[0006a] In one aspect, there is provided an ethylene/1-hexene copolymer that has a density from 0.9541 to 0.9600 gram per cubic centimeter (g/cm^3), as measured by ASTM D792-13, a molecular mass dispersity $Đ_M$ (wherein $Đ_M = M_W/M_n$) from 2.5 to 3.0, as measured by Gel Permeation Chromatography (GPC) Method; ~~and~~ a Z-average molecular weight (Mz) from 80,000 to 240,000 grams per mole (g/mol), as measured by the GPC Method; a melt flow rate from 4 to 25 g/10 min., as measured by ASTM D1238-13 (190° C., 5.0 kg, "I_5"); a high-load melt flow rate ("HLMFR") from 20 to 200 g/10 min., as measured by ASTM D1238-13 (190° C., 21.6 kg, "I_{21}"); a flow rate ratio, I_{21}/I_2, of 15 to 20, wherein I_{21} and I_2 are measured by ASTM D1238-13 (190° C., 21.6 kg and 2.16 kg, respectively); and a flow rate ratio, I_{21}/I_5, of 4 to 10, wherein I_{21} and I_5 are measured by ASTM D1238-13 (190° C., 21.6 kg and 5.0 kg, respectively).

[0007] We also provide a method of making the ethylene/1-hexene copolymer, a method manufacturing articles comprising the ethylene/1-hexene copolymer, manufactured articles containing or made from the ethylene/1-hexene copolymer, and use of the manufactured article.

[0007a] In another aspect, there is provided a method of making the ethylene/1-hexene copolymer as defined herein, the method comprising contacting ethylene and 1-hexene with the single hafnocene catalyst in a single gas phase reactor operating a single gas phase polymerization process to give the ethylene/1-hexene copolymer, wherein the polymerization reaction is conducted under effective gas phase polymerization conditions, and wherein the hafnocene catalyst is made by contacting bis(n-propylcyclopetadienyl)hafnium dichloride or bis(n-propylcyclopetadienyl)hafnium dimethyl with an activator.

[0007b] In another aspect, there is provided an ethylene/1-hexene copolymer made by the method as defined herein.

[0007c] In another aspect, there is provided a manufactured article comprising a shaped form of the ethylene/1-hexene copolymer as defined herein.

DETAILED DESCRIPTION

[0008] The Introduction, Summary and Abstract are incorporated here by reference.

[0009] Certain inventive embodiments are described below as numbered aspects for easy cross-referencing. Additional embodiments are described elsewhere herein.

[0010] Aspect 1. An ethylene/1-hexene copolymer that has a density from 0.9541 to 0.9600 gram per cubic centimeter (g/cm^3), as measured by ASTM D792-13, a molecular mass dispersity $Đ_M$ (wherein $Đ_M = M_W/M_n$) from greater than 2.0 to 3.5, as measured by Gel Permeation Chromatography (GPC) Method (described later); and a Z-average molecular

weight (Mz) from 80,000 to 240,000 grams per mole (g/mol), as measured by the GPC Method.

[0011] Aspect 2. The ethylene/1-hexene copolymer of aspect 1 characterized by any one of limitations (i) to (vii): (i) a density from 0.9541 to 0.9583 g/cm^3, alternatively 0.9547 to 0.9581 g/cm^3, alternatively 0.9548 to 0.9580 g/cm^3, alternatively 0.9549 to 0.9579 g/cm^3, alternatively 0.9579 ± 0.0010 g/cm^3, alternatively 0.9549 ± 0.0010 g/cm^3, as measured by ASTM D792-13; (ii) a $Đ_M$ from 2.5 to 3.5, alternatively 2.55 to 3.0, alternatively 2.60 to 2.90, alternatively 2.70 to 2.80, alternatively 2.74 ± 0.050, as measured by the GPC Method; (iii) a Mz from 110,000 to 240,000 g/mol, 121,000 to 229,000 g/mol, alternatively from 130,000 to 226,000 g/mol, alternatively 132,720 ± 5,000 g/mol, alternatively 224,525 ± 9,000 g/mol, as measured by the GPC Method; (iv) both limitations (i) and (ii); (v) both limitations (i) and (iii); (vi) both limitations (ii) and (iii); and (vii) each of limitations (i) to (iii).

[0012] Aspect 3. The ethylene/1-hexene copolymer of aspect 1 or 2 characterized by a melt index ("I_2") from 1.5 to 40 grams per 10 minutes (g/10 min.), alternatively 1.5 to 20 g/10 min., alternatively 1.5 to 10 g/10 min., alternatively 1.7 ± 0.10 g/10 min., alternatively 9.00 ± 0.50 g/10 min., as measured by ASTM D1238-13 (190° C., 2.16 kg, "I_2").

[0013] Aspect 4. The ethylene/1-hexene copolymer of any one of aspects 1 to 3 characterized by any one of limitations (i) to (vii): (i) a melt flow rate from 4 to 25 g/10 min., alternatively 4.4 ± 0.20 g/10 min., alternatively 23.4 ± 1.0 g/10 min., as measured by ASTM D1238-13 (190° C., 5.0 kg, "I_5"); (ii) a high-load melt flow rate ("HLMFR") from 20 to 200 g/10 min., alternatively 30 ± 10 g/10 min., alternatively 155 ± 10 g/10 min., as measured by ASTM D1238-13 (190° C., 21.6 kg, "I_{21}"); (iii) a flow rate ratio, I_{21}/I_2, of 15 to 20, alternatively 16

CLAIMS

1. An ethylene/1-hexene copolymer that has a density from 0.9541 to 0.9600 gram per cubic centimeter (g/cm^3), as measured by ASTM D792-13, a molecular mass dispersity $Đ_M$(wherein $Đ_M = M_W/M_n$) from 2.5 to 3.0, as measured by Gel Permeation Chromatography (GPC) Method; ~~and~~ a Z-average molecular weight (Mz) from 80,000 to 240,000 grams per mole (g/mol), as measured by the GPC Method; a melt flow rate from 4 to 25 g/10 min., as measured by ASTM D1238-13 (190° C., 5.0 kg, "I_5"); a high-load melt flow rate ("HLMFR") from 20 to 200 g/10 min., as measured by ASTM D1238-13 (190° C., 21.6 kg, "I_{21}"); a flow rate ratio, I_{21}/I_2, of 15 to 20, wherein I_{21} and I_2 are measured by ASTM D1238-13 (190° C., 21.6 kg and 2.16 kg, respectively); and a flow rate ratio, I_{21}/I_5, of 4 to 10, wherein I_{21} and I_5 are measured by ASTM D1238-13 (190° C., 21.6 kg and 5.0 kg, respectively).

2. The ethylene/1-hexene copolymer of claim 1 characterized by any one of limitations (i) to (vii): (i) a density from 0.9541 to 0.9583 g/cm^3, as measured by ASTM D792-13; (ii) a $Đ_M$ from 2.55 to 3.0, as measured by the GPC Method; (iii) a Mz from 110,000 to 240,000 g/mol, as measured by the GPC Method; (iv) both limitations (i) and (ii); (v) both limitations (i) and (iii); (vi) both limitations (ii) and (iii); and (vii) each of limitations (i) to (iii).

3. The ethylene/1-hexene copolymer of claim 1 or 2 characterized by a melt index ("I_2") from 1.5 to 40 grams per 10 minutes (g/10 min.), as measured by ASTM D1238-13 (190° C., 2.16 kg, "I_2").

~~4. The ethylene/1-hexene copolymer of any one of claims 1 to 3 characterized by any one of limitations (i) to (vii): (i) a melt flow rate from 4 to 25 g/10 min., as measured by ASTM D1238-13 (190° C., 5.0 kg, "I_5"); (ii) a high-load melt flow rate ("HLMFR") from 20 to 200 g/10 min., as measured by ASTM D1238-13 (190° C., 21.6 kg, "I_{21}"); (iii) a flow rate ratio, I_{21}/I_2, of 15 to 20, wherein I_{21} and I_2 are measured by ASTM D1238-13 (190° C., 21.6 kg and 2.16 kg, respectively); (iv) a flow rate ratio, I_{21}/I_5, of 4 to 10, wherein I_{21} and I_5 are measured by ASTM D1238-13 (190° C., 21.6 kg and 5.0 kg, respectively); (v) both limitations (i) and (ii); (vi) both limitations (iii) and (iv); and (vii) each of limitations (i) to (iv).~~

~~5~~4. The ethylene/1-hexene copolymer of any one of claims 1 to ~~4~~ 3 characterized by any one of limitations (i) to (iii): (i) an environmental stress crack resistance (ESCR) F50 of greater than 11 hours, as measured according to ASTM D1693-15 in 10 weight percent (wt%) Igepal CO-630 in water at 50° C.; (ii) a 2% Flexural Secant Modulus from 930 to 1140 megapascals (MPa), as measured according to ASTM D790-17; and (iii) both (i) and (ii).

~~6~~5. A method of making the ethylene/1-hexene copolymer of any one of claims 1 to ~~5~~4, the method comprising contacting ethylene and 1-hexene with the single hafnocene catalyst

in a single gas phase reactor operating a single gas phase polymerization process to give the ethylene/1-hexene copolymer, wherein the polymerization reaction is conducted under effective gas phase polymerization conditions, and wherein the hafnocene catalyst is made by contacting bis(n-propylcyclopetadienyl)hafnium dichloride or bis(n-propylcyclopetadienyl)hafnium dimethyl with an activator.

~~7~~6. The method of claim ~~6~~ 5 characterized by any one of limitations (i) to (viii): (i) externally-sourced (from outside the reactor) molecular hydrogen gas (H_2) is not added into the polymerization reactor and is not present during the contacting step of the method; (ii) the method further comprises adding externally-sourced H_2 gas into the polymerization reactor during the contacting step of the method; (iii) the method further comprises a (C_4) or (C_{8-20})alpha-olefin (second comonomer) and makes an ethylene/1-hexene/(C_4) or (C_{8-20})alpha-olefin copolymer, which contains monomeric constituent units that are derived from ethylene, comonomeric constituent units that are derived from 1-hexene, and comonomeric constituent units that are derived from the (C_4) or (C_{8-20})alpha-olefin; (iv) the method is free of any monomer and comonomer except the ethylene and 1-hexene and makes an ethylene/1-hexene copolymer having constitutional units consisting of ethylenic and 1-hexenic units; (v) both (i) and (iii); (vi) both (ii) and (iii); (vii) both (i) and (iv); and (viii) both (ii) and (iv).

~~8~~7. The method of claim ~~6~~ 5 or ~~7~~ 6 comprising a gas phase polymerization optionally in the presence of added external molecular hydrogen gas (H_2), optionally in the presence of an induced condensing agent (ICA); a reaction temperature from 60 degrees (°) to 120° Celsius (C.), and a molar ratio of the molecular hydrogen gas to the ethylene (H2/C2 molar ratio) from 0.001 to 0.050.

~~9~~8. An ethylene/1-hexene copolymer made by the method of claim ~~6~~5, ~~7~~6, or ~~8~~7.

~~10~~9. A manufactured article comprising a shaped form of the ethylene/1-hexene copolymer of claim ~~9~~8.