

THERMOPLASTIC POLYOLEFIN COMPOSITION WITH REACTIVE COMPATIBILIZATION

BACKGROUND

[0001] Polyolefin elastomers (POEs), including ethylene/ α -olefin copolymers are commonly used as impact modifiers for thermoplastic polyolefin (TPO) compounds. When blended with polypropylene, other additives, and optionally reinforcing fillers (such as talc), POEs can be applied to provide a balance of stiffness, impact toughness, and flow properties to the TPO.

[0002] The art recognizes the on-going need for blends that achieve greater impact efficiency and improved stiffness-toughness-flow balance in TPO compounds containing polypropylene. Further, the art recognizes the on-going need for TPO compounds with improved stiffness-toughness-flow-light transmittance balance.

SUMMARY

[0003] The present disclosure provides a composition. In an embodiment, the composition includes (A) a nonfunctionalized propylene-based polymer, (B) a functionalized propylene-based polymer, and (C) a functionalized ethylene-based polymer. The functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) each have a different functional group, the functional group selected from the group consisting of an anhydride and an amine.

DEFINITIONS

[0004] Any reference to the Periodic Table of Elements is that as published by CRC Press, Inc., 1990–1991. Reference to a group of elements in this table is by the new notation for numbering groups.

[0005] For purposes of United States patent practice, the contents of any referenced patent, patent application or publication are incorporated by reference in their entirety (or its equivalent US version is so incorporated by reference) especially with respect to the disclosure of definitions (to the extent not inconsistent with any definitions specifically provided in this disclosure) and general knowledge in the art.

[0006] The numerical ranges disclosed herein include all values from, and including, the lower and upper value. For ranges containing explicit values (*e.g.*, 1 or 2, or 3 to 5, or 6, or 7), any

subrange between any two explicit values is included (*e.g.*, the range 1-7 above includes subranges of 1 to 2; 2 to 6; 5 to 7; 3 to 7; 5 to 6; etc.).

[0007] Unless stated to the contrary, implicit from the context, or customary in the art, all parts and percents are based on weight, and all test methods are current as of the filing date of this disclosure.

[0008] The term "composition" refers to a mixture of materials which comprise the composition, as well as reaction products and decomposition products formed from the materials of the composition.

[0009] The terms "comprising," "including," "having" and their derivatives, are not intended to exclude the presence of any additional component, step or procedure, whether or not the same is specifically disclosed. In order to avoid any doubt, all compositions claimed through use of the term "comprising" may include any additional additive, adjuvant, or compound, whether polymeric or otherwise, unless stated to the contrary. In contrast, the term "consisting essentially of" excludes from the scope of any succeeding recitation any other component, step, or procedure, excepting those that are not essential to operability. The term "consisting of" excludes any component, step, or procedure not specifically delineated or listed. The term "or," unless stated otherwise, refers to the listed members individually as well as in any combination. Use of the singular includes use of the plural and vice versa.

[0010] An "ethylene-based polymer" or "ethylene polymer" is a polymer that contains a majority amount of polymerized ethylene based on the weight of the polymer and, optionally, may comprise at least one comonomer. Ethylene-based polymers typically comprise at least 50 mole percent (mol%) units derived from ethylene (based on the total amount of polymerizable monomers).

[0011] A "heteroatom" is an atom other than carbon or hydrogen. The heteroatom can be a non-carbon atom from Groups IV, V, VI and VII of the Periodic Table. Nonlimiting examples of heteroatoms include: F, Cl, N, O, P, B, S, and Si.

[0012] A "hydrocarbon" is a compound containing only hydrogen atoms and carbon atoms.

[0013] An "interpolymer" is a polymer prepared by the polymerization of at least two different types of monomers. The generic term interpolymer thus includes copolymers (employed to refer to polymers prepared from two different types of monomers), and polymers prepared from more than two different types of monomers.

[0014] An "olefin-based polymer" or "polyolefin" is a polymer that contains a majority mole percent polymerized olefin monomer (based on total amount of polymerizable monomers), and optionally, may contain at least one comonomer. Nonlimiting examples of olefin-based polymer include ethylene-based polymer and propylene-based polymer. Representative polyolefins include polyethylene, polypropylene, polybutene, polyisoprene and their various interpolymers.

[0015] A "polymer" is a polymeric compound prepared by polymerizing monomers, whether of the same or a different type. The generic term polymer thus embraces the term "homopolymer" (employed to refer to polymers prepared from only one type of monomer, with the understanding that trace amounts of impurities can be incorporated into the polymer structure), and the term "interpolymer," as defined hereinafter. Trace amounts of impurities, for example, catalyst residues, may be incorporated into and/or within the polymer. It also embraces all forms of copolymer, e.g., random, block, etc. The terms "ethylene/ α -olefin polymer" and "propylene/ α -olefin polymer" are indicative of copolymer as described above prepared from polymerizing ethylene or propylene respectively and one or more additional, polymerizable α -olefin monomer. It is noted that although a polymer is often referred to as being "made of" one or more specified monomers, "based on" a specified monomer or monomer type, "containing" a specified monomer content, or the like, in this context the term "monomer" is understood to be referring to the polymerized remnant of the specified monomer and not to the unpolymerized species. In general, polymers herein are referred to as being based on "units" that are the polymerized form of a corresponding monomer.

[0016] A "propylene-based polymer" is a polymer that contains a majority amount of polymerized propylene based on the weight of the polymer and, optionally, may comprise at least one comonomer. Propylene-based polymers typically comprise at least 50 mole percent (mol%) units derived from propylene (based on the total amount of polymerizable monomers).

TEST METHODS

[0017] Density is measured in accordance with ASTM D792, Method B (g/cc or g/cm³).

[0018] Differential Scanning Calorimetry (DSC) can be used to measure the melting, crystallization, and glass transition behavior of a polymer over a wide range of temperature. For example, the TA Instruments Discovery DSC, equipped with an RCS (refrigerated cooling system) and an autosampler was used to perform this analysis. During testing, a nitrogen purge gas flow of 50 ml/min was used. Each sample was melt pressed into a thin film at 190°C; the melted sample was then air-cooled to room temperature (25°C). A 3–10 mg, 6 mm diameter specimen

was extracted from the cooled polymer, weighed, placed in a light aluminum pan (ca 50 mg), and crimped shut. Analysis was then performed to determine its thermal properties.

[0019] The thermal behavior of the sample was determined by ramping the sample temperature up and down to create a heat flow versus temperature profile. First, the sample was rapidly heated to 180°C and held isothermal for 3 minutes in order to remove its thermal history. Next, the sample was cooled to -80°C at a 10°C/minute cooling rate and held isothermal at -80°C for 3 minutes. The sample was then heated to 180°C (this is the "second heat" ramp) at a 10°C/minute heating rate. The cooling and second heating curves were recorded. The values determined are peak melting temperature, T_m , and peak crystallization temperature, T_c . Heat of fusion (H_f) (in Joules per gram), and the calculated % crystallinity for polyethylene samples using the Equation: % Crystallinity = $((H_f)/292 \text{ J/g}) \times 100$.

[0020] The heat of fusion (H_f) and the peak melting temperature were reported from the second heat curve. Peak crystallization temperature was determined from the cooling curve.

[0021] Glass transition temperature, T_g , was determined from the DSC heating curve where half the sample has gained the liquid heat capacity as described in Bernhard Wunderlich, *The Basis of Thermal Analysis, in Thermal Characterization of Polymeric Materials* 92, 278–279 (Edith A. Turi ed., 2d ed. 1997). Baselines were drawn from below and above the glass transition region and extrapolated through the T_g region. The temperature at which the sample heat capacity was half-way between these baselines is the T_g .

[0022] Dynamic Mechanical Spectroscopy (DMS). The rheology of each composition was analyzed by DMS, using an Advanced Rheometric Expansion System (ARES), equipped with "25 mm stainless steel parallel plates," under a nitrogen purge. A constant temperature dynamic frequency sweep, in the range of 0.1 to 100 rad/s, was performed under nitrogen, at 230 °C. A sample of approximately "25 mm diameter x 3.3 mm thick" was cut from a compression molded disc (see below). The sample was placed on the lower plate, and allowed to melt for five minutes. The plates were then closed to a gap of "2.0 mm," and the sample trimmed to "25 mm" in diameter. The sample was allowed to equilibrate at 230 °C for five minutes, before starting the test. The complex viscosity was measured at a constant strain amplitude of 10%. The stress response was analyzed in terms of amplitude and phase, from which the storage modulus (G'), loss modulus (G''), dynamic viscosity η^* , and tan delta could be calculated. Each compression molded disc was formed at 230 °C, and 10 MPa molding

pressure, for five minutes, ambient atmosphere, and then quenched between chilled platens (15-20°C) for two minutes. The complex viscosity, η^* , measured at a frequency of 0.1 rad/s is reported as V0.1. The complex viscosity, η^* , measured at a frequency of 100 rad/s is reported as V100. The rheology ratio, RR, was calculated as the ratio of V0.1/V100. The tan delta measured at a frequency of 0.1 rad/s is reported as $\tan \delta$.

[0023] Flexural testing. Flexural testing was conducted in accordance with ASTM D790, Procedure A, Test Type 1. Specimens (5 inch long x 0.5 inch wide x 0.125 inch thick) were cut from the middle of ASTM D638 Type I injection molded tensile bars. Specimens were tested in a flat-wise orientation with a span of 2 inches and a cross-head speed of 0.05 in/min. Flexural modulus is reported as tangent modulus of elasticity, as mega Pascals (MPa).

[0024] Melt Flow Rate (MFR) for propylene-based polymers was measured according to ASTM D1238, Condition 230°C/2.16 kilogram (kg) weight unless otherwise noted.

[0025] Melt index (MI) for ethylene-based polymers was measured in accordance with ASTM D1238, Condition 190°C/2.16 kilogram (kg) weight, also known as I_2 , and is reported in g/10 min.

[0026] Multi-axial Instrumented Impact (MAII) Testing. Multi-axial Instrumented Impact (MAII) testing was conducted on an INSTRON CEAST 9350 Drop Tower Impact System (Dynatup), equipped with an environmental chamber and spring-assist, according to ASTM D3763. Four-inch diameter, 0.125 inch thick injection molded discs were tested. The discs were conditioned at the test temperature, for at least four hours, prior to testing. Specimens were removed from the conditioning freezer, and placed in an environmental chamber at the specified test temperature. A test speed of 6.7 m/s was used, with a total test mass of 29.131 kg, and a 12.7 mm diameter tup. Five specimens were tested for each sample, at each temperature. Samples were tested at temperatures ranging from 0 °C to -40 °C. Peak and total energy are reported along with the percentage of specimens with a ductile failure mode (no cracks radiating more than 10 mm beyond the center of the impact point). MAII peak and total energy is reported in Joules (J).

[0027] Notched Izod. Notched Izod impact tests were conducted according to ASTM D256, Method A. Specimens (2.5 inch long by 0.5 inch wide by 0.125 inch thick) were cut from either compression molded plaques or from the middle of ASTM D638 Type I injection molded tensile bars. The samples were conditioned for at least 40 hours at 23 +/- 2 °C and 50 +/- 10 % relative humidity. For samples that are tested at non-ambient temperatures, the specimens were further conditioned at the test temperature for a minimum of 1 hour. Testing

was conducted at 23°C, 0°C, and -30°C. The impact strength reported in kilojoules per square meter (kJ/m²) is the average of results for five specimens.

[0028] Tensile testing. Tensile testing was conducted in accordance with ASTM D638 using 3.2 mm thick injection molded Type I tensile bars and a cross-head speed of 2 in/min. Tensile yield strength (reported in MPa) and tensile elongation-at-break (reported in percent, %) are reported as the average for five specimens. In some cases, the specimens did not break at the maximum extension available on the tensile testing frame, in which case the elongation-at-break is reported to be greater than that maximum available elongation.

[0029] Transmittance testing. Total hemispherical luminous transmittance was measured according to ASTM D1003 using four-inch diameter, 0.125 inch thick injection molded discs. Transmittance is reported in percent, %.

DETAILED DESCRIPTION

[0030] The present disclosure provides a composition. In an embodiment, the composition includes (A) a nonfunctionalized propylene-based polymer, (B) a functionalized propylene-based polymer, and (C) a functionalized ethylene-based polymer. The functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) each has a different functional group. The functional groups for each of the functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) are selected from groups capable of reacting with each other to form a covalent bond between the functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C). The functional group for each of the functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) is selected from the group consisting of an anhydride and an amine.

A. *Nonfunctionalized propylene-based polymer*

[0031] The composition contains a nonfunctionalized propylene-based polymer. A "nonfunctionalized propylene-based polymer," as used herein, is a propylene-based polymer containing nonfunctional groups, such that the nonfunctionalized propylene-based polymer is a hydrocarbon and is void of a heteroatom. Nonlimiting examples of propylene-based polymer include propylene homopolymer, propylene/ α -olefin terpolymer, propylene/ α -olefin copolymer, propylene impact copolymer, and combinations thereof.

[0032] In an embodiment, the propylene-based polymer is a propylene homopolymer. The propylene homopolymer has one, some, or all of the following properties;

(i) a density from 0.89 g/cc to 0.91 g/cc, or 0.90 g/cc; and/or

(ii) a MFR from 0.1 g/10 min to 500 g/10 min, or from 1 g/10 min to 150 g/10 min, or from 10 g/10 min to 120 g/10 min, or from 10 g/10 min to 40 g/10min.

[0033] In an embodiment, the propylene-based polymer is a propylene/ α -olefin copolymer. Nonlimiting examples of suitable α -olefins include C_2 and C_4 – C_{20} α -olefins, or C_4 – C_{10} α -olefins, or C_4 – C_8 α -olefins. Representative α -olefins include ethylene, 1-butene, 1-pentene, 1-hexene, 1-heptene and 1-octene.

[0034] In an embodiment, the propylene-based polymer is a propylene impact copolymer. The propylene impact copolymer is a heterophasic polymer wherein a rubber phase (or a discontinuous phase) of discrete domains of ethylene/propylene copolymer is dispersed throughout a matrix phase (or a continuous phase) of propylene homopolymer. The propylene impact copolymer contains from 1 wt% to 40 wt%, or from 5 wt% to 25 wt%, or from 8 wt% to 15 wt% ethylene/propylene rubber phase, based on the total weight of the propylene impact copolymer.

[0035] In an embodiment, the propylene impact copolymer has one, some, or all of the following properties:

(i) from 1 wt% to 40 wt%, or from 5 wt% to 25 wt%, or from 8 wt% to 15 wt% ethylene/propylene rubber phase; and/or

(ii) a density from 0.88 g/cc to 0.90 g/cc; and/or

(iii) a MFR from 0.1 g/10 min to 500 g/10 min, or from 1 g/10 min to 150 g/10 min, or from 10 g/10min to 40 g/10 min.

[0036] A nonlimiting example of a suitable propylene impact copolymer is Pro-Fax SD242 available from LyondellBasell Industries.

B. Functionalized propylene-based polymer

[0037] The present composition includes (B) a functionalized propylene-based polymer and (C) a functionalized ethylene-based polymer. The functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) each has a respective functional group selected from an anhydride and an amine. The functional group of the functionalized propylene-based polymer is different than the functional group for the functionalized ethylene-based polymer. The functional group for each of the functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) is selected from an anhydride and an amine. When the functional group of the functionalized propylene-based polymer is an anhydride, the

functional group of the functionalized ethylene-based polymer (C) is an amine. When the functional group of the functionalized propylene-based polymer is an amine, the functional group of the functionalized ethylene-based polymer is an anhydride. In this way, the functionalized propylene-based polymer and the functionalized ethylene-based polymer each has "a different" functional group wherein the functional group of the functionalized propylene-based polymer is capable of reacting with the functional group of the functionalized ethylene-based polymer to form a covalent bond between the functionalized propylene-based polymer and the functionalized ethylene-based polymer.

[0038] A "functionalized propylene-based polymer," as used herein, is a propylene-based polymer with functional groups that are either anhydride or amine, the functional groups being pendant to the polymer chain backbone. The functionalized propylene-based polymer contains from 0.1 wt% to 10 wt%, or from 0.1 wt% to 5 wt%, or from 0.3 wt% to 1.2 wt% functional group (either anhydride or amine) based on the total weight of the functionalized propylene-based polymer. The functionalized propylene-based polymer (with functional group of either anhydride or amine) has a MFR (2.16 kg, 190 °C) from 1 g/10 min to 2000 g/10 min, or from 10 g/10 min to 500 g/10 min, or from 40 g/10 min to 150 g/10 min.

[0039] Nonlimiting examples of suitable anhydride-functionalized propylene-based polymers are prepared by grafting via a free radical mechanism, for example initiated thermally or by a peroxide, maleic anhydride to a propylene-based polymer.

[0040] Nonlimiting examples of suitable amine-functionalized propylene-based polymers are prepared by imidization of a maleic anhydride-grafted propylene-based polymer with a primary-secondary diamine. Suitable primary-secondary diamines include compounds of structure (I):



In structure (I), R_1 is a divalent hydrocarbon radical, and preferably a linear hydrocarbon of the formula $-(\text{CH}_2)_n-$, where n is greater than, or equal to, 2, or n is from 2 to 10, or from 2 to 8, or from 2 to 6. R_2 is a monovalent hydrocarbon radical containing at least 1 carbon atom, and optionally may be substituted with a heteroatom containing group, such as OH or SH. Preferably, R_2 is a linear hydrocarbon of the formula $-(\text{CH}_2)_n\text{CH}_3$, where n is from 0 to 10, or n is from 0 to 9, or from 0 to 7, or from 0 to 5. In an embodiment, the primary-secondary diamine is selected from N-ethylethylenediamine (DEDA), N-phenylethylenediamine, N-phenyl-1,2-phenylenediamine, N-phenyl-1,4-phenylenediamine, or 4-(aminomethyl)piperidine. Additional primary-secondary

diamines include, but are not limited to, N-(2-hydroxyethyl)ethylenediamine, N-ethyl-1,3-propanediamine, N-ethyl-1,4-butanediamine, N-(2-hydroxypropyl)ethylenediamine, N-methyl-ethylenediamine, N-methyl-1,3-propanediamine, N-methyl-1,4-butanediamine, and 1-(2-aminoethyl)-piperazine.

[0041] Nonlimiting examples of suitable functionalized propylene-based polymer include maleic anhydride (MAH)-grafted propylene homopolymer (MAH-g-PP), maleic anhydride-grafted propylene/ α -olefin copolymer (ethylene, butene, hexene, octene comonomer), DEDA-functionalized propylene homopolymer (DEDA-g-PP), DEDA-functionalized propylene/ α -olefin copolymer (ethylene, butene, hexene, and/or octene comonomer), and combinations thereof. In an embodiment, the functionalized propylene-based polymer is maleic anhydride (MAH)-grafted propylene homopolymer (MAH-g-PP) or DEDA-functionalized propylene homopolymer (DEDA-g-PP).

[0042] The present functionalized propylene-based polymer may comprise two or more embodiments disclosed herein.

C. Functionalized ethylene-based copolymer

[0043] A "functionalized ethylene-based polymer," as used herein, is an ethylene-based polymer with functional groups that are either anhydride or amine, the functional groups being pendant to the polymer chain backbone. Nonlimiting examples of suitable anhydride-functionalized ethylene-based polymers are prepared by grafting via a free radical mechanism, for example initiated thermally or by a peroxide, maleic anhydride to an ethylene-based polymer. Nonlimiting examples of suitable amine-functionalized ethylene-based polymers are prepared by imidization of a maleic anhydride-grafted ethylene-based polymer with a primary-secondary diamine. Suitable primary-secondary diamines include compounds of structure (I):



In structure (I), R_1 is a divalent hydrocarbon radical, and preferably a linear hydrocarbon of the formula $-(\text{CH}_2)_n-$, where n is greater than, or equal to, 2, or n is from 2 to 10, or from 2 to 8, or from 2 to 6. R_2 is a monovalent hydrocarbon radical containing at least 1 carbon atom, and optionally may be substituted with a heteroatom containing group, such as OH or SH. Preferably, R_2 is a linear hydrocarbon of the formula $-(\text{CH}_2)_n\text{CH}_3$, where n is from 0 to 10, or n is from 0 to 9, or from 0 to 7, or from 0 to 5. In an embodiment, the primary-secondary diamine is selected from N-ethylethylenediamine (DEDA), N-phenylethylenediamine, N-phenyl-1,2-phenylenediamine, N-

phenyl-1,4-phenylenediamine, or 4-(aminomethyl)piperidine. Additional primary-secondary diamines include, but are not limited to N-(2-hydroxyethyl)ethylenediamine, N-ethyl-1,3-propanediamine, N-ethyl-1,4-butanediamine, N-(2-hydroxypropyl)ethylenediamine, N-methyl-ethylenediamine, N-methyl-1,3-propanediamine, N-methyl-1,4-butanediamine, and 1-(2-aminoethyl)-piperazine. The functionalized ethylene-based polymer contains from 0.1 wt% to 10 wt%, or from 0.1 wt% to 5 wt%, or from 0.3 wt% to 1.2 wt% functional group (either anhydride or amine) based on the total weight of the functionalized ethylene-based polymer. The functionalized ethylene-based polymer (with functional group of either anhydride or amine) has a MI from 0.1 g/10 min to 2000 g/10 min, or from 0.2 g/10 min to 50 g/10 min, or from 0.3 g/10 min to 25 g/10 min, or from 1 g/10 min to 5 g/10min.

[0044] Nonlimiting examples of suitable functionalized ethylene-based polymer include maleic anhydride (MAH)-grafted ethylene homopolymer (MAH-g-PE), maleic anhydride-grafted ethylene/ α -olefin copolymer (propylene, butene, hexene, and/or octene comonomer), maleic anhydride-grafted ethylene/octene multi-block copolymer, DEDA-functionalized ethylene homopolymer (DEDA-g-PE), DEDA-functionalized ethylene/ α -olefin copolymer (propylene, butene, hexene, and/or octene comonomer), DEDA-functionalized ethylene/octene multi-block copolymer, and combinations thereof.

[0045] The present functionalized ethylene-based polymer may comprise two or more embodiments disclosed herein.

[0046] In an embodiment, the functionalized ethylene-based polymer is a functionalized ethylene/ α -olefin copolymer. Representative α -olefins include, but are not limited to, C₃–C₂₀ α -olefins, or C₃–C₁₀ α -olefins, or C₄–C₂₀ α -olefins, or C₄–C₁₀ α -olefins, or C₄–C₈ α -olefins. Representative α -olefins include propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene and 1-octene.

[0047] In an embodiment, the functionalized ethylene-based polymer is made using an ethylene/C₃–C₈ α -olefin copolymer ("base ethylene/C₃–C₈ α -olefin copolymer") having a density from 0.850 g/cc to 0.920 g/cc, or from 0.850 g/cc to 0.910 g/cc, or from 0.855 g/cc to 0.905 g/cc, or from 0.855 g/cc to 0.890 g/cc.

[0048] In an embodiment, the functionalized ethylene-based polymer is made using an ethylene/octene copolymer having a density from 0.850 g/cc to 0.920 g/cc, or from 0.850 g/cc to 0.910 g/cc, or from 0.855 g/cc to 0.905 g/cc, or from 0.855 g/cc to 0.890 g/cc.

[0049] In an embodiment, the functionalized ethylene-based polymer is made using an ethylene/octene multi-block copolymer having a density from 0.850 g/cc to 0.920 g/cc, or from 0.850 g/cc to 0.910 g/cc, or from 0.855 g/cc to 0.890 g/cc.

D. Nonfunctionalized ethylene-based polymer

[0050] In an embodiment, the composition contains a nonfunctionalized ethylene-based polymer. A "nonfunctionalized ethylene-based polymer," as used herein, is an ethylene-based polymer containing no functional groups, such that the nonfunctionalized ethylene-based polymer is a hydrocarbon and is void of a heteroatom.

[0051] Nonlimiting examples of nonfunctionalized ethylene-based polymer include ethylene homopolymer, ethylene/ α -olefin terpolymer, ethylene/ α -olefin copolymer, ethylene/octene multi-block copolymer, and combinations thereof.

[0052] In an embodiment, the nonfunctionalized ethylene-based polymer is a nonfunctionalized ethylene/ α -olefin copolymer. Representative α -olefins include, but are not limited to, C₃–C₂₀ α -olefins, or C₃–C₁₀ α -olefins, or C₄–C₂₀ α -olefins, or C₄–C₁₀ α -olefins, or C₄–C₈ α -olefins. Representative α -olefins include propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene and 1-octene.

[0053] In an embodiment, the nonfunctionalized ethylene-based polymer is a non-functionalized random ethylene/octene copolymer having one, some, or all of the following properties:

(i) a density from 0.850 g/cc to 0.920 g/cc, or from 0.850 g/cc to 0.910 g/cc, or from 0.860 g/cc to 0.905 g/cc, or from 0.860 g/cc to 0.890 g/cc; and/or

(ii) a MI from 0.1 g/10 min to 2000 g/10 min, or from 0.2 g/10 min to 50 g/10 min, or from 0.5 g/10 min to 35 g/10 min, or from 0.5 g/10min to 8 g/10min.

[0054] In an embodiment, the nonfunctionalized ethylene-based polymer is a nonfunctionalized ethylene/octene multi-block copolymer (consisting only of ethylene and octene comonomer) and has one, some, or all of the following properties:

(i) a Mw/Mn from 1.7, or 1.8 to 2.2, or 2.5, or 3.5; and/or

(ii) a density from 0.850 g/cc to 0.920 g/cc, or from 0.850 g/cc to 0.910 g/cc, or from 0.860 g/cc to 0.890 g/cc ; and/or

(iii) a melting point, T_m, from 115°C, or 118°C, or 119°C, or 120°C to 120°C, or 123°C, or 125°C; and/or

(iv) a MI from 0.1 g/10 min to 2000 g/ 10 min, or from 0.2 g/10 min to 50 g/10 min, or from 0.5 g/10 min to 8 g/10 min; and/or

(v) 50–93 wt% soft segment and 50–7 wt% hard segment; and/or

(vi) from 10 mol%, or 13 mol%, or 14 mol%, or 15 mol% to 16 mol%, or 17 mol%, or 18 mol%, or 19 mol%, or 20 mol% C₄–C₁₂ α -olefin in the soft segment; and/or

(vii) from 0.5 mol%, or 1.0 mol%, or 2.0 mol%, or 3.0 mol% to 4.0 mol%, or 5 mol%, or 6 mol%, or 7 mol%, or 9 mol% octene in the hard segment; and/or

(viii) an elastic recovery (Re) from 50%, or 60% to 70%, or 80%, or 90%, at 300%/min deformation rate at 21°C as measured in accordance with ASTM D 1708; and/or

(ix) a polydisperse distribution of blocks and a polydisperse distribution of block sizes. Ethylene/octene multi-block copolymer with properties (i)-(ix) is disclosed US Patent No. 7,608,668 the entire contents of which are incorporated by reference herein.

[0055] Nonlimiting examples of suitable nonfunctionalized ethylene/octene multi-block copolymers are INFUSE 9530 and INFUSE 9507 available from Dow Inc.

[0056] The present nonfunctionalized ethylene-based polymer may comprise two or more embodiments disclosed herein.

E. Filler

[0057] In an embodiment, the present composition may include one or more fillers. Nonlimiting examples of suitable filler include talc, mica, calcium carbonate, nanoclay, carbon nanotube, carbon nanofiber, and combinations thereof.

F. Composition

[0058] The present composition is produced in a batch mixer, a continuous mixer, and combinations thereof. In an embodiment, the present composition is produced in a continuous mixer. Nonlimiting examples of suitable continuous mixers include co-rotating twin screw extruders, counter-rotating continuous mixers, tangential counter-rotating twin screw extruders, reciprocating kneaders, single screw extruders, multi-screw planetary extruders, and combinations thereof. The continuous mixer can be used as a single unit or as a combination of multiple continuous mixers, in tandem, for example.

[0059] In an embodiment, the compositions includes:

(A) from 20 wt% to 98 wt%, or from 30 wt% to 95 wt%, or from 50 wt% to 85 wt% of the nonfunctionalized propylene-based polymer;

(B) from 1 wt% to 50 wt%, or from 1 wt% to 20 wt%, or from 2 wt% to 16 wt% amine-functionalized propylene-based polymer; and

(C) from 1 wt% to 50 wt%, or from 1 wt% to 20 wt%, or from 2 wt% to 16 wt% maleic anhydride-grafted ethylene-based polymer. Weight percent is based on total weight of the composition.

[0060] In an embodiment, the compositions includes:

(A) from 20 wt% to 98 wt%, or from 30 wt% to 95 wt%, or from 50 wt% to 85 wt% of the nonfunctionalized propylene-based polymer;

(B) from 1 wt% to 50 wt%, or from 1 wt% to 20 wt%, or from 2 wt% to 16 wt% maleic anhydride-grafted-propylene-based polymer; and

(C) from 1 wt% to 50 wt%, or from 1 wt% to 20 wt%, or from 2 wt% to 16 wt% amine-functionalized ethylene-based polymer. Weight percent is based on total weight of the composition. The composition has one, some, or all, or the following properties:

(i) an MFR from 1 g/10 min to 100 g/10 min, or from 2 g/10 min to 80 g/10 min, for from 4 g/10 min to 25 g/10min, and/or

(ii) a viscosity at 0.1 rad/s from 400 Pa.s to 11,000 Pa.s, or from 600 Pa.s to 6,000 Pa.s, or from 750 Pa.s to 3000 Pa.s, and/or

(iii) a viscosity at 100 rad/s from 100 Pa.s to 1000 Pa.s, or from 150 Pa.s to 700 Pa.s, or from 200 Pa.s to 400 Pa.s, and/or

(iv) a $\tan \delta$ at 0.1 rad/s from 0.1 to 50, or from 0.5 to 20, or from 1 to 10. In an embodiment, a molded article composed of the composition has one, some, or all, of the following molded article properties:

(v) a flexural modulus from 300 MPa to 3000 MPa, or from 500 MPa to 2500 MPa, or from 750 MPa to 1300 MPa, or from 750 MPa to 1000 MPa; and/or

(vi) a tensile yield strength from 10 MPa to 40 MPa, or from 15 MPa to 35 MPa, or from 15 MPa to 30 MPa, or from 15 MPa to 25 MPa; and/or

(vii) a tensile elongation at break greater than 30%, or greater than 50%, or greater than 200%, or greater than 500%; and/or

(viii) a notched Izod at 23°C from 8 kJ/m² to 100 kJ/m², or from 10 kJ/m² to 100 kJ/m², or from 8 kJ/m² to 80 kJ/m², or from 10 kJ/m² to 80 kJ/m², or from 8 kJ/m² to 75 kJ/m², or from 10 kJ/m² to 75 kJ/m²; and/or

(ix) a MAll total energy at -40 °C from 15 J to 60 J, or from 20 J to 55 J, or from 30 J to 50 J, or from 40 J to 50 J; and/or

(x) a transmittance from 30% to 99%, or from 35% to 80%, or from 40% to 70%, or from 40% to 60%.

[0061] In an embodiment, the present composition further includes (D) the nonfunctionalized ethylene-based polymer. The composition includes:

(A) from 50 wt% to 85 wt%, or from 55 wt% to 80 wt%, or from 60 wt% to 80 wt% nonfunctionalized propylene-based polymer;

(B) from 1 wt% to 10 wt%, or from 1 wt% to 7 wt%, or from 2 wt% to 5 wt% of an amine-functionalized propylene-based polymer having a MFR (2.16 kg, 190 °C) from 40 g/10 min to 60 g/10 min, or 55 g/10 min;

(C) from 1 wt% to 10 wt%, or from 1 wt% to 7 wt%, or from 2 wt% to 5 wt% of a maleic anhydride-grafted ethylene-based polymer having a MI from 0.3 g/10 min to 12.0 g/10 min, or from 1.0 g/10min to 2.0 g/10 min; and

(D) from 10 wt% to 25 wt%, or from 12 wt% to 25 wt% of the nonfunctionalized ethylene-based polymer (hereafter *Composition1*). Weight percent is based on total weight of the composition. *Composition1* has one, some, or all, or the following properties:

(i) an MFR from 1 g/10 min to 100 g/10 min, or from 2 g/10 min to 80 g/10 min, or from 4 g/10 min to 25 g/10min, and/or

(ii) a viscosity at 0.1 rad/s from 400 Pa.s to 11,000 Pa.s, or from 600 Pa.s to 6,000 Pa.s, or from 700 Pa.s to 3000 Pa.s, or from 750 Pa.s to 3,000 Pa.s, and/or

(iii) a viscosity at 100 rad/s from 100 Pa.s to 1000 Pa.s, or from 150 Pa.s to 700 Pa.s, or from 200 Pa.s to 400 Pa.s, and/or

(iv) a tan δ at 0.1 rad/s from 0.1 to 50, or from 0.5 to 20, or from 1 to 10. In an embodiment, a molded article composed of *Composition1* has one, some, or all, of the following molded article properties:

(v) a flexural modulus from 300 MPa to 3000 MPa, or from 500 MPa to 2500 MPa, or from 750 MPa to 1300 MPa, or from 750 MPa to 1000 MPa; and/or

(vi) a tensile yield strength from 10 MPa to 40 MPa, or from 15 MPa to 35 MPa, or from 15 MPa to 30 MPa, or from 15 MPa to 25 MPa; and/or

(vii) a tensile elongation at break greater than 20%, or greater than 50%, or greater than 200%, or greater than 500%; and/or

(viii) a notched Izod at 23°C from 5 kJ/m² to 100 kJ/m², or from 10 kJ/m² to 100 kJ/m², or from 7 kJ/m² to 90 kJ/m², or from 10 kJ/m² to 80 kJ/m², or from 10 kJ/m² to 75 kJ/m²; and/or

(ix) a MAI total energy at -40 °C from 2 J to 60 J, or from 15 J to 60 J, or from 20 J to 55 J, or from 40 J to 50 J; and/or

(x) a transmittance from 30% to 99%, or from 35% to 80%, or from 35% to 70%, or from 40% to 60%.

[0062] In an embodiment, the composition includes

(A) from 50 wt% to 85 wt%, or from 55 wt% to 80 wt%, or from 60 wt% to 80 wt% nonfunctionalized propylene-based polymer that is a propylene homopolymer having an MFR from 10 g/10 min to 15 g/10 min;

(B) from 1 wt% to 10 wt%, or from 1 wt% to 7 wt%, or from 2 wt% to 5 wt% of an amine-functionalized propylene-based polymer having an MFR (2.16 kg, 190 °C) from 40 g/10 min to 60 g/10 min, or 55 g/10 min;

(C) from 1 wt% to 10 wt%, or from 1 wt% to 7 wt%, or from 2 wt% to 5 wt% of a maleic anhydride-grafted ethylene-based polymer having a MI from 1.0 g/10 min to 12.0 g/10 min; and

(D) from 10 wt% to 25 wt%, or from 12 wt% to 25 wt% of the nonfunctionalized ethylene-based polymer that is an ethylene/octene copolymer having a density from 0.860 g/cc to 0.905 g/cc, or from 0.860 g/cc to 0.890 g/cc, and an MI from 0.1 g/10 min to 35 g/10 min, or from 0.1 g/10 min to 5 g/10min (hereafter *Composition2*). *Composition2* has the one, some, or all, or the following properties:

(i) an MFR from 5 g/10 min to 10 g/10 min, and/or

(ii) a viscosity at 0.1 rad/s from 1900 Pa.s to 2400 Pa.s, or from 2000 Pa.s to 2300 Pa.s, or from 2000 Pa.s to 2100 Pa.s, or from 2000 Pa.s to 2050 Pa.s, and/or

(iii) a viscosity at 100 rad/s from 200 Pa.s to 500 Pa.s, or from 220 Pa.s to 400 Pa.s, or from 350 Pa.s to 400 Pa.s, or from 375 Pa.s to 399 Pa.s, and/or

(iv) a tan δ at 0.1 rad/s from 2.4 to 4.5, or from 3.5 to 4.5. In an embodiment, a molded article composed of *Composition2* has one, some, or all, of the following molded article properties:

(v) a flexural modulus from 750 MPa to 1150 MPa, or from 750 MPa to 850 MPa; and/or

- (vi) a tensile yield strength from 15 MPa to 25 MPa; and/or
- (vii) a tensile elongation at break greater than 20%, or greater than 500%; and/or
- (viii) a notched Izod at 23°C from 30 kJ/m² to 80 kJ/m², or from 70 kJ/m² to 80 kJ/m²;
and/or
- (ix) a MAII total energy at -40 °C from 15 J to 50 J, or from 40 J to 50 J; and/or
- (x) a transmittance from 40% to 70%, or from 40% to 50%.

[0063] In an embodiment, the present composition further includes (D) the nonfunctionalized ethylene-based polymer. The composition includes

(A) from 50 wt% to 85 wt%, or from 55 wt% to 80 wt%, or from 60 wt% to 80 wt% nonfunctionalized propylene-based polymer that is a propylene impact copolymer;

(B) from 1 wt% to 10 wt%, or from 1 wt% to 7 wt%, or from 2 wt% to 5 wt% of an amine-functionalized propylene-based polymer having an MFR (2.16 kg, 190 °C) from 40 g/10 min to 60 g/10 min, or 55 g/10 min;

(C) from 1 wt% to 10 wt%, or from 1 wt% to 7 wt%, or from 2 wt% to 5 wt% of a maleic anhydride-grafted ethylene-based polymer having a MI from 1.0 g/10 min to 4.0 g/10 min, or from 1.0 g/10 min to 2.0 g/10min; and

(D) from 10 wt% to 25 wt%, or from 12 wt% to 25 wt% of the nonfunctionalized ethylene-based polymer having an MI from 0.5 g/10 min to 6.0 g/10 min, or from 0.5 g/10 min to 1.5 g/10 min, and a density from 0.860 g/cc to 0.890 g/cc, or from 0.860 g/cc to 0.88 g/cc (hereafter *Composition3*). *Composition3* has one, some, or all, of the following properties:

(i) an MFR from 15 g/10 min to 25 g/10 min, or from 20 g/10 min to 25 g/10 min;
and/or

(ii) a viscosity at 0.1 rad/s from 650 Pa.s to 800 Pa.s, or from 700 Pa.s to 800 Pa.s;
and/or

(iii) a viscosity at 100 rad/s from 200 Pa.s to 300 Pa.s, or from 200 Pa.s to 250 Pa.s;
and/or

(iv) a tan δ at 0.1 rad/s from 5.0 to 10.0. In an embodiment, a molded article composed of *Composition3* has one, some, or all, of the following molded article properties:

(v) a flexural modulus from 800 MPa to 1050 MPa, or from 800 MPa to 900 MPa;
and/or

(vi) a tensile yield strength from 15 MPa to 25 MPa; and/or

(vii) a tensile elongation at break from 100% to 500%; and/or

(viii) a notched Izod at 23°C from 10 kJ/m² to 50 kJ/m², or from 10 kJ/m² to 20 kJ/m²;

and/or

(ix) a MAII total energy at -40°C from 25 J to 40 J, or from 20 J to 30 J; and/or

(x) a transmittance from 45% to 60%, or from 50% to 60%.

[0064] In an embodiment, the composition includes

(A) from 50 wt% to 85 wt%, or from 50 wt% to 80 wt%, or from 50 wt% to 70 wt% nonfunctionalized propylene-based polymer that is a propylene homopolymer;

(B) from 1 to 20 wt%, or from 1 wt% to 15 wt%, or from 5 wt% to 15 wt% maleic anhydride-grafted propylene-based polymer having an MFR (2.16 kg, 190 °C) from 100 g/10 min to 140 g/10 min;

(C) from 1 wt% to 20 wt%, or from 1 wt% to 15 wt%, or from 5 wt% to 15 wt% amine-functionalized ethylene-based polymer; and

(D) from 10 wt% to 25 wt%, or from 12 wt% to 25 wt% nonfunctionalized ethylene-based polymer (hereafter *Composition4*). *Composition4* has one, some, or all of the following properties:

(i) an MFR from 1 g/10 min to 5 g/10 min; and/or

(ii) a viscosity at 0.1 rad/s from 1000 Pa.s to 3000 Pa.s, or from 2000 Pa.s to 3000 Pa.s, or from 1200 Pa.s to 2500 Pa.s; and/or

(iii) a viscosity at 100 rad/s from 200 Pa.s to 400 Pa.s, or from 300 Pa.s to 340 Pa.s; and/or

(iv) a tan δ at 0.1 rad/s from 1.0 to 3.0, or from 1.0 to 2.0. In an embodiment, a molded article composed of *Composition4* has one, some, or all, of the following molded article properties:

(v) a flexural modulus from 900 MPa to 1300 MPa, or from 900 MPa to 1000 MPa; and/or

(vi) a tensile yield strength from 15 MPa to 30 MPa, or from 15 MPa to 25 MPa; and/or

(vii) a tensile elongation at break greater than 30%, or from greater than 550%; and/or

(viii) a notched Izod at 23°C from 57 kJ/m² to 70 kJ/m², or from 60 kJ/m² to 70 kJ/m²; and/or

- (ix) a MAll total energy at -40 °C from 2 J to 40 J, or from 20 J to 40 J; and/or
- (x) a transmittance from 35% to 70%, or from 50% to 60%.

[0065] In an embodiment, the composition includes

(A) from 50 wt% to 85 wt%, or from 50 wt% to 80 wt%, or from 60 wt% to 80 wt% nonfunctionalized propylene-based polymer that is a propylene impact copolymer;

(B) from 1 to 20 wt%, or from 1 wt% to 15 wt%, or from 1 wt% to 5 wt% maleic anhydride-grafted propylene-based polymer having an MFR (2.16 kg, 190 °C) from 100 g/10 min to 140 g/10 min;

(C) from 1 wt% to 20 wt%, or from 1 wt% to 15 wt%, or from 1 wt% to 5 wt% amine-functionalized ethylene-based polymer; and

(D) from 10 wt% to 25 wt%, or from 12 wt% to 25 wt% nonfunctionalized ethylene-based polymer (hereafter *Composition5*). *Composition5* has one, some, or all of the following properties:

(i) an MFR from 1 g/10 min to 25 g/10 min; and/or

(ii) a viscosity at 0.1 rad/s from 500 Pa.s to 3000 Pa.s, or from 600 Pa.s to 1000 Pa.s;

and/or

(iii) a viscosity at 100 rad/s from 200 Pa.s to 240 Pa.s; and/or

(iv) a tan δ at 0.1 rad/s from 2.5 to 7.0. In an embodiment, a molded article composed of *Composition4* has one, some, or all, of the following molded article properties:

(v) a flexural modulus from 1000 MPa to 1100 MPa; and/or

(vi) a tensile yield strength from 15 MPa to 25 MPa; and/or

(vii) a tensile elongation at break greater than 80%; and/or

(viii) a notched Izod at 23°C from 10 kJ/m² to 60 kJ/m²; and/or

(ix) a MAll total energy at -40 °C from 25 J to 45 J; and/or

(x) a transmittance from 40% to 60%.

[0066] In an embodiment, the composition includes

(A) from 50 wt% to 85 wt%, or from 50 wt% to 80 wt%, or from 50 wt% to 70 wt% nonfunctionalized propylene-based polymer that is a propylene homopolymer;

(B) from 1 to 20 wt%, or from 1 wt% to 10 wt%, or from 1 wt% to 5 wt% maleic anhydride-grafted propylene-based polymer having an MFR (2.16 kg, 190 °C) from 100 g/10 min to 140 g/10 min;

(C) from 1 wt% to 20 wt%, or from 1 wt% to 15 wt%, or from 1 wt% to 10 wt%, or from 1 wt% to 5 wt% amine-functionalized ethylene-based polymer;

(D) from 10 wt% to 25 wt%, or from 10 wt% to 25 wt%, or from 12 wt% to 25 wt% nonfunctionalized ethylene-based polymer; and

(E) from 1 wt% to 15 wt%, or from 5 wt% to 10 wt% filler (hereafter *Composition6*). *Composition6* has one, some, or all of the following properties:

(i) a viscosity at 0.1 rad/s from 2500 Pa.s to 2700 Pa.s; and/or

(ii) a viscosity at 100 rad/s from 300 Pa.s to 400 Pa.s; and/or

(iii) a $\tan \delta$ at 0.1 rad/s from 1.0 to 3.0. In an embodiment, a molded article composed of *Composition6* has a notched Izod at 23°C from 10 kJ/m² to 15 kJ/m².

[0067] Each of *Composition1*, *Composition2*, *Composition3*, *Composition4*, *Composition5*, and *Composition6* is void of, or is otherwise free of, thermoplastic polyurethane and/or a polymer containing isocyanate moiety.

[0068] The present composition composed of (A) nonfunctionalized propylene-based polymer, (B) functionalized propylene-based polymer, (C) functionalized ethylene-based polymer, and (D) nonfunctionalized ethylene-based polymer undergo a reaction during compounding, wherein the functional groups of the functionalized propylene-based polymer react with the functional groups of the functionalized ethylene-based polymer to form covalent bonds between the functionalized propylene-based polymer and the functionalized ethylene-based polymer. The amine functional groups and the anhydride functional groups undergo an imidization reaction to form an imide linkage between the two functionalized polymers. Depending on the number of functional groups on each polymer, multiple imide bonds form between the functionalized polymer chains. Blends of the propylene-based polymers and ethylene-based polymers are immiscible. The propylene-based polymers and the ethylene-based polymers form separate domains in the blend. In-situ reaction between the functionalized propylene-based polymer and the functionalized ethylene-based polymer can improve the compatibility of the propylene-based polymer domains and the ethylene-based polymer domains and/or improve the interfacial strength between the propylene-based polymer domains and the ethylene-based polymer domains. The reaction during compounding results in a TPO composition with more shear-thinning rheology (as indicated by higher melt viscosity at low shear rates with similar melt viscosity at high shear rates) and higher melt elasticity (as indicated by lower $\tan \delta$), and that has improved impact toughness

when molded into an article. The present composition provides an improved balance of light transmittance, stiffness, and impact toughness. To form a blend of a propylene-based polymer and an ethylene-based polymer that has high light transmittance an ethylene-based polymer that has the same refractive index as the propylene-based polymer may be used, such as an ethylene/octene copolymer with density of 0.902 g/cc. It is known that ethylene/octene copolymers with lower density, for example from 0.857 g/cc to 0.870 g/cc, are more efficient impact modifiers for polypropylene, than ethylene/octene copolymers with 0.902 g/cc density. However, blends of propylene-based polymers with these lower density ethylene/octene copolymers tend to have lower light transmittance. In the present compositions, the functionalized ethylene-based polymer and/or the nonfunctionalized ethylene-based polymer can have higher density and a refractive index that more closely matches the refractive index of the nonfunctionalized propylene based polymer and functionalized propylene-based polymer, advantageously resulting in a light transmittance greater than 40% and suitable impact toughness for the present composition.

G. Article

[0069] The present composition can be molded into an article. Many types of molding operations can be used to form articles or parts from the present composition, including, but not limited to, injection molding, blow molding, compression molding, profile and sheet extrusion, and thermoforming. In an embodiment, the article is injection molded. Nonlimiting examples of molded articles formed from the present composition include automotive interior and exterior components such as bumper fascia, airbag covers, door trim panels, instrument panels, seat backrests, exterior body panels (liftgate panels, door panels, fenders), rocker panels, cladding, wheel flares; household and personal articles such as freezer containers, storage containers, toys, electronics and computer parts, footwear components, and building materials.

[0070] By way of example, and not limitation, examples of the present disclosure are provided.

EXAMPLES

[0071] The materials used in comparative samples (CS) and inventive examples (IE) are provided in Table 1.

Table 1: Materials

Component	Details	Source
(A) nonfunctionalized propylene-based polymer		
Braskem PP D115A	Homopolymer polypropylene, d 0.90g/cc, MFR 11 g/10 min (2.16 kg, 230 °C)	Braskem
Braskem PP F1000HC	Homopolymer polypropylene, MFR 115 g/10 min (2.16 kg, 230 °C)	Braskem
Pro-fax SD242	Impact copolymer polypropylene, d 0.898 g/cc, MFR 35 g/10 min (2.16 kg, 230 °C), 13.6 wt% ethylene/propylene rubber phase.	LyondellBasell Industries
(B) functionalized propylene-based polymer		
DEDA-g-PP	Amine functionalized homopolymer polypropylene, MFR 55 dg/min (2.16 kg, 190 °C)	Dow Inc
FUSABOND P613	Maleic anhydride grafted homopolymer polypropylene, 0.55 wt% MAH, MFR 50 g/10 min (1.0 kg, 190 °C), MFR 125 g/10 min (2.16 kg, 190 °C)	Dow Inc
Polybond 3200	Maleic anhydride grafted homopolymer polypropylene, 0.8 – 1.2 wt% MAH, d 0.91 g/cc, MFR 115 g/10 min (2.16 kg, 190 °C), MFR 384 g/10 min (2.16 kg, 230 °C)	Addivant
(C) functionalized ethylene-based polymer		
DEDA-g-INFUSE 9530	Amine functionalized polyolefin elastomer, MI 2.8 g/10 min	Dow Inc
DEDA-g-INFUSE 9507	Amine functionalized polyolefin elastomer, MI 4.9 g/10 min	Dow Inc
DEDA-g-ENGAGE 8450	Amine functionalized polyolefin elastomer, MI 0.4 g/10 min	Dow Inc
DEDA-g-ENGAGE 8402	Amine functionalized polyolefin elastomer, MI 22.4 g/10 min	Dow Inc
MAH-g-ENGAGE 8450	Maleic anhydride grafted polyolefin elastomer, 1.1 wt% MAH, MI 0.3 g/10 min	Dow Inc
MAH-g-ENGAGE 8402	Maleic anhydride grafted polyolefin elastomer, 1.1 wt% MAH, MI 11.4 g/10 min	Dow Inc
MAH-g-INFUSE 9507	Maleic anhydride grafted polyolefin elastomer, 1.0 wt% MAH, MI 3.7 g/10 min	Dow Inc
MAH-g-INFUSE 9530	Maleic anhydride grafted polyolefin elastomer, 1.1 wt% MAH, MI 2.7 g/10 min	Dow Inc
FUSABOND N493	Maleic anhydride grafted polyolefin elastomer, 0.5 wt% MAH, MI 1.6 g/10 min	Dow Inc
(D) nonfunctionalized ethylene-based polymer		
POE1	Ethylene-octene copolymer, density 0.862 g/cc, MI 1.0 g/10 min	Dow Inc
INFUSE 9530	Ethylene/octene multi-block copolymer, density 0.887 g/cc, MI 5.0 g/10 min	Dow Inc
INFUSE 9507	Ethylene/octene multi-block copolymer, density 0.866 g/cc, MI 5.0 g/10 min	Dow Inc
ENGAGE 8402	Ethylene-octene copolymer, density 0.902 g/cc, MI 30 g/10 min	Dow Inc
ENGAGE 8450	Ethylene-octene copolymer, density 0.902 g/cc, MI 3.0 g/10 min	Dow Inc
(E) filler		
Jetfil 700C	Talc	Imerys
Other		
MAH	Maleic anhydride	Sigma Aldrich
DEDA	N-ethylethylenediamine	Sigma Aldrich
Luperox 101	peroxide	Arkema
Irganox B225	Anti-oxidant	BASF

1. Preparation of POE1

[0072] Copolymer POE1 was prepared using a single loop reactor operated at steady state conditions. The catalyst and cocatalysts were as follows: catalyst was 6',6'''-(((diisopropylsilanediyl)bis(methylene)) bis(oxy))bis(3-(3,6-di-tert-butyl-9H-carbazol-9-yl)-3'-fluoro-5-(2,4,4-trimethylpentan-2-yl)-[1,1'-biphenyl]-2-ol)dimethyl-hafnium (as described in WO2018/022975) supplied by Boulder Scientific; cocatalyst-1 was a mixture of methyl(C₁₄₋₁₈ alkyl)ammonium salts of tetrakis(pentafluorophenyl)-borate, prepared by reaction of a long chain trialkylamine (Armeen M2HT, available from Akzo-Nobel, Inc.), HCl and Li[B(C₆F₅)₄], substantially as disclosed in USP 5,919,983, Ex. 2 (no further purification performed) supplied by Boulder Scientific; and cocatalyst-2 was iso-butyl, methyl, branched, cyclic and linear modified methyl aluminosiloxane (MMAO), available from AkzoNobel.

[0073] All materials (ethylene, 1-octene) and the process solvent (a narrow boiling range high-purity isoparaffinic solvent, ISOPAR E commercially available from Exxon Mobil Corporation), were purified with molecular sieves, before introduction into the reaction environment. Hydrogen was supplied in pressurized cylinders, as a high purity grade, and was not further purified. The reactor monomer feed (ethylene) stream was pressurized to above reaction pressure at 575 psig. The solvent and comonomer (1-octene) feed was pressurized to above reaction pressure. The individual catalyst components were diluted to specified component concentrations with purified solvent (ISOPAR E) and pressured to above reaction pressure.

[0074] All reaction feed flows were measured with mass flow meters, and independently controlled. The continuous solution polymerization reactor was a controlled loop. The reactor had independent control of all fresh solvent, monomer, comonomer, hydrogen, and catalyst component feeds. The combined solvent, monomer, comonomer and hydrogen feed to the reactor was temperature controlled from 5°C to 50°C, and typically 40°C, by passing the feed stream through a heat exchanger. The fresh comonomer feed to the polymerization reactor was fed in, with the solvent feed.

[0075] The primary catalyst component feed was controlled, to maintain the reactor monomer concentration at a specified target. The two cocatalyst components were fed, based on specified molar ratios to the primary catalyst component. Immediately following each fresh injection location (either feed or catalyst), the feed streams were mixed with the

circulating polymerization reactor contents. The contents of each reactor were continuously circulated through heat exchangers to maintain isothermal reaction environment at the specified temperature. The effluent from the first polymerization reactor (containing solvent, monomer, comonomer, hydrogen, catalyst components, and molten polymer) exited the reactor loop, and then contacted with water, to stop the reaction. In addition, various additives, such as anti-oxidants, can be added at this point. The stream then entered a two stage separation and devolatilization system, where the polymer was removed from the solvent, hydrogen, and unreacted monomer and comonomer. The solvent (plus dissolved components) was recycled. The recycled stream was purified, before entering the reactor again. The separated and devolatilized polymer melt was pumped through a die, and pelletized.

[0076] Process conditions to produce POE1 are provided in Table A below. POE1 has a density of 0.862 g/cc and melt index of 1.0 g/10 min (2.19 kg, 190 °C).

Table A: Polymerization Conditions for POE11

Name	POE1
Catalyst Metal Conc., ppm metal	14.9
Catalyst solution flow, lb/hr	2.39
Cocatalyst-1 conc., ppm cocat	122
Cocatalyst-1 solution flow, lb/hr	2.31
Cocatalyst-2 conc., ppm Al	48.8
Cocatalyst-2 solution flow, lb/hr	1.10
Reactor Temperature, °C	170
Solvent Flow, lb/hr	840
Ethylene Flow, lb/hr	170
Octene Flow, lb/hr	216
Hydrogen Flow, sccm	3944
Ethylene Conversion, %	85
Polymer Concentration, %	23
Production Rate, lb/hr	261

2A. Functionalization: Preparation of DEDA-g-PP

[0077] A Coperion ZSK-26MC twin-screw extruder was used for imidization reactions of MAH-g-PP. The 26 mm diameter extruder was equipped with 15 barrel segments for a total length to diameter ratio of 60. Polybond 3200 MAH-g-PP pellets were fed to the extruder hopper under nitrogen purge in the first barrel section using a K-Tron Model T20 feeder. The DEDA was injected into the extruder using an Eldex piston (HPLC) pump in the main hopper. The unreacted DEDA was removed by pulling a 20 inch Hg vacuum via a devolatilization port

located at the 13th barrel and trapped in 2 knock-out pots cooled with dry ice. The polymer melt was extruded through a two-hole die into a water bath and strand pelletized. Extruder barrel temperature was set between 180 °C and 230 °C. Process conditions to produce the DEDA-g-PP are provided in Table B.

Table B

Process Conditions	Value
Polymer Feed Rate, lb/hr	10
DEDA Feed Rate, mL/min	0.44
Extruder RPM	300

2B. Functionalization: Preparation of Functionalized Polyolefin Elastomers

[0078] A Coperion ZSK-25MC twin-screw extruder was used for both the reactive extrusion process of the MAH-grafting and imidization reactions of the INFUSE 9530, INFUSE 9507, ENGAGE 8402, and ENGAGE 8450 resins. The extruder is equipped with 25-mm diameter twin screws and 12 barrel segments for a total length to diameter ratio of 48. There are 11 independently controlled barrel sections with electric heating and water cooling. Polymer pellets were fed to the extruder hopper under nitrogen purge in the first barrel section using a K-Tron Model KCLQX3 loss-in-weight feeder. The maleic anhydride was first dissolved in methyl ethyl ketone at a weight ratio of 1:1, and then a predetermined amount of peroxide (Luperox 101 peroxide, 2,5 dimethyl 2,5-Di-t-butylperoxyhexane) was added to the solution in the fume hood (MAH/Peroxide = 20). The maleic anhydride/peroxide/methyl ethyl ketone solution was injected into the extruder at the 4th barrel section using an HPLC pump. The methyl ethyl ketone, un-reactive maleic anhydride, and peroxide byproducts were removed via the devolatilization port located at the 11th barrel and trapped in 3 knock-out pots cooled with dry ice. This devolatilization system was protected with a nitrogen atmosphere. The polymer melt was extruded through a two-hole die (0.125" hole diameter) into an underwater pelletizing system quenched by chilled water (15 °C). Extruder barrel temperature was set between 180 °C and 230 °C. A summary of the process conditions for the maleation step are in Table C below.

Table C

Process Condition	Value
Polymer Feed Rate, lb/hr	19.33
HPLC Feed Rate (MAH, peroxide, MEK solution), mL/min	4.83
HPLC injection pressure, psi	350
Extruder RPM	350
Vacuum, in Hg	26

[0079] Upon maleation, the resins exhibited average MAH-grafting level of 0.9 to 1.1 wt% and MI of 0.3 to 11.4 g/10 min. MAH grafting level was determined by a Fourier Transform Infrared (FTIR) spectroscopy measurement. Polymer pellets were molded into film using a Carver hydraulic press at 200 °C for 30 seconds under 3,000 lb force at ambient atmosphere. The polymer film with a thickness of 3 mil was cooled by transferring the plates to the lower level platens set at ambient temperature. FTIR spectra were collected using a Nicolet 6700 FTIR at a resolution of 4 cm⁻¹. The maleic anhydride grafting level was determined from the ratio of the height of the peak at ca. 1790 cm⁻¹ corresponding to the carbonyl stretch of the anhydride, to the height of 2751 cm⁻¹ by using the following equation based on a second order polynomial models.

$$wt\% MAH = 0.0344 \times \left[\frac{(peak\ height\ @\ ca.\ 1790\ cm^{-1})}{(peak\ height\ @\ ca.\ 2751\ cm^{-1})} \right]^2 + 0.1925 \times \frac{(peak\ height\ @\ ca.\ 1790\ cm^{-1})}{(peak\ height\ @\ ca.\ 2751\ cm^{-1})} + 0.0767$$

[0080] The amine-functionalization reactive extrusion of the MAH-g-POEs resin with N-ethylethylenediamine (DEDA) utilized the same reactive extrusion system as MAH-g-POEs described above, except that an ISCO pump (1000D) instead of a HPLC pump was employed to inject the N-ethylethylenediamine into the extruder. The MAH-g-POE pellets were fed to the extruder hopper under nitrogen purge in the first barrel section using a K-Tron Model KCLQX3 loss-in-weight feeder. The liquid N-ethylethylenediamine was injected into the extruder at 4th barrel section using an ISCO pump. Extruder barrel temperature was set between 180 °C and 230 °C. The un-reactive N-ethylethylenediamine and water byproduct were removed via a vacuum line-trap system, which was made of three knock-out pots and a vacuum pump, through a devolatilization port located at the 11th barrel. This devolatilization system was protected with a nitrogen atmosphere. The polymer melt was extruded through

a two-hole die (0.125" hole diameter) into an underwater pelletizing system quenched by chilled water (15 °C). The MI of the resulting materials was from 0.4 g/10 min to 22.4 g/10 min. Process conditions for the imidization step are in Table D below.

Table D

Process Condition	Value
Polymer Feed Rate, lb/hr	15
DEDA Feed Rate, mL/min	2.74
ISCO pump injection pressure, psi	300
Extruder RPM	350
Vacuum, in Hg	28

3. Compounding of Blends

A. *Haake Blending*

[0081] Blends (CS F – CS K, IE 5 – IE 8) were prepared on a RS5000 Torque Rheometer (Rheometer Services, Inc.) equipped with a Haake Rheomix 600 mixer and standard roller blades. The temperature was set to 200 °C. Rotor speed was initially 10 RPM. All components were added to the mixer under a nitrogen sweep (total batch size was 50 g) and the plunger on the mixer was lowered. Once the components had melted (as indicated by the measured torque decreasing and reaching a steady state) mixing was continued at 50 RPM for 5 minutes. The sample was then immediately offloaded from the mixer and compressed into a patty using a Carver hydraulic press set at 20 °C and 200 psi for a time of three minutes. Portions of the sample were used for measurement of rheology and for preparation of compression molded plaques.

B. *Twin Screw Extrusion*

[0082] Blends (CS A – CS E, IE 1 – IE 4) were prepared on a Coperion ZSK 26 twin screw extruder (1125 mm barrel length with 11 barrel sections, screw diameter was 25.5 mm, extruder barrel inner diameter was 26 mm, 40 horsepower motor, maximum screw speed was 1,200 RPM, maximum torque was 106 Nm) equipped with a two-hole die, water bath, and strand cutter. The polymer components were dry-blended along with the anti-oxidant powder. All components were added via the main feed throat under a nitrogen sweep via a K-Tron T-20 single screw loss-in-weight feeder. The compound was extruded as strands, which were cooled in a 6-foot-long water bath (water temperature was 13 °C), passed under an air knife, pelletized using a strand cutter, and dropped into a plastic bag. All compounds

were dried by purging with a nitrogen stream overnight. The process conditions used for the twin screw extrusion compounding are in Table E1. Portions of the pelletized sample were used for measurement of rheology and melt flow rate and for preparation of injection molded parts.

Table E1

Process Condition	Value
Temperature, Zone 2, °C	130
Temperature, Zone 3, °C	180
Temperature, Zone 4 – Zone 11, °C	200
Die Temperature, °C	200
Extruder RPM	300
Total Feed Rate, lb/hr	30

C. *Twin Screw Extrusion (Genome Line)*

[0083] Blends (CS L – CS T, IE 9 – IE 24) were prepared on a Coperion ZSK18 MEGAlab co-rotating twin screw extruder (maximum screw speed was 1,200 RPM, maximum torque was 18 Nm/cm³, length/diameter = 40, outer diameter/inner diameter = 1.55). The polymer components were dry-blended along with the anti-oxidant powder. All components were added via the main feed throat via a loss-in-weight feeder. The compounds were immediately injection molded. The process conditions used for the twin screw extrusion compounding are in Table E2.

Table E2

Process Condition	Value
Temperature, Zone 1, °C	145
Temperature, Zone 2, °C	175
Temperature, Remaining Zones, °C	190
Extruder RPM	300
Total Feed Rate, lb/hr	10

4. Molding of Parts

A. *Compression Molding*

[0084] Compounds prepared by Haake blending were converted to test samples for mechanical testing by compression molding. Samples were compression molded in accordance with ASTM D4703 using a Carver 30-ton hydraulic press. Plaques 4.5 inch x 4.5 inch x 0.125 inch were molded using a pressure of 30,000 psi and platen temperature of 220

°C for 4 min, followed by quench cooling on a separate set of platens at a temperature of 20 °C and pressure of 30,000 psi for 3 min.

B. *Injection Molding*

[0085] Compounds (CS A – CS E, IE 1 – IE 4) in pellet form prepared by twin screw extrusion were converted to test samples for mechanical testing by injection molding on a Toyo Plastar Si-90 electric injection molding machine equipped with an Axxicon ISO Manufactured (AIM) Quick Change Mould base. ASTM D638, Type I tensile bars (0.125 inch thick) were molded using an insert gated according to ASTM D3641-02 table I (2.1 x 19 mm) with a Z-runner (2 tensile bars per shot). 4-inch diameter, 0.125 inch thick discs were molded using an insert with 2 parts per shot that are side-gated. Injection molding conditions are listed in Table F1 below. The tensile bars were used to measure flexural modulus, tensile yield strength, tensile elongation at break and notched Izod impact properties. The discs were used to measure MAII, dart impact, and light transmittance properties. (1) Flexural modulus, tensile yield strength, tensile elongation at break, and notched Izod impact properties (measured on the tensile bars) and (2) MAII, dart impact and light transmittance properties (measured on 4-inch diameter, 0.125 inch discs) are referred to as "molded article property" or "molded article properties."

Table F1--Injection mold conditions for molded article properties

Condition	4 in dia, 0.125 in thick Disc	ASTM D638 Type I Tensile Bar
Temperature, Feed throat, °C	48	48
Temperature, Zone 1 – Zone 5, °C	226	226
Dosage volume, mm	63.25	61.5
Injection switch-over volume, mm	15	15
Back-up delay, sec	5.5	5.5
Injection pressure, Bar	2000	2000
Injection speed, mm/s	40	40
Hold pressure, Bar	175	230
Back Pressure, Bar	50	50
Screw speed, RPM	90	90
Decompression volume, mm	5	5
Mold Temperature, °C	32	32
Hold Time, sec	25	25
Cool Time, sec	20	20

C. *Injection Molding at Genome line*

[0086] Compounds (CS L – CS T, IE 9 – IE 24) prepared by twin screw extrusion were converted to test samples for mechanical testing by injection molding on a Sodick GL100A 100-ton injection molding machine equipped with a Master Unit Die frame manufactured by Master Precision. ASTM D638, Type 1 tensile bars (0.125 inch thick) were molded using an insert gated according to ASTM D3641-02 table I (2.1 x 19 mm) with a Z-runner (2 tensile bars per shot). 4 inch diameter, 0.125 inch thick discs were molded using a side-gated insert. Injection molded conditions are listed in Table F2 below. The tensile bars were used to measure flexural modulus, tensile yield strength, tensile elongation at break, and notched Izod impact properties. The discs were used to measure MAll, dart impact, and light transmittance properties. (1) Flexural modulus, tensile yield strength, tensile elongation at break, and notched Izod impact properties (measured on the tensile bars) and (2) MAll, dart impact and light transmittance properties (measured on 4-inch diameter, 0.125 inch discs) are referred to as "molded article property" or "molded article properties."

Table F2--Injection mold conditions for molded article properties

Condition	Value
Temperature, all zones, °C	190
Injection speed, cc/s	30
Mold Temperature, °C	38
Hold Time, sec	7
Cool Time, sec	20

Table 1A: Compositions

	CS A	IE 1	CS L	IE 9	CS M	IE 10	CS N	IE 11	IE 12	CS O	IE 13	CS P	IE 14	CS Q	IE 15
Braskem PP D115A, wt%	69.8	64.8	69.8	64.8	69.8	64.8	69.8	64.8	64.8	69.8	64.8	41.9	39.4	41.9	39.4
Braskem PP F1000HC, wt%												27.9	25.4	27.9	25.4
FUSABOND P613, wt%		5.0				5.0		5.0	5.0		5.0		5.0		5.0
Polybond 3200, wt%				5.0											
INFUSE 9530, wt%	30.0	25.0	30.0	25.0											
INFUSE 9507, wt%					30.0	25.0						30.0	25.0		
ENGAGE 8450, wt%							30.0	25.0	25.0					30.0	25.0
ENGAGE 8402, wt%										30.0	25.0				
DEDA-g-INFUSE 9530, wt%		5.0		5.0				5.0							
DEDA-g-ENGAGE 8450, wt%									5.0						5.0
DEDA-g-ENGAGE 8402, wt%											5.0				
DEDA-g-INFUSE 9507, wt%													5.0		
Irganox B225, wt%	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MFR (2.16 kg, 230 °C), dg/min	10.9	4.4	--	--	--	--	--	--	--	--	--	--	--	--	--
DMS (230 °C) Viscosity at 0.1 rad/s, Pa-s	1,639	2,372	1,749	2,323	1,750	2,460	1,898	2,291	2,007	1,296	1,906	988	1,539	1,145	1,301
DMS (230 °C) Viscosity at 100 rad/s, Pa-s	308	309	355	338	339	332	381	348	362	234	218	230	236	260	255
DMS (230 °C) tan δ at 0.1 rad/s	3.6	1.8	3.3	2.2	3.6	2.2	3.6	2.1	2.8	3.0	2.2	3.8	2.3	4.6	2.6

Table 1B: Molded article properties for molded articles made from the compositions of Table 1A

	CS A	IE 1	CS L	IE 9	CS M	IE 10	CS N	IE 11	IE 12	CS O	IE 13	CS P	IE 14	CS Q	IE 15
Flexural Modulus, MPa	851	966	1012	1076	1011	1057	1164	1160	1169	1053	1166	1244	1145	1377	1275
Tensile Yield Strength, MPa	20.9	22.7	20.2	20.8	19.6	21.2	24.8	24.2	23.6	23.2	26.0	22.9	21.5	26.3	27.6
Tensile Elongation at break, %	482	>550	254	32	168	181	155	621	120	181	174	152	209	115	225
Notched Izod, 23 °C, kJ/m ²	31.6	64.4	36.1	53.0	57.3	56.9	11.7	30.6	25.9	8.4	34.5	50.9	51.5	8.3	8.2
Notched Izod, 0 °C, kJ/m ²	8.4	33.6	4.7	24.1	25.0	35.1	4.0	4.6	4.2	4.4	5.4	12.7	17.4	4.0	4.2
Notched Izod, -30 °C, kJ/m ²	5.5	7.5	4.0	4.6	4.8	6.7	3.0	2.7	3.0	2.3	2.8	5.7	5.1	2.7	2.7
MAI, 0 °C, Ductility, %	--	--	--	--	--	--	100%	100%	100%	0%	100%	--	--	60%	100%
MAI, -10 °C, Ductility, %	--	--	--	--	--	--	100%	100%	80%	--	--	--	--	20%	60%
MAI, -20 °C, Ductility, %	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	100%	100%	0%	0%
MAI, -30 °C, Ductility, %	--	100%	100%	40%	100%	100%	--	--	--	--	--	100%	100%	--	--
MAI, -40 °C, Ductility, %	--	100%	40%	20%	100%	100%	--	--	--	--	0%	60%	60%	--	--
MAI, 0 °C, Peak Energy, J	--	--	--	--	--	--	24.6	24.2	23.1	12.3	23.4	--	--	20.9	22.2
MAI, -10 °C, Peak Energy, J	--	--	--	--	--	--	26.3	24.0	25.7	--	--	--	--	23.7	24.4
MAI, -20 °C, Peak Energy, J	21.5	23.9	28.5	24.2	23.2	22.8	21.5	9.0	11.8	10.3	6.4	22.6	24.9	10.1	13.9
MAI, -30 °C, Peak Energy, J	--	22.3	24.2	22.5	23.4	22.2	--	--	--	--	--	22.2	22.0	--	--
MAI, -40 °C, Peak Energy, J	--	24.6	12.3	6.5	22.1	22.8	--	--	--	--	1.6	18.7	19.8	--	--
MAI, 0 °C, Total Energy, J	--	--	--	--	--	--	39.7	38.4	39.8	12.7	34.4	--	--	33.0	37.5
MAI, -10 °C, Total Energy, J	--	--	--	--	--	--	41.8	38.3	38.4	--	--	--	--	36.1	35.5
MAI, -20 °C, Total Energy, J	24.4	38.4	44.6	40.0	40.4	37.2	24.4	10.0	12.5	10.6	6.8	37.3	47.5	11.6	15.0
MAI, -30 °C, Total Energy, J	--	33.1	40.4	31.2	38.2	36.8	--	--	--	--	--	37.3	36.0	--	--
MAI, -40 °C, Total Energy, J	--	35.9	19.0	10.3	34.7	36.4	--	--	--	--	2.3	28.6	31.0	--	--
Transmittance, %	64%	59%	65%	60%	42%	39%	73%	69%	69%	71%	69%	42%	40%	71%	68%

Table 2A: Compositions

	CS B	IE 2	CS L	IE 16	CS M	IE 17	CS O	IE 18
Braskem PP D115A, wt%	69.8	64.8	69.8	64.8	69.8	64.8	69.8	64.8
DEDA-g-PP, wt%		5.0		5.0		5.0		5.0
INFUSE 9530, wt%			30.0	25.0				
POE 1, wt%	30.0	25.0						
INFUSE 9507, wt%					30.0	25.0		
ENGAGE 8402, wt%							30.0	25.0
MAH-g-ENGAGE 8402, wt%								5.0
MAH-g-INFUSE 9530, wt%				5.0				
FUSABOND N493, wt%		5.0						
Irganox B225, wt%	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MFR (2.16 kg, 230 °C), dg/min	7.0	6.6	--	--	--	--	--	--
DMS (230 °C) Viscosity at 0.1 rad/s, Pa-s	1,965	2,004	1,749	2,290	1,750	2,241	1,296	2,141
DMS (230 °C) Viscosity at 100 rad/s, Pa-s	440	399	355	345	339	332	234	228
DMS (230 °C) tan δ at 0.1 rad/s	6.2	4.0	3.3	2.9	3.6	2.7	3.0	2.5

Table 2B: Molded article properties for molded articles made from the compositions of Table 2A

Example	CS B	IE 2	CS L	IE 16	CS M	IE 17	CS O	IE 18
Flexural Modulus, MPa	830	798	1012	1066	1011	969	1053	1135
Tensile Yield Strength, MPa	20.7	20.5	20	18	20	20	23	24
Tensile Elongation at break, %	519	>550	254	148	168	329	181	22
Notched Izod, 23 °C, kJ/m ²	67.1	72.3	36.1	49.4	57.3	63.5	8.4	34.8
Notched Izod, 0 °C, kJ/m ²	54.3	62.1	4.7	6.3	25.0	47.3	4.4	5.4
Notched Izod, -30 °C, kJ/m ²	8.6	10.1	4.0	4.4	4.8	5.6	2.3	3.4
MAI, 0 °C, Ductility, %							0%	100%
MAI, -10 °C, Ductility, %								100%
MAI, -20 °C, Ductility, %	100%	100%	100%	100%	100%	100%	0%	0%
MAI, -30 °C, Ductility, %	100%	100%	100%	100%	100%	100%		
MAI, -40 °C, Ductility, %	100%	100%	40%	20%	100%	80%		
MAI, 0 °C, Peak Energy, J							12.3	22.9
MAI, -10 °C, Peak Energy, J								24.8
MAI, -20 °C, Peak Energy, J	23.1	23.6	28.5	27.4	23.2	24.3	10.3	7.4
MAI, -30 °C, Peak Energy, J	21.5	25.7	24.2	22.4	23.4	23.7		
MAI, -40 °C, Peak Energy, J	26.7	26.2	12.3	13.6	22.1	22.4		
MAI, 0 °C, Total Energy, J							12.7	32.5
MAI, -10 °C, Total Energy, J								37.7
MAI, -20 °C, Total Energy, J	42.0	42.2	44.6	43.3	40.4	41.3	10.6	7.9
MAI, -30 °C, Total Energy, J	36.6	44.1	40.4	37.4	38.2	38.6		
MAI, -40 °C, Total Energy, J	41.9	40.5	19.0	17.5	34.7	33.1		
Transmittance, %	42%	42%	65%	63%	42%	41%	71%	69%

[0087] Table 1A, 1B, 2A, and 2B include formulations with nonfunctionalized propylene-based polymer (A) as propylene homopolymer and the formulations do not include filler. Tables 1A and 2A includes the formulations and properties of the blends as prepared by twin screw extrusion. Tables 1B and 2B includes properties of injection molded parts made from the compositions. As compared to CS A, Inventive Example (IE) 1 has higher notched Izod impact across different temperatures, higher stiffness (flexural modulus), higher tensile yield strength, higher tensile elongation-at-break, higher ductility, similar high-shear viscosity, and slightly lower transmittance. IE 1 can be used as a translucent TPO with a good balance of light transmittance, stiffness, and impact toughness. IE 2 demonstrates that the amine and MAH functionality can also be inverted, with polypropylene functionalized with the amine and MAH grafted to the POE. In this case, a lower density POE is used as the majority POE. Even when using a lower density POE, IE 2 has higher notched Izod impact strength and higher tensile elongation than comparative sample (CS) B, while retaining other properties. In both cases, the inventive examples have lower $\tan \delta$ at low shear rate, indicating higher melt elasticity for IE1 and IE2 compared to CS A and CS B, respectively. Higher melt elasticity can be beneficial for reducing tiger stripping in injection molded parts or improving processability for thermoformed compounds. Similarly, comparing IE 9 vs CS L, or IE 10 vs CS M, or IE 11 vs CS M, or IE 12 vs CS N, or IE 13 vs CS O, or IE 14 vs CS P, or IE 15 vs CS Q, or IE 16 vs CS L, or IE 17 vs CS M, or IE 18 vs CS O, the inventive compositions have higher notched Izod impact strength and/or higher dart impact ductility, with higher or comparable modulus, and similar light transmittance as the comparative examples, demonstrating that the functionality can be present on ethylene-based polymers of a range of different density, melt index, and polymer type (i.e. random interpolymer or multi-block interpolymer), the nonfunctionalized ethylene-based polymer can be of a range of different density, melt index, and polymer type (i.e. random interpolymer or multi-block interpolymer), and that the nonfunctionalized propylene homopolymer can be of a range of different melt flow rates.

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Table 3A: Compositions

	CS C	CS D	CS E	IE 3	IE 4	CS R	IE 19	CS S	IE 20
Profax SD242, wt%	80.9	75.1	80.9	78.5	75.1	80.9	75.1	80.9	75.1
DEDA-g-PP, wt%		5.0		2.0	5.0		5.0		5.0
POE 1, wt%	18.9	19.7	13.9	17.3	14.7				
INFUSE 9530, wt%						18.9	14.7		
INFUSE 9507, wt%								18.9	14.7
FUSABOND N493, wt%			5.0	2.0	5.0				
MAH-g-INFUSE 9530, wt%							5.0		
MAH-g-INFUSE 9507, wt%									5.0
Irganox B225, wt%	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MFR (2.16 kg, 230 °C), dg/min	21.6	23.5	19.5	21.6	21.9				
DMS (230 °C) Viscosity at 0.1 rad/s, Pa-s	651	717	848	765	754	668	658	598	668
DMS (230 °C) Viscosity at 100 rad/s, Pa-s	215	229	240	235	217	226	213	213	207
DMS (230 °C) tan δ at 0.1 rad/s	15.0	13.2	8.6	10.0	7.0	7.53	8.713	8.406	7.056

Table 3B: Molded article properties for molded articles made from the compositions of Table 3A

	CS C	CS D	CS E	IE 3	IE 4	CS R	IE 19	CS S	IE 20
Flexural Modulus, MPa	989	875	818	885	846	1108	1043	1035	988
Tensile Yield Strength, MPa	19.1	18.7	18.1	18.7	18.4	22	21	18	20
Tensile Elongation at break, %	53	175	155	134	411	69	170	159	360
Notched Izod, 23 °C, kJ/m ²	10.5	11.9	12.3	12.9	14.4	13.1	23.8	13.4	44.3
Notched Izod, 0 °C, kJ/m ²	7.6	6.4	7.3	8.0	6.9	8.3	9.7	8.2	11.5
Notched Izod, -30 °C, kJ/m ²	6.3	6.0	7.0	7.2	7.6	6.1	7.6	7.0	8.5
MAI, -20 °C, Ductility, %	40%	80%	60%	80%	100%	80%	100%	100%	40%
MAI, -30 °C, Ductility, %	20%	40%	60%	20%	60%	100%	100%	60%	60%
MAI, -40 °C, Ductility, %	0%	0%	0%	0%	40%	60%	60%	20%	60%
MAI, -20 °C, Peak Energy, J	24.0	21.6	21.8	28.4	27.0	29.3	27.6	28.6	13.4
MAI, -30 °C, Peak Energy, J	20.6	22.9	23.7	26.6	24.3	26.4	24.3	21.7	21.8
MAI, -40 °C, Peak Energy, J	22.9	24.6	24.5	25.2	25.4	22.2	18.4	25.3	18.7
MAI, -20 °C, Total Energy, J	38.1	33.6	35.8	41.1	40.8	40.8	46.9	44.3	18.8
MAI, -30 °C, Total Energy, J	32.4	36.2	37.9	38.5	38.0	46.3	39.6	32.7	33.4
MAI, -40 °C, Total Energy, J	27.0	33.6	37.3	35.3	37.6	34.0	27.0	39.5	32.1
Transmittance, %	50%	50%	52%	51%	51%	51%	52%	47%	47%

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Table 4A: Compositions

	CS R	IE 21	IE 22	CS S	IE 23	CS T	IE 24
Profax SD242, wt%	80.9	75.1	75.1	80.9	75.1	80.9	75.1
FUSABOND P613, wt%		5.0			5.0		5.0
Polybond 3200, wt%			5.0				
INFUSE 9530, wt%	18.9	14.7	14.7				
INFUSE 9507, wt%				18.9	14.7		
ENGAGE 8450, wt%						18.9	14.7
DEDA-g-ENGAGE 8450, wt%							5.0
DEDA-g-INFUSE 9530, wt%		5.0	5.0				
DEDA-g-INFUSE 9507, wt%					5.0		
Irganox B225, wt%	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MFR (2.16 kg, 230 °C), dg/min	--	--	--	--	--	--	--
DMS (230 °C) Viscosity at 0.1 rad/s, Pa-s	668	666	914	598	673	612	889
DMS (230 °C) Viscosity at 100 rad/s, Pa-s	226	211	225	213	203	213	232
DMS (230 °C) tan δ at 0.1 rad/s	7.53	6.84	2.68	8.406	5.483	14.227	4.173

Table 4B: Molded article properties for molded articles made from the compositions of Table 4A

Example	CS R	IE 21	IE 22	CS S	IE 23	CS T	IE 24
Flexural Modulus, MPa	1108	1082	1041	1035	1028	1111	1031
Tensile Yield Strength, MPa	22	20	20	18	20	22	
Tensile Elongation at break, %	69	114	92	159	237	62	
Notched Izod, 23 °C, kJ/m ²	13.1	24.3	41.6	13.4	58.7	12.4	13.1
Notched Izod, 0 °C, kJ/m ²	8.3	10.3	11.0	8.2	11.9	6.9	7.6
Notched Izod, -30 °C, kJ/m ²	6.1	7.6	7.5	7.0	9.2	5.8	5.5
MAII, -20 °C, Ductility, %	80%	100%	80%	100%	80%	100%	75%
MAII, -30 °C, Ductility, %	100%	80%	40%	60%	100%	60%	40%
MAII, -40 °C, Ductility, %	60%	100%	100%	20%	100%	60%	0%
MAII, -20 °C, Peak Energy, J	29.3	23.7	21.8	28.6	25.8	23.8	24.8
MAII, -30 °C, Peak Energy, J	26.4	25.2	26.2	21.7	22.1	24.9	16.5
MAII, -40 °C, Peak Energy, J	22.2	21.5	21.7	25.3	25.0	23.3	20.9
MAII, -20 °C, Total Energy, J	40.8	38.4	32.8	44.3	39.7	38.0	37.5
MAII, -30 °C, Total Energy, J	46.3	39.0	35.8	32.7	36.3	35.7	22.4
MAII, -40 °C, Total Energy, J	34.0	36.6	37.2	39.5	41.4	39.7	25.5
Transmittance, %	51%	49%	49%	47%	44%	56%	50%

[0088] In Table 3A, 3B, 4A, and 4B nonfunctionalized propylene-based polymer (A) is propylene impact copolymer (ICP) and the formulations do not include filler. Tables 3A and 4A include the formulations and properties of the blends as prepared by twin screw extrusion. Table 3B and 4B includes properties of injection molded parts made from the compositions.

;

ICP contains ethylene-propylene rubber phase. IE 4 has higher tensile elongation-at-break, higher notched Izod impact strength (particularly at 23 °C), and higher ductility in multi-axial impact testing when compared to CS C-E. IE 3 contains a lower level of the grafted components and some improvement in multi-axial impact peak and total energy are observed versus CS C-E, but no significant improvement in notched Izod impact strength or multi-axial impact ductility are observed. CS C is a formulation without either functionalized component. CS D and CS E each contain only one of the functionalized components. Comparing IE 19 vs CS R, or IE 20 vs. CS S, or IE 21 and IE 22 vs CS R, or IE 23 vs CS S, or IE 24 vs CS T, the inventive compositions have higher notched Izod impact strength, similar modulus, and similar light transmittances as the comparative examples, demonstrating that a range of functionalized ethylene-based polymers and a range of different nonfunctionalized ethylene-based polymers can also be used with a propylene impact copolymer to achieve improvements in properties.

Table 5A: Compositions

	CS F	CS G	CS H	IE 5	IE 6	IE 7
Braskem PP D115A, wt%	69.8	64.8	69.8	64.8	64.8	54.8
FUSABOND P613, wt%		5.0		5.0	5.0	15.0
INFUSE 9530, wt%	30.0	30.0	25.0	25.0	20.0	15.0
DEDA-g-INFUSE 9530, wt%			5.0	5.0	10.0	15.0
Jetfil 700C, wt%						
Irganox B225, wt%	0.2	0.2	0.2	0.2	0.2	0.2
DMS (230 °C) Viscosity at 0.1 rad/s, Pa-s	1,623	1,417	1,570	2,191	2,271	2,927
DMS (230 °C) Viscosity at 100 rad/s, Pa-s	336	306	342	317	329	306
DMS (230 °C) tan δ at 0.1 rad/s	3.3	3.3	3.8	1.9	1.8	1.2

Table 5B: Molded article properties for molded articles made from the compositions of Table 5A

	CS F	CS G	CS H	IE 5	IE 6	IE 7
Notched Izod, 23 °C, kJ/m ²	5.4	5.5	5.9	62.6	64.5	65.9

[0089] Table 5A and 5B provide additional formulations based on nonfunctionalized propylene homopolymer (A) that do not contain talc. Table 5A includes the formulations and properties of the blends as prepared by Haake blending. Table 5B includes properties of compression molded parts made from the compositions. CS F is a formulation without either functionalized component. CS G and CS H each contain only one of the functionalized

;

components. IE 5, IE 6, and IE 7 contain both functionalized components at various levels. IE 5-7 each has higher notched Izod impact strength compared to CS F-H. Similar to the inventive compositions in Table 1A/1B, IE 5-7 have similar high shear viscosity as CS F-H, but lower $\tan \delta$ (indicating that IE 5-7 have higher melt elasticity compared to CS F, G, H).

Table 6A: Talc-filled Compositions

	CS I	CS J	CS K	IE 8
Braskem PP D115A, wt%	62.8	57.8	62.8	57.8
FUSABOND P613, wt%		5.0		5.0
INFUSE 9530, wt%	27.0	27.0	22.5	22.5
DEDA-g-INFUSE 9530, wt%			4.5	4.5
Jetfil 700C Talc, wt%	10.0	10.0	10.0	10.0
Irganox B225, wt%	0.2	0.2	0.2	0.2
DMS (230 °C) Viscosity at 0.1 rad/s, Pa-s	2,059	1,584	1,894	2,656
DMS (230 °C) Viscosity at 100 rad/s, Pa-s	397	352	423	386
DMS (230 °C) $\tan \delta$ at 0.1 rad/s	3.0	3.3	5.0	2.1

Table 6B: Molded article properties for molded articles made from the compositions of Table 6A

	CS I	CS J	CS K	IE 8
Notched Izod, 23 °C, kJ/m ²	3.4	3.5	5.7	11.2

[0090] Table 6A and Table 6B provide formulations based on nonfunctionalized propylene homopolymer (A) and also contain filler (E), namely, talc. Table 6A includes the formulations and properties of the blends as prepared by Haake blending. Table 6B includes properties of compression molded parts made from the compositions. CS I is a formulation without either functionalized component. CS J and CS K each contain only one of the functionalized components. IE 8, with both functionalized components, has higher notched Izod impact strength, similar high shear rate viscosity, and lower $\tan \delta$ compared to CS I, J, and K.

[0091] It is specifically intended that the present disclosure not be limited to the embodiments and illustrations contained herein, but include modified forms of those embodiments including portions of the embodiments and combinations of elements of different embodiments as come within the scope of the following claims.

We Claim:

1. A composition comprising:
 - (A) a nonfunctionalized propylene-based polymer;
 - (B) a functionalized propylene-based polymer, and
 - (C) a functionalized ethylene-based polymer,the functionalized propylene-based polymer (B) and the functionalized ethylene-based polymer (C) each having a different functional group, the functional group selected from the group consisting of an anhydride and an amine.
2. The composition of claim 1 comprising
 - (A) from 20 wt% to 98 wt% nonfunctionalized propylene-based polymer;
 - (B) from 1 wt% to 50 wt% amine-functionalized propylene-based polymer;and
 - (C) from 1 wt% to 50 wt% maleic anhydride-grafted ethylene-based polymer.
3. The composition of claim 2 wherein the amine-functionalized propylene-based polymer is an N-ethylethylenediamine-functionalized propylene homopolymer having
 - (i) a melt flow rate (2.16 kg, 190 °C) from 1 g/10 min to 2000 g/10 min, and
 - (ii) from 0.1 wt% to 10 wt% N-ethylethylenediamine, based on the total weight of the functionalized N-ethylethylenediamine-functionalized propylene homopolymer.
4. The composition of any of claims 2-3 wherein the maleic anhydride-grafted ethylene-based polymer has
 - (i) a melt index (2.16 kg, 190 °C) from 0.1 g/10 min to 2000 g/10 min,
 - (ii) a maleic anhydride content from 0.1 wt% to 10 wt%, based on the total weight of the functionalized ethylene-based polymer, and
 - (iii) a base ethylene/C₃-C₈ α -olefin copolymer having a density from 0.850 g/cc to 0.920 g/cc.
5. The composition of claim 1 comprising
 - (A) from 20 wt% to 98 wt% nonfunctionalized propylene-based polymer;
 - (B) from 1 wt% to 50 wt% maleic anhydride-grafted propylene-based polymer; and
 - (C) from 1 wt% to 50 wt% amine-functionalized ethylene-based polymer.

6. The composition of claim 5 wherein the maleic anhydride-grafted propylene-based polymer is a maleic anhydride-grafted propylene homopolymer having
- (i) a melt flow rate (2.16 kg, 190 °C) from 1 g/10 min to 2000 g/10 min, and
 - (ii) a maleic anhydride content from 0.1 wt% to 10 wt%, based on the total weight of the functionalized propylene-based polymer.
7. The composition of any of claims 5-6 wherein the amine-functionalized ethylene-based polymer is an N-ethylethylenediamine-functionalized ethylene/C₃-C₈ α-olefin copolymer having
- (i) a melt index (2.16 kg, 190 °C) from 0.1 g/10 min to 2000 g/10 min,
 - (ii) an N-ethylethylenediamine content from 0.1 wt% to 10 wt%, based on the total weight of the N-ethylethylenediamine-functionalized ethylene/C₃-C₈ α-olefin copolymer, and
 - (iii) a base ethylene/C₃-C₈ α-olefin copolymer having a density from 0.850 g/cc to 0.920 g/cc.
8. The composition of any of claims 1-7 comprising
- (D) a nonfunctionalized ethylene-based polymer.
9. The composition of claim 8 wherein the nonfunctionalized ethylene-based polymer is an ethylene/C₃-C₈ α-olefin copolymer having
- (i) a density from 0.850 g/cc to 0.920 g/cc, and
 - (ii) a melt index (2.16 kg, 190 °C) from 0.1 g/10 min to 2000 g/10 min.
10. The composition of claim 9 comprising
- (A) from 50 wt% to 85 wt% nonfunctionalized propylene-based polymer;
 - (B) from 1 wt% to 10 wt% amine-functionalized propylene-based polymer having a melt flow rate (2.16 kg, 190 °C) from 40 g/10 min to 60 g/10 min;
 - (C) from 1 wt% to 10 wt% maleic anhydride-grafted ethylene-based polymer; and
 - (D) from 10 wt% to 25 wt% nonfunctionalized ethylene-based polymer.
11. The composition of claim 10 wherein the nonfunctionalized propylene-based polymer is a propylene homopolymer; and
- the composition has a property selected from the group consisting of

- (i) a melt flow rate (2.16 kg, 230 °C) from 5 g/10 min to 10 g/10 min,
- (ii) a viscosity (230 °C) at 0.1 rad/s from 1900 Pa.s to 2400 Pa.s,
- (iii) a viscosity (230 °C) at 100 rad/s from 200 Pa.s to 500 Pa.s,
- (iv) a $\tan \delta$ at 0.1 rad/s from 2.4 to 4.5, and
- (v) combinations thereof.

12. A molded article composed of the composition of claim 11, the molded article having a molded article property selected from the group consisting of

- a flexural modulus from 750 MPa to 1150 MPa,
- a tensile yield strength from 15 MPa to 25 MPa,
- a tensile elongation at break greater than 20%,
- a notched Izod at 23°C from 30 kJ/m² to 80 kJ/m²,
- a MAI total energy at -40 °C from 15 J to 50 J,
- a transmittance from 40% to 70%, and
- combinations thereof.

13. The composition of claim 10 wherein the nonfunctionalized propylene-based polymer is a propylene impact copolymer; and

- the composition has
- a melt flow rate (2.16 kg, 230 °C) from 15 g/10 min to 25 g/10 min,
- a viscosity (230 °C) at 0.1 rad/s from 650 Pa.s to 800 Pa.s,
- a viscosity (230 °C) at 100 rad/s from 200 Pa.s to 300 Pa.s, and
- a $\tan \delta$ at 0.1 rad/s from 5.0 to 10.0.

14. A molded article composed of the composition of claim 13, the molded article having a molded article property selected from the group consisting of

- a flexural modulus from 800 MPa to 1050 MPa,
- a tensile yield strength from 15 MPa to 25 MPa,
- a tensile elongation at break from 100% to 500%,
- a notched Izod at 23°C from 10 kJ/m² to 50 kJ/m²,
- a MAI total energy at -40 °C from 25 J to 40 J,
- a transmittance from 45% to 60%, and
- combinations thereof.

15. The composition of claim 9 comprising
- (A) from 50 wt% to 85 wt% nonfunctionalized propylene-based polymer that is a propylene homopolymer;
 - (B) from 1 wt% to 20 wt% maleic anhydride-grafted propylene-based polymer having a melt flow rate (2.16 kg, 190 °C) from 100 g/10 min to 140 g/10 min;
 - (C) from 1 wt% to 20 wt% functionalized ethylene-based polymer; and
 - (D) from 10 wt% to 30 wt% nonfunctionalized ethylene-based polymer.
16. The composition of claim 15 wherein the composition has
- a melt flow rate (2.16 kg, 230 °C) from 1 g/10 min to 5 g/10 min,
 - a viscosity (230 °C) at 0.1 rad/s from 1000 Pa.s to 3000 Pa.s,
 - a viscosity (230 °C) at 100 rad/s from 200 Pa.s to 400 Pa.s, and
 - a tan δ at 0.1 rad/s from 1.0 to 3.0.
17. A molded article composed of the composition of claim 16, the molded article having a molded article property selected from the group consisting of
- a flexural modulus from 900 MPa to 1300 MPa,
 - a tensile yield strength from 15 MPa to 30 MPa,
 - a tensile elongation at break greater than 30%,
 - a notched Izod at 23°C from 57 kJ/m² to 70 kJ/m²,
 - a MAI total energy at -40 °C from 2 J to 40 J,
 - a transmittance from 35% to 70%, and
 - combinations thereof.
18. The composition of claim 15 wherein the nonfunctionalized propylene-based polymer is a propylene impact copolymer; and
- the composition has
 - a melt flow rate (2.16 kg, 230 °C) from 1 g/10 min to 25 g/10 min,
 - a viscosity (230 °C) at 0.1 rad/s from 500 Pa.s to 3000 Pa.s,
 - a viscosity (230 °C) at 100 rad/s from 200 Pa.s to 240 Pa.s, and
 - a tan δ at 0.1 rad/s from 2.5 to 7.0.
19. A molded article composed of the composition of claim 18, the molded article having a molded article property selected from the group consisting of

a flexural modulus from 1000 MPa to 1100 MPa,
a tensile yield strength from 15 MPa to 25 MPa,
a tensile elongation at break greater than 80%,
a notched Izod at 23°C from 10 kJ/m² to 60 kJ/m²,
a MAII total energy at -40 °C from 25 J to 45 J,
a transmittance from 40% to 60%, and
combinations thereof.

20. The composition of claim 9 comprising

(E) a filler.

21. The composition of claim 20 comprising

(A) from 50 wt% to 85 wt% nonfunctionalized propylene-based polymer that
is a propylene homopolymer;

(B) from 1 wt% to 20 wt% maleic anhydride-grafted propylene-based
polymer having a melt flow rate (2.16 kg, 190 °C) from 40 g/10 min to 60 g/10 min;

(C) from 1 wt% to 20 wt% functionalized ethylene-based polymer;

(D) from 10 wt% to 25 wt% nonfunctionalized ethylene-based polymer;

(E) from 1 wt% to 15 wt% filler; and

the composition has

a viscosity (230 °C) at 0.1 rad/s from 2500 Pa.s to 2700 Pa.s,

a viscosity (230 °C) at 100 rad/s from 300 Pa.s to 400 Pa.s, and

a tan δ at 0.1 rad/s from 1.0 to 3.0.

22. A molded article composed of the composition of claim 21, the molded article
having

a notched Izod at 23°C from 10 kJ/m² to 15 kJ/m².