

CLAIMS

1. A bimodal ethylene-*co*-1-hexene copolymer composition having a density from 0.945 to 0.960 gram per cubic centimeter (g/cm^3), measured according to ASTM D792-13, Method B; a molecular mass dispersity (M_w/M_n), $\bar{M}_w$, from 11.0 to 25.0, wherein M_w and M_n are measured according to the Gel Permeation Chromatography (GPC) Test Method; and consisting essentially of a higher molecular weight ethylene-*co*-1-hexene copolymer component (HMW component), having a molecular weight distribution (M_w/M_n) greater than 3.75 (> 3.75), and a lower molecular weight polyethylene homopolymer or a lower molecular weight ethylene-*co*-1-hexene copolymer component (LMW component), wherein the LMW component has a molecular weight distribution (M_w/M_n) from 2.75 to 3.35; and having a component fraction split characterized by a weight fraction of the HMW component from 35.0 to 65.0 wt% and a weight fraction of the LMW component fraction from 65.0 to 35.0 wt%, respectively, of the combined weight of the HMW and LMW components, measured according to the GPC Test Method; and wherein when in melted form at 190° C., the bimodal ethylene-*co*-1-hexene copolymer composition is characterized by properties (a), (b), and optionally (c): (a) a melt flow index(5 kg) (I_5 or MFI_5) from 0.15 to 0.30 gram per 10 minutes ($\text{g}/10 \text{ min.}$), (b) peak melt strength from 18 to 29 centiNewtons (cN), and, optionally, (c) shear thinning index, $\eta_{0.01}/\eta_{100}$, from 96 to 125; and when in solid form the bimodal ethylene-*co*-1-hexene copolymer composition is characterized by properties (d) and (e): (d) strain hardening modulus from 50.0 to 75 megapascals (MPa) and (e) accelerated full-notch creep test (FNCT) performance from 401 to 700.0 hours; wherein the melt flow index (5 kg) is measured according to ASTM D1238-13 (190° C., 5.0 kg), the shear thinning index is measured according to Shear Thinning Index Test Method (190° C.), the peak melt strength is measured at the highest peak in a plot of melt strength versus a range of velocity from 10 to 50 millimeters per second (mm/s) according to Melt Strength Test Method, the strain hardening modulus is measured according to ISO 18488:2015, and the accelerated FNCT performance is measured according to ISO 16770:2004 at 90° C. and under an actual stress of 5.0 MPa in 2 weight percent (wt%) lauramine oxide in water.
2. The bimodal ethylene-*co*-1-hexene copolymer composition of claim 1 characterized by any one of property limitations (i) to (viii): (i) the density is from 0.9450 to 0.9590 g/cm^3 ; (ii) the component fraction split is characterized by a weight fraction of the HMW component from 44.0 to 52.0 wt%; and a weight fraction of the LMW component fraction from 56.0 to 48.0 wt%, respectively, of the combined weight of the HMW and LMW components; (iii) the molecular mass dispersity (M_w/M_n), $\bar{M}_w$, is from 11.0 to 23.0; (iv) the (a) MFI_5 is from 0.15

to 0.24 g/10 min.; (v) the (c) shear thinning index, $\eta_{0.01}/\eta_{100}$, is from 99 to 115; (vi) the (b) peak melt strength is from 20.0 to 28 cN; (vii) the (d) strain hardening modulus is from 55 to 70.0 MPa; and (viii) the (e) accelerated FNCT performance is from 401 to 600.0 hours.

3. The bimodal ethylene-*co*-1-hexene copolymer composition of claim 1 or 2 further characterized by any one of melt property limitations (i) to (iii): (i) a high load melt index from 1 to 10 g/10min., measured according to ASTM D1238-13 (190° C., 21.6 kg, HLMI or I_{21}); (ii) a melt flow ratio I_{21}/I_5 ("MFR5") from 20 to 40, 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); (iii) both (i) and (ii).

4. The bimodal ethylene-*co*-1-hexene copolymer composition of any one of claims 1 to 3 further characterized by any one of resin property limitations (i) to (xii): (i) a weight-average molecular weight (M_w) from 300,000 to 400,000 grams per mole (g/mol); (ii) a number-average molecular weight (M_n) from 10,000 to 30,000 grams g/mol; (iii) a z-average molecular weight (M_z) from 2,000,000 to 3,400,000 g/mol; (iv) a butyl branch frequency per 1,000 carbon atoms (bbf/1000C) from 1.2 to 1.5, as measured according to the Butyl Branch Frequency Test Method; and wherein M_w , M_n and M_z are measured according to the GPC Test Method.

5. A method of synthesizing the bimodal ethylene-*co*-1-hexene copolymer composition of any one of claims 1 to 4, the method consisting essentially of copolymerizing ethylene and 1-hexene, and copolymerizing fresh ethylene and, optionally, fresh 1-hexene, with a combination of a bimodal catalyst system and a trim catalyst in the presence of molecular hydrogen gas and, optionally, an induced condensing agent in one polymerization reactor under effective polymerizing conditions to give an initial bimodal ethylene-*co*-1-hexene copolymer composition; wherein the bimodal catalyst system is made by contacting a first activator with bis(2-(pentamethylphenylamido)ethyl)-amine zirconium dibenzyl and a (methylcyclopentadienyl)(1,3-dimethyl-4,5,6,7-tetrahydroindenyl)zirconium dimethyl; wherein the trim catalyst is made by contacting a second activator with (methylcyclopentadienyl)(1,3-dimethyl-4,5,6,7-tetrahydroindenyl)zirconium dimethyl; wherein the first and second activators are the same or different; and wherein the effective polymerizing conditions comprise a reaction temperature from 90 degrees (°) to 110° Celsius (C.); a molar ratio of the molecular hydrogen gas to the ethylene from 0.001 to 0.0050; and a molar ratio of the 1-hexene to the ethylene from 0.00450 to 0.01000.

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

7. A pipe consisting essentially of the bimodal ethylene-co-1-hexene copolymer composition of any one of claims 1 to 4.

8. A method of making a pipe, the method comprising method of making a pipe, the method comprising steps (A), (B1) or (B2), optionally (C), and (D): (A) melting the bimodal ethylene-co-1-hexene copolymer composition to give a melt thereof; (B1) extruding the melt through an annular die configured for forming a cylinder so as to make an initial solid wall cylinder of the bimodal ethylene-co-1-hexene copolymer composition or (B2) extruding and spirally winding the melt around a mandrel configured for forming an unsealed-seam profile wall so as to make an unsealed-seam profile wall, and heat-fusing the unsealed seam of the unsealed-seam profile wall to make an initial sealed-seam wall cylinder; (C) optionally resizing the initial solid wall cylinder or the initial sealed-seam wall cylinder to make a resized wall cylinder having a different diameter; and (D) cooling the initial solid wall cylinder, the initial sealed-seam wall cylinder, or the resized wall cylinder, thereby making a solid wall pipe or a seam-sealed wall pipe, respectively.

9. A pipe made by the method of claim 8 and consisting essentially of the bimodal ethylene-co-1-hexene copolymer composition of any one of claims 1 to 4.

10. A manufactured article comprising the bimodal ethylene-co-1-hexene copolymer composition, wherein the manufactured article is not a pipe.