)	0	0	0	0	0	0	0	0	0	0.0
Rx2 Co-Catalyst-1 Molar Ratio	4.49	0	0	0	6.59	0.49	0	0	0	0.0
ASC Co-Catalyst-1 Type	4	None	None	None	1	None	None	None	None	1
ASC Co-Catalyst-1 Flow (g/h)	136.59	0	0	0	10.55	1.38	0	0	0	91.7
ASC Co-Catalyst-1 Concentration (mmol/kg)	4.5	0	0	0	0.18	0.01	0	0	0	0.0

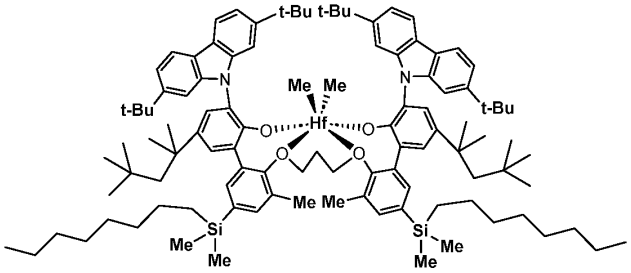
[0069] In Table 1, the catalysts are as follows:



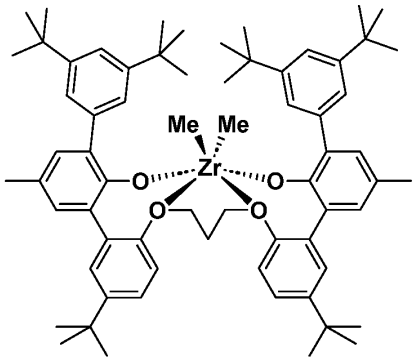
(A)



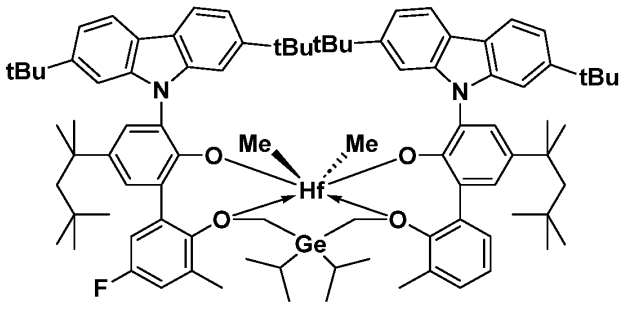
(B)



(C)



(D)



(E)

Ziegler Natta (F)

Table 1

Co-Cat	**Name**	**Source**
1	hydrogenated tallow alkyl)methyl, tetrakis(pentafluorophenyl)borate(1-) amine	Boulder Scientific
2	MMAO-3A	Nouryon
3	MMAO-7	Nouryon
4	triethylaluminum	Nouryon

[0070] Comparative Polymers

[0071] Additionally, EXCEED™ 1018, a metallocene catalyst ethylene/hexane copolymer having an I_2 of 1 g/10 minutes and density of 0.918 g/cm^3, and commercially available from ExxonMobil Chemical was utilized as comparative example C1.

[0072] DOWLEX™ GM 8090, a linear low density polyethylene (LLDPE) having a density of 0.916 g/cc and melt index (12) of 1.0 g/10 min, and commercially available from The Dow Chemical Company (Midland, MI), was utilized as comparative example C2. DOWLEX™ GM 8090 is an ethylene-based polymer as that term is defined herein.

[0073] A linear low density polyethylene (LLDPE) having a density of 0.917 g/cc and melt index (12) of 1.0 g/10 min was utilized as comparative example C3.

[0074] Characterization of Bimodal Ethylene-Based Polymers

[0075] The bimodal ethylene-based polymers described herein, and the comparative examples, were subjected to GPC testing, the results of which are given in Table 3.

Table 3

Ex	**Conv Mn (g/mol)**	**Conv Mw (g/mol)**	**Conv Mz (g/mol)**	**Conv PDI**	**Abs Mn (g/mol)**	**Abs Mw (g/mol)**	**Mz (Abs) (g/mol)**	**Mz/Mw**
E1	51540	114142	218513	2.2	50612	119811	221617	1.8
E2	50679	109357	203536	2.2	46755	114535	219749	1.9
E3	50833	110896	209164	2.2	50055	117837	223815	1.9
E4	50542	114201	221811	2.3	49738	118339	222211	1.9
E5	44660	119683	317090	2.7	45641	121993	291117	2.4
E6	52480	115634	224812	2.2	51789	120146	225931	1.9
E7	44380	104727	207615	2.4	44003	106989	211187	2
C1	47039	111454	199099	2.4	230579	109897	23725.6	
C2	31436	100052	196943	3.2	30361	105261	202660	1.9

C3	33434	110544	210937	3.3	38577	116297	215928	1.9

[0076] The samples were subjected to iCCD testing, the results of which are given in Table 4.

Table 4

Ex	T Purge	T LDF (°C)	T HDF (°C)	% Purge	% LDF	% HDF	Mw LDF (g/mol)	Mw HDF (g/mol)	Δ Mw (g/mol)	Δ T (°C)
E1	31	75	98	0.38	73.5	26.1	114467	158181	43714	23
E2	30	82	99	0.2	76.2	23.6	105928	152039	46111	17
E3	30	77	100	0.22	72	27.7	119000	107884	39755	23
E4	30	78	98	0.38	70.8	28.9	112514	143923	31408	20
E5	30	76	99	1.38	73	25.6	96708	186107	89399	23
E6	30	77	100	0.8	72.5	26.7	111101	159760	48658	22
E7	31	85	100	0.13	87.4	12.5	93097	164030	70933	16
C1	30	85	93	0.23	92.7	7.03	119239	99148	-20091	8
C2	30	84	93	0.9	96.6	2.46	107906	95865	-12041	9
C3	30	83	96	0.82	97.7	1.49	110680	118874	8195	13
CR-1	30	83	99	1.75	83.7	14.6	95451	210349	16.1	16.1
CR-2	30	69	93	0.51	49.7	49.8	159337	91057	24.4	24.4

[0077] The samples were subjected to rheology testing. Results are given in Table 5.

Table 5

Example	I_2 (dg/min)	I_{10}/I_2	Density (g/cm^3)	$V_{0.1}/V_{100}$	Zero Shear Viscosity (Pa*s)	Viscosity at 100/s (Pa*s)
E1	0.94	6.5	0.914	2.81	7577	2608
E2	0.98	5.9	0.914	2.84	7205	2439
E3	0.95	6.4	0.917	2.94	7785	2551
E4	0.87	5.7	0.916	2.91	7690	2555
E5	0.87	6.4	0.916	3.69	8856	2223
E6	0.82	5.8	0.916	3.25	8699	2534
E7	0.95	6.5	0.919	3.66	8570	2311
C1	1	5.7	0.918	2.73	6846	2445
C2	1	7.1	0.916	4.53	9989	2000
C3	1	5.7	0.917	3.09	7684	2368

[0078] Bimodal Ethylene-Based Polymer Films

[0079] **Line 1**

[0080] Two mil blown films were made using a monolayer Dr. Collin blown film line. The line utilizes a 30:1 L/D single screw extruder, equipped with grooved feed zones, and a 30 mm screw diameter. The annular die was 60 mm in diameter and used a dual lip air ring cooling system. The die lip gap was 2 mm and the blow up ratio (BUR) was 2.0. The lay flat width was around 48 cm. The frost line height was 5-6 inches. The total output rate was 5-8 kg/hour. The melt temperature was 200-220 °C, and the die temperature was set at 225°C.

[0081] **Line 2**

[0082] Two mil blown films were made by using a gravimetric feeders to dose resin formulations into a Labtech LTE20-32 twin screw extruder at rate of 15 lbs/hr. From the extruder, the resin formulation was conveyed into the 2" die diameter die with gap of 1.0 mm. The Labtech feed throat was set to 193 °C and the remaining barrel, conveying portion, and die temperature were set and maintained to 215 °C. Pressurized ambient air was used to inflate the film bubble to a 2.5 blow-up ratio. A dual lip air ring driven by a variable speed blower was used for all experiments. The frost line height (FLH) was maintained between 8.8 and 10.8 inches. Film thickness was targeted at 2 mils and was controlled within ± 15% by adjusting the nip roller speed. The films are wound up into a roll.

[0083] **Line A**

[0084] Two mil blown films were made on a single 3.5 inch diameter 30:1 L/D Sterling ran at a rate of 250 lbs/hr. Film was fabricated using an 8 inch die diameter using IBC (internal bubble cooling). External cooling was provided by a Hosokowa Alpine air ring which operated in sequence with a Kundig gauge scanner to control gauge variation. Film then passed on to a single turret Gloucester high speed (1000 ft/min max) winder where it was collected on a 3" core for sampling. The blow up ratio (BUR) was 2.0 with film thickness targeted at 2 mils.

[0085] Properties of the resulting films are given in Table 6.

Table 6

Example	Blown Film Line	Haze (%)	Dart Impact (g)	IDI - Total Energy (J)	Elmendorf MD Tear (gf)
E1	Line 1	15		3.8	
E1	Line 2	19	1172	1.9	889
E2	Line 1	11		1.8	
E2	Line 2	13	699	1.3	865
E3	Line 1	9.1		1.8	
E3	Line 2	8.3	548	1.5	852
E4	Line 1	11		1.9	
E4	Line 2	17	1196	2.8	874
E5	Line 1	9.2		1.1	
E5	Line 2	15	807	1	996
E6	Line 1	11		1.4	
E6	Line 2	15	1190	2.4	979
E7	Line 2	20	512	1.2	926
C1	Line 1	29	1212	1.7	650
C2	Line 1	7.1	740	1.6	590
C3	Line-A	13	1449	2.8	597

[0086] As can be seen from Table 6, the bimodal ethylene-based polymer films of the present disclosure have improved tear resistance, relative to the comparative films. Additionally, higher ΔT is correlated with higher MD Tear.

[0087] Films Formed From Polymer Blends

[0088] AVANGARD™ NATURA PCR-LDPCR-100, a PCR commercially available from Avangard Innovative LP, Houston, Texas (hereinafter "PCR"), is a post-consumer recycled ethylene-based polymer with a melt index (I_2) of 2 dg/min and a density of 0.914 g/cc.

[0089] DOWLEX™ 2045G, a monomodal LLDPE produced in a single reactor, with a melt index (I_2) of 1 dg/min, and a density of 0.92 g/cc, commercially available from Dow Inc. Midland MI, was used as comparative resin CR-1.

[0090] INNATE™ ST50, an LLDPE with a melt index (I_2) of 0.83 dg/min, and a density of 0.918 g/cc, commercially available from Dow Inc. Midland MI, was used as comparative resin CR-2.

[0091] Examples E5 and E6 were used as the bimodal ethylene-based polymers.

[0092] 2 mil films containing blends of PCR and bimodal ethylene-based polymers in varying ratios were prepared on Line 2 as described above. Additionally, films comprising other LLDPEs and PCR, as well as virgin resin controls were prepared. The Dart and Tear performance of the films was then tested.

[0093] Table 7 discloses the ASTM normalized dart drop impact, Elmendorf MD-Tear, and instrumented dart impact performance of virgin bimodal ethylene-based polymers and mixtures of 75 wt. % virgin ethylene-based polymer with 25 wt. % PCR.

Table 7

Base Sample	IDI (Joules)		Normalized Dart Drop Impact (g)		Normalized Elmendorf MD Tear (gf)	
	0 wt. % PCR	25 wt. % PCR	0 wt. % PCR	25 wt. % PCR	0 wt. % PCR	25 wt. % PCR
E5	1.64	0.72				
E6	2.85	1.53	346	244	475	445
CR-1	0.60	0.45	146	113	428	391
CR-2	5.95	1.32	890	333	337	392

[0094] As can be seen from Table 7, the bimodal ethylene-based polymer E5 shows a slight increase in MD-Tear when PCR is incorporated.

[0095] Table 8 shows the effect on Haze of incorporating PCR into the polymers of Example E6 and comparative resins CR-1 and CR-2.

Table 8

Base Sample	Haze	
	0 wt. % PCR	25 wt. % PCR
E6	10.4	9.3
CR-1	6.7	9.2
CR-2	10.7	11.8

[0096] As can be seen from Table 8, unlike the comparative resins, E6 does not show an increase in haze when PCR is incorporated.

CLAIMS

1. A bimodal ethylene-based polymer, the bimodal ethylene-based polymer being the polymerized reaction product of ethylene and one or more C_3-C_{14} olefinic comonomers, wherein the bimodal ethylene-based polymer comprises:

a high density fraction (HDF) from 12.0% to 35.0%, the HDF being defined as a ratio of the mass eluted at temperatures from 93 °C to 119 °C to the total mass eluted when measured using an improved comonomer content distribution (iCCD) curve of mass eluted versus temperature;

an I_{10}/I_2 ratio from 5.5 to 7.0, wherein I_2 is the melt index when measured according to ASTM D 1238 at a load of 2.16 kg and temperature of 190° C. and I_{10} is the melt index when measured according to ASTM D 1238 at a load of 10 kg and temperature of 190° C; and

the high density fraction has a molecular weight of at least 120,000 g/mol.

2. The bimodal ethylene-based polymer of claim 1, a soluble fraction (SF) less than 2.0%, the SF being defined as a ratio of the mass eluted at temperatures less than 35 °C to the total mass eluted when measured according to iCCD.

3. The bimodal ethylene-based polymer of any one of claims 1 to 2, wherein the bimodal ethylene-based polymer has a Δ Mw between the HDF and the LDF of at least 30,000 g/mol.

4. The bimodal ethylene-based polymer of any one of claims 1 to 3, wherein the bimodal ethylene-based polymer has a Δ T between the HDF and the LDF of at least 15 °C.

5. The bimodal ethylene-based polymer of any one of claims 1 to 4, wherein the bimodal ethylene-based polymer has a molecular weight Mn (conventional) of at least 40,000 g/mol.

6. The bimodal ethylene-based polymer of any one of claims 1 to 5, wherein the bimodal ethylene-based polymer has a density from 0.900 g/cc to 0.925 g/cc.

7. The bimodal ethylene-based polymer of any one of claims 1 to 6, wherein the bimodal ethylene-based polymer has a melt index (I_2) from 0.5 g/10 mins to 7.0 g/10 mins.

8. The bimodal ethylene-based polymer of any one of claims 1 to 7, wherein the bimodal ethylene-based polymer has an I_{10}/I_2 ratio from 5.5 to 6.0.

9. The bimodal ethylene-based polymer of any one of claims 1 to 8, wherein the bimodal ethylene-based polymer has a $V_{0.1}/V_{100}$ of from 2 to 4.

10. A polymer blend comprising:

the bimodal ethylene-based polymer of any one of claims 1 to 9, wherein the bimodal ethylene-based polymer is a virgin polymer; and

post-consumer recycled (PCR) ethylene-based polymer having a density of 0.910 to 0.930 g/cc and a melt index (I_2) of 0.3 to 2 dg/min as measured according to ASTM D1238 (190 °C, 2.16 Kg).

11. The polymer blend of claim 10, wherein the polymer blend comprises from 10 to 50 wt.% PCR ethylene-based polymer.

12. A film comprising the bimodal ethylene-based polymer any one of claims 1 to 11, wherein the film is a monolayer film or a multilayer film.

13. The film of claim 12, wherein the film has a haze of less than 25% at a thickness of 2 mm.

14. The film of claim 12 or 13, wherein the film has an MD-Tear of greater than 800 gf at a thickness of 2 mm.

15. The film of any one of claims 12 to 14, wherein the film has a dart impact of at least 500 g at a thickness of 2 mm.