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(54) **LUBRICANT COMPOSITION**

(57) To provide a lubricating oil composition having excellent shear stability and temperature viscosity characteristics and also having high heat dissipation performance from the viewpoint of fuel saving and energy saving of an electric vehicle.

A lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle, the composition including: a lubricating base oil; and an ethylene- α -olefin copolymer with an ethylene molar content rate of 30 to 70 mol%, a kinematic viscosity

at 100°C of 10 to 5,000 mm²/s, a Hasen chromaticity of 30 or lower, a molecular weight distribution of 2.5 or less, and a B-value of 1.1 or more, the composition having a kinematic viscosity at 100°C of 4 to 10 mm²/s, and the lubricating base oil including a mineral oil with a kinematic viscosity at 100°C of 2 to 6 mm²/s, a viscosity index of 105 or more, and a pour point of -5°C or lower, and/or a synthetic oil with a kinematic viscosity at 100°C of 1 to 9 mm²/s, a viscosity index of 110 or more, and a pour point of -30°C or lower.

EP 4 488 348 A1

Description

Technical Field

- 5 **[0001]** The present invention relates to a lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle.

Background Art

- 10 **[0002]** In recent years, there has been a strong demand for CO₂ reduction from the viewpoint of global environmental protection, and for this reason, efforts have been made in the automotive field to develop technologies for fuel saving. Electric vehicles are one of the mainstream technologies in such fuel saving. Examples thereof include electric automobiles, plug-in hybrid vehicles, hybrid vehicles, and fuel cell vehicles, which are expected to spread rapidly in the future. Electric vehicles are characterized by having electric motors, and run partially or entirely on electric motors.
- 15 **[0003]** In electric vehicles having transmissions, transmissions for equipment with shared lubrication systems between the transmission and the electric motor are often employed, and existing automatic transmission fluid (ATF) and continuously variable transmission fluid (CVTF) are mainly used as lubricating oil compositions. In these lubricating oil compositions, a variety of additives are blended to impart characteristics that control friction in wet clutches and suppress metal-to-metal wear (metal-to-metal wear resistance), and the volume resistivity is about 10⁷ Ωm. Also, there is
- 20 a problem of the volume resistivity of these lubricating oil compositions decreasing significantly with the lubricating oil itself deteriorating. Accordingly, lubricating oil compositions used for electric vehicles are required not only to have excellent metal-to-metal wear resistance, but also to have excellent electric insulation in order to maintain reliability over a long period of time in terms of the insulation of electric motors. Furthermore, due to the recent needs for improved fuel saving performance and simplified lubrication systems for transmissions and electric motors, lubricating oil compositions are
- 25 required to have lower viscosity than that of existing ATF and CVTF, as well as to improve power transmission efficiency and reduce size and weight, resulting in an even higher load being applied to transmissions. Therefore, along with insulation, high wear resistance and durability performance such as shear stability and thermal stability of lubricating oil compositions are also increasingly required.
- [0004]** Then, for example, lubricating oil compositions containing specific phosphorous compounds or specific sulfur compounds are proposed in Patent Literatures 1 and 2, and electrical characteristics such as volume resistivity are
- 30 discussed in addition to lubricating oil performance such as wear resistance and extreme pressure performance of the lubricating oil compositions.
- [0005]** In-wheel motors, as motors driven inside the wheels of electric vehicles, are increasingly being installed as the power train in electric automobiles and fuel cell vehicles. By incorporating the motor in the wheels of vehicle wheels, driving power is transmitted directly to the wheels, thus reducing energy loss due to gears, drive shafts, **etc.**, as in conventional gasoline engine automobiles. In-wheel motors, which have low energy loss, require higher heat dissipation since it is
- 35 difficult for such a mechanism to dissipate heat generated by the transmission and motor.
- [0006]** For example, Patent Literature 3 describes that lubricating oils used for in-wheel motors are in a smaller amount compared to ATF and CVTF, and thus their viscosity easily decreases when subjected to severe shear, and lubrication performance tends to be particularly valued.
- 40 **[0007]** Patent Literature 4 provides an in-wheel motor that can improve fuel saving, as there is a need for lubricating oils used in in-wheel motors to extend the driving distance per battery charging as much as possible, such as for electric wheelchairs.

45 Citation List

Patent Literature

[0008]

- 50 [Patent Literature 1] JP5771532B
 [Patent Literature 2] JP5779376B
 [Patent Literature 3] JP2007-284564A
 [Patent Literature 4] JP2012-244810A
- 55

Summary of Invention

Technical Problem

[0009] For electric vehicles in recent years, in order to reduce size and weight from the viewpoint of fuel saving, so-called chassis-type systems have been developed, in which an electric motor and a transmission that transfers power from the electric motor to the drive unit, or a speed reduction mechanism are integrated, and an increasing number of vehicles are employing this type of system. Therefore, in addition to the conventional lubricating function, lubricating oils are now required to have a cooling function to suppress excessive heat generation in the electric motor. For this reason, there has been a demand for improvement in the electric motor cooling performance of lubricating oils.

[0010] The above Patent Literatures do not sufficiently discuss the cooling performance for electric motors, such as heat generation and heat dissipation suppression, and there is still room for improvement in the cooling performance of lubricating oil compositions.

[0011] In view of these problems in such conventional technologies, from the viewpoint of fuel saving and energy saving in electric vehicles such as hybrid automobiles and electric automobiles, an object to be solved by the present invention is to provide a lubricating oil composition that is extremely excellent in shear stability and is excellent, with a good balance at a high level, in temperature viscosity characteristics such as oil film retention performance at a high temperature and pourability at a low temperature, compared to conventional lubricating oils containing the same lubricating base oil, the lubricating oil composition also having high heat dissipation performance from the viewpoint of cooling of an electric motor.

Solution to Problem

[0012] As a result of diligent investigations in order to develop a lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle with excellent performance, the present inventors have found that a lubricating oil composition containing a specific ethylene- α -olefin (co)polymer with a specific lubricating base oil and satisfying specific conditions can solve the aforementioned problems, and thus have completed the present invention. Specifically, the following aspects are included:

[1] A lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle, the composition including: a lubricating base oil composed of a (A) mineral oil having the following characteristics (A1) to (A3) and/or a (B) synthetic oil having the following characteristics (B1) to (B3); and an (C) ethylene- α -olefin copolymer having the following characteristics (C1) to (C5), the composition having a kinematic viscosity at 100°C of 4 to 10 mm²/s:

(A1) a kinematic viscosity at 100°C of 2 to 6 mm²/s;

(A2) a viscosity index of 105 or more;

(A3) a pour point of -5°C or lower;

(B1) a kinematic viscosity at 100°C of 1 to 9 mm²/s;

(B2) a viscosity index of 110 or more;

(B3) a pour point of -30°C or lower;

(C1) an ethylene molar content rate within a range of 30 to 70 mol%;

(C2) a kinematic viscosity at 100°C of 10 to 5,000 mm²/s;

(C3) a Hasen chromaticity of 30 or lower;

(C4) a molecular weight distribution (Mw/Mn) of 2.5 or less in molecular weight obtained in terms of polystyrene, as measured by gel permeation chromatography (GPC); and

(C5) a B value represented by the following formula [1] of 1.1 or more:

$$B = \frac{P_{OE}}{2 P_O \cdot P_E} \dots [1]$$

wherein P_E represents a molar fraction of ethylene component, P_O represents a molar fraction of α -olefin component, and P_{OE} represents a molar fraction of ethylene- α -olefin sequence in the total dyad sequence.

[2] The lubricating oil composition according to [1], wherein the (C) ethylene- α -olefin copolymer has any one or more of the following characteristics (C6) to (C8):

- (C6) a thermal diffusivity at 50°C of 8.0×10^{-5} to 1.0×10^{-4} m²/s;
 (C7) a volume resistivity at 50°C and 250 V of 1.0×10^{15} to 1.0×10^{17} $\Omega \cdot \text{cm}$; and
 (C8) a relative permittivity at 50°C of 2.00 to 2.30.

[3] The lubricating oil composition according to [1] or [2], wherein the ethylene molar content rate of the (C) ethylene- α -olefin copolymer is within a range of 40 to 60 mol%.

[4] The lubricating oil composition according to any of [1] to [3], wherein the kinematic viscosity of the (C) ethylene- α -olefin copolymer at 100°C is 20 to 2,500 mm²/s.

[5] The lubricating oil composition according to any of [1] to [4], wherein the α -olefin of the (C) ethylene- α -olefin copolymer is propylene.

[6] The lubricating oil composition according to any of [1] to [5], wherein the content of the (C) ethylene- α -olefin copolymer is 1 to 10% by mass based on the total amount of the lubricating base oil and the (C) ethylene- α -olefin copolymer of 100% by mass.

[7] The lubricating oil composition according to any of [1] to [6], wherein the electric vehicle is an electric automobile, a plug-in hybrid vehicle, a hybrid vehicle, or a fuel cell vehicle.

[7a] The lubricating oil composition according to [7], wherein the electric vehicle is a hybrid vehicle or an electric automobile.

[8] The lubricating oil composition according to any of [1] to [6], wherein the electric motor equipped in the electric vehicle is an in-wheel motor.

[9] The lubricating oil composition according to any of [1] to [6], wherein the electric vehicle is an electric wheelchair or an electric cart.

[10] The lubricating oil composition according to any of [1] to [6], wherein the electric vehicle is an electric skateboard or an electric roller skate.

Advantageous Effects of Invention

[0013] The lubricating oil composition of the present invention is a lubricating oil composition that is, compared to conventional lubricating oils containing the same lubricating base oil, extremely superior in temperature viscosity characteristics, that is, excellent, with a good balance at a high level, in temperature viscosity characteristics such as oil film retention at a high temperature and pourability at a low temperature, that is also extremely excellent in shear stability, and that can maintain lubricating oil performance over a long period of use. In addition, it has high heat dissipation performance, and therefore can be suitably applied to cooling of an electric motor and lubrication of a gear in an electric vehicle.

Description of Embodiments

[0014] The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle according to the present invention (hereinafter, also referred to simply as "lubricating oil composition") will be described in detail below.

[Lubricating oil composition used for cooling of electric motor and lubrication of gear in electric vehicle]

[0015] The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle according to the present invention is characterized in that the composition includes a lubricating base oil composed of a (A) mineral oil and/or a (B) synthetic oil, and an (C) ethylene- α -olefin copolymer, and has a kinematic viscosity at 100°C within a specific range.

<(C) Ethylene- α -olefin copolymer>

[0016] The (C) ethylene- α -olefin copolymer has the following characteristics (C1) to (C5).

(C1) An ethylene molar content rate within a range of 30 to 70 mol%

[0017] The ethylene molar content rate of the (C) ethylene- α -olefin copolymer is usually 30 to 70 mol%, preferably 40 to 60 mol%, and particularly preferably 45 to 58 mol%. Outside this range of the ethylene molar content rate, crystals easily

form from the ethylene- α -olefin copolymer at low temperature, a low temperature viscosity increases, and the fuel saving properties of the lubricating oil composition deteriorate.

[0018] The ethylene molar content rate of the (C) ethylene- α -olefin copolymer is measured by ^{13}C -NMR according to the method described in "Polymer Analysis Handbook" (Asakura Publishing Co., Ltd., P163-170). A sample obtained by this method can also be measured by Fourier transform infrared spectroscopy (FT-IR) as a known sample.

(C2) A kinematic viscosity at 100°C of 10 to 5,000 mm²/s

[0019] This value of the kinematic viscosity at 100°C is that measured by the method described in JIS K2283. The kinematic viscosity of the (C) ethylene- α -olefin copolymer at 100°C is 10 to 5,000 mm²/s, preferably 20 to 4,000 mm²/s, more preferably 25 to 3,500 mm²/s, still more preferably 30 to 3,000 mm²/s, and particularly preferably 35 to 2,500 mm²/s. When the kinematic viscosity of the (C) ethylene- α -olefin copolymer at 100°C exceeds the above range, the shear stability of the lubricating oil composition decreases and fuel saving properties deteriorate. Below the above range, the low temperature pourability decreases, and fuel efficiency deteriorates significantly upon startup in a low temperature environment.

(C3) A Hasen chromaticity of 30 or lower

[0020] This value of the Hasen chromaticity is that measured by the method described in JIS K0071. The Hasen chromaticity of the (C) ethylene- α -olefin copolymer is 30 or lower, preferably 0 to 30, more preferably 0 to 25, and still more preferably 0 to 20. The Hasen chromaticity of the (C) ethylene- α -olefin copolymer exceeding this range means that an oxygen-containing functional group is excess in amount in a molecule of the (C) ethylene- α -olefin copolymer, whereby heat resistance and electric insulation of the resulting lubricating oil composition deteriorate.

(C4) A molecular weight distribution of **2.5** or less

[0021] The molecular weight distribution of the (C) ethylene- α -olefin copolymer is measured by gel permeation chromatography (GPC) according to the method described below and calculated as a ratio (Mw/Mn) of a weight-average molecular weight (Mw) to a number-average molecular weight (Mn) obtained in terms of standard polystyrene. The Mw/Mn is **2.5** or less, preferably 1.0 to **2.5**, more preferably **1.0 to 2.3**, and still more preferably **1.0 to 2.2**. The molecular weight distribution exceeding this range means that low molecular weight components and high molecular weight components are included more, and containing low molecular weight components more increases a component that is easy to volatilize, increases the amount of evaporation loss in the lubricating oil composition, and lowers a thickening effect, and containing high molecular weight components more causes deterioration of shear stability and thermal stability of the lubricating oil composition.

(C5) B value of **1.1** or more

[0022] The B value represented by the following formula [1] of the (C) ethylene- α -olefin copolymer is **1.1** or more, preferably 1.1 to 1.5, and more preferably **1.2 to 1.4**. The B value exceeding this range means that the alternating polymerization of ethylene or α -olefin in the (C) ethylene- α -olefin copolymer decreases, and the (C) ethylene- α -olefin copolymer crystallizes at low temperature, resulting in deterioration of the low temperature characteristics of the lubricating oil composition and significant deterioration of fuel saving properties.

$$B = \frac{P_{OE}}{2 P_O \cdot P_E} \dots [1]$$

wherein in formula [1], P_E represents a molar fraction of ethylene component, P_O represents a molar fraction of α -olefin component, and P_{OE} represents a molar fraction of ethylene- α -olefin sequence in the total dyad sequence.

[0023] The B value is an index of randomness of a comonomer sequence distribution in a copolymer, and P_E , P_O , and P_{OE} in the above formula [1] can be determined by measuring ^{13}C -NMR spectra and based on known literature such as reports of J. C. Randall [Macromolecules, 15, 353 (1982)] and J. Ray et al. [Macromolecules, 10, 773 (1977)], and "Polymer Analysis Handbook" (published by Asakura Publishing Co, pp. 163-170). The larger the above B value, the less the sequence structure of ethylenes and the sequence structure of α -olefins, the more uniform the distribution of ethylene

and the α -olefin, and the narrower the composition distribution. As a result, the larger the B value, the lower the pour point of the (C) ethylene- α -olefin copolymer and the more favorable the low temperature viscosity characteristics of the lubricating oil composition. The specific measurement conditions of the B value are as described in Examples.

[0024] The (C) ethylene- α -olefin copolymer preferably further has at least one characteristic of (C6) to (C8)

(C6) A thermal diffusivity at 50°C of 8.0×10^{-5} to 1.0×10^{-4} m²/s.

[0025] This value of the thermal diffusivity at 50°C is represented by the following formula by determining each of the thermal conductivity, specific heat, and density.

$$\text{Thermal diffusivity (m}^2\text{/s)} = \frac{\text{[Thermal conductivity of lubricating oil composition]}}{\text{[Specific heat of lubricating oil composition]} \times \text{[Density of lubricating oil composition]}}$$

[0026] The thermal conductivity is measured at a test temperature of 50°C in accordance with JIS R2616. The specific heat is measured continuously under adiabatic conditions between 30°C and 80°C in an air atmosphere using a specific heat measuring apparatus (for example, specific heat measuring apparatus SH-3000 model manufactured by SHINKU-RIKO Inc.), and the specific heat at 50°C is employed. The density is measured at 50°C in accordance with JIS K2249.

[0027] Desirably, the thermal diffusivity of the (C) ethylene- α -olefin copolymer at 50°C is preferably 8.5×10^{-5} to 9.8×10^{-5} m²/s, more preferably 8.8×10^{-5} to 9.6×10^{-5} m²/s, and still more preferably 9.0×10^{-5} to 9.4×10^{-5} m²/s. When the thermal diffusivity of the (C) ethylene- α -olefin copolymer at 50°C is at or above the lower limit value described above, the heat generation in the motor is inhibited, and the lubricating oil composition has good heat resistance and electric insulation.

(C7) A volume resistivity at 50°C and 250 V of 1.0×10^{15} to 1.0×10^{17} $\Omega \cdot \text{cm}$

[0028] This value of the volume resistivity at 50°C and 250 V is that in the case when measured at a test temperature of 50°C and at 250 V by the method described in JIS C2101. Desirably, the volume resistivity of the (C) ethylene- α -olefin copolymer at 50°C and 250 V is 1.0×10^{15} to 1.0×10^{17} $\Omega \cdot \text{cm}$, preferably 2.0×10^{15} to 9.0×10^{16} $\Omega \cdot \text{cm}$, and more preferably 3.0×10^{15} to 8.0×10^{16} $\Omega \cdot \text{cm}$. When the volume resistivity of the (C) ethylene- α -olefin copolymer at 50°C and 250 V is at or above the lower limit value described above, the lubricating oil composition has high electric insulation, and thus the safety of electric vehicles can be maintained.

(C8) A relative permittivity at 50°C of 2.00 to 2.30

[0029] This value of the relative permittivity at 50°C is that in the case when measured at a test temperature of 50°C by the method described in JIS C2138. Desirably, the relative permittivity of the (C) ethylene- α -olefin copolymer at 50°C is 2.00 to 2.30, preferably 2.00 to 2.27, and more preferably 2.00 to 2.25. When the relative permittivity of the (C) ethylene- α -olefin copolymer at 50°C is at or below the upper limit value described above, the lubricating oil composition has high electric insulation, and thus the safety of electric vehicles can be maintained.

[0030] The (C) ethylene- α -olefin copolymer more preferably further has at least one characteristic of (C9) and (C10).

(C9) A weight-average molecular weight of 1,000 to 30,000

[0031] The weight-average molecular weight (Mw) of the (C) ethylene- α -olefin copolymer is measured by gel permeation chromatography (GPC) according to the method described below and obtained in terms of standard polystyrene. This weight-average molecular weight (Mw) is preferably 1,200 to 25,000, more preferably 1,400 to 20,000, and still more preferably 1,500 to 16,000. The (C) ethylene- α -olefin copolymer with a weight-average molecular weight (Mw) of 1,000 or higher has a few components that are easy to volatilize, whereby the lubricating oil composition has less evaporation loss and is excellent in viscosity thickening effect and temperature viscosity characteristics, and the (C) ethylene- α -olefin copolymer having a Mw of 30,000 or lower allows the lubricating oil composition to have a low pour point, excellent shear stability and heat resistance.

(C10) No melting point observed

[0032] The (C) ethylene- α -olefin copolymer preferably has no melting point observed in differential scanning calorimetry (DSC). The phrase no melting point (Tm) is observed means that the heat of fusion (ΔH) (unit: J/g) measured by differential

scanning calorimetry (DSC) is not substantially measured. The phase heat of fusion (ΔH) is not substantially measured means that no peaks are observed in differential scanning calorimetry (DSC) or that the heat of fusion observed is 1 J/g or less. The melting point (T_m) and heat of fusion (ΔH) of the (C) ethylene- α -olefin copolymer are obtained by carrying out differential scanning calorimetry (DSC), and analyzing a DSC curve obtained when a specimen is cooled to -100°C , and then raised to 150°C at a rate of temperature rise of $10^\circ\text{C}/\text{min}$, referring to JIS K7121. If the melting point is not observed, no crystalline components are generated at a low temperature, thereby inhibiting a rise in low temperature viscosity, and the lubricating oil composition has excellent low temperature viscosity characteristics.

[0033] Examples of an α -olefin used in the (C) ethylene- α -olefin copolymer include linear or branched C3-C20 α -olefins such as propylene, 1-butene, 1-pentene, 3-methyl-1-butene, 1-hexene, 4-methyl-1-pentene, 3-methyl-1-pentene, 1-octene, 1-decene, 1-dodecene, 1-tetradecene, 1-hexadecene, 1-octadecene, 1-eicosene, and vinylcyclohexane. The α -olefin is preferably a linear or branched C3-C10 α -olefin, more preferably propylene, 1-butene, 1-hexene, and 1-octene, and most preferably propylene from the standpoint of shear stability of the lubricating oil with the resulting copolymer. These α -olefins can be used singly or in combinations of two or more thereof.

[0034] Polymerization can also proceed by coexisting in the reaction system at least one type of an optional monomer selected from the group consisting of a polar group-containing monomer, an aromatic vinyl compound, and a cyclic olefin. The optional monomer can be used, for example, in an amount of 20 parts by mass or less and preferably 10 parts by mass or less, based on 100 parts by mass in total of ethylene and a C3-C20 α -olefin.

[0035] Examples of the polar group-containing monomer include α,β -unsaturated carboxylic acids such as acrylic acid, methacrylic acid, fumaric acid, and maleic anhydride, and metal salts such as sodium salts thereof, α,β -unsaturated carboxylic esters such as methyl acrylate, ethyl acrylate, n-propyl acrylate, methyl methacrylate, and ethyl methacrylate, vinyl esters such as vinyl acetate and vinyl propionate, and unsaturated glycidyl compounds such as glycidyl acrylate and glycidyl methacrylate.

[0036] Examples of the aromatic vinyl compound include styrene, o-methylstyrene, m-methylstyrene, p-methylstyrene, o,p-dimethylstyrene, methoxystyrene, vinyl benzoate, vinyl methyl benzoate, vinyl benzyl acetate, hydroxystyrene, p-chlorostyrene, divinylbenzene, α -methylstyrene, allylbenzene, for example.

[0037] Examples of the cyclic olefin include C3-C30 cyclic olefins such as cyclopentene, cycloheptene, norbornene, 5-methyl-2-norbornene, and tetracyclododecene and preferably C3-C20 cyclic olefins.

[0038] The origin of a monomer used for the (C) ethylene- α -olefin copolymer is not particularly limited, but for example, monomers derived from fossil fuel or monomers derived from biomass can be used, and these monomers may be used singly or in combinations of two or more thereof. In other words, the (C) ethylene- α -olefin copolymer may be constituted solely with a monomer derived from fossil fuel, may be constituted solely with a monomer derived from biomass, or a monomer derived from fossil fuel and a monomer derived from biomass may be used in combination. The fossil fuel is petroleum, coal, natural gas, shale gas, or a combination thereof. The biomass is any renewable natural raw material and residues thereof, such as of plant origin or animal origin, including fungi, yeasts, algae, and bacteria.

[0039] The method for producing the (C) ethylene- α -olefin copolymer in the present invention is not particularly limited, and include methods such as those described in patent literature JPH2-1163B and JPH2-7998B wherein using a vanadium-based catalyst including a vanadium compound and an organoaluminum compound. As a method for producing a copolymer with high polymerization activity, methods using a catalyst system composed of a metallocene compound such as zirconocene and organoaluminum oxy compounds (aluminoxanes) as described in patent literature JPS61-221207A, JPH7-121969B, and JP2796376B can be employed. This method can reduce the chlorine content of the resulting copolymer and 2,1-insertion of propylene, which is more preferred. The method by the vanadium-based catalyst uses more chlorine compounds as an auxiliary catalyst than the method using the metallocene-based catalyst, whereby a trace amount of chlorine may remain in the resulting the (C) ethylene- α -olefin copolymer.

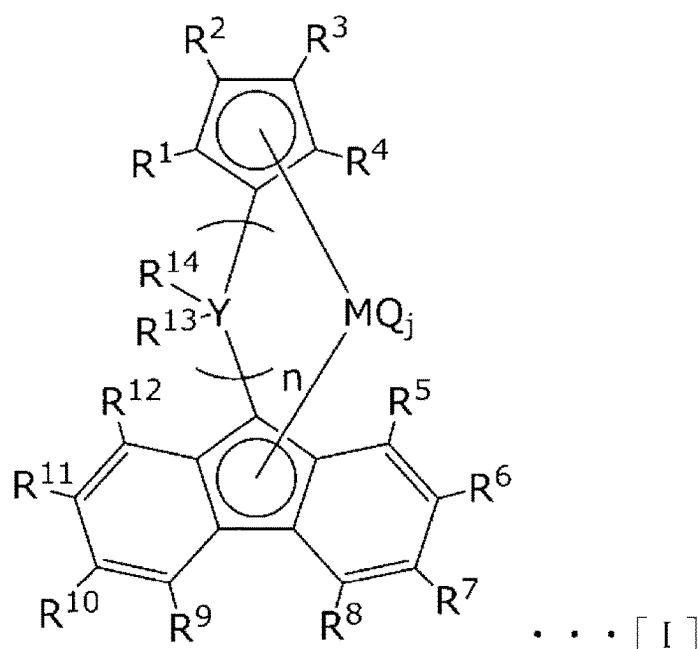
[0040] The method using the metallocene-based catalyst, on the other hand, leaves no residual chlorine substantially, eliminating the need to consider the possibility of corrosion of metal parts in machines, for example. The chlorine content is preferably 100 ppm or less, more preferably 50 ppm or less, still more preferably 20 ppm or less, and particularly preferably 5 ppm or less. The chlorine content can be quantified by various known methods. Specific measurement methods in the present invention are as described in Examples.

[0041] The reduction of 2,1-insertion of propylene can further decrease the amount of ethylene sequence in a copolymer molecule and inhibit intramolecular crystallinity of ethylene, thereby enabling improvement on the viscosity/temperature characteristics and the low temperature viscosity characteristics of the lubricating oil composition.

[0042] In particular, by using the following method, an (C) ethylene- α -olefin copolymer having a favorable performance balance in terms of molecular weight control, molecular weight distribution, amorphous properties, and the B-value, can be obtained.

[0043] The (C) ethylene- α -olefin copolymer can be produced by copolymerizing ethylene and a C3-C20 α -olefin in the presence of an olefin polymerization catalyst including a bridged metallocene compound (a) represented by the general formula [I] below, and at least one compound (b) selected from the group consisting of an organometallic compound (b-1), an organoaluminum oxy compound (b-2), and a compound (b-3) that reacts with the bridged metallocene compound (a) to

form an ion pair.



<Bridged metallocene compound>

[0044] The bridged metallocene compound (a) is represented by the above formula [I]. Y, M, R¹ to R¹⁴, Q, n and j in formula [I] will be described below.

(Y, M, R¹ to R¹⁴, Q, n and j)

[0045] Y is a Group XIV atom, is, for example, a carbon atom, a silicon atom, a germanium atom, or a tin atom, and is preferably a carbon atom or a silicon atom, more preferably a carbon atom.

[0046] M is a titanium atom, a zirconium atom, or a hafnium atom, preferably a zirconium atom.

[0047] R¹ to R¹² are each an atom or a substituent selected from the group consisting of a hydrogen atom, a C1-C20 hydrocarbon group, a silicon-containing group, a nitrogen-containing group, an oxygen-containing group, a halogen atom, and a halogen-containing group, and may be the same as or different from each other. The substituents R¹ to R¹² that are adjacent to each other may also be bonded together to form a ring or may not be bonded to each other.

[0048] Examples of the C1-C20 hydrocarbon group include C1-C20 alkyl groups, C3-C20 cyclic saturated hydrocarbon groups, C2-C20 linear unsaturated hydrocarbon groups, C3-C20 cyclic unsaturated hydrocarbon groups, C1-C20 alkylene groups and C6-C20 arylene groups.

[0049] Examples of the C1-C20 alkyl groups include linear saturated hydrocarbon groups such as a methyl group, an ethyl group, a n-propyl group, an allyl group, a n-butyl group, a n-pentyl group, a n-hexyl group, a n-heptyl group, a n-octyl group, a n-nonyl group and a n-decanyl group, and branched saturated hydrocarbon groups such as an isopropyl group, an isobutyl group, a s-butyl group, a t-butyl group, a t-amyl group, a neopentyl group, a 3-methylpentyl group, a 1,1-diethylpropyl group, a 1,1-dimethylbutyl group, a 1-methyl-1-propylbutyl group, a 1,1-propylbutyl group, a 1,1-dimethyl-2-methylpropyl group, a 1-methyl-1-isopropyl-2-methylpropyl group, and a cyclopropylmethyl group. The number of carbon atoms in such an alkyl group is preferably 1 to 6.

[0050] Examples of the C3-C20 cyclic saturated hydrocarbon groups include cyclic saturated hydrocarbon groups such as a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, a norbornenyl group, a 1-adamantyl group and a 2-adamantyl group, and groups resulting from the substitution of cyclic saturated hydrocarbon groups with a C1-C17 hydrocarbon group in place of a hydrogen atom, such as a 3-methylcyclopentyl group, a 3-methylcyclohexyl group, a 4-methylcyclohexyl group, a 4-cyclohexylcyclohexyl group and a 4-phenylcyclohexyl group. The number of carbon atoms in such a cyclic saturated hydrocarbon group is preferably 5 to 11.

[0051] Examples of the C2-C20 linear unsaturated hydrocarbon groups include alkenyl groups such as an ethenyl group (vinyl group), a 1-propenyl group, a 2-propenyl group (allyl group) and a 1-methylethenyl group (isopropenyl group), and alkynyl groups such as an ethynyl group, a 1-propynyl group and a 2-propynyl group (propargyl group). The number of carbon atoms in such a linear unsaturated hydrocarbon group is preferably 2 to 4.

[0052] Examples of the C3-C20 cyclic unsaturated hydrocarbon groups include cyclic unsaturated hydrocarbon groups such as a cyclopentadienyl group, a norbornyl group, a phenyl group, a naphthyl group, an indenyl group, an azulenyl group, a phenanthryl group and an anthracenyl group, groups resulting from the substitution of cyclic unsaturated hydrocarbon groups with a C1-C15 hydrocarbon group in place of a hydrogen atom, such as a 3-methylphenyl group (m-tolyl group), a 4-methylphenyl group (p-tolyl group), a 4-ethylphenyl group, a 4-t-butylphenyl group, a 4-cyclohexylphenyl group, a biphenyl group, a 3,4-dimethylphenyl group, a 3,5-dimethylphenyl group and a 2,4,6-trimethylphenyl group (mesityl group), and groups resulting from the substitution of linear hydrocarbon groups or branched saturated hydrocarbon groups with a C3-C19 cyclic saturated hydrocarbon group or cyclic unsaturated hydrocarbon group in place of a hydrogen atom, such as a benzyl group and a cumyl group. The number of carbon atoms in such a cyclic unsaturated hydrocarbon group is preferably 6 to 10.

[0053] Examples of the C1-C20 alkylene groups include a methylene group, an ethylene group, a dimethylmethylene group (isopropylidene group), an ethylmethylene group, a methylethylene group and a n-propylene group. The number of carbon atoms in such an alkylene group is preferably 1 to 6.

[0054] Examples of the C6-C20 arylene groups include an o-phenylene group, a m-phenylene group, a p-phenylene group and a 4,4'-biphenylene group. The number of carbon atoms in such an arylene group is preferably 6 to 12.

[0055] Examples of the silicon-containing group include groups resulting from the substitution of C1-C20 hydrocarbon groups with a silicon atom in place of a carbon atom, for example, alkylsilyl groups such as a trimethylsilyl group, a triethylsilyl group, a t-butyldimethylsilyl group and a triisopropylsilyl group, arylsilyl groups such as a dimethylphenylsilyl group, a methylphenylsilyl group and a t-butyldiphenylsilyl group, and a pentamethyldisilanyl group and a trimethylsilylmethyl group. The number of carbon atoms in such an alkylsilyl group is preferably 1 to 10, and the number of carbon atoms in such an arylsilyl group is preferably 6 to 18.

[0056] Examples of the nitrogen-containing group include an amino group, groups resulting from the substitution of the above C1 to C20 hydrocarbon groups or silicon-containing groups with a nitrogen atom in place of a =CH- structural unit, groups resulting from the substitution of the above C1 to C20 hydrocarbon groups or silicon-containing groups with a nitrogen atom to which a C1 to C20 hydrocarbon group is bonded in place of a -CH₂- structural unit, and groups resulting from the substitution of the above C1 to C20 hydrocarbon groups or silicon-containing groups with a nitrogen atom to which a C1 to C20 hydrocarbon group is bonded or a nitrile group in place of a -CH₃ structural unit, such as a dimethylamino group, a diethylamino group, an N-morpholinyl group, a dimethylaminomethyl group, a cyano group, a pyrrolidinyl group, a piperidinyl group, and a pyridinyl group, for example, and a N-morpholinyl group and a nitro group. The nitrogen-containing group is preferably a dimethylamino group or an N-morpholinyl group.

[0057] Examples of the oxygen-containing group include a hydroxide group, groups resulting from the substitution of the above C1 to C20 hydrocarbon groups, silicon-containing groups, or nitrogen-containing groups with an oxygen atom or a carbonyl group in place of a -CH₂- structural unit, and groups resulting from the substitution of the above C1 to C20 hydrocarbon groups, silicon-containing groups, or nitrogen-containing groups with an oxygen atom to which a C1 to C20 hydrocarbon group is bonded in place of a -CH₃ structural unit, such as a methoxy group, an ethoxy group, a t-butoxy group, a phenoxy group, a trimethylsiloxy group, a methoxyethoxy group, a hydroxymethyl group, a methoxymethyl group, an ethoxymethyl group, t-butoxymethyl group, a 1-hydroxyethyl group, a 1-methoxyethyl group, a 1-ethoxyethyl group, a 2-hydroxyethyl group, a 2-methoxyethyl group, an 2-ethoxyethyl group, a n-2-oxabutylene group, a n-2-oxapentylene group, a n-3-oxapentylene group, an aldehyde group, an acetyl group, a propionyl group, a benzoyl group, a trimethylsilylcarbonyl group, a carbamoyl group, a methylaminocarbonyl group, a carboxy group, a methoxycarbonyl group, a carboxymethyl group, an ethoxycarbonylmethyl group, a carbamoylmethyl group, a furanyl group, and a pyranyl group. The oxygen-containing group is preferably a methoxy group.

[0058] Examples of the halogen atom include Group XVII atoms such as fluorine, chlorine, bromine, and iodine. Examples of the halogen-containing group include groups resulting from the substitution of the above C1-C20 hydrocarbon groups, silicon-containing groups, nitrogen-containing groups, or oxygen-containing groups with a halogen atom in place of a hydrogen atom, such as a trifluoromethyl group, a tribromomethyl group, a pentafluoroethyl group and a pentafluorophenyl group.

[0059] Q is selected as a combination of the same or different members of a halogen atom, a C1-C20 hydrocarbon group, an anion ligand, and a neutral ligand capable of coordinating to a lone electron pair. The details of the halogen atom and the C1-C20 hydrocarbon group are as described above. When Q is the halogen atom, Q is preferably a chlorine atom. When Q is the C1-C20 hydrocarbon group, the number of carbon atoms in the hydrocarbon group is preferably 1 to 7.

[0060] Examples of the anion ligand include alkoxy groups such as a methoxy group, a t-butoxy group, and a phenoxy group, carboxylate groups such as acetate and benzoate, and sulfonate groups such as methylate and tosylate.

[0061] Examples of the neutral ligand capable of coordinating to a lone electron pair include phosphororganic compounds such as trimethylphosphine, triethylphosphine, triphenylphosphine and diphenylmethylphosphine, and ether compounds such as tetrahydrofuran, diethyl ether, dioxane, and 1,2-dimethoxyethane.

[0062] j is an integer of 1 to 4, and is preferably 2.

[0063] n is an integer of 1 to 4, preferably 1 or 2, and still more preferably 1.

[0064] R^{13} and R^{14} are each an atom or a substituent selected from the group consisting of a hydrogen atom, a C1 to C20 hydrocarbon group, an aryl group, a substituted aryl group, a silicon-containing group, a nitrogen-containing group, an oxygen-containing group, a halogen atom and a halogen-containing group, and R^{13} and R^{14} may be the same as or different from each other. Moreover, R^{13} and R^{14} may be bonded to each other to form a ring or may not be bonded to each other.

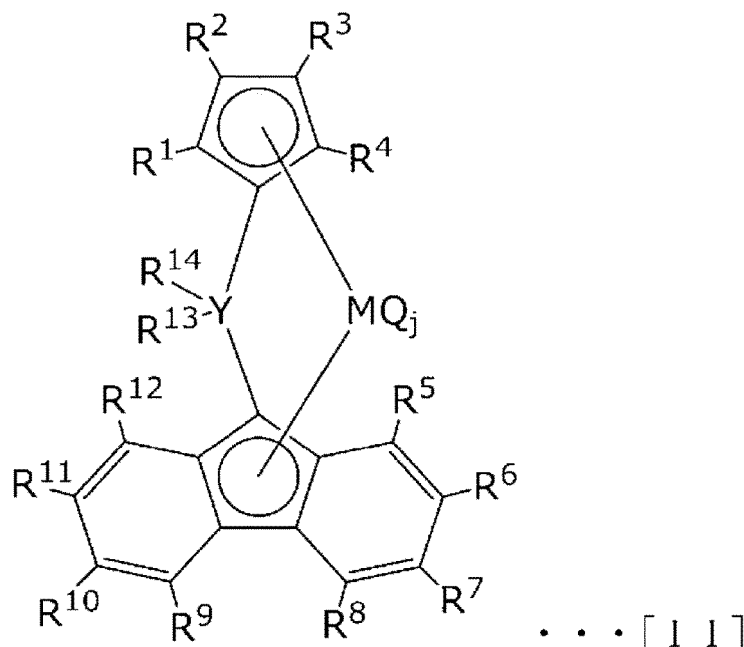
[0065] The details of the C1-C20 hydrocarbon group, the silicon-containing group, the nitrogen-containing group, the oxygen-containing group, the halogen atom and the halogen-containing group are as described above.

[0066] Examples of the aryl group are partially overlapped with examples of the C3-C20 cyclic unsaturated hydrocarbon groups, and include aromatic compound-derived substituents such as a phenyl group, a 1-naphthyl group, a 2-naphthyl group, an anthracenyl group, a phenanthrenyl group, a tetracenyl group, a chrysenyl group, a pyrenyl group, an indenyl group, an azulenyl group, a pyrrolyl group, a pyridyl group, a furanyl group and a thiophenyl group. The aryl group is preferably a phenyl group or a 2-naphthyl group.

[0067] Examples of the aromatic compound include aromatic hydrocarbon and heterocyclic aromatic compounds, such as benzene, naphthalene, anthracene, phenanthrene, tetracene, chrysene, pyrene, indene, azulene, pyrrole, pyridine, furan and thiophene.

[0068] Examples of such a substituted aryl group are partially overlapped with examples of the C3-C20 cyclic unsaturated hydrocarbon groups, and include groups resulting from the substitution of the aryl group with at least one substituent selected from the group consisting of a C1-C20 hydrocarbon group, an aryl group, a silicon-containing group, a nitrogen-containing group, an oxygen-containing group, a halogen atom and a halogen-containing group in place of one or more hydrogen atoms, and specifically include a 3-methylphenyl group (m-tolyl group), a 4-methylphenyl group (p-tolyl group), a 3-ethylphenyl group, a 4-ethylphenyl group, a 3,4-dimethylphenyl group, a 3,5-dimethylphenyl group, a biphenyl group, a 4-(trimethylsilyl)phenyl group, a 4-aminophenyl group, a 4-(dimethylamino)phenyl group, a 4-(diethylamino)phenyl group, a 4-morpholinylphenyl group, a 4-methoxyphenyl group, a 4-ethoxyphenyl group, a 4-phenoxyphenyl group, a 3,4-dimethoxyphenyl group, a 3,5-dimethoxyphenyl group, a 3-methyl-4-methoxyphenyl group, a 3,5-dimethyl-4-methoxyphenyl group, a 3-(trifluoromethyl)phenyl group, a 4-(trifluoromethyl)phenyl group, a 3-chlorophenyl group, a 4-chlorophenyl group, a 3-fluorophenyl group, a 4-fluorophenyl group, a 5-methylnaphthyl group and a 2-(6-methyl)pyridyl group.

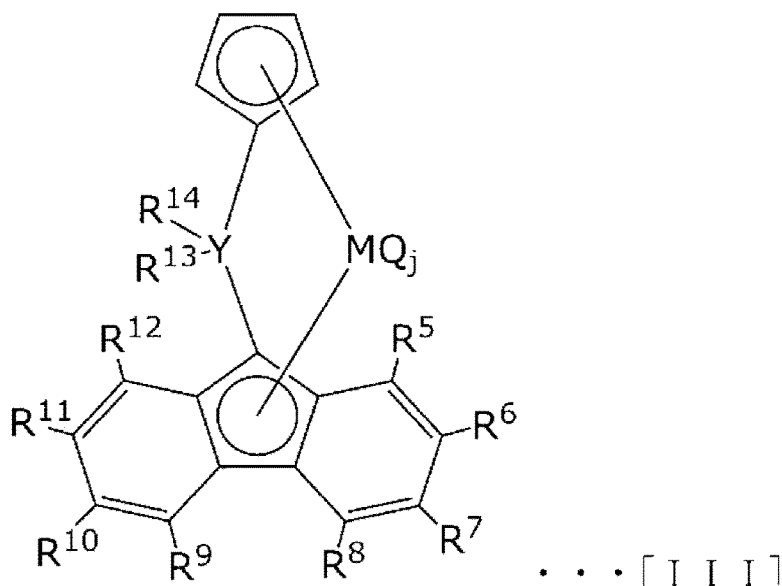
[0069] In the bridged metallocene compound (a) represented by the above formula [I], n is preferably 1. Such a bridged metallocene compound (hereinafter also referred to as "bridged metallocene compound (a-1)") is represented by the following general formula [II]:



[0070] In formula [II], the definitions, for example, of Y, M, R^1 to R^{14} , Q and j are as described above.

[0071] The bridged metallocene compound (a-1) allows production steps to be simplified and production cost to be lowered, compared to a compound in which n in the above formula [I] is an integer of 2 to 4, and furthermore, use of this bridged metallocene compound (a-1) provides an advantage of production cost of the (C) ethylene- α -olefin copolymer being lowered.

[0072] In the bridged metallocene compound (a-1) represented by the above formula [II], R^1 , R^2 , R^3 and R^4 are preferably all hydrogen. Such a bridged metallocene compound (hereinafter also referred to as "bridged metallocene compound (a-2)") is represented by the following general formula [III].



[0073] In formula [III], the definitions, for example, of Y, M, R^5 to R^{14} , Q and j are as described above.

[0074] The bridged metallocene compound (a-2) allows production steps to be simplified and production cost to be lowered, compared to the compound in which any one or more of R^1 , R^2 , R^3 , and R^4 in the above formula [I] is substituted with a substituent other than a hydrogen atom, and furthermore, use of this bridged metallocene compound (a-2) provides an advantage of the production cost of the (C) ethylene- α -olefin copolymer being lowered. Moreover, high temperature polymerization has been generally known to decrease randomness of the (C) ethylene- α -olefin copolymer, however, in a case in which ethylene and one or more types of monomers selected from C3-C20 α -olefins are copolymerized in the presence of an olefin polymerization catalyst containing the bridged metallocene compound (a-2), an advantage of high randomness of the obtained (C) ethylene- α -olefin copolymer even in high temperature polymerization, is obtained.

[0075] In the bridged metallocene compound (a-2) represented by the above formula [III], either one of R^{13} and R^{14} is preferably an aryl group or a substituted aryl group. Such a bridged metallocene compound (a-3) provides an advantage that the amount of double bonds in the generated (C) ethylene- α -olefin copolymer is smaller than when both R^{13} and R^{14} are substituents other than aryl groups and substituted aryl groups.

[0076] In the bridged metallocene compound (a-3), still more preferably either one of R^{13} and R^{14} is an aryl group or a substituted aryl group and the other is a C1-C20 alkyl group, and particularly preferably either one of R^{13} and R^{14} is an aryl group or a substituted aryl group and the other is methyl group. Such a bridged metallocene compound (hereinafter also referred to as "bridged metallocene compound (a-4)") has an excellent balance between the amount of double bonds and polymerization activity in an (C) ethylene- α -olefin copolymer formed, compared to the case where both R^{13} and R^{14} are both aryl groups or substituted aryl groups, and use of this bridged metallocene compound provides an advantage of the production cost of the (C) ethylene- α -olefin copolymer being lowered.

[0077] In a case in which polymerization is carried out under the conditions of constant total pressure and temperature in a polymerizer, an increase in hydrogen partial pressure due to hydrogen introduction results in a decrease in partial pressure of an olefin that is a polymerized monomer, particularly causing reduction of a polymerization rate in a region where hydrogen partial pressure is high. Since the total internal pressure allowed in the polymerization reactor is limited due to its design, particularly when an excessive hydrogen is required to be introduced upon producing a low molecular weight olefin polymer, olefin partial pressure is significantly reduced, which may reduce the polymerization activity. However, when the bridged metallocene compound (a-4) is used to produce the (C) ethylene- α -olefin copolymer in the present invention, the amount of hydrogen introduced in the polymerization reactor is reduced and the polymerization activity is improved, compared to the case of using the above bridged metallocene compound (a-3), whereby an advantage of the production cost of the (C) ethylene- α -olefin copolymer being reduced is obtained.

[0078] In the above bridged metallocene compound (a-4), R^6 and R^{11} are preferably a C1-C20 alkyl group or a C1-C20 alkylene group, which may be bonded to an adjacent substituent to form a ring. Such a bridged metallocene compound (hereinafter referred to as a "bridged metallocene compound (a-5)") simplifies the production process more and further reduces the production cost, compared to a compound in which R^6 and R^{11} are substituted with substituents other than the

C1-C20 alkyl group or the C1-C20 alkylene group, and furthermore use of this bridged metallocene compound (a-5) provides an advantage of the production cost of the (C) ethylene- α -olefin copolymer being reduced.

[0079] In the bridged metallocene compound (a) represented by the general formula [I] above, the bridged metallocene compound (a-1) represented by the general formula [II], the bridged metallocene compound (a-2) represented by the general formula [III], and the above bridged metallocene compounds (a-3), (a-4) and (a-5), M is preferably a zirconium atom. In a case in which ethylene and one or more monomers selected from C3-C20 α -olefins are copolymerized in the presence of an olefin polymerization catalyst containing the above bridged metallocene compound wherein M is a zirconium atom, the polymerization activity is higher than when M is a titanium atom or a hafnium atom, whereby an advantage of the production cost of the (C) ethylene- α -olefin copolymer being reduced, is obtained.

[0080] Examples of the bridged metallocene compound (a) include

[dimethylmethylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [dimethylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [dimethylmethylene (η^5 -cyclopentadienyl)(η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [dimethylmethylene (η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [dimethylmethylene (η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[cyclohexylidene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [cyclohexylidene(η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [cyclohexylidene (η^5 -cyclopentadienyl)(η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [cyclohexylidene(η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [cyclohexylidene (η^5 -cyclopentadienyl)(η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride, [diphenylmethylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [diphenylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, diphenylmethylene(η^5 -2-methyl-4-t-butylcyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [diphenylmethylene (η^5 -cyclopentadienyl)(η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [diphenylmethylene (η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, diphenylmethylene(η^5 -(2-methyl-4-i-propylcyclopentadienyl))(η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [diphenylmethylene (η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[methylphenylmethylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [methylphenylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [methylphenylmethylene (η^5 -cyclopentadienyl) (η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [methylphenylmethylene (η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [methylphenylmethylene (η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[methyl (3-methylphenyl)methylene(η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [methyl(3-methylphenyl)methylene(η^5 -cyclopentadienyl)(η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [methyl(3-methylphenyl)methylene(η^5 -cyclopentadienyl) (η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [methyl(3-methylphenyl)methylene (η^5 -cyclopentadienyl)(η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [methyl (3-methylphenyl)methylene(η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[diphenylsilylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [diphenylsilylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [diphenylsilylene (η^5 -cyclopentadienyl) (η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [diphenylsilylene(η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [diphenylsilylene (η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[bis(3-methylphenyl)silylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [bis(3-methylphenyl)silylene (η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [bis(3-methylphenyl)silylene (η^5 -cyclopentadienyl) (η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [bis(3-methylphenyl)silylene (η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [bis(3-methylphenyl)silylene (η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[dicyclohexylsilylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [dicyclohexylsilylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [dicyclohexylsilylene (η^5 -cyclopentadienyl) (η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [dicyclohexylsilylene (η^5 -cyclopentadienyl) (η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, [dicyclohexylsilylene (η^5 -cyclopentadienyl) (η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride,

[ethylene (η^5 -cyclopentadienyl) (η^5 -fluorenyl)]zirconium dichloride, [ethylene (η^5 -cyclopentadienyl)(η^5 -2,7-di-t-butylfluorenyl)]zirconium dichloride, [ethylene(η^5 -cyclopentadienyl) (η^5 -3,6-di-t-butylfluorenyl)]zirconium dichloride, [ethylene (η^5 -cyclopentadienyl)(η^5 -octamethyloctahydrodibenzofluorenyl)]zirconium dichloride, and [ethylene (η^5 -cyclopentadienyl)(η^5 -tetramethyloctahydrodibenzofluorenyl)]zirconium dichloride.

[0081] Examples of the bridged metallocene compound (a) include compounds resulting from the substitution of the above compounds with a hafnium atom in place of a zirconium atom or with a methyl group in place of a chloro ligand, but

the bridged metallocene compound (a) is not limited thereto. Herein, η^5 -tetramethyloctahydrodibenzofluorenyl and η^5 -octamethyloctahydrodibenzofluorenyl, as constituent moieties of the bridged metallocene compound (a) exemplified, respectively represent a 4,4,7,7-tetramethyl-(5a,5b,11a,12,12a- η^5)-1,2,3,4,7,8,9,10-octahydrodibenzo[b,H]fluorenyl group and a 1,1,4,4,7,7,10,10-octamethyl-(5a,5b,11a,12,12a- η^5)-1,2,3,4,7,8,9,10-octahydrodibenzo[b,H]fluorenyl group.

<Compound (b)>

[0082] The olefin polymerization catalyst includes the above bridged metallocene compound (a) and at least one compound (b) selected from the group consisting of an organometallic compound (b-1), an organoaluminum oxy compound (b-2), and a compound (b-3) that reacts with the bridged metallocene compound (a) to form an ion pair.

[0083] As the organometallic compound (b-1), specifically, the following organometallic compounds of Groups I and II and Groups XII and XIII of the periodic table, are used.

[0084] (b-1a) An organoaluminum compound represented by the general formula $R^a_mAl(OR^b)_nH_pX_q$ wherein in the formula, R^a and R^b may be the same as or different from each other and represent a C1-C15 hydrocarbon group, preferably a C1-C4 hydrocarbon group, X represents a halogen atom, m is a number of $0 < m \leq 3$, n is a number $0 \leq n < 3$, p is a number of $0 \leq p < 3$, q is a number of $0 \leq q < 3$, and $m + n + p + q = 3$.

[0085] Examples of such a compound include

tri-n-alkylaluminum such as trimethylaluminum, triethylaluminum, tri-n-butylaluminum, tri-n-hexylaluminum and tri-n-octylaluminum,
tri-branched alkylaluminum such as triisopropylaluminum, triisobutylaluminum, tri-sec-butylaluminum, tri-t-butylaluminum, tri-2-methylbutylaluminum, tri-3-methylhexylaluminum and tri-2-ethylhexylaluminum,
tricycloalkylaluminum such as tricyclohexylaluminum and tricyclooctylaluminum,
triarylaluminum such as triphenylaluminum and tri(4-methylphenyl)aluminum,
dialkylaluminum hydrides such as diisopropylaluminum hydride and diisobutylaluminum hydride,
alkenylaluminum represented by the general formula $(i-C_4H_9)_xAl_y(C_5H_{10})_z$ wherein in the formula, x, y and z are positive numerals and $z \leq 2x$, such as isoprenylaluminum,
alkylaluminum alkoxides such as isobutylaluminum methoxide and isobutylaluminum ethoxide,
dialkylaluminum alkoxides such as dimethylaluminum methoxide, diethylaluminum ethoxide and dibutylaluminum butoxide,
alkylaluminum sesquialkoxides such as ethylaluminum sesquiethoxide and butylaluminum sesquibutoxide,
partially alkoxyated alkylaluminum having an average composition represented by the general formula $R^{a_{2.5}}Al(OR^b)_{0.5}$, alkylaluminum aryloxides such as diethylaluminum phenoxide and diethylaluminum(2,6-di-t-butyl-4-methylphenoxide),
dialkylaluminum halides such as dimethylaluminum chloride, diethylaluminum chloride, dibutylaluminum chloride, diethylaluminum bromide and diisobutylaluminum chloride,
alkylaluminum sesquihalides such as ethylaluminum sesquichloride, butylaluminum sesquichloride and ethylaluminum sesquibromide,
partially halogenated alkylaluminum such as an alkylaluminum dihalide such as ethylaluminum dichloride,
dialkylaluminum hydrides such as diethylaluminum hydride and dibutylaluminum hydride,
alkylaluminum dihydrides such as ethylaluminum dihydride and propylaluminum dihydride and other partially hydrogenated alkylaluminum, and
partially alkoxyated and halogenated alkylaluminum such as ethylaluminum ethoxychloride, butylaluminum butoxychloride and ethylaluminum ethoxybromide.

[0086] A compound analogous to those represented by the above general formula $R^a_mAl(OR^b)_nH_pX_q$ can also be used, and examples thereof include an organoaluminum compound in which two or more aluminum compounds are bonded via a nitrogen atom. Specific examples of such a compound include $(C_2H_5)_2AlN(C_2H_5)Al(C_2H_5)_2$, for example.

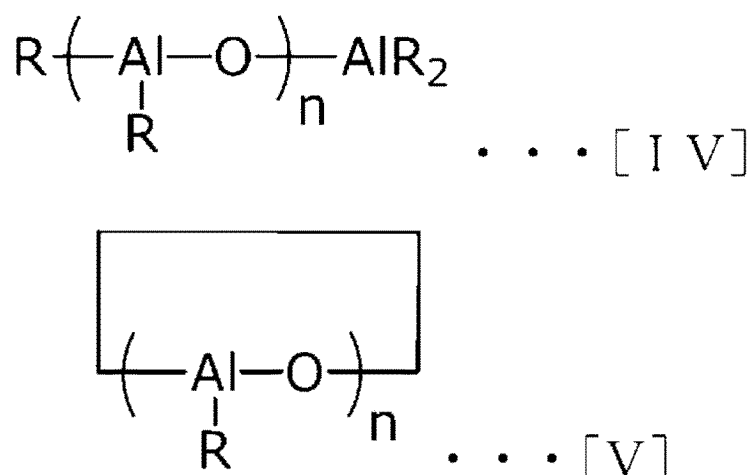
[0087] (b-1b) A complex alkylated compound of a Group I metal of the periodic table and aluminum, represented by the general formula $M^2AlR^a_4$ wherein in the formula, M^2 represents Li, Na or K, and R^a represents a C1-C15 hydrocarbon group, preferably a C1-C4 hydrocarbon group.

[0088] Examples of such a compound include $LiAl(C_2H_5)_4$ and $LiAl(C_7H_{15})_4$, for example.

[0089] (b-1c) A dialkylated compound of a Group II or Group XII metal of the periodic table, represented by the general formula $R^aR^bM^3$ wherein in the formula, R^a and R^b may be the same as or different from each other and represent a C1-C15 hydrocarbon group, preferably a C1-C4 hydrocarbon group, and M^3 is Mg, Zn or Cd.

[0090] As the organoaluminum oxy compound (b-2), conventionally known aluminoxanes can be used as they are. Specific examples thereof include the compound represented by the following general formula [IV] and the compound

represented by the following general formula [V].

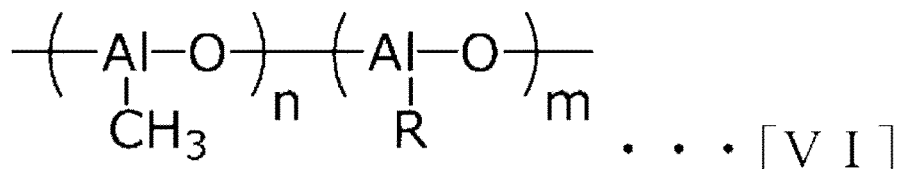


In formulas [IV] and [V], R is a C1-C10 hydrocarbon group and n is an integer of 2 or more.

[0091] In particular, methylaluminoxane is utilized in which R is a methyl group and n is 3 or more, preferably 10 or more. An organoaluminum compound is allowed to be slightly incorporated in such aluminoxane.

[0092] When copolymerization of ethylene and a C3 or higher α -olefin is performed at a high temperature in the present invention, a benzene-insoluble organoaluminum oxy compound exemplified in patent literature JP H2-78687A can also be applied. An organoaluminum oxy compound described in patent literature JP H2-167305A, or aluminoxane having two or more alkyl groups, described in patent literature JP H2-24701A and JP H3-103407A, can also be suitably utilized. The "benzene-insoluble organoaluminum oxy compound" that may be used in the present invention is a compound that usually contains 10% or less, preferably 5% or less, particularly preferably 2% or less of an Al component to be dissolved in benzene at 60°C, in terms of Al atom, and that is insoluble or hardly soluble in benzene.

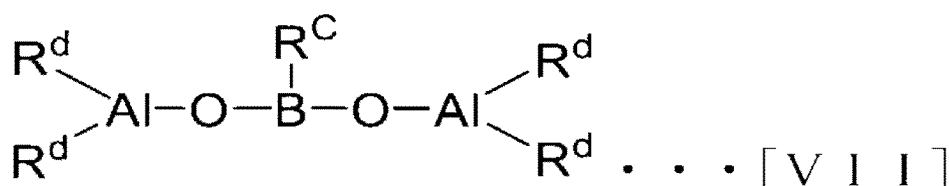
[0093] Examples of the organoaluminum oxy compound (b-2) can also include a modified methylaluminoxane represented by the following general formula [VI], for example.



In formula [VI], R is a C1-C10 hydrocarbon group, and m and n each independently represent an integer of 2 or more.

[0094] This modified methylaluminoxane is prepared by using trimethylaluminum and alkylaluminum other than trimethylaluminum. Such a compound is commonly referred to as MMAO. Such MMAO can be prepared by the methods described in patent literature USP4960878 and USP5041584. A compound prepared by using trimethylaluminum and triisobutylaluminum, is commercially available from Tosoh-Finechem Corporation, for example, under the names MMAO and TMAO wherein R is an isobutyl group. Such MMAO is aluminoxane with improved solubility in various solvents and storage stability, and is specifically soluble in an aliphatic hydrocarbon or an alicyclic hydrocarbon, unlike the compounds that are insoluble or difficult to be soluble in benzene, among the compounds represented by the above formula [IV] and those represented by the above formula [V].

[0095] Examples of the organoaluminum oxy compound (b-2) can also include an organoaluminum oxy compound containing boron, represented by the following general formula [VII].

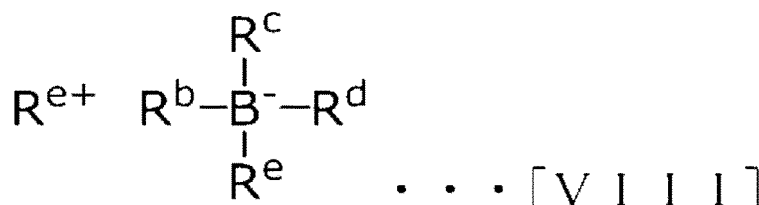


In formula [VII], R^c represents a C1-C10 hydrocarbon group. R^d may be the same as or different from each other and

represents a hydrogen atom, a halogen atom or a C1-C10 hydrocarbon group.

[0096] Examples of the compound (b-3) that reacts with the bridged metallocene compound (a) to form an ionic pair (hereinafter may be abbreviated and referred to as "ionized ionic compound" or simply "ionic compound") include Lewis acids, ionic compounds, borane compounds and carborane compounds, for example, which are described in patent literature JPH1-501950A, JPH1-502036A, JPH3-179005A, JPH3-179006A, JPH3-207703A, JPH3-207704A, USP 5321106, for example. Examples thereof can further include heteropoly compounds and isopoly compounds.

[0097] The ionized ionic compound preferably used in the present invention is the boron compound represented by the following general formula [VIII].



In formula [VIII], examples of R^{e+} include H^+ , a carbenium cation, an oxonium cation, an ammonium cation, a phosphonium cation, a cycloheptyltrienyl cation, and a ferrocenium cation with transition metal, for example. R^f to R^i may be the same as or different from each other and are substituents selected from C1-C20 hydrocarbon groups, silicon-containing groups, nitrogen-containing groups, oxygen-containing groups, halogen atoms and halogen-containing groups and R^f to R^i are preferably substituted aryl groups.

[0098] Specific examples of the carbenium cation include trisubstituted carbenium cations such as triphenylcarbenium cation, tris(4-methylphenyl)carbenium cation and tris(3,5-dimethylphenyl)carbenium cation.

[0099] Specific examples of the ammonium cation include trialkyl-substituted ammonium cations such as trimethylammonium cation, triethylammonium cation, tri(n-propyl)ammonium cation, triisopropylammonium cation, tri(n-butyl)ammonium cation and triisobutylammonium cation, N,N-dialkylanilinium cations such as N,N-dimethylanilinium cation, N,N-diethylanilinium cation and N,N-2,4,6-pentamethylanilinium cation, and dialkylammonium cations such as diisopropylammonium cation and dicyclohexylammonium cation.

[0100] Specific examples of the phosphonium cation include triarylphosphonium cations such as triphenylphosphonium cation, tris(4-methylphenyl)phosphonium cation and tris(3,5-dimethylphenyl)phosphonium cation.

[0101] As the R^{e+} , a carbenium cation and an ammonium cation, for example, is preferred among the above specific examples, and particularly a triphenylcarbenium cation, a N,N-dimethylanilinium cation and a N,N-diethylanilinium cation are preferred.

[0102] Examples of compounds containing the carbenium cation as the ionized ionic compounds preferably used in the present invention include triphenylcarbenium tetrakis(pentafluorophenyl)borate, triphenylcarbenium tetrakis(3,5-di(trifluoromethyl)phenyl)borate, tris(4-methylphenyl)carbenium tetrakis(pentafluorophenyl)borate and tris(3,5-dimethylphenyl)carbenium tetrakis(pentafluorophenyl)borate.

[0103] Examples of compounds containing the trialkyl-substituted ammonium cation as the ionized ionic compounds preferably used in the present invention include triethylammonium tetrakis(pentafluorophenyl)borate, tripropylammonium tetrakis(pentafluorophenyl)borate, tri(n-butyl)ammonium tetrakis(pentafluorophenyl)borate, trimethylammonium tetrakis(4-methylphenyl)borate, trimethylammonium tetrakis(2-methylphenyl)borate, tri(n-butyl)ammonium tetrakis(pentafluorophenyl)borate, triethylammonium tetrakis(pentafluorophenyl)borate, tripropylammonium tetrakis(pentafluorophenyl)borate, tripropylammonium tetrakis(2,4-dimethylphenyl)borate, tri(n-butyl)ammonium tetrakis(3,5-dimethylphenyl)borate, tri(n-butyl)ammonium tetrakis{4-(trifluoromethyl)phenyl}borate, tri(n-butyl)ammonium tetrakis{3,5-di(trifluoromethyl)phenyl}borate, tri(n-butyl)ammonium tetrakis(2-methylphenyl)borate, dioctadecylmethylammonium tetrakis(pentafluorophenyl)borate, dioctadecylmethylammonium tetrakis(4-methylphenyl)borate, dioctadecylmethylammonium tetrakis(pentafluorophenyl)borate, dioctadecylmethylammonium tetrakis(2,4-dimethylphenyl)borate, dioctadecylmethylammonium tetrakis(3,5-dimethylphenyl)borate, dioctadecylmethylammonium tetrakis{4-(trifluoromethyl)phenyl}borate, dioctadecylmethylammonium tetrakis{3,5-di(trifluoromethyl)phenyl}borate and dioctadecylmethylammonium.

[0104] Examples of compounds containing a N,N-dialkylanilinium cation as the ionized ionic compounds preferably used in the present invention include N,N-dimethylanilinium tetrakis(pentafluorophenyl)borate, N,N-dimethylanilinium tetrakis(3,5-di(trifluoromethyl)phenyl)borate, N,N-diethylanilinium tetrakis(pentafluorophenyl)borate, N,N-diethylanilinium tetrakis(3,5-di(trifluoromethyl)phenyl)borate, N,N-2,4,6-pentamethylanilinium tetrakis(pentafluorophenyl)borate, N,N-2,4,6-pentamethylanilinium tetrakis(3,5-di(trifluoromethyl)phenyl)borate, for example.

[0105] Examples of compounds containing the dialkylammonium cation as the ionized ionic compounds preferably used in the present invention include di-n-propylammonium tetrakis(pentafluorophenyl)borate and dicyclohexylammo-

nium tetraphenylborate.

[0106] Other ionic compounds exemplified in patent literature JP2004-51676A can also be used without any limitation.

[0107] The above ionic compound (b-3) may be used singly or combined for use with two or more types thereof.

[0108] As the organometallic compound (b-1), trimethylaluminum, triethylaluminum, and triisobutylaluminum, which are readily available as commercial products, are preferred. Of these, triisobutylaluminum is particularly preferred for its handleability.

[0109] As the organoaluminum oxy compounds (b-2), methylaluminoxane that is readily available as a commercial product and MMAO prepared with trimethylaluminum and triisobutylaluminum are preferred. Of these, MMAO is particularly preferred because of its improved solubility in various solvents and storage stability.

[0110] As the ionic compounds (b-3), triphenylcarbenium tetrakis(pentafluorophenyl)borate and N,N-dimethylanilinium tetrakis(pentafluorophenyl)borate, are preferred because they are readily available as commercial products and significantly contribute to polymerization activity.

[0111] As the compounds (b), a combination of triisobutylaluminum and triphenylcarbenium tetrakis(pentafluorophenyl)borate and a combination of triisobutylaluminum and N,N-dimethylanilinium tetrakis(pentafluorophenyl)borate, are particularly preferred because they greatly improve polymerization activity.

<Carrier (c)>

[0112] In the present invention, a carrier (c) may be used as a constituent of the olefin polymerization catalyst, if necessary.

[0113] The carrier (c) that may be used in the present invention is an inorganic or organic compound, which is a granular or particulate solid. In particular, the inorganic compound is preferably a porous oxide, an inorganic chloride, clay, a clay mineral or an ion-exchangeable layered compound.

[0114] As the porous oxides, specifically SiO_2 , Al_2O_3 , MgO , ZrO , TiO_2 , B_2O_3 , CaO , ZnO , BaO , and ThO_2 , for example, or composites or mixtures containing these materials, such as natural or synthetic zeolite, SiO_2 - MgO , SiO_2 - Al_2O_3 , SiO_2 - TiO_2 , SiO_2 - V_2O_5 , SiO_2 - Cr_2O_3 , SiO_2 - TiO_2 - MgO , for example, can be used. Of these, those with SiO_2 and/or Al_2O_3 as major components are preferred. The properties of such porous oxides vary depending on the type and production methods, but the carrier preferably used in the present invention has a particle size of 0.5 to 300 μm , preferably 1.0 to 200 μm , a specific surface area in a range of 50 to 1000 m^2/g , preferably 100 to 700 m^2/g , and a pore volume in a range of 0.3 to 3.0 cm^3/g . Such a carrier is, if necessary, fired at 100 to 1000°C, preferably 150 to 700°C, and then used.

[0115] The inorganic chlorides that are MgCl_2 , MgBr_2 , MnCl_2 , and MnBr_2 , for example, are used. The inorganic chloride may be used as it is, or may be pulverized by a ball mill or a vibrating mill, and then used. Alternatively, the inorganic chloride, which is dissolved in a solvent such as an alcohol and then precipitated in the form of fine particles by a precipitating agent, may also be used.

[0116] Clay is usually composed of clay minerals as a main component. The ion-exchangeable layered compound is a compound having a crystal structure in which surfaces configured are mutually stacked in parallel by a weak force with, for example, an ionic bond, and includes an exchangeable ion. Most clay mineral corresponds to such an ion-exchangeable layered compound. Such clay, clay mineral, and ion-exchangeable layered compounds here used are not limited to natural products, and can also be artificially synthesized products. Examples of the clay, clay mineral, or ion-exchangeable layered compound include clay, clay mineral, and also ion crystalline compounds with layered crystal structures such as hexagonal fine packing type, antimony type, CdCl_2 type, and CdI_2 type, for example. Examples of such clay and clay mineral include kaolin, bentonite, kibushi clay, gairome clay, allophane, hisingerite, pyrophyllite, micas, montmorillonites, vermiculite, chlorite rocks, parigorskite, kaolinite, nacrite, dickite, and haloysite, for example, and examples of the ion-exchangeable layered compounds include crystalline acidic salts of polyvalent metals such as α -Zr (HAsO_4)₂ · H_2O , α -Zr (HPO_4)₂, α -Zr (KPO_4)₂ · 3 H_2O , α -Ti (HPO_4)₂, α -Ti (HAsO_4)₂ · H_2O , α -Sn (HPO_4)₂ · H_2O , γ -Zr (HPO_4)₂, γ -Ti (HPO_4)₂, and γ -Ti (NH_4PO_4)₂ · H_2O . The clay and the clay mineral for use in the present invention are also preferably subjected to a chemical treatment. The chemical treatment here used can be any treatment such as a surface treatment for removal of impurities attached to a surface, or a treatment having an effect on the crystal structure of the clay. Specific examples of the chemical treatment include an acid treatment, an alkali treatment, a salt treatment and an organic substance treatment.

[0117] The ion-exchangeable layered compound may be a layered compound where a space between layers is enlarged by exchanging an exchangeable ion in the space between layers with another large and bulky ion by means of ion exchangeability. Such a bulky ion serves as a shore supporting a layered structure, and is usually referred to as pillar. Such introduction of another substance (guest compound) into the space between layers in the layered compound is referred to as intercalation. Examples of the guest compound include cationic inorganic compounds such as TiCl_4 and ZrCl_4 , metal alkoxides such as $\text{Ti}(\text{OR})_4$, $\text{Zr}(\text{OR})_4$, $\text{PO}(\text{OR})_3$, and $\text{B}(\text{OR})_3$ (R is a hydrocarbon group, for example.), and metal hydroxide ions such as $[\text{Al}_{13}\text{O}_4(\text{OH})_{24}]^{7+}$, $[\text{Zr}_4(\text{OH})_{14}]^{2+}$, and $[\text{Fe}_3\text{O}(\text{OCOCH}_3)_6]^{+}$. Such a compound may be used singly or in combinations of two or more kinds thereof. When intercalating these compounds, a polymerization product obtained by hydrolytic polycondensation of metal alkoxides such as $\text{Si}(\text{OR})_4$, $\text{Al}(\text{OR})_3$, and $\text{Ge}(\text{OR})_4$ (R is a hydrocarbon group, for

example.), or a colloidal inorganic compound such as SiO_2 , can be co-present. Examples of the pillar include oxide generated by intercalation of the metal hydroxide ion into the space between layers and then heating and dehydration.

[0118] Of these, the clay or the clay mineral is preferable, and montmorillonite, vermiculite, pectolite, tainiolite and synthetic mica are particularly preferable.

[0119] Examples of the organic compound as the carrier (c) include a granular or particulate solid with a particle size in a range of 0.5 to 300 μm . Specific examples include a (co)polymer generated with as a main component a C2-C14 α -olefin such as ethylene, propylene, 1-butene or 4-methyl-1-pentene, a (co)polymer generated with vinylcyclohexane or styrene as a main component, and modified products thereof.

[0120] A polymerization method using an olefin polymerization catalyst capable of producing the (C) ethylene- α -olefin copolymer with high randomness enables high temperature polymerization. In other words, the use of the olefin polymerization catalyst can inhibit decrease in randomness of the (C) ethylene- α -olefin copolymer formed upon the high temperature polymerization. In solution polymerization, the viscosity of the polymerization solution containing the (C) ethylene- α -olefin copolymer formed decreases at high temperatures, whereby a concentration of the (C) ethylene- α -olefin copolymer in a polymerizer can be increased compared to that of low temperature polymerization, resulting in higher productivity per unit of polymerizer. Copolymerization of ethylene and α -olefin in the present invention can be carried out by either liquid-phase polymerization methods such as solution polymerization and suspension polymerization (slurry polymerization) or by gas-phase polymerization methods, however, the solution polymerization is particularly preferred from the viewpoint of maximizing the effects of the present invention in such a manner.

[0121] A method of use and order of addition of each component of the olefin polymerization catalyst may be arbitrarily selected. At least two or more components in the catalyst may be contacted with each other in advance.

[0122] The bridged metallocene compound (a) (hereinafter also referred to as "component (a)") is usually used in an amount of 1×10^{-9} to 1×10^{-1} moles and preferably 1×10^{-8} to 1×10^{-2} moles per liter of reaction volume.

[0123] The organometallic compound (b-1) (hereinafter also referred to as "component (b-1)") is used in an amount such that a molar ratio of the component (b-1) to a transition metal atom (M) in the component (a) [(b-1)/M] is usually 0.01 to 50,000 and preferably 0.05 to 10,000.

[0124] The organoaluminum oxy compound (b-2) (hereinafter also referred to as "component (b-2)") is used in an amount such that a molar ratio of an aluminum atom in the component (b-2) to a transition metal atom (M) in the component (a) [(b-2)/M] is usually 10 to 5,000 and preferably 20 to 2,000.

[0125] The ionic compound (b-3) (hereinafter also referred to as "component (b-3)") is used in an amount such that a molar ratio of the component (b-3) to a transition metal atom (M) in the component (a) [(b-3)/M] is usually 1 to 10,000 and preferably 1 to 5,000.

[0126] The polymerization temperature is usually -50°C to 300°C , preferably 30 to 250°C , more preferably 100°C to 250°C , and still more preferably 130°C to 200°C . As the temperature in the polymerization temperature region in the above range is higher, the solution viscosity during polymerization is lower, and removal of heat of polymerization is also easier.

The polymerization pressure is usually ordinary pressure to 10 MPa-gauge pressure (MPa-G), preferably ordinary pressure to 8 MPa-G.

[0127] The polymerization reaction can be carried out in any method of batchwise, semi-continuous, and continuous methods. Such polymerization can also be continuously carried out in two or more polymerization instruments different in reaction conditions.

[0128] The molecular weight of the resulting copolymer can be regulated by the changes in hydrogen concentration and polymerization temperature in a polymerization system. Furthermore, the molecular weight can be adjusted according to the amount of component (b) used. In the case of addition of hydrogen, the amount added is properly about 0.001 to 5,000 NL per kg of the copolymer.

[0129] The polymerization solvent for use in a liquid phase polymerization method is usually an inert hydrocarbon solvent, and is preferably a saturated hydrocarbon having a boiling point of 50°C to 200°C under ordinary pressure. Specific examples of the polymerization solvent include aliphatic hydrocarbons such as propane, butane, pentane, hexane, heptane, octane, decane, dodecane and kerosene oil, and alicyclic hydrocarbons such as cyclopentane, cyclohexane and methylcyclopentane, and particularly preferably include hexane, heptane, octane, decane and cyclohexane. The α -olefin to be polymerized, by itself, can also be used as the polymerization solvent. While an aromatic hydrocarbon such as benzene, toluene or xylene, or a halogenated hydrocarbon such as ethylene chloride, chlorobenzene or dichloromethane can also be used as the polymerization solvent, use thereof is not preferable in terms of a reduction in load on the environment and in terms of minimization of the influence on human health.

[0130] The kinematic viscosity at 100°C of the olefin polymer depends on the molecular weight of the polymer. In other words, a high molecular weight leads to a high viscosity and a low molecular weight leads to a low viscosity, and thus the kinematic viscosity at 100°C is adjusted by the above molecular weight adjustment. A low molecular weight component in a polymer obtained can be removed by a conventionally known method such as distillation under reduced pressure, to thereby allow for adjustment of the molecular weight distribution (Mw/Mn) of the polymer obtained. The polymer obtained may be further subjected to hydrogen addition (hereinafter, also referred to as hydrogenation.) by a conventionally known

method. If the number of double bonds in the polymer obtained by such hydrogenation is reduced, oxidation stability and heat resistance are enhanced.

[0131] The resulting (C) ethylene- α -olefin copolymer may be used singly or combined for use with two or more types of those with different molecular weights or with different monomer compositions.

[0132] The (C) ethylene- α -olefin copolymer may undergo graft-modification in its functional group and may further undergo secondary modification. Examples thereof include, for example, the method described in patent literature JPS61-126120A and JP2593264B, for example, and examples of the secondary modification include the method described in patent literature JP2008-508402A, for example.

<(A) Mineral oil>

[0133] The (A) mineral oil has the following characteristics (A1) to (A3).

(A1) A kinematic viscosity at 100°C of 2 to 6 mm²/s

[0134] This value of the kinematic viscosity at 100°C is that measured according to the method described in JIS K2283. The kinematic viscosity of (A) mineral oil at 100°C is 2 to 8 mm²/s, preferably 2.3 to 5.5 mm²/s, and more preferably 2.8 to 5 mm²/s. Within this range of the kinematic viscosity at 100°C, the lubricating oil composition of the present invention is excellent in terms of a balance of volatility and temperature viscosity characteristics.

(A2) A viscosity index of 105 or more

[0135] This value of the viscosity index is that measured according to the method described in JIS K2283. The viscosity index of (A) mineral oil is 105 or more, preferably 110 or more, and still more preferably 115 or more. Within this range of the viscosity index, the lubricating oil composition of the present invention is excellent in temperature viscosity characteristics.

(A3) A pour point of -5°C or lower

[0136] This value of the pour point is that measured according to the method described in ASTM D97. The pour point of (A) mineral oil is -5°C or lower, more preferably -10°C or lower, and still more preferably -12°C or lower. Within this range of the pour point, the lubricating oil composition of the present invention is excellent in low temperature viscosity characteristics.

<(B) Synthetic oil>

[0137] The (B) synthetic oil has the following characteristics (B1) to (B3).

(B1) A kinematic viscosity at 100°C of 1 to 9 mm²/s

[0138] This value of the kinematic viscosity at 100°C is that measured according to the method described in JIS K2283. The kinematic viscosity of (B) synthetic oil at 100°C is 1 to 9 mm²/s, preferably 1.5 to 7 mm²/s, and more preferably 1.8 to 5 mm²/s. Within this range of the kinematic viscosity at 100°C, the lubricating oil composition of the present invention is excellent in terms of a balance of volatility and temperature viscosity characteristics.

(B2) A viscosity index of 110 or more

[0139] This value of the viscosity index is that measured according to the method described in JIS K2283. The viscosity index of (B) synthetic oil is 110 or more, preferably 115 or more, and more preferably 120 or more. Within this range of the viscosity index, the lubricating oil composition of the present invention is excellent in temperature viscosity characteristics.

(B3) A pour point of -30°C or lower

[0140] This value of the pour point is that measured according to the method described in ASTM D97. The pour point of (B) synthetic oil is -30°C or lower, preferably -40°C or lower, more preferably -50°C or lower, and still more preferably -60°C or lower. Within this range of the pour point, the lubricating oil composition of the present invention is excellent in low temperature viscosity characteristics.

[0141] The lubricating base oil used in the present invention is different in its performance and quality, such as viscosity characteristics, heat resistance, and oxidation stability, depending on its production methods and refining methods, for

EP 4 488 348 A1

example. The lubricating base oil is generally classified into mineral oil and synthetic oil. In the American Petroleum Institute (API), lubricating base oil is also classified into five categories: Group I, II, III, IV, and V. These API categories are defined in API Publication 1509, 15th Edition, Appendix E, April 2002 and are as shown in Table 1. The (A) mineral oil can be any of Groups I to III in the API categories, and the (B) synthetic oil can be any of Groups IV and V in the API categories.

The details will be described below:

[Table 1]

Group	Oil type	Viscosity index*1	Saturated hydrocarbon component*2 (vol%)	Sulfur content*3 (% by weight)
I	Mineral oil	80-120	<90	>0.03
II	Mineral oil	80-120	≥90	≤0.03
III	Mineral oil	≥120	≥90	≤0.03
IV	Poly-α-olefin			
V	Lubricating oil base material other than the above			
*1: Measured in accordance with ASTM D445 (JIS K2283).				
*2: Measured in accordance with ASTM D3338.				
*3: Measured in accordance with ASTM D4294 (JIS K2541).				
*2: Mineral oil with less than 90 vol% of saturated hydrocarbon and more than 0.03% by weight of sulfur content is also included in Group I.				

<(A) Mineral oil>

[0142] The (A) mineral oil belongs to Groups I to III in the API categories described above.

[0143] The quality of (A) mineral oil is as described above, and mineral oil of the respective qualities described above will be obtained by refining methods. Specific examples of the mineral oil include a lubricating base oil obtained by a process in which the lubricating oil fraction obtained by vacuum distillation of the atmospheric residual oil obtained by atmospheric distillation of crude oil is refined by carrying out one or more processes such as solvent deasphalting, solvent extraction, hydrocracking, solvent dewaxing, and hydrogenation refining or a lubricating base oil such as wax isomerized mineral oil.

[0144] Gas-to-liquid (GTL) base oil obtained by the Fischer-Tropsch method is also suitable base oil that can be used as Group III mineral oil. Such GTL base oil may be treated as Group III + lubricating base oil and is described, for example, in Patent Literatures of EP0776959, EP0668342, WO97/21788, WO00/15736, WO00/14188, WO00/14187, WO00/14183, WO00/14179, WO00/08115, WO99/41332, EP1029029, WO01/18156 and WO01/57166.

<(B) Synthetic oil>

[0145] The (B) synthetic oil belongs to Group IV or Group V in the API categories described above.

[0146] The poly- α -olefin belonging to Group IV can be obtained by acid catalyzed oligomerization using boron trifluoride, a chromic acid catalyst, for example, as described in patent literature USP3,382,291, USP3,763,244, USP5,171,908, USP3,780,128, USP4,032,591, JPH1-163136A, USP4,967,032, and USP4,926,004. The poly- α -olefin can also be obtained by methods, for example, such as employing a catalyst system using complexes of transition metal such as zirconium, titanium, and hafnium, including a metallocene compound as described in patent literature JPS63-037102A, JP2005-200447A, JP2005-200448A, JP2009-503147A, and JP2009-501836A. When the poly- α -olefin is used as the lubricating base oil, a lubricating oil composition extremely excellent in temperature viscosity characteristics and low temperature viscosity characteristics, and even heat resistance, can be obtained.

[0147] The poly- α -olefin is also industrially available and a poly- α -olefin with 100°C kinematic viscosity of 2 mm²/s to 300 mm²/s is commercially available. Among them, use of poly- α -olefin with 2 to 6 mm²/s is preferred in terms of providing a lubricating oil composition excellent in temperature viscosity characteristics. Examples thereof include NEXBASE 2000 series manufactured by NESTE Corporation, Spectrasyn series manufactured by ExxonMobil Chemical Company, Durasyn series manufactured by Ineos Oligomers, and Synfluid series manufactured by Chevron Phillips Chemical Co LLC., for example.

[0148] Examples of synthetic oil belonging to Group V include, for example, alkyl benzenes, alkyl naphthalenes, isobutene oligomers or their hydrides, paraffins, a polyoxyalkylene glycol, a dialkyl diphenyl ether, and polyphenyl ether and esters.

[0149] The majority of alkylbenzenes and alkylnaphthalenes are typically a dialkylbenzene or a dialkylnaphthalene with

a C6-C14 alkyl chain length, and such alkylbenzenes or alkylnaphthalenes are produced by the Friedel-Craft alkylation reaction of benzene or naphthalene with an olefin. An alkylated olefin used in production of alkylbenzenes or alkylnaphthalenes may be a linear or branched olefin or combinations thereof. These production methods are described, for example, in USP3,909,432.

[0150] A fatty acid ester is preferred as the esters in terms of compatibility with the (C) ethylene- α -olefin copolymer. The fatty acid ester is not particularly limited, but examples thereof include the following fatty acid esters composed solely of carbon, oxygen, and hydrogen, such as a monoester produced from a monobasic acid and an alcohol; a diester produced from a dibasic acid and an alcohol, or from a diol and a monobasic acid or an acid mixture; a polyol ester produced by reacting a diol, a triol (for example, trimethylolpropane), a tetraol (for example, pentaerythritol), or a hexanol (for example, dipentaerythritol), for example, with a monobasic acid or an acid mixture. Examples of these esters include dtridecyl glutarate, di-2-ethylhexyl adipate, diisodecyl adipate, dtridecyl adipate, di-2-ethylhexyl sebacate, tridecyl pelargonate, di-2-ethylhexyl adipate, di-2-ethylhexyl azelate, trimethylolpropane caprylate, trimethylolpropane pelargonate, trimethylolpropane triheptanoate, pentaerythritol-2-ethylhexanoate, pentaerythritol pelargonate, and pentaerythritol tetraheptanoate, for example.

[0151] From the viewpoint of compatibility with the (C) ethylene- α -olefin copolymer, an alcohol with two or more functional hydroxyl groups is preferred as the alcohol moiety constituting the ester, and a C8 or more fatty acid is preferred as the fatty acid moiety. However, a C20 or less fatty acid that is readily industrially available, is more preferred in terms of production cost. The fatty acid constituting the ester may be of one type, and use of a fatty acid ester produced by using a mixture of two or more types of acids allows an effect of the present invention to be sufficiently exhibited. More specific examples of the fatty acid ester include a trimethylolpropane lauric acid-stearic acid mixed triester and diisodecyl adipate, for example, which are preferred due to compatibility between a saturated hydrocarbon component such as the (C) ethylene- α -olefin copolymer and stabilizers such as an antioxidant, a corrosion inhibitor, an antiwear agent, a friction modifier, a pour point depressant, a rust inhibitor and an antifoaming agent, which have a polar group as described below.

[0152] When the (B) synthetic oil in particular the poly- α -olefin, is used as the lubricating base oil, the lubricating oil composition of the present invention preferably contains a fatty acid ester in an amount of 1 to 20% by mass based on the total lubricating oil composition of 100% by mass. Containing 1% by mass or more of the fatty acid ester renders favorable compatibility with lubricating oil sealing materials such as resins and elastomers in an electric vehicle. Specifically, swelling of the lubricating oil sealing material can be inhibited. From the viewpoint of oxidation stability or heat resistance, the amount of ester is preferably 20% by mass or less. When the mineral oil is contained in the lubricating oil composition, the fatty acid ester is not necessarily required because the mineral oil itself has an effect of inhibiting swelling of the lubricating oil sealing material.

[0153] The (B) synthetic oil is preferred compared to the (A) mineral oil in terms of superior heat resistance and temperature viscosity characteristics. In the lubricating oil composition of the present invention, one type of (A) mineral oil or (B) synthetic oil may be used singly as the lubricating base oil, or an arbitrary mixture of two or more types of lubricating oil selected from among the (A) mineral oil and the (B) synthetic oil, for example, may be used.

[0154] The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle according to the present invention contains the (A) mineral oil and/or (B) synthetic oil, and the (C) ethylene- α -olefin copolymer, and has the following characteristic (D1).

(D1) A kinematic viscosity at 100°C is 4 to 10 mm²/s.

[0155] This kinematic viscosity at 100°C (kinematic viscosity measured according to the method described in JIS K2283) is 4 to 10 mm²/s, preferably 4 to 7.5 mm²/s, more preferably 4 to 6.5 mm²/s, and still more preferably 4.2 to 6 mm²/s. When the kinematic viscosity of the lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle at 100°C excessively exceeds 10 mm²/s, the stirring resistance of the lubricating oil to gears or metal chains, for example, increases, resulting in poor fuel saving performance, and when the kinematic viscosity is excessively smaller than 4 mm²/s, metal contact between gears or metal chains may occur.

[0156] The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle according to the present invention preferably further has characteristics (D2) and (D3).

(D2) A viscosity index is 110 or more.

[0157] This viscosity index (the viscosity index measured according to the method described in JIS K2283) is preferably 110 or more, more preferably 120 or more, still more preferably 125 or more, and particularly preferably 130 or more. Within this range of the viscosity index, the lubricating oil composition has excellent temperature viscosity characteristics and can achieve both the aforementioned energy saving and lubricity over a wide range of temperatures.

(D3) A pour point is -40°C or lower.

[0158] The pour point (the pour point measured according to the method described in ASTM D97) of the lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle according to the present invention is preferably -40°C or lower, more preferably -45°C or lower, and still more preferably -50°C or lower. A low pour point indicates that the lubricating oil composition has excellent low temperature characteristics.

[0159] The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle of the present invention preferably contains the lubricating base oil including the (A) mineral oil and/or (B) synthetic oil at a proportion of 90 to 99% by mass, and the (C) ethylene- α -olefin copolymer at a proportion of 10 to 1% by mass. However, the total of the lubricating base oil and the (C) ethylene- α -olefin copolymer is taken as 100% by mass. The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle of the present invention preferably contains the lubricating base oil at a proportion of 92 to 99% by mass and the (C) ethylene- α -olefin copolymer at a proportion of 8 to 1% by mass, more preferably contains the lubricating base oil at a proportion of 95 to 99% by mass and the (C) ethylene- α -olefin copolymer at a proportion of 5 to 1% by mass, and still more preferably contains the lubricating base oil at a proportion of 96 to 99% by mass and the (C) ethylene- α -olefin copolymer at a proportion of 4 to 1% by mass.

[0160] Examples of one preferred aspect include an aspect in which 30 to 100% by mass of the lubricating base oil is the (A) mineral oil. A high proportion of (A) mineral oil occupied in the lubricating base oil provides excellent solubility of the additives described below, as well as facilitation of availability and excellent economic efficiency. 50 to 100% by mass of mineral oil is more preferred, and 80 to 100% by mass of mineral oil is still more preferred. Among the mineral oil, the Group III in the API categories is preferred because the Group III has excellent temperature viscosity characteristics and can achieve both oil film retention at a high temperature and a low torque at a low temperature.

[0161] Examples of another preferred aspect include an aspect in which 30 to 100% by mass of the lubricating base oil is the (B) synthetic oil, and the (B) synthetic oil is a poly- α -olefin and/or ester oil. 50 to 100% by mass of synthetic oil is more preferred, and 80 to 100% by mass of synthetic oil is still more preferred. A high proportion of the (B) synthetic oil occupied in the lubricating base oil is preferred since it renders heat resistance, temperature viscosity characteristics, and low temperature characteristics excellent.

[0162] The lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle of the present invention may also contain additives such as an extreme pressure agent, a detergent dispersant, a viscosity index improver, an antioxidant, a corrosion inhibitor, an antiwear agent, a friction modifier, a pour point depressant, a rust inhibitor, and an antifoam agent.

[0163] Examples of the additive used in the lubricating oil compositions of the present invention include the following additives, and one type of these additives can be used singly or in combinations of two or more thereof.

[0164] The extreme pressure agent is a general term for those having an anti-seizing effect when metals with each are exposed to a high load condition, and the agent is not particularly limited, and examples thereof include sulfur-based extreme pressure agents such as sulfides, sulfoxides, sulfones, thiophosphinates, thiocarbonates, sulfide oil and fat, and a sulfide olefin; phosphates such as a phosphate, a phosphite, a phosphate amine salt, and phosphite amines; halogene-based compounds such as a chlorinated hydrocarbon. These compounds may also be used in combinations of two or more types thereof.

[0165] Before reaching extreme pressure lubrication conditions, a hydrocarbon or other organic components constituting the lubricating oil composition may be carbonized before the extreme pressure lubrication conditions due to heating and shearing, whereby a carbide coating may be formed on a metal surface. Therefore, a single use of the extreme pressure agent inhibits contact between the extreme pressure agent and a metal surface by the carbide coating, whereby the extreme pressure agent may not be expected to be fully effective.

[0166] A single extreme pressure agent may be added, however, since the lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle in the present invention is mainly composed of a saturated hydrocarbon such as the copolymer, it is preferable for the extreme pressure agent to be added in a state of being dissolved in advance in lubricating base oil such as mineral oil or synthetic hydrocarbon oil, together with other additive to be used, from the viewpoint of dispersibility. Specifically, more preferred is a method for selecting a so-called additive package in which various components such as an extreme pressure agent component are preliminarily compounded and further dissolved in lubricating base oil such as mineral oil or synthetic hydrocarbon oil, followed by adding the package to a lubricating oil composition.

[0167] For lubricating oils used for cooling of an electric motor and lubrication of a gear in an electric vehicle, so-called DI packages are industrially supplied, in which various necessary additives for automatic transmission fluid and continuously variable transmission fluid are blended, and concentrated and dissolved in a lubricating oil such as mineral oil or synthetic hydrocarbon oil. Examples of DI packages for automatic transmission fluid include HITEC 3419D manufactured by Afton Chemical Corporation and HITEC 2426 manufactured by Afton Chemical Corporation, and examples of DI packages for continuously variable transmission fluid include Lubrizol 6373 manufactured by Lubrizol Corporation. These DI packages can also be applied to the lubricating oil composition of the present invention.

[0168] The extreme pressure agent is used in a range of 0 to 10% by mass relative to 100% by mass of the lubricating oil composition, if necessary. Examples of the antiwear agent include an inorganic or organic molybdenum compound such as molybdenum disulfide, graphite, antimony sulfide, and polytetrafluoroethylene. The antiwear agent is used in a range of 0 to 3% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0169] Examples of the friction modifier include amine compounds, imide compounds, fatty acid esters, fatty acid amides, and fatty acid metal salts, for example, which have at least one C6-C30 alkyl or alkenyl group in the molecule and particularly a linear C6-C30 alkyl or linear C6-C30 alkenyl group.

[0170] Examples of the amine compound include a linear or branched, preferably linear C6-C30 aliphatic monoamine, a linear or branched, preferably linear aliphatic polyamine, or an alkylene oxide adduct of these aliphatic amines, for example. Examples of the imide compound include succinic imide having a linear or branched C6-C30 alkyl or alkenyl group and/or its modified compounds by carboxylic acid, boric acid, phosphoric acid, and sulfuric acid, for example. Examples of the fatty acid ester include an ester of a linear or branched, preferably linear C7-C31 fatty acid and an aliphatic monovalent alcohol or an aliphatic polyhydric alcohol, for example. Examples of the fatty acid amide include an amide of a linear or branched, preferably linear C7-C31 fatty acid and an aliphatic monoamine or an aliphatic polyamine, for example. Examples of the fatty acid metal salt include alkaline earth metal salts (a magnesium salt and a calcium salt, for example) and zinc salts, for example, of linear or branched, preferably linear C7-C31 fatty acids.

[0171] The friction modifier is used in a range of 0.01 to 5.0% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0172] Examples of the detergent dispersant include a metal sulfonate, a metal phenate, a metal phosphanate, and succinimide, for example. The detergent dispersant is used in a range of 0 to 15% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0173] As the viscosity index improver, in addition to an ethylene- α -olefin copolymer (excluding the (C) ethylene- α -olefin copolymer), known viscosity index improvers such as an olefin copolymer having a molecular weight exceeding 50,000, a methacrylate-based copolymer, a liquid polybutene, and a poly- α -olefin with 100°C kinematic viscosity of 15 mm²/s or higher, can be combined for use. The viscosity index improver is used in a range of 0 to 10% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0174] Examples of the antioxidant include phenolic and amine-based compounds such as 2,6-di-*t*-butyl-4-methylphenol. The antioxidant is used in a range of 0 to 3% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0175] Examples of the corrosion inhibitor include compounds such as benzotriazole, benzimidazole, and thiadiazole. The corrosion inhibitor is used in a range of 0 to 3% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0176] Examples of the rust inhibitor include compounds such as various amine compounds, carboxylic acid metal salts, polyhydric alcohol esters, phosphorus compounds, and sulfonates. The rust inhibitor is used in a range of 0 to 3% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0177] Examples of the antifoaming agent include silicone-based compounds such as dimethylsiloxane and a silica gel dispersion, and an alcohol-based or ester-based compound. The antifoaming agent is used in a range of 0 to 0.2% by mass relative to 100% by mass of the lubricating oil composition, if necessary.

[0178] Various known pour point depressants can be used as the pour point depressant. Specifically, a polymer compound containing an organic acid ester group is used, and a vinyl polymer containing an organic acid ester group is particularly suitably used. Examples of the vinyl polymer containing an organic acid ester group include (co)polymers of an alkyl methacrylate, (co)polymers of an alkyl acrylate, (co)polymers of an alkyl fumarate, (co)polymers of an alkyl maleate, and alkylated naphthalenes. It is preferably a (co)polymer of an alkyl acrylate, and more preferably a (co)polymer of an alkyl acrylate that is an ester compound of a C1-C10 alcohol and acrylic acid.

[0179] Such a pour point depressant has a melting point of -13°C or lower, preferably -15°C, and still more preferably -17°C or lower. The melting point of the pour point depressant is measured by using a differential scanning calorimeter (DSC). Specifically, the melting point is determined from the endothermic curve obtained when approximately 5 mg of a sample was filled in an aluminum pan, raised to a temperature of 200°C, held at 200°C for 5 minutes, then cooled to -40°C at 10°C/min, held at -40°C for 5 minutes, and then heated at 10°C/min.

[0180] The aforementioned pour point depressant further has a weight-average molecular weight in terms of polystyrene, obtained by gel permeation chromatography, in a range of 20,000 to 400,000, preferably 30,000 to 300,000, and more preferably 40,000 to 200,000.

[0181] The pour point depressant is used in a range of 0 to 2% by mass, preferably 0.01 to 1% by mass, more preferably 0.02 to 0.4% by mass, and still more preferably 0.05 to 0.35% by mass, relative to 100% by mass of the lubricating oil composition, if necessary. When the amount of the pour point depressant added exceeds the above range, shear stability of the lubricating oil composition may decrease, and lubricity may deteriorate due to lower viscosity. The pour point depressing ability may also be impaired.

[0182] In addition to the above additives, an antiemulsifier, a coloring agent, and an oily agent (oiliness agent), for

example, can be used, if necessary.

[0183] In electric vehicles, so-called DI packages may also be used, in which various necessary additives used in automatic transmission fluid and continuously variable transmission fluid are blended, and concentrated and dissolved in a lubricating oil such as mineral oil or synthetic hydrocarbon oil. DI packages are industrially supplied, and examples of DI packages for automatic transmission fluid include HITEC 3419D manufactured by Afton Chemical Corporation and HITEC 2426 manufactured by Afton Chemical Corporation, and examples of DI packages for continuously variable transmission fluid include Lubrizol 6373 manufactured by Lubrizol Corporation. These DI packages can also be applied to the lubricating oil composition of the present invention.

<Use>

[0184] The lubricating oil composition of the present invention can be used, for example, for cooling of an electric motor and lubrication of a gear installed in an electric vehicle such as an electric automobile, a plug-in hybrid vehicle, a hybrid vehicle, or a fuel cell vehicle, and has extremely superior temperature viscosity characteristics compared to conventional lubricating oils containing the same lubricating base oil, that is, oil film retention at a high temperature and low temperature viscosity characteristics, and can greatly contribute to energy saving in electric vehicles. As for electric vehicles, it is particularly useful in electric vehicles equipped with in-wheel motors, where the distance between the gear and the electric motor is short, that is, high heat dissipation is required. Also, as for electric vehicles, it is particularly useful in electric wheelchairs and electric carts for persons requiring nursing care, where high lubricity is required for smooth running. Furthermore, it is particularly useful in electric skateboards and electric roller skates that require instantaneous high output, as heat dissipation is also required. It also maintains lubrication performance in electric vehicles over a long period of use due to its excellent shear stability, contributing to maintaining system performance. In addition, the lubricating oil composition of the present invention is extremely excellent in heat dissipation performance, and thus has high electric motor cooling performance as well as lubricating performance for a gear and a bearing in an electric vehicle. The lubricating oil composition of the present invention is extremely useful in cooling of an electric motor and lubrication of a gear in an electric vehicle.

EXAMPLES

[0185] The present invention will be more specifically described below based on Examples, but the present invention is not limited to these Examples.

[Evaluation method]

[0186] In the following Examples and Comparative Examples, physical properties of ethylene- α -olefin copolymers and lubricating oil compositions, for example, were measured by the following methods.

<Ethylene molar content rate (mol%)>

[0187] By using a Fourier transform infrared spectrophotometer FT/IR-610 or FT/IR-6100 manufactured by JASCO Corporation, an absorbance ratio of absorption in the vicinity of 1155cm^{-1} based on propylene backbone vibration to absorbance in the vicinity of 721cm^{-1} based on transverse vibration of a long chain methylene group ($D_{1155\text{cm}^{-1}}/D_{721\text{cm}^{-1}}$), was calculated, and an ethylene content rate (% by weight) was obtained from a calibration curve preliminarily prepared (prepared by using a standard sample in ASTM D3900). The ethylene content rate (ethylene weight content rate (% by weight)) obtained was then used to determine the ethylene content rate (ethylene molar content rate (mol%)) according to the following formula.

$$\text{Ethylene molar content rate (mol\%)} = \frac{[\text{Ethylene weight content rate (wt\%)} \div 28]}{[\text{Ethylene weight content rate (wt\%)} \div 28] + [\text{Propylene weight content rate (wt\%)} \div 42]}$$

<Kinematic viscosity and viscosity index>

[0188] The 100°C kinematic viscosity, the 40°C kinematic viscosity, and the viscosity index were measured by the method described in JIS K2283.

<Weight-average molecular weight (Mw) and molecular weight distribution (Mw/Mn)>

[0189] The molecular weight distribution was measured by using a HLC-8320 GPC manufactured by Tosoh Corporation as follows. TSKgel SuperMultipore HZ-M columns (4 columns) were used as separation columns, a column temperature was 40°C, tetrahydrofuran (manufactured by Wako Pure Chemical Industries, Ltd.) was used as a mobile phase, an expansion rate was set at 0.35 ml/min, a sample concentration was 5.5 g/L, sample injection volume was 20 µl, and a differential refractometer was used as a detector. Standard polystyrenes manufactured by Tosoh Corporation (PStQuick MP-M) were used. According to general calibration procedures, the weight-average molecular weight (Mw) and the number-average molecular weight (Mn) were calculated in terms of polystyrene molecular weight and the molecular weight distribution (Mw/Mn) was calculated from these values.

<Hasen chromaticity>

[0190] The APHA value was determined according to the method described in JIS K0071.

<B value>

[0191] ¹³C-NMR spectra were measured by using o-dichlorobenzene/benzene-d₆ (4/1 [vol/vol%]) as a measurement solvent under the measurement conditions of measurement temperature 120°C, spectral width 250 ppm, pulse repetition time 5.5 s, and pulse width 4.7 µs (45° pulse) (100 MHz, JEOL ECX400P), or under the measurement conditions of measurement temperature 120°C, spectral width 250 ppm, pulse repetition time 5.5 s, and pulse width 5.0 µs (45° pulse) (125 MHz, Bruker Biospin AVANCEIIIcryo-500), and the B value was calculated based on formula [1] below. The assignment of peaks was carried out with reference to the previously published literature.

$$B = \frac{P_{OE}}{2 P_O \cdot P_E} \dots [1]$$

wherein in formula [1], P_E represents a molar fraction of ethylene component, P_O represents a molar fraction of α-olefin component, and P_{OE} represents a molar fraction of ethylene-α-olefin sequence in the total dyad sequence.

<Thermal diffusivity>

[0192] The thermal diffusivity is represented by the following formula by determining each of the thermal conductivity, specific heat, and density of the lubricating oil composition.

$$\text{Thermal diffusivity (m}^2\text{/s)} = \frac{\text{[Thermal conductivity of lubricating oil composition]}}{\text{[Specific heat of lubricating oil composition]} \times \text{[Density of lubricating oil composition]}}$$

[0193] The thermal conductivity was measured at a test temperature of 50°C in accordance with JIS R2616. The specific heat was measured continuously under adiabatic conditions between 30°C and 80°C in an air atmosphere using a specific heat measuring apparatus SH-3000 model manufactured by SHINKU-RIKO Inc., and the specific heat at 50°C was employed. The density was measured at 50°C in accordance with JIS K2249.

<Volume resistivity>

[0194] The volume resistivity was measured at a test temperature of 50°C and at 250 V in accordance with JIS C2101.

<Relative permittivity>

[0195] The relative permittivity was measured at a test temperature of 50°C in accordance with JIS C2138.

<Melting point>

[0196] By using a Seiko Instruments Inc. X-DSC-7000, approximately 8 mg of ethylene- α -olefin copolymer was placed in an aluminum sample pan that can be easily sealed and set in a DSC cell, and it was raised from room temperature to 150°C at 10°C/min under a nitrogen atmosphere, then held at 150°C for 5 minutes, and thereafter lowered at 10°C/min to -100°C (temperature lowering process). The DSC cell was then held at 100°C for 5 minutes, raised at 10°C/min, and a temperature at which the enthalpy curve obtained during a temperature raising process exhibits the maximum value was determined as a melting point (T_m), and the total endothermic value accompanying melting was defined as heat of fusion (ΔH). No peak observed or a value of heat of fusion (ΔH) of 1 J/g or less was deemed to indicate no melting point (T_m). The melting point (T_m) and the heat of fusion (ΔH) were determined based on JIS K7121.

<Chlorine content>

[0197] By using a Thermo Fisher Scientific Inc. ICS-1600, an ethylene- α -olefin copolymer was placed in a sample boat, and underwent fire decomposition at a combustion furnace at a set temperature of 900°C in an Ar/O₂ gas stream. The generated gas obtained was absorbed into an absorbent solution, and the chlorine content was determined by ion chromatography.

<Pour point>

[0198] The pour point was measured according to the method described in ASTM D97. Note that when the pour point was below -50°C, it was described as < -50.

<Low temperature viscosity>

[0199] The low temperature viscosity at -40°C was measured by the method described in ASTM D6821.

<Shear stability>

[0200] The lubricating oil composition was subjected to ultrasonic irradiation for 60 minutes in accordance with JASO M347, a test method for automatic transmission fluid shear stability, and the rate of decrease in kinematic viscosity at 100°C due to irradiation (rate of decrease in viscosity after shear test) represented by the following formula was evaluated.

$$\text{Rate of decrease in viscosity after shear test (\%)} = \frac{[100^\circ\text{C kinematic viscosity before ultrasonic irradiation}] - [100^\circ\text{C kinematic viscosity after ultrasonic irradiation}]}{[100^\circ\text{C kinematic viscosity before ultrasonic irradiation}]} \times 100$$

[Production of ethylene- α -olefin copolymer (B)]

[0201] Ethylene- α -olefin copolymers (B) were produced according to the following Polymerization Examples. Note, however, the obtained ethylene- α -olefin copolymer (B) underwent hydrogenation operation, if necessary, by the following method.

<Hydrogenation operation>

[0202] A stainless steel autoclave with an internal volume of 1 L was added with 100 mL of a hexane solution of a 0.5% by mass Pd/alumina catalyst and 500 mL of a 30% by mass hexane solution of the ethylene- α -olefin copolymer, and was sealed followed by nitrogen substitution. The mixture was then raised to a temperature of 140°C under stirring, and then the inner system was substituted with hydrogen and was increased to a pressure of 1.5 MPa with hydrogen to carry out a hydrogenation reaction for 15 minutes.

<Synthesis of metallocene compound>

[Synthesis Example 1]

Synthesis of [methylphenylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-*t*-butylfluorenyl)]zirconium dichloride

(i) Synthesis of 6-methyl-6-phenylfulvene

[0203] Under a nitrogen atmosphere, a 200 mL three-neck flask was added with 7.3 g (101.6 mmol) of lithium cyclopentadiene and 100 mL of dehydrated tetrahydrofuran and the mixture was stirred. The solution was cooled in an ice bath and 15.0 g (111.8 mmol) of acetophenone was added dropwise. Thereafter, the solution was stirred at room temperature for 20 hours, and the resulting solution was quenched with a diluted hydrochloric acid aqueous solution. 100 mL of hexane was added thereto to extract a soluble material, and this organic layer was washed with water and saturated brine, then dried over anhydrous magnesium sulfate. The solvent was then removed, and the resulting viscous liquid was separated by column chromatography (hexane) to obtain a target product (red viscous liquid).

(ii) Synthesis of methyl(cyclopentadienyl)(2,7-di-*t*-butyl fluorenyl) (phenyl) methane

[0204] Under a nitrogen atmosphere, a 100 mL three-neck flask was added with 2.01 g (7.20 mmol) of 2,7-di-*t*-butylfluorene and 50 mL of dehydrated *t*-butylmethyl ether. While cooling it in an ice bath, a *n*-butyl lithium/hexane solution (1.65 M) 4.60 mL (7.59 mmol) was added gradually, and stirred at room temperature for 16 hours. After having added 1.66 g (9.85 mmol) of 6-methyl-6-phenylfulvene, the mixture was stirred under heat refluxing for 1 hour. While cooling it in an ice bath, 50 mL of water was gradually added, and the resulting two-layer solution was transferred to a 200 mL separatory funnel. After 50 mL of diethyl ether was added and the mixture was shaken several times to remove an aqueous layer, and an organic layer was washed with 50 mL of water three times and with 50 mL of saturated brine once. The organic layer was dried over anhydrous magnesium sulfate for 30 minutes, and the solvent was distilled off under reduced pressure. When ultrasound waves were applied to the solution obtained by having added a small amount of hexane, a solid precipitated, which was collected and washed with a small amount of hexane. The precipitated substance was dried under reduced pressure to obtain 2.83 g of methyl (cyclopentadienyl)(2,7-di-*t*-butylfluorenyl)(phenyl)methane as a white solid.

(iii) Synthesis of [methylphenylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-*t*-butylfluorenyl)]zirconium dichloride

[0205] Under a nitrogen atmosphere, a 100 mL Schlenk tube was sequentially added with 1.50 g (3.36 mmol) of methyl (cyclopentadienyl)(2,7-di-*t*-butylfluorenyl)(phenyl)methane, 50 mL of dehydrated toluene and 570 μ L (7.03 mmol) of THF. While cooling it in an ice bath, a *n*-butyl lithium/hexane solution (1.65 M) 4.20 mL (6.93 mmol) was added gradually, and stirred at 45°C for 5 hours. The solvent was removed under reduced pressure and 40 mL of dehydrated diethyl ether was added to prepare a red solution. While cooling it in a methanol/dry ice bath, 728 mg (3.12 mmol) of zirconium tetrachloride was added, and the mixture was stirred for 16 hours while being gradually raised to room temperature to obtain a red-orange slurry. The solid obtained by removing the solvent under reduced pressure was brought into a glove box, washed with hexane, and extracted with dichloromethane. The solvent was removed under reduced pressure and concentrated, a small amount of hexane was added, and the mixture was left at -20°C, resulting in precipitation of a red-orange solid. This solid was washed with a small amount of hexane and dried under reduced pressure to yield 1.20 g of [methylphenylmethylene(η^5 -cyclopentadienyl)(η^5 -2,7-di-*t*-butylfluorenyl)]zirconium dichloride as a red-orange solid.

[Synthesis Example 2]

Synthesis of [ethylene (η^5 -cyclopentadienyl)(η^5 -2,7-di-*t*-butylfluorenyl)]zirconium dichloride

[ethylene (η^5 -cyclopentadienyl)(η^5 -2,7-di-*t*-butylfluorenyl)]zirconium dichloride was synthesized by the method described in patent literature JP4367687B.

<Polymerization Example 1>

[0206] A fully nitrogen-substituted stainless steel autoclave with an internal volume of 2 L, was charged with 910 mL of heptane and 45 g of propylene, the temperature in the system was raised to 130°C, and total pressure was then set to 3 MPaG by applying 2.24 MPa of hydrogen and 0.09 MPa of ethylene. Then 0.4 mmol of triisobutylaluminum, 0.0006 mmol of [methylphenylmethylene(η^5 -cyclopentadienyl)(η^5 -2,7-di-*t*-butyl fluorenyl)] zirconium dichloride and 0.006 mmol of *N,N*-dimethylanilinium tetrakis(pentafluorophenyl) borate were then injected under pressure with nitrogen, and polymerization

was started by setting a stirring rotation speed to 400 rpm. Thereafter, the polymerization was carried out at 130°C for 5 minutes, keeping the total pressure at 3 MPaG by continuously feeding only ethylene. The polymerization was completed by having added a small amount of ethanol to the system, and then the unreacted ethylene, propylene, and hydrogen were purged. The resulting polymer solution was washed with 1000 mL of 0.2 mol/l hydrochloric acid three times and then with 1000 mL of distilled water three times, dried over magnesium sulfate, and the solvent was removed under reduced pressure. The resulting polymer was dried overnight under reduced pressure at 80°C, to obtain 22.2 g of an ethylene-propylene copolymer. Furthermore, the ethylene-propylene copolymer was subjected to the hydrogenation operation, and thus a polymer 1 was obtained.

<Polymerization Example 2>

[0207] A fully nitrogen-substituted stainless steel autoclave with an internal volume of 2 L, was charged with 770 mL of heptane and 130 g of propylene, the temperature in the system was raised to 150°C, and total pressure was then set to 3 MPaG by applying 0.95 MPa of hydrogen and 0.18 MPa of ethylene. Then 0.4 mmol of triisobutylaluminum, 0.0002 mmol of [methylphenylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-*t*-butyl fluorenyl)] zirconium dichloride and 0.002 mmol of N,N-dimethylanilinium tetrakis(pentafluorophenyl) borate were then injected under pressure with nitrogen, and polymerization was started by setting a stirring rotation speed to 400 rpm. Thereafter, the polymerization was carried out at 150°C for 5 minutes, keeping the total pressure at 3 MPaG by continuously feeding only ethylene. The polymerization was completed by having added a small amount of ethanol to the system, and then the unreacted ethylene, propylene, and hydrogen were purged. The resulting polymer solution was washed with 1000 mL of 0.2 mol/l hydrochloric acid three times and then with 1000 mL of distilled water three times, dried over magnesium sulfate, and the solvent was removed under reduced pressure. The resulting polymer was dried overnight under reduced pressure at 80°C, to obtain 34.2 g of an ethylene-propylene copolymer. Furthermore, the ethylene-propylene copolymer was subjected to the hydrogenation operation, and thus a polymer 2 was obtained.

<Polymerization Example 3>

[0208] A fully nitrogen-substituted stainless steel autoclave with an internal volume of 2 L, was charged with 710 mL of heptane and 145 g of propylene, the temperature in the system was raised to 150°C, and total pressure was then set to 3 MPaG by applying 0.40 MPa of hydrogen and 0.27 MPa of ethylene. Then 0.4 mmol of triisobutylaluminum, 0.0001 mmol of [methylphenylmethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-*t*-butyl fluorenyl)] zirconium dichloride and 0.001 mmol of N,N-dimethylanilinium tetrakis(pentafluorophenyl) borate were then injected under pressure with nitrogen, and polymerization was started by setting a stirring rotation speed to 400 rpm. Thereafter, the polymerization was carried out at 150°C for 5 minutes, keeping the total pressure at 3 MPaG by continuously feeding only ethylene. The polymerization was completed by having added a small amount of ethanol to the system, and then the unreacted ethylene, propylene, and hydrogen were purged. The resulting polymer solution was washed with 1000 mL of 0.2 mol/l hydrochloric acid three times and then with 1000 mL of distilled water three times, dried over magnesium sulfate, and the solvent was removed under reduced pressure. The resulting polymer was dried overnight under reduced pressure at 80°C, to obtain 52.2 g of an ethylene-propylene copolymer. Furthermore, the ethylene-propylene copolymer was subjected to the hydrogenation operation, and thus a polymer 3 was obtained.

<Polymerization Example 4>

[0209] A fully nitrogen-substituted glass polymerizer with an internal volume of 1 L, was charged with 250 mL of heptane, a temperature in the system was raised to 50°C, and then ethylene, propylene, and hydrogen at a flow rate of 25 L/hr, 75 L/hr, and 100 L/hr, respectively, were continuously fed into the polymerizer, and the mixture was stirred at a stirring speed of 600 rpm. Then 0.2 mmol of triisobutylaluminum was fed into the polymerizer, and then a mixture of 0.688 mmol of MMAO and 0.00230 mmol of [ethylene(η^5 -cyclopentadienyl) (η^5 -2,7-di-*t*-butyl fluorenyl)] zirconium dichloride, which were preliminarily mixed in toluene for not shorter than 15 minutes, was fed into the polymerizer to then start polymerization. Thereafter, the polymerization was carried out at 50°C for 15 minutes by continuing continuous feeding of ethylene, propylene, and hydrogen. After stopping the polymerization by adding a small amount of isobutyl alcohol into the system, unreacted monomer was purged. The obtained polymer solution was washed with 100 mL of 0.2 mol/l hydrochloric acid three times and then with 100 mL of distilled water three times, dried over magnesium sulfate, and then the solvent was distilled off under reduced pressure. The resulting polymer was dried overnight under reduced pressure at 80°C, to obtain 1.43 g of an ethylene-propylene copolymer. Furthermore, the ethylene-propylene copolymer was subjected to the hydrogenation operation, and thus a polymer 4 was obtained.

[0210] The physical properties of the ethylene-propylene copolymers obtained in Polymerization Examples 1 to 4 (Polymer 1 to Polymer 4, respectively), polymethacrylate (PMA), poly- α -olefin (PAO), and polybutene (PIB) are shown in

Table 2.

[0211]

Polymethacrylate (PMA); Viscoplex 0-220 manufactured by Evonik Industries AG
 Poly- α -olefin (PAO); Spectrasyn PAO-100 manufactured by ExxonMobil Chemical Company
 Polybutene (PIB); Nisseki Polybutene HV-1900 manufactured by JX Nippon Oil & Energy Corporation
 (A) Mineral oil; API (American Petroleum Institute) Group II mineral oil with 100°C kinematic viscosity: 3.1 mm²/s,
 viscosity index: 115, and pour point: -24°C (Yubase-3 manufactured by SK Lubricants Co., Ltd.)

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Table 2

		Polymer 1	Polymer 2	Polymer 3	Polymer 4	PMA	PAO	PIB
Polymerization Ex-ample		Polymerization Ex-ample 1	Polymerization Ex-ample 2	Polymerization Ex-ample 3	Polymerization Ex-ample 4	-	-	-
Ethylene molar content rate	mol%	51.9	51.1	52.7	53.4	-	-	-
100°C kinematic viscosity	mm ² /s	40	100	600	2,000	650	100	3,700
Mw		2,700	4,100	5,800	12,500	42,000	4,000	8,400
Mw/Mn		1.4	1.6	1.9	2.0	1.9	1.6	2.6
Hasen chromaticity		5	5	5	5	50	30	20
B value		1.2	1.2	1.2	1.2	-	-	-
Thermal diffusivity	m ² /s	9.12E-05	9.26E-05	9.24E-05	9.23E-05	6.43E-05	9.01E-05	5.62E-05
Volume resistivity	Ω•cm	4.0E+15	7.4E+15	3.9E+15	6.3E+16	8.9E+14	4.1E+15	1.1E+16
Relative permittivity		2.08	2.09	2.11	2.20	2.51	2.39	2.16
Melting point	°C	None	None	None	None	-	None	None
Chlorine content	ppm	<0.1	<0.1	<0.1	<0.1	-	-	-

[Preparation of lubricating oil composition used for cooling of electric motor and lubrication of gear in electric vehicle]

[0212] In preparing lubricating oil compositions used for cooling of an electric motor and lubrication of a gear in an electric vehicle, the following were used in addition to the aforementioned (C) ethylene- α -olefin copolymer, PMA, PAO, PIB, and (A) mineral oil.

Pour point depressant; Irgaflow 720P manufactured by BASF Corporation

[0213] DI package; HITEC 3419D manufactured by Afton Chemical Corporation

<Lubricating oil composition used for cooling of electric motor and lubrication of gear in electric vehicle>

[Example 1]

[0214] A lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle was compounded and prepared so that viscosity thereof was equivalent to ISO 46 and the total amount of the (A) mineral oil and the polymer 1 as the (C) ethylene- α -olefin copolymer, together with the DI package and pour point depressant, was 100% by mass. The amounts of each component added and the physical properties of the lubricating oil composition are shown in Table 3.

[Example 2]

[0215] A lubricating oil composition was compounded and prepared in the same manner as in Example 1, except that the polymer 1 was replaced with the polymer 2 and the amount of each component added was adjusted as described in Table 3. The physical properties of the lubricating oil composition are shown in Table 3.

[Example 3]

[0216] A lubricating oil composition was compounded and prepared in the same manner as in Example 1, except that the polymer 1 was replaced with the polymer 3 and the amount of each component added was adjusted as described in Table 3. The physical properties of the lubricating oil composition are shown in Table 3.

[Example 4]

[0217] A lubricating oil composition was compounded and prepared in the same manner as in Example 1, except that the polymer 1 was replaced with the polymer 4 and the amount of each component added was adjusted as described in Table 3. The physical properties of the lubricating oil composition are shown in Table 3.

[Comparative Example 1]

[0218] A lubricating oil composition was compounded and prepared in the same manner as in Example 1, except that the polymer 1 was replaced with the polymethacrylate (PMA), no pour point depressant was added, and the amount of each component added was adjusted as described in Table 3. The physical properties of the lubricating oil composition are shown in Table 3.

[Comparative Example 2]

[0219] A lubricating oil composition was compounded and prepared in the same manner as in Example 1, except that the polymer 1 was replaced with the poly- α -olefin (PAO) and the amount of each component added was adjusted as described in Table 3. The physical properties of the lubricating oil composition are shown in Table 3.

[Comparative Example 3]

[0220] A lubricating oil composition was compounded and prepared in the same manner as in Example 1, except that the polymer 1 was replaced with the polybutene (PIB) and the amount of each component added was adjusted as described in Table 3. The physical properties of the lubricating oil composition are shown in Table 3.

Table 3

		Example 1	Example 2	Example 3	Example 4	Comparative Example 1	Comparative Example 2	Comparative Example 3
5	Polymer 1	% by mass	5.0					
	Polymer 2	% by mass		3.5				
10	Polymer 3	% by mass			1.9			
	Polymer 4	% by mass				1.4		
15	PMA	% by mass				2.6		
	PAO	% by mass					3.0	
20	PIB	% by mass						4.8
	Pour point depressant	% by mass	0.3	0.3	0.3	0.3	0.3	0.3
25	DI package	% by mass	12.0	12.0	12.0	12.0	12.0	12.0
	Mineral oil	% by mass	82.7	84.2	85.8	86.3	85.4	84.7
30	100°C kine- matic visc- osity	mm ² /s	4.38	4.36	4.35	4.39	4.32	4.36
	40°C kine- matic visc- osity	mm ² /s	20.3	20.0	19.7	19.7	18.9	19.9
35	Viscosity in- dex	-	128	131	134	135	141	132
	Pour point	°C	-40	-45	<-50	<-50	<-50	-45
40	Low tem- perature viscosity	mPa·s	15,000	13,000	6,500	6,800	4,000	12,000
	Rate of de- crease in viscosity after shear test	%	<0.1	<0.1	<0.1	<0.1	3.0	<0.1
45	Thermal dif- fusivity	m ² /s	7.08E-02	7.10E-02	7.13E-02	7.25E-02	-	6.95E-02
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[0221] In comparison of Examples 1 to 3 each containing the (C) ethylene- α -olefin copolymer with Comparative Example 1 containing PMA instead of the (C) ethylene- α -olefin copolymer as lubricating oil compositions used for cooling of an electric motor and lubrication of a gear in an electric vehicle using the (A) mineral oil for lubricating base oil, the lubricating oil compositions of the present invention can continue to protect the mechanism of the electric vehicle for a long period of time since the viscosity does not decrease even after the shear test. Meanwhile, the lubricating oil compositions of Comparative Examples 2 and Comparative Example 3, which contain PAO or PIB instead of the (C) ethylene- α -olefin copolymer, have a thermal diffusivity below 7.0×10^{-2} , which does not provide sufficient motor cooling performance. The

(C) ethylene- α -olefin copolymer has a methylene sequence as the main backbone, and the degree of freedom at the molecular ends is smaller than that of PAO and PIB, which inhibits heat generation due to molecular vibration. Therefore, when used in lubricating oil compositions, it is thought to exhibit excellent cooling and/or heat dissipation performance. In addition, they have poor pourability at a low temperature, resulting in significantly inferior fuel saving properties in a low temperature environment.

Claims

1. A lubricating oil composition used for cooling of an electric motor and lubrication of a gear in an electric vehicle, the composition comprising: a lubricating base oil composed of a (A) mineral oil having the following characteristics (A1) to (A3) and/or a (B) synthetic oil having the following characteristics (B1) to (B3); and an (C) ethylene- α -olefin copolymer having the following characteristics (C1) to (C5), the composition having a kinematic viscosity at 100°C of 4 to 10 mm²/s:

(A1) a kinematic viscosity at 100°C of 2 to 6 mm²/s;

(A2) a viscosity index of 105 or more;

(A3) a pour point of -5°C or lower;

(B1) a kinematic viscosity at 100°C of 1 to 9 mm²/s;

(B2) a viscosity index of 110 or more;

(B3) a pour point of -30°C or lower;

(C1) an ethylene molar content rate within a range of 30 to 70 mol%;

(C2) a kinematic viscosity at 100°C of 10 to 5,000 mm²/s;

(C3) a Hasen chromaticity of 30 or lower;

(C4) a molecular weight distribution (Mw/Mn) of 2.5 or less in molecular weight obtained in terms of polystyrene, as measured by gel permeation chromatography (GPC); and

(C5) a B value represented by the following formula [1] of 1.1 or more:

$$B = \frac{P_{OE}}{2 P_O \cdot P_E} \dots [1]$$

wherein P_E represents a molar fraction of ethylene component, P_O represents a molar fraction of α -olefin component, and P_{OE} represents a molar fraction of ethylene- α -olefin sequence in the total dyad sequence.

2. The lubricating oil composition according to claim 1, wherein the (C) ethylene- α -olefin copolymer has any one or more of the following characteristics (C6) to (C8):

(C6) a thermal diffusivity at 50°C of 8.0×10^{-5} to 1.0×10^{-4} m²/s;

(C7) a volume resistivity at 50°C and 250 V of 1.0×10^{15} to 1.0×10^{17} $\Omega \cdot \text{cm}$; and

(C8) a relative permittivity at 50°C of 2.00 to 2.30.

3. The lubricating oil composition according to claim 1, wherein the ethylene molar content rate of the (C) ethylene- α -olefin copolymer is within a range of 40 to 60 mol%.

4. The lubricating oil composition according to claim 1, wherein the kinematic viscosity of the (C) ethylene- α -olefin copolymer at 100°C is 20 to 2,500 mm²/s.

5. The lubricating oil composition according to claim 1, wherein the α -olefin of the (C) ethylene- α -olefin copolymer is propylene.

6. The lubricating oil composition according to claim 1, wherein the content of the (C) ethylene- α -olefin copolymer is 1 to 10% by mass based on the total amount of the lubricating base oil and the (C) ethylene- α -olefin copolymer of 100% by mass.

EP 4 488 348 A1

7. The lubricating oil composition according to any one of claims 1 to 6, wherein the electric vehicle is any of an electric automobile, a plug-in hybrid vehicle, a hybrid vehicle, or a fuel cell vehicle.
8. The lubricating oil composition according to any one of claims 1 to 6, wherein the electric motor equipped in the electric vehicle is an in-wheel motor.
9. The lubricating oil composition according to any one of claims 1 to 6, wherein the electric vehicle is either an electric wheelchair or an electric cart.
10. The lubricating oil composition according to any one of claims 1 to 6, wherein the electric vehicle is either an electric skateboard or an electric roller skate.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/007952

A. CLASSIFICATION OF SUBJECT MATTER

C10M 169/04(2006.01)i; *C10N 20/00*(2006.01)n; *C10N 20/02*(2006.01)n; *C10N 20/04*(2006.01)n; *C10N 30/00*(2006.01)n; *C10N 30/02*(2006.01)n; *C10N 40/00*(2006.01)n; *C10N 40/04*(2006.01)n; *C10M 101/02*(2006.01)n; *C10M 143/04*(2006.01)n
 FI: C10M169/04; C10N30:02; C10N30:00 Z; C10N40:04; C10M143/04 ZHV; C10M101/02 ZAB; C10N20:02; C10N20:00 Z; C10N20:04; C10N20:00 A; C10N40:00 D

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C10M169/04; C10N20/00; C10N20/02; C10N20/04; C10N30/00; C10N30/02; C10N40/00; C10N40/04; C10M101/02; C10M143/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2023
 Registered utility model specifications of Japan 1996-2023
 Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2016-069405 A (MITSUI CHEMICALS INC) 09 May 2016 (2016-05-09) claims, paragraph [0002], examples	1-10
Y	claims, paragraph [0002], examples	1-10
Y	JP 2021-500463 A (TOTAL MARKETING SERVICES) 07 January 2021 (2021-01-07) claims	1-10
A	JP 2016-108406 A (TONENGENERAL SEKIYU KK) 20 June 2016 (2016-06-20) paragraph [0002]	1-10
A	JP 2019-154115 A (HONDA MOTOR CO LTD) 12 September 2019 (2019-09-12) paragraph [0002]	1-10
A	JP 2006-325369 A (NISSAN MOTOR CO LTD) 30 November 2006 (2006-11-30) paragraph [0028]	1-10

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/007952

C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2021-164298 A (NIHON DENSAN KK) 11 October 2021 (2021-10-11) paragraph [0017]	1-10
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2023/007952

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JP 2006-325369 A	30 November 2006	(Family: none)	
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