

BIMODAL POLYETHYLENE COPOLYMER AND FILM THEREOF**FIELD**

[0001] Polyethylene copolymers, films, manufactured articles, and related methods.

INTRODUCTION

[0002] Patent application publications in or about the field include US 2016/0068623 A1; US 2016/0297907 A1; and WO 2017/132092 A1. Patents in or about the field include US 5,332,706; US 5,882,750; US 6,989,344 B2; US 7,078,467 B1; US 7,090,927 B2; US 7,157,531 B2; US 7,223,825 B2; US 7,300,988 B2; US 8,227,552 B2 and US 8,497,329 B2.

SUMMARY

[0003] A bimodal ethylene-*co*-1-hexene copolymer consisting essentially of a higher molecular weight (HMW) component and a lower molecular weight (LMW) component and, when in melted form at 190 degrees Celsius (° C.), is characterized by a unique melt property space defined by a combination of high-load melt index, melt flow ratio, and melt elasticity properties (“the bimodal ethylene-*co*-1-hexene copolymer”). With “consisting essentially of”, the bimodal ethylene-*co*-1-hexene copolymer is free of a distinct third or more component as determined by gel permeation chromatography (GPC) measured according to the GPC Test Method.

[0004] A method of synthesizing the bimodal ethylene-*co*-1-hexene copolymer, the method consisting essentially of polymerizing ethylene (monomer) and 1-hexene (comonomer) with a single bimodal catalyst system in a single fluidized-bed, gas phase polymerization (FB-GPP) reactor under effective operating conditions, thereby making the bimodal ethylene-*co*-1-hexene copolymer. With “consisting essentially of”, the method is free of Ziegler-Natta catalysts and chrome catalysts, and the polymerizing is carried out in a single reactor (i.e., in the FB-GPP reactor), and the operating conditions are effective for imparting the unique combination of high-load melt index, melt flow ratio, and melt elasticity properties to the bimodal ethylene-*co*-1-hexene copolymer. Other than that, the method is not particularly limited.

[0005] A film consisting essentially of the bimodal ethylene-*co*-1-hexene copolymer (“the film”). The film is characterized by enhanced (increased) toughness comprising enhanced (increased) tear resistance and enhanced (increased) dart impact. With “consisting essentially of”, the film is free of other polyolefin polymers, but otherwise its constituents are not particularly limited.

[0006] A method of making a blown film, the method comprising melting the bimodal ethylene-*co*-1-hexene copolymer to give a melt thereof, extruding the melt through a die configured for forming a bubble so as to make a bubble of the bimodal ethylene-*co*-1-hexene

copolymer, and blowing (inflating) the bubble with a film-blowing machine, thereby making the blown film.

[0007] A manufactured article comprising the bimodal ethylene-co-1-hexene copolymer.

DETAILED DESCRIPTION

[0008] The Summary and Abstract are incorporated here by reference. Certain embodiments are described below as numbered aspects for easy cross-referencing.

[0009] Aspect 1. A bimodal ethylene-co-1-hexene copolymer consisting essentially of a higher molecular weight (HMW) component and a lower molecular weight (LMW) component and, when in melted form at 190° C., is characterized by a melt property space defined by a combination of high-load melt index ("HLMI" or " I_{21} "), melt flow ratio I_{21}/I_5 ("MFR5"), and melt elasticity ($G'/G''@0.1$ rad/s) properties, wherein the HLMI is 7.0 to 11.0 grams per 10 minutes (g/10 min.), alternatively 7.3 to 10.0 g/10 min., alternatively 7.4 to 9.5 g/10 min. and is measured according to ASTM D1238-13 (190° C., 21.6 kg); the MFR5 is 22.0 to 35.0, alternatively 25 to 32, alternatively 26.6 to 30.6 wherein the I_{21} and I_5 values used to calculate the MFR5 are each in g/10 min. and are measured according to ASTM D1238-13 (190° C., 21.6 kg, " I_{21} "; and 190° C., 5.0 kg, " I_5 ", respectively), and the melt elasticity is 0.5 to 0.8 pascals (Pa), alternatively 0.50 to 0.70 Pa, alternatively 0.525 to 0.684 Pa, and wherein melt elasticity = G'/G'' determined at 0.1 radian per second (rad/s) according to Melt Elasticity Test Method (described herein). The "/" means division. The melt elasticity characterizes the relationship between melt storage modulus (G') and loss modulus (G'') at the dynamic frequency of 0.1 rad/s. This relationship is useful for evaluating polyethylene resins for films applications.

[0010] Aspect 2. The bimodal ethylene-co-1-hexene copolymer of aspect 1 wherein the melt property space of the bimodal ethylene-co-1-hexene copolymer is further defined by any one of limitations (i) to (iii): (i) a melt index I_2 from 0.05 to 0.10, alternatively 0.055 to 0.084, alternatively 0.060 to 0.080 g/10 min. measured according to ASTM D1238-13 (190° C., 2.16 kg, " I_2 "); (ii) a melt index I_5 from 0.20 to 0.40, alternatively from 0.25 to 0.35, alternatively from 0.27 to 0.33 g/10 min., measured according to ASTM D1238-13 (190° C., 5.0 kg, " I_5 "); and (iii) a melt flow ratio I_{21}/I_2 ("MFR2") from 80.0 to 150.0, alternatively 99 to 140.0, alternatively 101 to 139 wherein the I_{21} and I_2 values used to calculate the MFR2 are each in g/10 min. and are measured according to ASTM D1238-13 (190° C., 21.6 kg, " I_{21} "; and 190° C., 2.16 kg, " I_2 ", respectively). In some aspects the melt property space is further defined by any one of limitations (iv) to (vii): (iv) both (i) and (ii); (v) both (i) and (iii); (vi) both (ii) and (iii); and (vii) each of (i) to (iii).

[0011] Aspect 3. The bimodal ethylene-co-1-hexene copolymer of aspect 1 or 2 characterized by any one of resin property limitations (i) to (iv): (i) a density from 0.9410 to 0.9550 gram per cubic centimeter (g/cm^3), alternatively 0.9450 to 0.9530 g/cm^3 , alternatively 0.9480 to 0.9500 g/cm^3 , measured according to ASTM D792-13, Method B; (ii) a component fraction split characterized by a weight fraction of the HMW component from 50.0 to 63 wt%, alternatively from 55 to 60.0 wt%, alternatively from 57.0 to 59.4 wt%; and a weight fraction of the LMW component fraction is from 50.0 to 37 wt%, alternatively from 45 to 40.0 wt%, alternatively from 43.0 to 40.6 wt%, respectively, of the combined weight of the HMW and LMW components, measured according to the Gel Permeation Chromatography (GPC) Test Method; (iii) a component molecular weight spread characterized by a ratio of the weight-average molecular weight of the HMW component ($M_{w\text{-HMW}}$) to the weight-average molecular weight of the LMW component ($M_{w\text{-LMW}}$) (i.e., $M_{w\text{-HMW}}/M_{w\text{-LMW}}$ ratio) from 30.0 to 50.0, alternatively 40.0 to 45, alternatively 40.9 to 42.5, measured according to the GPC Test Method; and (iv) a molecular mass dispersity (M_w/M_n), $\bar{M}_M$, from 30.0 to 40.0, alternatively from 34 to 39, alternatively from 34.8 to 38.6, wherein M_w and M_n are measured according to the GPC Test Method. In some aspects the copolymer is further characterized by any one of resin property limitations (v) to (xii): (v) both (i) and (ii); (vi) both (i) and (iii); (vii) both (i) and (iv); (viii) both (ii) and (iii); (ix) both (ii) and (iv); (x) both (iii) and (iv); (xi) any three of (i) to (iv); and (xii) each of (i) to (iv). In some aspects the bimodal ethylene-co-1-hexene copolymer may have a transition metal content, alternatively a Zr content, of less than 10 weight parts per million (ppm) measured according to inductively coupled plasma mass spectrometry (ICP-MS).

[0012] Aspect 4. The bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 3 that, when characterized in the form of a blown film and having a thickness of 0.0127 millimeter (mm, 12.7 micrometer (μm), 0.500 mil), is characterized by any one of limitations (i) to (iv): (i) a dart impact from 250 to 400 grams (g), alternatively 270 to 380 g, alternatively 275 to 376 g, measured according to the Dart Impact Test Method; (ii) an Elmendorf tear in cross direction (CD) from 60.0 to 190.0 gram-force (gf), alternatively 61 to 185 gf, alternatively 83 to 182 gf, measured according to the Elmendorf Tear Test Method; (iii) an Elmendorf tear in machine direction (MD) from 15 to 35 gf, alternatively 17 to 33 gf, alternatively 18 to 32 gf, measured according to the Elmendorf Tear Test Method; and (iv) a gauge variation from 10.5% to 17%, alternatively from 11.0% to 16.4%, alternatively from 11.2% to 16.2%, measured according to the Gauge Variation Test Method. In some aspects the copolymer, when characterized in the form of the blown film, is further characterized by any one of limitations (v) to (xii): (v) both (i) and (ii); (vi) both (i) and (iii); (vii) both (i) and (iv);

(viii) both (ii) and (iii); (ix) both (ii) and (iv); (x) both (iii) and (iv); (xi) any three of (i) to (iv); and (xii) each of (i) to (iv).

[0013] Aspect 5. A method of synthesizing the bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 4, the method consisting essentially of copolymerizing ethylene (monomer) and 1-hexene (comonomer) with a combination of a bimodal catalyst system and a trim catalyst in the presence of molecular hydrogen gas (H_2) and, optionally, an induced condensing agent (ICA) in one polymerization reactor (e.g., one fluidized bed, gas phase polymerization reactor (FB-GPP reactor)) under effective polymerizing conditions to give an initial bimodal ethylene-co-1-hexene copolymer, and optionally oxygen tailoring the initial bimodal ethylene-co-1-hexene copolymer to give an oxygen-tailored bimodal ethylene-co-1-hexene copolymer; wherein the bimodal catalyst system is made by contacting a first activator with bis(2-(pentamethylphenylamido)ethyl)-amine zirconium dibenzyl and a bis(butylcyclopentadienyl)zirconium dihalide; wherein the trim catalyst is made by contacting a second activator with bis(butylcyclopentadienyl)zirconium dialkyl; wherein the first and second activators are the same or different; and wherein the effective polymerizing conditions comprise a reaction temperature from 80 degrees ($^{\circ}$) to 110 $^{\circ}$ Celsius ($C.$), alternatively 83 $^{\circ}$ to 106 $^{\circ}$ $C.$, alternatively 83 $^{\circ}$ to 87 $^{\circ}$ $C.$, alternatively 91 $^{\circ}$ to 100 $^{\circ}$ $C.$, alternatively 101 $^{\circ}$ to 106 $^{\circ}$ $C.$; a molar ratio of the molecular hydrogen gas to the ethylene (H_2/C_2 molar ratio) from 0.001 to 0.020, alternatively 0.002 to 0.015, alternatively 0.005 to 0.010; and a molar ratio of the 1-hexene (" C_6 ") to the ethylene (C_6/C_2 molar ratio) from 0.005 to 0.050, alternatively 0.008 to 0.030, alternatively 0.015 to 0.025. In some aspects the bis(butylcyclopentadienyl)zirconium dihalide is bis(butylcyclopentadienyl)zirconium dichloride; and the bis(butylcyclopentadienyl)zirconium dialkyl is bis(butylcyclopentadienyl)zirconium dimethyl or bis(butylcyclopentadienyl)zirconium diethyl, alternatively bis(butylcyclopentadienyl)zirconium dimethyl. In some aspects the first activator is an alkylaluminoxane (alkylalumoxane) and the second activator independently is an alkylaluminoxane or an alkylaluminum compound.

[0014] Aspect 6. The method of aspect 5 further consisting essentially of removing the bimodal ethylene-co-1-hexene copolymer (initial and/or oxygen tailored embodiment(s)) from the reactor (e.g., the FB-GPP reactor) to give a removed bimodal ethylene-co-1-hexene copolymer. In some aspects the removed bimodal ethylene-co-1-hexene copolymer may be the initial bimodal ethylene-co-1-hexene copolymer, the oxygen-tailored bimodal ethylene-co-1-hexene copolymer, or both. In some aspects the removed bimodal ethylene-co-1-hexene copolymer may be purged with an inert gas (e.g., N_2) to remove entrained hydrocarbons therefrom and/or treated with a stream of humidified nitrogen (N_2) gas to

deactivate *in situ* any residual amount of the bimodal catalyst system contained therein to give a purged bimodal ethylene-co-1-hexene copolymer. In some aspects the removed or purged bimodal ethylene-co-1-hexene copolymer is degassed to remove volatile organic compounds therefrom to give a degassed bimodal ethylene-co-1-hexene copolymer. In some aspects the removed, purged, or degassed bimodal ethylene-co-1-hexene copolymer is pelletized to give pellets thereof (pelletized bimodal ethylene-co-1-hexene copolymer). The initial, oxygen-tailored, removed, purged, degassed, and pelletized embodiments of the bimodal ethylene-co-1-hexene copolymer are collectively referred to as “the bimodal ethylene-co-1-hexene copolymer”, which may be that of any one of aspects 1 to 4. The bimodal ethylene-co-1-hexene copolymer may be combined with one or more film additives useful in polyethylene films. The combining may comprising melt mixing the one or more film additives into a melt of the bimodal ethylene-co-1-hexene copolymer. Alternatively, the combining may comprise soaking or injecting the one or more film additives into the pellets of the pelletized bimodal ethylene-co-1-hexene copolymer.

[0015] Aspect 7. A manufactured article comprising the bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 4.

[0016] Aspect 8. A film consisting essentially of the bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 4 (“the film”). The “consisting essentially of” transitional phrase means the film is free of other polyolefin polymers, but otherwise its constituents are not particularly limited. The film may be used in packaging applications to protect a substance in need of covering, wherein the film is disposed to at least partially cover the substance. Examples of substances in need of covering are paper, paperboard (e.g., cardboard), food, pharmaceutical compounds, and a stack of paperboard boxes (e.g., wherein the film is a shrink wrap used for wrapping a pallet stacked with paperboard boxes). The film may be the blown film made below.

[0017] Aspect 9. A method of making a blown film, the method comprising melting the bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 5 so as to give a melt thereof, extruding the melt through a die configured for forming a bubble so as to make a bubble of the bimodal ethylene-co-1-hexene copolymer, and blowing (inflating) the bubble with a film-blowing machine, thereby making the blown film. The bubble is restricted in one dimension. The blown film may be made or fabricated without internal bubble cooling (IBC) by any suitable method, including high stalk film blowing without IBC, such as by using a high stalk film blowing manufacturing line without (active) IBC equipment. The blown film consists essentially of the bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 5 (“the blown film”). The “consisting essentially of” transitional phrase means the blown

film is free of other polyolefin polymers, but otherwise its constituents are not particularly limited.

[0018] Aspect 10. A blown film made by the method of aspect 9 and consisting essentially of the bimodal ethylene-co-1-hexene copolymer of any one of aspects 1 to 4 (“the blown film”). With “consisting essentially of”, the blown film is free of other polyolefin polymers, but otherwise its constituents are not particularly limited. The blown film may be characterized by enhanced (increased) toughness (tear or dart impact) and/or enhanced gauge variation (decreased film thickness variability). The blown film may be used in the packaging applications.

Definitions

[0019] Activator. A substance, other than the catalyst or one of the substrates, that increases the rate of a catalyzed reaction without itself being consumed. Typically, the activator contains aluminum and/or boron.

[0020] Bimodal. Two, and only two, modalities or modes.

[0021] Bimodal in reference to a copolymer (e.g., the ethylene-co-1-hexene copolymer) means a composition consisting essentially of a higher molecular weight component and a lower molecular weight component, wherein the higher molecular weight component consists of a first group of polymer macromolecules made by a first catalyst in a first reactor under a first set of molecular weight-effective polymerization process conditions (e.g., first reactor bed temperature, first H_2/C_2 gas molar ratio, first comonomer/monomer molar ratio, and/or use or not of oxygen tailoring) and the lower molecular weight component consists of a second group of polymer macromolecules made by a second catalyst in a second reactor under a second set of molecular weight-effective polymerization process conditions (e.g., second reactor bed temperature, second H_2/C_2 gas molar ratio, second comonomer/monomer molar ratio, and/or use or not of oxygen tailoring), wherein at least one of the following differences are present: (a) the first catalyst is different in catalytic metal and/or ligand composition than that/those of the second catalyst; (b) the first reactor is different than the second reactor or the first and second reactors are the same reactor but the polymerization reaction making the higher molecular weight component is done at a different time than the polymerization reaction making the lower molecular weight component; (c) at least one of the first set of molecular weight-effective polymerization process conditions is different than that one of the second set of molecular weight-effective polymerization process conditions. Bimodal polymer compositions include post-reactor blends and reactor blends (wherein the lower and higher molecular weight components are synthesized in the same reactor). The bimodal copolymer may be characterized by a two peaks separated by a distinguishable local minimum therebetween in a plot of $dW/d\text{Log}(MW)$

on the y-axis versus Log(MW) on the x-axis to give a Gel Permeation Chromatograph (GPC) chromatogram, wherein Log(MW) and $dW/d\text{Log(MW)}$ are as defined herein and are measured by Gel Permeation Chromatograph (GPC) Test Method described herein.

[0022] Bimodal when referring to a catalyst system means a catalyst system that contains two different catalysts for catalyzing a same polymerization process (e.g., olefin polymerization) and producing a bimodal polymer composition. Two catalysts are different if they differ from each other in at least one of the following characteristics: (a) their catalytic metals are different (Ti versus Zr, Zr versus Hf, Ti versus Hf; not activator metals such as Al); (b) one catalyst has a functional ligand covalently bonded to its catalytic metal and the other catalyst is free of functional ligands bonded to its catalytic metal; (c) both catalysts have functional ligands covalently bonded to their catalytic metal and the structures of at least one of functional ligand of one of the catalysts is different than the structure of each of the functional ligand(s) of the other catalyst (e.g., cyclopentadienyl versus propylcyclopentadienyl or butylcyclopentadienyl versus (pentamethylphenylamido)ethylamine); and (d) for catalysts disposed on a support material, the compositions of the support materials are different. Functional ligands do not include leaving groups X as defined later. Two catalysts of a bimodal catalyst system may be disposed on the same support material, either on the same particles of the same support material or each on different particles of the same support material. The same catalyst in terms of catalytic metal and ligands wherein a portion thereof is disposed on a support material and a different portion thereof is dissolved in an inert solvent, the different portions do not by themselves constitute a bimodal catalyst system.

[0023] Catalyst. A material that enhances rate of a reaction (e.g., the polymerization of ethylene and 1-hexene) and is not completely consumed thereby.

[0024] Catalyst system. A combination of a catalyst *per se* and a companion material such as a modifier compound for attenuating reactivity of the catalyst, a support material on which the catalyst is disposed, a carrier material in which the catalyst is disposed, or a combination of any two or more thereof, or a reaction product of a reaction thereof.

[0025] Consisting essentially of, consist(s) essentially of, and the like. Partially-closed ended expressions that exclude anything that would affect the basic and novel characteristics of that which they describe, but otherwise allow anything else. In some aspects any one, alternatively each "comprising" or "comprises" may be replaced by "consisting essentially of" or "consists essentially of", respectively; alternatively by "consisting of" or "consists of", respectively.

[0026] Consisting of and consists of. Closed ended expressions that exclude anything that is not specifically described by the limitation that it modifies. In some aspects any one,

alternatively each expression “consisting essentially of” or “consists essentially of” may be replaced by the expression “consisting of” or “consists of”, respectively.

[0027] Dry. Generally, a moisture content from 0 to less than 5 parts per million based on total parts by weight. Materials fed to the reactor(s) during a polymerization reaction are dry.

[0028] Feed. Quantity of reactant or reagent that is added or “fed” into a reactor. In continuous polymerization operation, each feed independently may be continuous or intermittent. The quantities or “feeds” may be measured, e.g., by metering, to control amounts and relative amounts of the various reactants and reagents in the reactor at any given time.

[0029] Feed line. A pipe or conduit structure for transporting a feed.

[0030] Film: an article restricted in one dimension. The restricted dimension may be called a thickness of the film, and the thickness (gauge variation) is substantially uniform therein. Claimed film properties are measured on 13 (12.7) micrometers thick monolayer films.

[0031] Inert. Generally, not (appreciably) reactive or not (appreciably) interfering therewith in the inventive polymerization reaction. The term “inert” as applied to the purge gas or ethylene feed means a molecular oxygen (O₂) content from 0 to less than 5 parts per million based on total parts by weight of the purge gas or ethylene feed.

[0032] Internal bubble cooling or IBC is an aspect of film blowing performed by actively using ancillary, special purpose IBC equipment such as that of US 2002/0150648 A1 to R. E. Cree.

[0033] Metallocene catalyst. Homogeneous or heterogeneous material that contains a cyclopentadienyl ligand-metal complex and enhances olefin polymerization reaction rates. Substantially single site or dual site. Each metal is a transition metal Ti, Zr, or Hf. Each cyclopentadienyl ligand independently is an unsubstituted cyclopentadienyl group or a hydrocarbyl-substituted cyclopentadienyl group. In some aspects the metallocene catalyst has two cyclopentadienyl ligands, and at least one, alternatively both of the cyclopentenyl ligands independently is a hydrocarbyl-substituted cyclopentadienyl group. Each hydrocarbyl-substituted cyclopentadienyl group may independently have 1, 2, 3, 4, or 5 hydrocarbyl substituents. Each hydrocarbyl substituent may independently be a (C₁-C₄)alkyl.

[0034] Trim catalyst. A quantity of a metallocene catalyst that is identical, except for X group described later, to the metallocene catalyst of the bimodal catalyst system. Trim catalyst is usually fed (e.g., to the FB-GPP reactor) as a solution of the catalyst dissolved in an inert liquid (non-polar, aprotic, e.g., hydrocarbon solvent). The trim catalyst is used with the bimodal catalyst system to modify at least one property of the copolymer made thereby.

Examples of such at least one property are density, melt index I_2 , flow index I_{21} , melt flow ratio (I_{21}/I_2), and molecular mass dispersity (M_w/M_n), $\bar{D}_M$.

[0035] Ziegler-Natta catalysts. Heterogeneous materials that enhance olefin polymerization reaction rates and are prepared by contacting inorganic titanium compounds, such as titanium halides supported on a magnesium chloride support, with an activator.

Polymerization Reactor and Method

[0036] In an illustrative pilot plant process for making the bimodal ethylene-co-1-hexene copolymer, a fluidized bed, gas-phase polymerization reactor ("FB-GPP reactor") having a reaction zone dimensioned as 304.8 mm (twelve inch) internal diameter and a 2.4384 meter (8 feet) in straight-side height and containing a fluidized bed of granules of the bimodal ethylene-co-1-hexene copolymer. Configure the FB-GPP reactor with a recycle gas line for flowing a recycle gas stream. Fit the FB-GPP reactor with gas feed inlets and polymer product outlet. Introduce gaseous feed streams of ethylene and hydrogen together with comonomer (e.g., 1-hexene) below the FB-GPP reactor bed into the recycle gas line.

[0037] Polymerization operating conditions are any variable or combination of variables that may affect a polymerization reaction in the GPP reactor or a composition or property of a bimodal ethylene-co-1-hexene copolymer product made thereby. The variables may include reactor design and size, catalyst composition and amount; reactant composition and amount; molar ratio of two different reactants; presence or absence of feed gases such as H_2 and/or O_2 , molar ratio of feed gases versus reactants, absence or concentration of interfering materials (e.g., H_2O), absence or presence of an induced condensing agent (ICA), average polymer residence time in the reactor, partial pressures of constituents, feed rates of monomers, reactor bed temperature (e.g., fluidized bed temperature), nature or sequence of process steps, time periods for transitioning between steps. Variables other than that/those being described or changed by the method or use may be kept constant.

[0038] In operating the polymerization method, control individual flow rates of ethylene (" C_2 "), hydrogen (" H_2 ") and 1-hexene (" C_6 " or " C_x " wherein x is 6) to maintain a fixed comonomer to ethylene monomer gas molar ratio (C_x/C_2 , e.g., C_6/C_2) equal to a described value (e.g., 0.0050), a constant hydrogen to ethylene gas molar ratio (" H_2/C_2 ") equal to a described value (e.g., 0.0020), and a constant ethylene (" C_2 ") partial pressure equal to a described value (e.g., 1,000 kPa). Measure concentrations of gases by an in-line gas chromatograph to understand and maintain composition in the recycle gas stream. Maintain a reacting bed of growing polymer particles in a fluidized state by continuously flowing a make-up feed and recycle gas through the reaction zone. Use a superficial gas velocity of 0.49 to 0.67 meter per second (m/sec) (1.6 to 2.2 feet per second (ft/sec)). Operate the FB-

GPP reactor at a total pressure of about 2344 to about 2413 kilopascals (kPa) (about 340 to about 350 pounds per square inch-gauge (psig)) and at a described first reactor bed temperature RBT. Maintain the fluidized bed at a constant height by withdrawing a portion of the bed at a rate equal to the rate of production of particulate form of the bimodal ethylene-co-1-hexene copolymer, which production rate may be from 10 to 20 kilograms per hour (kg/hr), alternatively 13 to 18 kg/hr. Remove the product bimodal ethylene-co-1-hexene copolymer semi-continuously via a series of valves into a fixed volume chamber, wherein this removed bimodal ethylene-co-1-hexene copolymer is purged to remove entrained hydrocarbons and treated with a stream of humidified nitrogen (N_2) gas to deactivate any trace quantities of residual catalyst. See polymerization method described herein.

[0039] The bimodal catalyst system may be fed into the polymerization reactor(s) in “dry mode” or “wet mode”, alternatively dry mode, alternatively wet mode. The dry mode is a dry powder or granules. The wet mode is a suspension in an inert liquid such as mineral oil.

[0040] Comonomer/ethylene gas molar ratio C_X/C_2 of comonomer (1-hexene/ethylene or C_6/C_2) and ethylene being fed into the gas-phase polymerization (GPP) reactor may be from 0.0001 to 0.1, alternatively from 0.0002 to 0.05, alternatively from 0.0004 to 0.02.

[0041] Gas molar ratio of comonomer to ethylene (“ C_X/C_2 gas molar ratio”) is the quantity of all alpha-olefin comonomer(s) (e.g., 1-hexene “ C_6 ”), in moles, being fed in a gaseous or vaporous state into the GPP reactor divided by the quantity of ethylene monomer (C_2), in moles, being fed in a gaseous state into the GPP reactor. The moles of comonomer and moles of ethylene are measured by gas flow meters or other suitable means.

[0042] Ethylene partial pressure (e.g., C_2P) in the GPP reactor. From 690 to 2070 kilopascals (kPa, i.e., from 100 to 300 psia (pounds per square inch absolute)); alternatively from 830 to 1655 kPa (120 to 240 psia), alternatively from 1300 to 1515 kPa (190 to 220 psia). Alternatively, the partial pressure of ethylene may be from 690 to 3450 kilopascals (kPa, 100 to 500 pounds per square inch absolute (psia)), alternatively 1030 to 2070 kPa (150 to 300 psia), alternatively 1380 to 1720 kPa (200 to 250 psia), alternatively 1450 to 1590 kPa (210 to 230 psia), e.g., 1520 kPa (220 psia). 1.000 psia = 6.8948 kPa.

[0043] Hydrogen to ethylene (H_2/C_2) gas molar ratio in the GPP reactor is from 0.010 to 0.100, alternatively from 0.011 to 0.094.

[0044] Induced condensing agent (ICA). An inert liquid useful for cooling materials in the polymerization reactor(s) (e.g., a fluidized bed reactor); its use is optional. The ICA may be a (C_5 - C_{20})alkane, alternatively a (C_{11} - C_{20})alkane, alternatively a (C_5 - C_{10})alkane, alternatively a (C_5)alkane, e.g., pentane or 2-methylbutane; a hexane; a heptane; an octane; a nonane; a decane; or a combination of any two or more thereof. The ICA may be 2-

methylbutane (i.e., isopentane). Aspects of the method of polymerization that use the ICA may be referred to as being an induced condensing mode operation (ICMO). ICMO is described in US 4,453,399; US 4,588,790; US 4,994,534; US 5,352,749; US 5,462,999; and US 6,489,408. Measure concentration of ICA in gas phase measured using gas chromatography by calibrating peak area percent to mole percent (mol%) with a gas mixture standard of known concentrations of ad rem gas phase components. Concentration of ICA may be from 1 to 10 mol%, alternatively from 3 to 8 mol%.

[0045] Oxygen (O₂) concentration relative to ethylene (“[O₂/C₂]”, volume parts O₂ per million volume parts ethylene (ppmv)) in the GPP reactor. In some embodiments the [O₂/C₂] is from 0.0000 to 0.20 ppmv, alternatively from 0.0001 to 0.200 ppmv, alternatively from 0.0000 to 0.183 ppmv, alternatively from 0.0000 to 0.163 ppmv.

[0046] The polymerization method uses a gas-phase polymerization (GPP) reactor, such as a stirred-bed gas phase polymerization reactor (SB-GPP reactor) or a fluidized-bed gas-phase polymerization reactor (FB-GPP reactor), to make the bimodal ethylene-co-1-hexene copolymer. Such reactors and methods are generally well-known in the art. For example, the FB-GPP reactor/method may be as described in US 3,709,853; US 4,003,712; US 4,011,382; US 4,302,566; US 4,543,399; US 4,882,400; US 5,352,749; US 5,541,270; EP-A-0 802 202; and Belgian Patent No. 839,380. These SB-GPP and FB-GPP polymerization reactors and processes either mechanically agitate or fluidize by continuous flow of gaseous monomer and diluent the polymerization medium inside the reactor, respectively. Other useful reactors/processes contemplated include series or multistage polymerization processes such as described in US 5,627,242; US 5,665,818; US 5,677,375; EP-A-0 794 200; EP-B1-0 649 992; EP-A-0 802 202; and EP-B-634421.

[0047] The polymerization conditions may further include one or more additives such as a chain transfer agent or a promoter. The chain transfer agents are well known and may be alkyl metal such as diethyl zinc. Promoters are known such as in US 4,988,783 and may include chloroform, CFC₃, trichloroethane, and difluorotetrachloroethane. Prior to reactor start up, a scavenging agent may be used to react with moisture and during reactor transitions a scavenging agent may be used to react with excess activator. Scavenging agents may be a trialkylaluminum. Gas phase polymerizations may be operated free of (not deliberately added) scavenging agents. The polymerization conditions for gas phase polymerization reactor/method may further include an amount (e.g., 0.5 to 200 ppm based on all feeds into reactor) of a static control agent and/or a continuity additive such as aluminum stearate or polyethyleneimine. The static control agent may be added to the FB-GPP reactor to inhibit formation or buildup of static charge therein.

[0048] Start-up or restart of the GPP reactor may be illustrated with a fluidized bed, GPP reactor. The start-up of a recommissioned FB-GPP reactor (cold start) or restart of a transitioning FB-GPP reactor (warm start) includes a time period that is prior to reaching steady-state polymerization conditions of step (a). Start-up or restart may include the use of a polymer seedbed preloaded or loaded, respectively, into the fluidized bed reactor. The polymer seedbed may be composed of powder of a polyethylene such as a polyethylene homopolymer or previously made batch of the bimodal ethylene-co-1-hexene copolymer.

[0049] Start-up or restart of the FB-GPP reactor may also include gas atmosphere transitions comprising purging air or other unwanted gas(es) from the reactor with a dry (anhydrous) inert purge gas, followed by purging the dry inert purge gas from the FB-GPP reactor with dry ethylene gas. The dry inert purge gas may consist essentially of molecular nitrogen (N₂), argon, helium, or a mixture of any two or more thereof. When not in operation, prior to start-up (cold start), the FB-GPP reactor contains an atmosphere of air. The dry inert purge gas may be used to sweep the air from a recommissioned FB-GPP reactor during early stages of start-up to give a FB-GPP reactor having an atmosphere consisting of the dry inert purge gas. Prior to restart (e.g., after a change in seedbeds), a transitioning FB-GPP reactor may contain an atmosphere of unwanted ICA or other unwanted gas or vapor. The dry inert purge gas may be used to sweep the unwanted vapor or gas from the transitioning FB-GPP reactor during early stages of restart to give the FB-GPP reactor an atmosphere consisting of the dry inert purge gas. Any dry inert purge gas may itself be swept from the FB-GPP reactor with the dry ethylene gas. The dry ethylene gas may further contain molecular hydrogen gas such that the dry ethylene gas is fed into the fluidized bed reactor as a mixture thereof. Alternatively the dry molecular hydrogen gas may be introduced separately and after the atmosphere of the fluidized bed reactor has been transitioned to ethylene. The gas atmosphere transitions may be done prior to, during, or after heating the FB-GPP reactor to the reaction temperature of the polymerization conditions.

[0050] Start-up or restart of the FB-GPP reactor also includes introducing feeds of reactants and reagents thereinto. The reactants include the ethylene and the alpha-olefin (e.g., 1-hexene). The reagents fed into the fluidized bed reactor include the molecular hydrogen gas and the induced condensing agent (ICA) and the bimodal catalyst system (e.g., PRODIGY™ BMC-300 catalyst) and the trim catalyst.

[0051] In an embodiment the method uses a pilot scale fluidized bed gas phase polymerization reactor (Pilot Reactor) that comprises a reactor vessel containing a fluidized bed of a powder of the bimodal ethylene-co-1-hexene copolymer, and a distributor plate disposed above a bottom head, and defining a bottom gas inlet, and having an expanded section, or cyclone system, at the top of the reactor vessel to decrease amount of resin fines

that may escape from the fluidized bed. The expanded section defines a gas outlet. The Pilot Reactor further comprises a compressor blower of sufficient power to continuously cycle or loop gas around from out of the gas outlet in the expanded section in the top of the reactor vessel down to and into the bottom gas inlet of the Pilot Reactor and through the distributor plate and fluidized bed. The Pilot Reactor further comprises a cooling system to remove heat of polymerization and maintain the fluidized bed at a target temperature. Compositions of gases such as ethylene, alpha-olefin (e.g., 1-hexene), hydrogen, and oxygen being fed into the Pilot Reactor are monitored by an in-line gas chromatograph in the cycle loop in order to maintain specific concentrations that define and enable control of polymer properties. In some embodiments the gases are cooled, resulting in their temperature dropping below their dew point, at which time the Pilot Reactor is in condensing mode operation (CMO) or induced condensing mode operation (ICMO). In CMO, liquids are present downstream of the cooler and in the bottom head below the distributor plate. The bimodal catalyst system (e.g., PRODIGY™ BMC-300) may be fed as a slurry or dry powder into the Pilot Reactor from high pressure devices, wherein the slurry is fed via a syringe pump and the dry powder is fed via a metered disk. The bimodal catalyst system typically enters the fluidized bed in the lower 1/3 of its bed height. The Pilot Reactor further comprises a way of weighing the fluidized bed and isolation ports (Product Discharge System) for discharging the powder of bimodal ethylene-co-1-hexene copolymer from the reactor vessel in response to an increase of the fluidized bed weight as polymerization reaction proceeds.

[0052] In some embodiments the FB-GPP reactor is a commercial scale reactor such as a UNIPOL™ reactor or UNIPOL™ II reactor, which are available from Univation Technologies, LLC, a subsidiary of The Dow Chemical Company, Midland, Michigan, USA.

Catalysts, Support Materials, Activators

[0053] The bimodal catalyst system used in the method of synthesizing may consist essentially of a metallocene catalyst and a non-metallocene molecular catalyst, which are different in functional ligand and/or catalytic metal M. The bimodal catalyst system may also consist essentially of a solid support material and/or at least one activator and/or at least one activator species, which is a by-product of reacting the metallocene catalyst or non-metallocene molecular catalyst with the first activator. The metallocene catalyst of the bimodal catalyst system may be bis(butylcyclopentadienyl)zirconium dihalide and the non-metallocene molecular catalyst of the bimodal catalyst system may be bis(2-(pentamethylphenylamido)ethyl)-amine zirconium dibenzyl. The bimodal catalyst system may be PRODIGY BMC-300, available from Univation Technologies LLC, Houston, Texas, USA.

[0054] Without being bound by theory, it is believed that the bis(2-(pentamethylphenylamido)ethyl)-amine zirconium dibenzyl is effective for making the HMW component of the bimodal ethylene-co-1-hexene copolymer and each of the bis(butylcyclopentadienyl)zirconium dihalide and bis(butylcyclopentadienyl)zirconium dialkyl is independently effective for making the LMW component of the bimodal ethylene-co-1-hexene copolymer. The molar ratio of the two catalysts of the bimodal catalyst system may be based on the molar ratio of their respective catalytic metal atom (M, e.g., Zr) contents, which may be calculated from ingredient weights thereof or may be analytically measured.

[0055] In an alternative embodiment of the method of making the bimodal ethylene-co-1-hexene copolymer, any one or both of the bis(butylcyclopentadienyl)zirconium dihalide (i.e., (butylcyclopentadienyl)₂MX₂ wherein each X is halide) and the bis(butylcyclopentadienyl)zirconium dialkyl (i.e., (butylcyclopentadienyl)₂MX₂ wherein each X is alkyl) may be independently replaced with any one of the following metallocene catalysts:

(pentamethylcyclopentadienyl)(propylcyclopentadienyl)MX₂;
 (tetramethylcyclopentadienyl)(propylcyclopentadienyl)MX₂;
 (tetramethylcyclopentadienyl)(butylcyclopentadienyl)MX₂; bridged (CH₃)₂Si(indenyl)MX₂;
 bridged (CH₃)₂Si(4,5,6,7-tetrahydro-indenyl)MX₂; (propylcyclopentadienyl)₂MX₂; (1-methyl-3-butyl-cyclopentadienyl)₂MX₂; wherein each M is independently zirconium (Zr) or hafnium (Hf); and wherein each X is independently selected from F, Cl, Br, I, -CH₃, -CH₂CH₃, benzyl, -CH₂Si(CH₃)₃, a (C₁-C₅)alkyl, and a (C₂-C₅)alkenyl.

[0056] The catalysts of the bimodal catalyst system may be disposed by spray-drying onto a solid support material prior to being contacted with an activator. The solid support material may be uncalcined or calcined prior to being contacted with the catalysts. The solid support material may be a hydrophobic fumed silica (e.g., a fumed silica treated with dimethyldichlorosilane). The bimodal (unsupported or supported) catalyst system may be in the form of a powdery, free-flowing particulate solid.

[0057] Support material. The support material may be an inorganic oxide material. The terms "support" and "support material" are the same as used herein and refer to a porous inorganic substance or organic substance. In some embodiments, desirable support materials may be inorganic oxides that include Group 2, 3, 4, 5, 13 or 14 oxides, alternatively Group 13 or 14 atoms. Examples of inorganic oxide-type support materials are silica, alumina, titania, zirconia, thoria, and mixtures of any two or more of such inorganic oxides. Examples of such mixtures are silica-chromium, silica-alumina, and silica-titania.

[0058] The inorganic oxide support material is porous and has variable surface area, pore volume, and average particle size. In some embodiments, the surface area is from 50 to

1000 square meter per gram (m^2/g) and the average particle size is from 20 to 300 micrometers (μm). Alternatively, the pore volume is from 0.5 to 6.0 cubic centimeters per gram (cm^3/g) and the surface area is from 200 to 600 m^2/g . Alternatively, the pore volume is from 1.1 to 1.8 cm^3/g and the surface area is from 245 to 375 m^2/g . Alternatively, the pore volume is from 2.4 to 3.7 cm^3/g and the surface area is from 410 to 620 m^2/g . Alternatively, the pore volume is from 0.9 to 1.4 cm^3/g and the surface area is from 390 to 590 m^2/g . Each of the above properties are measured using conventional techniques known in the art.

[0059] The support material may comprise silica, alternatively amorphous silica (not quartz), alternatively a high surface area amorphous silica (e.g., from 500 to 1000 m^2/g). Such silicas are commercially available from a number of sources including the Davison Chemical Division of W.R. Grace and Company (e.g., Davison 952 and Davison 955 products), and PQ Corporation (e.g., ES70 product). The silica may be in the form of spherical particles, which are obtained by a spray-drying process. Alternatively, MS3050 product is a silica from PQ Corporation that is not spray-dried. As procured, all of these silicas are not calcined (i.e., not dehydrated). Silica that is calcined prior to purchase may also be used as the support material.

[0060] Prior to being contacted with a catalyst, the support material may be pre-treated by heating the support material in air to give a calcined support material. The pre-treating comprises heating the support material at a peak temperature from 350° to 850° C., alternatively from 400° to 800° C., alternatively from 400° to 700° C., alternatively from 500° to 650° C. and for a time period from 2 to 24 hours, alternatively from 4 to 16 hours, alternatively from 8 to 12 hours, alternatively from 1 to 4 hours, thereby making a calcined support material. In some aspects the support material is a calcined support material.

[0061] The trim catalyst may be any one of the aforementioned metallocene catalysts. For convenience the trim catalyst is fed into the reactor in solution in a hydrocarbon solvent (e.g., mineral oil or heptane). The hydrocarbon solvent may be an alkane, or a mixture of alkanes, wherein each alkane independently has from 5 to 20 carbon atoms, alternatively from 5 to 12 carbon atoms, alternatively from 5 to 10 carbon atoms. Each alkane independently may be acyclic or cyclic. Each acyclic alkane independently may be straight chain or branched chain. The acyclic alkane may be pentane, 1-methylbutane (isopentane), hexane, 1-methylpentane (isohexane), heptane, 1-methylhexane (isoheptane), octane, nonane, decane, or a mixture of any two or more thereof. The cyclic alkane may be cyclopentane, cyclohexane, cycloheptane, cyclooctane, cyclononane, cyclodecane, methycyclopentane, methylcyclohexane, dimethylcyclopentane, or a mixture of any two or more thereof.

[0062] For solubility in the hydrocarbon solvent, typically each of the group X of the trim catalyst independently is hydrocarbyl (e.g., benzyl, a (C₁-C₅)alkyl, or a (C₂-C₅)alkenyl; e.g., methyl or ethyl) or -CH₂Si(CH₃)₃. The groups X of the trim catalyst may be different than the X groups of the metallocene catalyst of the bimodal catalyst system. Nevertheless, upon activation by contact thereof with an activator, the active catalyst species resulting from the activation of the trim catalyst is essentially the same as the active catalyst species resulting from the activation of the metallocene catalyst of the bimodal catalyst system. For example, the metallocene catalyst of the bimodal catalyst system may be bis(n-butylcyclopentadienyl) zirconium dichloride (each X is Cl), and the trim catalyst may be bis(n-butylcyclopentadienyl) zirconium dialkyl (e.g., dimethyl wherein X is CH₃). Upon activation by treatment thereof with a suitable activator or cocatalyst, both the bis(n-butylcyclopentadienyl) zirconium dichloride and the bis(n-butylcyclopentadienyl) zirconium dimethyl effectively yield the same activated catalyst species.

[0063] Activator. Each catalyst of the bimodal catalyst system is activated by contacting it with the first activator. The trim catalyst is activated by contacting it with the second activator. Additional activators may be used. Any activator may be the same or different as another and independently may be a Lewis acid, a non-coordinating ionic activator, or an ionizing activator, or a Lewis base, an alkylaluminum, or an alkylaluminumoxane (alkylalumoxane). The alkylaluminum may be a trialkylaluminum, alkylaluminum halide, or alkylaluminum alkoxide (diethylaluminum ethoxide). The trialkylaluminum may be trimethylaluminum, triethylaluminum ("TEAL"), tripropylaluminum, or tris(2-methylpropyl)aluminum. The alkylaluminum halide may be diethylaluminum chloride. The alkylaluminum alkoxide may be diethylaluminum ethoxide. The alkylaluminumoxane may be a methylaluminoxane (MAO), ethylaluminoxane, 2-methylpropyl-aluminumoxane, or a modified methylaluminoxane (MMAO). Each alkyl of the alkylaluminum or alkylaluminumoxane independently may be a (C₁-C₇)alkyl, alternatively a (C₁-C₆)alkyl, alternatively a (C₁-C₄)alkyl. The molar ratio of activator's metal (Al) to a particular catalyst compound's metal (catalytic metal, e.g., Zr) may be 1000:1 to 0.5:1, alternatively 300:1 to 1:1, alternatively 150:1 to 1:1. Suitable activators are commercially available.

[0064] Once the first activator and the (bis(2-(pentamethylphenylamido)ethyl)-amine zirconium dibenzyl and bis(butylcyclopentadienyl)zirconium dihalide) of the bimodal catalyst system contact each other, the catalysts of the bimodal catalyst system are activated and a first activator species may be made *in situ*. Once the second activator and the trim catalyst (a bis(butylcyclopentadienyl)zirconium dialkyl) contact each other, the trim catalyst is activated and a second activator species may be made *in situ*. The activator species may

have a different structure or composition than the activator from which it is derived and may be a by-product of the activation of the catalyst or may be a derivative of the by-product. The corresponding activator species may be a derivative of the Lewis acid, non-coordinating ionic activator, ionizing activator, Lewis base, alkylaluminum, or alkylaluminumoxane, respectively. An example of the derivative of the by-product is a methylaluminumoxane species that is formed by devolatilizing during spray-drying of a bimodal catalyst system made with methylaluminumoxane.

[0065] Each contacting step between activator and catalyst independently may be done either (a) in a separate vessel outside the GPP reactor (e.g., outside the FB-GPP reactor), (b) in a feed line to the GPP reactor, and/or (c) inside the GPP reactor (*in situ*). In option (a) the bimodal catalyst system, once its catalysts are activated, may be fed into the GPP reactor as a dry powder, alternatively as a slurry in a non-polar, aprotic (hydrocarbon) solvent. In option (c) the bimodal catalyst system may be fed into the reactor prior to activation via a first feed line, the first activator may be fed into the reactor via a second feed line, the trim catalyst may be fed into the reactor via a third feed line, and the second activator may be fed into the reactor via a fourth feed line. Any two of the first to fourth feed lines may be the same or different. The activator(s) may be fed into the reactor in "wet mode" in the form of a solution thereof in an inert liquid such as mineral oil or toluene, in slurry mode as a suspension, or in dry mode as a powder. Each contacting step may be done in separate vessels, feed lines, or reactors at the same or different times, or in the same vessel, feed line, or reactor at different times, to separately give the bimodal catalyst system and trim catalyst. Alternatively, the contacting steps may be done in the same vessel, feed line, or reactor at the same time to give a mixture of the bimodal catalyst system and trim catalyst *in situ*.

Bimodal ethylene-co-1-hexene copolymer

[0066] Ethylene. A polymerizable monomer of formula $\text{H}_2\text{C}=\text{CH}_2$.

[0067] 1-hexene. A polymerizable monomer of formula $\text{H}_2\text{C}=\text{C}(\text{H})\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$.

[0068] Bimodal ethylene-co-1-hexene copolymer. A macromolecule, or collection of macromolecules, composed of repeat units wherein 50.0 to < 100 mole percent (mol%), alternatively 70.0 to 99.99 mol%, alternatively 95.0 to 99.9 mol% of such repeat units are derived from ethylene monomer, and from > 0 to 50.0 mol%, alternatively from 0.01 to 30.0 mol%, alternatively 0.1 to 5.0 mol% of the remaining repeat units are comonomeric units derived from 1-hexene; or collection of such macromolecules. The collection of macromolecules is characterized by two distinct peaks (not shoulders) in a plot of dW/dLog(MW) on the y-axis versus Log(MW) on the x-axis to give a Gel Permeation Chromatograph (GPC) chromatogram, wherein Log(MW) and dW/dLog(MW) are as defined

below and measured by Gel Permeation Chromatograph (GPC) Test Method described herein.

[0069] The bimodal ethylene-co-1-hexene copolymer is a high molecular weight high density polyethylene (HMW HDPE). The bimodal ethylene-co-1-hexene copolymer may be further characterized by any one of the following limitations: a weight-average molecular weight (M_w) from 200,000.0 to 400,000.0 grams per mole (g/mol), alternatively 250,000.0 to 320,000.0 g/mol; a number-average molecular weight (M_n) from 6,000.0 to 11,000.0 g/mol, alternatively 7,000.0 to 9,000.0 g/mol; a z-average molecular weight (M_z) from 1,200,000.0 to 2,500,000.0 g/mol; a combination of any two thereof; and a combination of all three thereof; all measured according to the Gel Permeation Chromatography (GPC) Test Method.

[0070] Melt elasticity of the bimodal ethylene-co-1-hexene copolymer can be thought of as the behavior of a melt of the copolymer during a shaping process such as extrusion or film formation. It is one of the determinants of viscoelastic melt behavior, wherein viscosity decreases with increasing shear rate. Unsatisfactory melt elasticity may undesirably cause die swell during extrusion or problems with bubble stability during film blowing. A measure of, or proxy for, melt elasticity used herein is a ratio of melt storage modulus (G') value to melt loss modulus (G'') that is measured using DMA (Dynamic Mechanical Analysis) on polymer melts at 190° C. by performing small-strain (10%) oscillatory shear at varying frequency from 100 radians per second (rad/s) to about 0.1 rad/s using an ARES-G2 Advanced Rheometric Expansion System, from TA Instruments, with parallel-plate geometry to obtain the G'/G'' ratio value at a dynamic frequency equal to 0.1 rad/s.

[0071] The bimodal ethylene-co-1-hexene copolymer, film, and methods of making same are free of Ti and Cr metals.

[0072] The polymerizing conditions in the method of synthesizing are effective for making the bimodal ethylene-co-1-hexene copolymer characterized by the melt space described earlier and, optionally, the resin properties and/or film properties.

Film

[0073] The film. The film may be unembossed or embossed. The film may be tailored for specific uses by adjusting thickness of the film, combination with other films or additives, or not. The film may be a monolayer film. The film may have a thickness from 0.0051 to 0.051 mm (0.200 mil to 2 mils), alternatively from 0.0077 mm to 0.051 mm (0.300 mil to 2 mils), alternatively from 0.0077 mm to 0.0254 mm (0.300 mil to 1.00 mils), alternatively from 0.0077 mm to 0.0203 mm (0.300 mil to 0.80 mils), alternatively from 0.0077 mm to 0.0152 mm (0.300 mil to 0.6 mils).

[0074] The film may be made using any extrusion or co-extrusion methods including blown, tenter, and cast film methods. The blown film may be made on a blown-film-line machine

configured for making polyethylene films. The machine may be configured with a feed hopper in fluid communication with an extruder in heating communication with a heating device capable of heating a polyethylene in the extruder to a temperature of up to 500° C. (e.g., 430° C.), and wherein the extruder is in fluid communication with a die having an inner diameter of 12 centimeters (4.72 inches) and a fixed die gap (e.g., 1.2 millimeter gap (47 mils)), a blow up ratio of 4.0:1, and a Neck Height (NH) of 96 centimeters (38 inches) from the die. Step (a) may be done in the feed hopper.

[0075] The film may be unoriented, uniaxially oriented, or biaxially oriented. The uniaxially film may be oriented in the direction of extrusion (machine direction or MD), alternatively in the direction transverse to the direction of extrusion (transverse direction or TD). The biaxially oriented film may be oriented in both MD and TD by stretching or pulling in the MD, simultaneously or followed by stretching or pulling in the TD.

[0076] The film may have one or more improved properties such as enhanced (increased) bubble stability, enhanced (increased) MD and/or TD Elmendorf Tear performance, enhanced (increased) MD tensile strength and/or TD tensile strength, enhanced (increased) dart impact performance, or a combination of any two or more thereof.

[0077] The film may constitute a layer of a multilayer film or laminate.

[0078] The (blown) film may optionally contain zero, one or more film additives. The “film additive” is a compound or material other than a polyolefin polymer that imparts one or more properties to, and/or enhances one or more properties of, the blown film. Examples of film additives are antimicrobial agents, antioxidants, catalyst neutralizers (of single site catalysts), colorants, and light stabilizers. The film additive(s), when present, may be pre-mixed with the bimodal ethylene-co-1-hexene copolymer prior to the melting step in the method of making the blown film. Alternatively, the film additive(s) may be added to the melt of the bimodal ethylene-co-1-hexene copolymer during or after the melting step and prior to the extruding step in the method of making the blown film. When two or more film additives are used, one or more film additives may be pre-mixed with the bimodal ethylene-co-1-hexene copolymer prior to the melting step in the method of making the blown film and a one or more film additives may be added to the melt of the bimodal ethylene-co-1-hexene copolymer during or after the melting step and prior to the extruding step in the method of making the blown film. In some aspects the blown film consists essentially of the bimodal ethylene-co-1-hexene copolymer, at least one antioxidant, and at least one catalyst neutralizer.

[0079] The film is useful for making containers and wraps that have enhanced puncture resistance. Examples of such containers are bags such as ice bags and grocery bags.

Examples of such wraps are stretch films, meat wraps, and food wraps. The inventive copolymer is also useful in a variety of non-film related applications including in vehicle parts. [0080] Alternatively precedes a distinct embodiment. ASTM means the standards organization, ASTM International, West Conshohocken, Pennsylvania, USA. Any comparative example is used for illustration purposes only and shall not be prior art. Free of or lacks means a complete absence of; alternatively not detectable. IUPAC is International Union of Pure and Applied Chemistry (IUPAC Secretariat, Research Triangle Park, North Carolina, USA). May confers a permitted choice, not an imperative. Operative means functionally capable or effective. Optional(ly) means is absent (or excluded), alternatively is present (or included). Properties may be measured using standard test methods and conditions. Ranges include endpoints, subranges, and whole and/or fractional values subsumed therein, except a range of integers does not include fractional values. Room temperature: 23° C. $\pm$ 1° C.

EXAMPLES

[0081] Bimodality Test Method: determine presence or absence of resolved bimodality by plotting $dWf/dLogM$ (mass detector response) on y-axis versus $LogM$ on the x-axis to obtain a GPC chromatogram curve containing local maxima $log(MW)$ values for LMW and HMW polyethylene component peaks, and observing the presence or absence of a local minimum between the LMW and HMW polyethylene component peaks. The dWf is change in weight fraction, $dLogM$ is also referred to as $dLog(MW)$ and is change in logarithm of molecular weight, and $LogM$ is also referred to as $Log(MW)$ and is logarithm of molecular weight.

[0082] Dart Impact Test Method: measured according to ASTM D1709-16a, *Standard Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Test Method*, Method A. Method A employs a dart with a 38.10 ± 0.13 -mm (1.500 ± 0.005 -in.) diameter hemispherical head dropped from a height of 0.66 ± 0.01 m (26.0 ± 0.4 in.). This test method can be used for films whose impact resistances require masses of about 50 g or less to about 6 kg to fracture them. Results expressed in grams (g).

[0083] Deconvoluting Test Method: segment the chromatogram obtained using the Bimodality Test Method into nine (9) Schulz-Flory molecular weight distributions. Such deconvolution method is described in US 6,534,604. Assign the lowest four MW distributions to the LMW polyethylene component and the five highest MW distributions to the HMW polyethylene component. Determine the respective weight percents (wt%) for each of the LMW and HMW polyethylene components in the bimodal ethylene- α -1-hexene copolymer by using summed values of the weight fractions (Wf) of the LMW and HMW polyethylene components and the respective number average molecular weights (M_n) and weight average

molecular weights (M_w) by known mathematical treatment of aggregated Schulz-Flory MW distributions.

[0084] Density is measured according to ASTM D792-13, *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*, Method B (for testing solid plastics in liquids other than water, e.g., in liquid 2-propanol). Report results in units of grams per cubic centimeter (g/cm^3).

[0085] Elmendorf Tear Test Method: measured according to ASTM D1922-09, *Standard Test Methods for Propagation Tear Resistance of Plastic Film and Thin Sheeting by Pendulum Method*, Type B (constant radius). (Technically equivalent to ISO 6383-2.) Report results as normalized tear in cross direction (CD) or machine direction (MD) in gram-force (gf).

[0086] Film Puncture Test Method: ASTM D5748 – 95(2012), *Standard Test Method for Protrusion Puncture Resistance of Stretch Wrap Film*. Determines the resistance to puncture of a film as resistance to penetration of the film by a probe impinging the film at a standard speed such as 250 millimeters per minute (mm/min.). The probe is coated with a polytetrafluoroethylene and has an outer diameter of 1.905 cm (0.75 inch). The film is clamped during the test. The probe eventually penetrates or breaks the clamped film. The peak force at break, i.e., the maximum force, energy (work) to break or penetrate the clamped film, and the distance that the probe has penetrated at break, are recorded using mechanical testing software. The probe imparts a biaxial stress to the clamped film that is representative of the type of stress encountered by films in many product end-use applications. This resistance is a measure of the energy-absorbing ability of a film to resist puncture under these conditions.

[0087] Gauge Variation Test Method: determined according to ASTM D8136-17, *Standard Test Method for Determining Plastic Film Thickness and Thickness Variability Using a Non-Contact Capacitance Thickness Gauge*. Prior to testing, samples are conditioned at $23^\circ \pm 2^\circ \text{C.}$ and $50\% \pm 10\%$ relative humidity (RH) for at least 40 hours (per ASTM D618), and then tested under the same conditions. The Gauge Variation is calculated using the following equation: $(\text{Thickness standard deviation/average thickness}) \times 100\%$.

[0088] Gel permeation chromatography (GPC) Test Method: Weight-Average Molecular Weight Test Method: determine M_w , number-average molecular weight (M_n), and M_w/M_n using chromatograms obtained on a High Temperature Gel Permeation Chromatography instrument (HTGPC, Polymer Laboratories). The HTGPC is equipped with transfer lines, a differential refractive index detector (DRI), and three Polymer Laboratories PLgel $10\mu\text{m}$ Mixed-B columns, all contained in an oven maintained at 160°C. Method uses a solvent composed of BHT-treated TCB at nominal flow rate of 1.0 milliliter per minute (mL/min.) and

a nominal injection volume of 300 microliters (μL). Prepare the solvent by dissolving 6 grams of butylated hydroxytoluene (BHT, antioxidant) in 4 liters (L) of reagent grade 1,2,4-trichlorobenzene (TCB), and filtering the resulting solution through a 0.1 micrometer (μm) Teflon filter to give the solvent. Degas the solvent with an inline degasser before it enters the HTGPC instrument. Calibrate the columns with a series of monodispersed polystyrene (PS) standards. Separately, prepare known concentrations of test polymer dissolved in solvent by heating known amounts thereof in known volumes of solvent at 160°C . with continuous shaking for 2 hours to give solutions. (Measure all quantities gravimetrically.) Target solution concentrations, c , of test polymer of from 0.5 to 2.0 milligrams polymer per milliliter solution (mg/mL), with lower concentrations, c , being used for higher molecular weight polymers. Prior to running each sample, purge the DRI detector. Then increase flow rate in the apparatus to 1.0 mL/min , and allow the DRI detector to stabilize for 8 hours before injecting the first sample. Calculate M_w and M_n using universal calibration relationships with the column calibrations. Calculate MW at each elution volume with following equation:

$$\log M_X = \frac{\log(K_X / K_{PS})}{a_X + 1} + \frac{a_{PS} + 1}{a_X + 1} \log M_{PS}$$

, where subscript "X" stands for the test

sample, subscript "PS" stands for PS standards, $a_{PS} = 0.67$, $K_{PS} = 0.000175$, and a_X and K_X are obtained from published literature. For polyethylenes, $a_X/K_X = 0.695/0.000579$. For polypropylenes $a_X/K_X = 0.705/0.0002288$. At each point in the resulting chromatogram, calculate concentration, c , from a baseline-subtracted DRI signal, I_{DRI} , using the following equation: $c = K_{DRI} I_{DRI} / (dn/dc)$, wherein K_{DRI} is a constant determined by calibrating the DRI, / indicates division, and dn/dc is the refractive index increment for the polymer. For polyethylene, $dn/dc = 0.109$. Calculate mass recovery of polymer from the ratio of the integrated area of the chromatogram of concentration chromatography over elution volume and the injection mass which is equal to the pre-determined concentration multiplied by injection loop volume. Report all molecular weights in grams per mole (g/mol) unless otherwise noted. Further details regarding methods of determining M_w , M_n , MWD are described in US 2006/0173123 page 24-25, paragraphs [0334] to [0341]. Plot of $dW/d\text{Log}(MW)$ on the y-axis versus $\text{Log}(MW)$ on the x-axis to give a GPC chromatogram, wherein $\text{Log}(MW)$ and $dW/d\text{Log}(MW)$ are as defined above.

[0089] High Load Melt Index (HLMI) I_{21} Test Method: use ASTM D1238-13, *Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Platometer*, using conditions of

190° C./21.6 kilograms (kg). Report results in units of grams eluted per 10 minutes (g/10 min.).

[0090] Melt Index (“I₂”) Test Method: for ethylene-based (co)polymer is measured according to ASTM D1238-13, using conditions of 190° C./2.16 kg, formerly known as “Condition E”.

[0091] Melt Index I₅ (“I₅”) Test Method: use ASTM D1238-13, using conditions of 190° C./5.0 kg. Report results in units of grams eluted per 10 minutes (g/10 min.).

[0092] Melt Flow Ratio MFR5: (“I₂₁/I₅”) Test Method: calculated by dividing the value from the HLMI I₂₁ Test Method by the value from the Melt Index I₅ Test Method.

[0093] Melt Elasticity Test Method: On polymer melts at 190° C. perform small-strain (10%) oscillatory shear at varying frequency from 100 radians per second (rad/s) to about 0.1 rad/s using an ARES-G2 Advanced Rheometric Expansion System, from TA Instruments, with parallel-plate geometry to obtain the G'/G'' ratio value at a dynamic frequency equal to 0.1 rad/s.

[0094] Antioxidants: 1. Pentaerythritol tetrakis(3-(3,5-di(1',1'-dimethylethyl)-4-hydroxyphenyl)propionate); obtained as IRGANOX 1010 from BASF. 2. Tris(2,4-di(1',1'-dimethylethyl)-phenyl)phosphite. Obtained as IRGAFOS 168 from BASF.

[0095] Catalyst Neutralizers: 1. Calcium stearate. 2. Zinc stearate.

[0096] Bimodal Catalyst system: the PRODIGY™ BMC-300 catalyst system. Obtained from Univation Technologies LLC, Houston, Texas, USA.

[0097] Trim catalyst: bis(butylcyclopentadienyl)zirconium dimethyl obtained as UT-TR-300 trim catalyst from Univation Technologies LLC, Houston, Texas, USA.

[0098] Comonomer: 1-hexene. See later for C₆/C₂ gas molar ratio.

[0099] Ethylene (“C₂”): See later for partial pressure of C₂.

[00100] Molecular hydrogen gas (“H₂”): See later for H₂/C₂ gas molar ratio.

[00101] Molecular oxygen gas (“O₂”): See later for O₂/C₂ gas volume ratio.

[00102] Inventive Examples 1 to 7 (IE1 to IE7): polymerization procedure: Runs began with PRODIGY™ BMC-300 Bimodal Catalyst and comonomer 1-hexene according to the Pilot Reactor and method described earlier to give in different parts, as described below, different embodiments of the bimodal ethylene-co-1-hexene copolymer as granular resins and having targeted properties of high load melt index (I₂₁) 8.0 to 10.0 g/10 minutes, melt flow ratio I₂₁/I₅ from 26.6 to 30.6, a melt index I₅ from 0.25 to 0.35 g/10 min., melt elasticity 0.50 to 0.70, and density 0.948 to 0.950 g/cm³. The polymerization operating conditions are reported below in Table 1 (IE1 to IE4) or Table 2 (IE5 to IE7).

[00103] Table 1: Operating conditions for IE1 to IE4.

	IE1	IE2	IE3	IE4
PART No.	13	11	11	11
Reactor Type	S,CM, PP, FB GPP*	S,CM, PP, FB GPP	S,CM, PP, FB GPP	S,CM, PP, FB GPP
Reactor Purging gas	Anhydrous N ₂	Anhydrous N ₂	Anhydrous N ₂	Anhydrous N ₂
Bed Temp. (° C.)	90.0	90.0	90.0	90.0
Rx Pressure (kpa)^	2400	2400	2400	2400
C ₂ Partial Pressure (kpa)	1520	1520	1520	1520
H ₂ /C ₂ Molar Ratio	0.0041	0.0042	0.0042	0.0042
C ₆ /C ₂ Molar Ratio	0.0054	0.0054	0.0054	0.0054
Induced Conden. Agent (mol%)	1-methyl- butane (11.4)	1-methyl- butane (11.4)	1-methyl- butane (11.4)	1-methyl- butane (11.4)
Superficial Gas Velocity (m/sec)	0.646	0.616	0.616	0.616
Bimodal Catalyst System	PRODIGY™ BMC-300	PRODIGY™ BMC-300	PRODIGY™ BMC-300	PRODIGY™ BMC-300
Trim catalyst	UT-TR-300	UT-TR-300	UT-TR-300	UT-TR-300
Catalyst Zr conc. (wt%)	0.49	0.49	0.49	0.49
Catalyst Al conc. (wt%)	18.29	18.29	18.29	18.29
Starting seedbed = granular HDPE resin	Preloaded	Preloaded	Preloaded	Preloaded
Fluidized Bed Weight (kg)	45.8	46.3	46.3	46.3
Copolymer Production Rate (kg/hour)	17.5	17.9	17.9	17.9

Copolymer Residence Time (hour)	2.63	2.59	2.59	2.59
Copolymer Fluid Bulk Density, (kg/m ³)	275	280	280	280
O ₂ tailoring level (%)	0	4	7	10
Residual Zr (ppmw)	1.48	1.51	1.51	1.51

*S,CM, PP, FB, GPP: single, continuous mode, pilot plant, fluidized bed gas phase polymerization. ^Rx Pressure (kPa): reactor total pressure in kilopascals.

[00104] Table 2: Operating conditions for IE5 to IE7.

	IE5	IE6	IE7
PART No.	12	12	12
Reactor Type	S,CM, PP, FB GPP	S,CM, PP, FB GPP	S,CM, PP, FB GPP
Reactor Purging gas	Anhydrous N ₂	Anhydrous N ₂	Anhydrous N ₂
Bed Temp. (° C.)	90.0	90.0	90.0
Rx Pressure (kpa)^	2400	2400	2400
C ₂ Partial Pressure (kpa)	1520	1520	1520
H ₂ /C ₂ Molar Ratio	0.0040	0.0040	0.0040
C ₆ /C ₂ Molar Ratio	0.0055	0.0055	0.0055
Induced Condensing Agent	1-methyl- butane (11.4)	1-methyl- butane (11.4)	1-methyl- butane (11.4)
Superficial Gas Velocity (m/sec)	0.671	0.671	0.671
Bimodal Catalyst System	PRODIGY™ BMC-300	PRODIGY™ BMC-300	PRODIGY™ BMC-300
Trim catalyst	UT-TR-300	UT-TR-300	UT-TR-300
Catalyst Zr concentration (wt%)	0.49	0.49	0.49
Catalyst Al concentration (wt%)	18.29	18.29	18.29

Starting seedbed = granular HDPE resin	Preloaded	Preloaded	Preloaded
Fluidized Bed Weight (kg)	45.4	45.4	45.4
Copolymer Production Rate (kg/hour)	17.6	17.6	17.6
Copolymer Residence Time (hour)	2.57	2.57	2.57
Copolymer Fluid Bulk Density, (kg/m ³)	271	271	271
O ₂ tailoring level (%)	4	7	10
Residual Zr (ppmw)	1.52	1.52	1.52

[00105] *S,CM, PP, FB, GPP: single, continuous mode, pilot plant, fluidized bed gas phase polymerization. ^Rx Pressure (kPa): reactor total pressure in kilopascals.

[00106] As shown in Tables 1 and 2, the operating conditions used to make the bimodal ethylene-co-1-hexene copolymers of IE1 to IE7 comprise a bed temperature of 90.0° C.; an ethylene (C₂) partial pressure of 1520 kpa; an H₂/C₂ Molar Ratio from 0.0040 to 0.0042; a C₆/C₂ Molar Ratio from 0.0054 to 0.0055; and a superficial gas velocity from 0.616 to 0.671 m/sec (meter per second). In certain embodiments, the method of synthesizing the bimodal ethylene-co-1-hexene copolymer employ the aforementioned operating conditions.

[00107] Formulation and Pelletization Procedure: Each of the different granular resins of IE1 to IE7 was separately mixed with 800 parts per million weight/weight (ppm) of Antioxidant 1, 200 ppm Antioxidant 2, 1,000 ppm Catalyst Neutralizer 1, and 500 ppm Catalyst Neutralizer 2 in a ribbon blender, and then compounded into strand cut pellets using a twin-screw extruder LCM100 according to the methods described in US 5,728,335; US 6,456,976; and US 6,989,423. The resulting pellets of each resin were tested for HLMI (I₂₁), MFR5 (I₂₁/I₅), melt elasticity and density according to their aforementioned respective test methods. Results are reported later. In certain embodiments, the bimodal ethylene-co-1-hexene copolymer further comprises at least one antioxidant selected from Antioxidants 1 and 2; at least one catalyst neutralizer selected from Catalyst Neutralizers 1 and 2; or a combination thereof. Results are reported below in Table 3, which also includes the oxygen (O₂) tailoring level again for convenience.

[00108] Table 3: Melt properties of IE1 to IE7.

Test	IE1	IE2	IE3	IE4	IE5	IE6	IE7
O ₂ tailoring level (%)	0	4	7	10	4	7	10
I ₂₁ (190° C., 21.6 kg) (g/ 10 min.)	8.4	9.4	9.5	7.4	9.2	9.2	8.2
MFR5 (I ₂₁ / I ₅)	26.6	28.4	29.6	27.6	30.4	30.6	29.2
melt elasticity (G'/G''@0.1 rad/s)	0.53	0.58	0.65	0.68	0.57	0.62	0.66
I ₂ (190° C., 2.16 kg) (g/ 10 min.)	0.08	0.08	0.07	0.06	0.08	0.07	0.06
I ₅ (190° C., 5.0 kg) (g/ 10 min.)	0.32	0.33	0.32	0.27	0.30	0.30	0.28

[00109] As shown in Table 3, the melt properties of the bimodal ethylene-*co*-1-hexene copolymers of IE1 to IE7 comprise a high-load melt index I₂₁ (190° C., 21.6 kg) from 7.4 to 9.5 g/ 10 min.; a melt flow ratio MFR5 (I₂₁/ I₅) from 26.6 to 30.6; a melt elasticity (G'/G''@0.1 rad/s) from 0.53 to 0.68 Pa; a melt index I₂ (190° C., 2.16 kg) from 0.06 to 0.08 g/10 min.; and a melt index I₅ (190° C., 5.0 kg) from 0.27 to 0.33 g/10 min.). In certain embodiments, the bimodal ethylene-*co*-1-hexene copolymer is characterized by any one, alternatively all but one, alternatively each of the aforementioned melt properties.

[00110] The melt properties data in Table 3 for the bimodal ethylene-*co*-1-hexene copolymer were analyzed to discover on what reactor/process operating conditions the melt properties depend. The following operating conditions are found to influence the melt properties of the bimodal ethylene-*co*-1-hexene copolymer made thereby: increasing H₂/C₂ gas molar ratio in the process yielded inventive bimodal ethylene-*co*-1-hexene copolymer beneficially having a melt property space enhanced for use in blown film processes and for making blown films.

[00111] Granular resins of IE1 to IE7 were characterized by density; component molecular weight spread (M_w-HMW/M_w-LMW ratio); component fraction split; molecular weights; and molecular mass dispersity (M_w/M_n), Đ_M. Results are reported below in Table 4.

[00112] Table 4: Resin properties of IE1 to IE7.

Test	IE1	IE2	IE3	IE4	IE5	IE6	IE7
Density (g/cm ³)	0.949	0.949	0.949	0.949	0.949	0.949	0.949
HMW Component Split (wt%)	58.6	59.0	58.1	59.4	57.9	57.6	58.4
LMW Component Split (wt%)	41.4	41.0	41.9	40.6	42.1	42.4	41.6
M _w -HMW/M _w -LMW ratio	42.1	41.6	42.4	41.0	41.7	41.5	41.7
M _n (kg/mol)	7.61	7.68	7.47	7.74	7.82	7.61	7.92
M _w (kg/mol)	293.7	281.6	278.9	268.8	295.3	288.1	286.2
M _w /M _n (Đ _M)	38.6	36.7	37.3	34.8	37.8	37.8	36.2
M _z (kg/mol)	2,110	1,952	1,835	1,594	2,088	2,023	1,844

[00113] As shown in Table 4, the resin properties of the bimodal ethylene-co-1-hexene copolymers of IE1 to IE7 comprise a density of 0.949 g/cm³; a high molecular weight (HMW) component split from 57.6 to 59.4 wt%; a low molecular weight (LMW) component split from 42.4 to 40.6 wt%; a number-average molecular weight from 7,470 to 7,920 g/mol; a weight-average molecular weight from 268,800 to 295,300 g/mol; a molecular mass dispersity M_w/M_n (Đ_M) from 34.8 to 38.6; and a z-average molecular weight from 1,835,000 to 2,110,000 g/mol. In certain embodiments, the bimodal ethylene-co-1-hexene copolymer is characterized by any one, alternatively all but one, alternatively each of the aforementioned resin properties.

[00114] Film Forming Procedure: Pellets of granular resins of the bimodal ethylene-co-1-hexene copolymer of IE1 to IE7 are separately melted at melt temperature described herein, and separately blown into films using an Alpine 50 millimeter (mm) 25:1 length to diameter (L/D) dimensioned barrier single screw extruder, a 120 mm inner diameter die, a 1.2 mm die gap, without IBC (internal bubble cooling). The gauge variation, dart impact, and Elmendorf tear properties were measured on films having a thickness of 0.0127 millimeter (mm) = 12.7 micrometer (μm) and according to the aforementioned test methods. See below Table 5.

[00115] Table 5: Film properties of IE1 to IE7.

Test	IE1	IE2	IE3	IE4	IE5	IE6	IE7
Extruder speed (rpm)	97	97	97	97	97	97	97
Motor load (%)	73.6	71.9	73.2	75.4	73.8	74.4	75.0
melt temp. (° C.)	206.0	205.2	205.9	207.0	206.3	204.9	205.6
Die Press (MPa)	N/a	N/a	N/a	N/a	N/a	N/a	N/a
Gauge Variation (%)	14.7	16.2	11.2	14.3	15.2	12.9	14.5
Avg. Tear CD (gf)	181	143	103	61	136	85	83
Avg. Tear MD (gf)	18	20	26	30	21	28	32
Dart Impact (g)	315	291	294	276	312	375	360

[00116] N/a means not available. As shown in Table 5, the film properties of the blown films of the bimodal ethylene-co-1-hexene copolymers of IE1 to IE7 comprise a gauge variation from 11.2% to 16.2%, an average Elmendorf Tear in cross-direction (CD) from 61 to 181 gf, an average Elmendorf tear in machine direction (MD) from 18 to 32 gf, and a dart impact from 276 to 375 g. In certain embodiments, the bimodal ethylene-co-1-hexene copolymer, and the blown films thereof, are independently characterized by any one, alternatively all but one, alternatively each of the aforementioned film properties.

CLAIMS

1. A bimodal ethylene-co-1-hexene copolymer consisting essentially of a higher molecular weight (HMW) component and a lower molecular weight (LMW) component and, when in melted form at 190° C., is characterized by a melt property space defined by a combination of high-load melt index ("HLMI" or " I_{21} "), melt flow ratio I_{21}/I_5 ("MFR5"), and melt elasticity ($G'/G''@0.1$ rad/s) properties, wherein the HLMI is 7.0 to 11.0 grams per 10 minutes (g/10 min.) and is measured according to ASTM D1238-13 (190° C., 21.6 kg); the MFR5 is 22.0 to 35.0, wherein the I_{21} and I_5 values used to calculate the MFR5 are each in g/10 min. and are measured according to ASTM D1238-13 (190° C., 21.6 kg, " I_{21} "; and 190° C., 5.0 kg, " I_5 ", respectively), and the melt elasticity is 0.5 to 0.8 pascals (Pa), wherein melt elasticity = G'/G'' determined at 0.1 radian per second (rad/s) according to Melt Elasticity Test Method.
2. The bimodal ethylene-co-1-hexene copolymer of claim 1 wherein the melt property space of the bimodal ethylene-co-1-hexene copolymer is further defined by any one of limitations (i) to (iii): (i) a melt index I_2 from 0.05 to 0.10, measured according to ASTM D1238-13 (190° C., 2.16 kg, " I_2 "); (ii) a melt index I_5 from 0.20 to 0.40 g/10 min., measured according to ASTM D1238-13 (190° C., 5.0 kg, " I_5 "); and (iii) a melt flow ratio I_{21}/I_2 ("MFR2") from 80.0 to 150.0, wherein the I_{21} and I_2 values used to calculate the MFR2 are each in g/10 min. and are measured according to ASTM D1238-13 (190° C., 21.6 kg, " I_{21} "; and 190° C., 2.16 kg, " I_2 ", respectively).
3. The bimodal ethylene-co-1-hexene copolymer of claim 1 or 2 characterized by any one of resin property limitations (i) to (iv): (i) a density from 0.9410 to 0.9550 gram per cubic centimeter (g/cm³), alternatively 0.9450 to 0.9530 g/cm³, alternatively 0.9480 to 0.9500 g/cm³, measured according to ASTM D792-13, Method B; (ii) a component fraction split characterized by a weight fraction of the HMW component from 50.0 to 63 wt%, alternatively from 55 to 60.0 wt%, alternatively from 57.0 to 59.4 wt%; and a weight fraction of the LWM component fraction is from 50.0 to 37 wt%, alternatively from 45 to 40.0 wt%, alternatively from 43.0 to 40.6 wt%, respectively, of the combined weight of the HMW and LMW components, measured according to the Gel Permeation Chromatography (GPC) Test Method; (iii) a component molecular weight spread characterized by a ratio of the weight-average molecular weight of the HMW component (M_{w-HMW}) to the weight-average molecular weight of the LMW component (M_{w-LMW}) (i.e., M_{w-HMW}/M_{w-LMW} ratio) from 30.0 to 50.0, alternatively 40.0 to 45, alternatively 40.9 to 42.5, measured according to the GPC Test Method; and (iv) a molecular mass dispersity (M_w/M_n), $\bar{M}$, from 30.0 to 40.0,

alternatively from 34 to 39, alternatively from 34.8 to 38.6, wherein M_w and M_n are measured according to the GPC Test Method.

4. The bimodal ethylene-co-1-hexene copolymer of any one of claims 1 to 3 that, when characterized in the form of a blown film and having a thickness of 0.0127 millimeter, is characterized by any one of limitations (i) to (iv): (i) a dart impact from 250 to 400 grams (g), measured according to the Dart Impact Test Method; (ii) an Elmendorf tear in cross direction (CD) from 60.0 to 190.0 gram-force (gf), measured according to the Elmendorf Tear Test Method; (iii) an Elmendorf tear in machine direction (MD) from 15 to 35 gf, measured according to the Elmendorf Tear Test Method; and (iv) a gauge variation from 10.5% to 17%, measured according to the Gauge Variation Test Method.

5. A method of synthesizing the bimodal ethylene-co-1-hexene copolymer of any one of claims 1 to 4, the method consisting essentially of copolymerizing ethylene and 1-hexene with a combination of a bimodal catalyst system and a trim catalyst in the presence of molecular hydrogen gas (H_2) and, optionally, an induced condensing agent (ICA) in one polymerization reactor under effective polymerizing conditions to give an initial bimodal ethylene-co-1-hexene copolymer, and optionally oxygen tailoring the initial bimodal ethylene-co-1-hexene copolymer to give an oxygen-tailored bimodal ethylene-co-1-hexene copolymer; wherein the bimodal catalyst system is made by contacting a first activator with bis(2-(pentamethylphenylamido)ethyl)-amine zirconium dibenzyl and a bis(butylcyclopentadienyl)zirconium dihalide; wherein the trim catalyst is made by contacting a second activator with bis(butylcyclopentadienyl)zirconium dialkyl; wherein the first and second activators are the same or different; and wherein the effective polymerizing conditions comprise a reaction temperature from 80 degrees ($^{\circ}$) to 110 $^{\circ}$ Celsius ($C.$); a molar ratio of the molecular hydrogen gas to the ethylene (H_2/C_2 molar ratio) from 0.001 to 0.020; and a molar ratio of the 1-hexene (" C_6 ") to the ethylene (C_6/C_2 molar ratio) from 0.005 to 0.050.

6. The method of claim 5 further consisting essentially of removing the bimodal ethylene-co-1-hexene copolymer from the reactor to give a removed bimodal ethylene-co-1-hexene copolymer.

7. A manufactured article comprising the bimodal ethylene-co-1-hexene copolymer of any one of claims 1 to 4.

8. A film consisting essentially of the bimodal ethylene-co-1-hexene copolymer of any one of claims 1 to 4.

9. A method of making a blown film, the method comprising melting the bimodal ethylene-co-1-hexene copolymer of any one of claims 1 to 5 so as to give a melt thereof, extruding the melt through a die configured for forming a bubble so as to make a bubble of

the bimodal ethylene-co-1-hexene copolymer, and blowing the bubble with a film-blowing machine, thereby making the blown film.

10. A blown film made by the method of claim 9 and consisting essentially of the bimodal ethylene-co-1-hexene copolymer of any one of claims 1 to 4.