

POLYPROPYLENE INSULATED DIRECT-CURRENT CABLE AND PREPARATION METHOD THEREFOR

FIELD OF THE INVENTION

The present invention relates to the field of cable insulation material preparation, and in particular to a polypropylene insulated direct-current cable and a preparation method therefor.

DESCRIPTION OF THE RELATED ART

In recent years, with the development of economy and increasing electricity demand, power systems are continuously developing toward higher voltage levels to meet requirements of electrical load. High-voltage direct current cables are a key component in direct-current power transmission network systems. PP (polypropylene) is a highly competitive and potential material for high-voltage direct-current insulation cables, being a thermoplastic general-purpose plastic with excellent performance. PP has been widely used in numerous fields of daily life, such as medical instruments, mechanical equipment components, chemical containers, clothing, and automobiles, due to its excellent electrical insulation, light specific gravity, chemical corrosion resistance, heat resistance, and other properties. PP also exhibits better thermal stability, sufficient mechanical toughness, and excellent electrical properties at high temperatures. Furthermore, PP is a major product of the petrochemical industry, and has a low cost, and its thermoplastic properties make it easier to recycle and reprocess. Therefore, PP is considered a promising, recyclable, and environmentally friendly direct-current cable insulation material. However, PP fails to meet the requirements for high-voltage direct-current cable insulation materials, due to its disadvantages such as high elastic modulus, high rigidity, poor aging resistance, high low-temperature brittleness, and the decrease of its electrical properties under high-temperature and high-electric-field operating conditions, in particular space charge accumulation under high temperature and high electric field.

Currently, modifications are mainly performed through blending modification, nanoparticle doping modification, nucleating agent modification, and chemical grafting modification. By modifying PP, its physical and chemical properties are improved to meet the requirements for high-voltage cable insulation materials.

1. Blending modification: the addition of an elastomer reduces the rigidity of PP and increases its toughness, but charges generated by interfacial polarization between different phases and charges injected from electrodes can also reduce the dielectric properties of the material.

2. Nanoparticle doping modification: when the interfacial contact between nanoparticles and

the polymer is poor and their interaction is weak, the composite material may undergo separation between the nanoparticles and the polymer when subjected to strong external forces, thus destroying the integrity of the material.

3. The β -spherulite structure formed by adding a β -nucleating agent is loose and can slip to dissipate energy when subjected to external forces and the deep traps introduced by β can inhibit space charge injection, thereby achieving the effect of simultaneously improving mechanical and dielectric properties. However, it is difficult to ensure the dispersibility of the nucleating agent in large-scale production.

Although adding an EPDM elastomer reduces the rigidity of PP and increases its toughness, the addition of a large amount of elastomer forms interfaces within the composite material. Due to differences in relative permittivity and electrical conductivity between the elastomer and the polymer matrix, polarization occurs at the interfaces, and the polarization process accumulates space charge, thereby causing electric field distortion. Furthermore, EPDM particles exhibit poor dispersibility on the PP matrix, with large differences in particle size between particles.

SUMMARY OF THE INVENTION

The present invention improves the preparation process of polypropylene and selects a nano-doped elastomer to expand its application scope, enhancing the mechanical properties of polypropylene, ensuring that electrical properties are not adversely affected, while also addressing the problem of space charge accumulation of polypropylene insulated material under high temperature and high electric field.

To solve the above-mentioned technical problems, the present application provides the following technical solutions:

The present invention provides a preparation method for a polypropylene insulated direct-current cable, wherein the preparation method includes:

S11: stranding to prepare a conductor core;

S12: preparing a conductor shielding layer, a polypropylene insulation layer, and an insulation shielding layer in sequence using three-layer coextrusion outside the conductor core from inside to outside, to obtain a crosslinked cable core; the polypropylene insulation layer is obtained by extruding a nano-doped EPDM elastomer through an extruder; in parts by weight, the nano-doped EPDM elastomer is obtained by mixing 100 parts of polypropylene, 5-15 parts of ethylene propylene diene monomer, and 1-5 parts of nano-magnesia;

1. Selection of elastomer:

(1) EVA

EVA is interlinked in the PP matrix, which excessively disrupts the regularity of PP molecules.

(2) EPDM

Although EPDM particles exhibit poor dispersibility on the PP matrix and have large differences in particle size between particles, by nano-doping the EPDM and then blending it with PP, the EPDM doped with a large amount of nanofiller can reduce the differences between particles. Moreover, the problem of poor dispersibility of EPDM on the PP matrix can be fully improved by adjusting the production process.

2. Selection of nano-dopant:

Nano-ZnO, Al₂O₃, MgO, and TiO₂ can all inhibit space charge and improve the direct-current breakdown strength of the insulation. However, nano-MgO can better alter the electrical properties of PP and has greater potential for widespread application as a high-voltage direct-current cable insulation material.

Therefore, the present invention uses EPDM and nano-MgO to modify polypropylene.

During the extrusion, temperature zones are set to: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C;

S13: passing the crosslinked cable core through a cooling channel for zoned cooling, wherein temperature zones are set to: zone 1: 190°C, zone 2: 160°C, zone 3: 130°C, zone 4: 120°C, zone 5: 110°C, zone 6: 100°C, zone 7: 60°C, and zone 8: 30°C;

S14: performing metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion onto a surface of the crosslinked cable core in sequence after zoned cooling in step S13, to obtain the polypropylene insulated direct-current cable.

Preferably, the extruder is a Type 175 screw extruder.

Preferably, in parts by weight, the nano-doped EPDM elastomer consists of 100 parts of polypropylene, 15 parts of ethylene propylene diene monomer, and 5 parts of nano-magnesia.

Preferably, the conductor shielding layer is obtained by extrusion using a Type 75 screw extruder.

Further, during extrusion of the conductor shielding layer, temperature zones are set to: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C.

Preferably, the insulation shielding layer is obtained by extrusion using a Type 90 screw extruder.

Further, during extrusion of the insulation shielding layer, temperature zones are set to: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.

The present invention also provides a polypropylene insulated direct-current cable prepared by the above-described method.

The influence of factors such as extrusion temperature, cooling temperature gradient, and doping ratio on the blending effect during the preparation process was verified through multiple experiments, thereby producing polypropylene-based insulated material with good mechanical and electrical properties.

The results indicate that when 100 parts of PP, 15 parts of EPDM, and 5 parts of MgO are used, the mechanical and electrical properties of the polypropylene insulated material are optimized.

EPDM particles exhibit poor dispersibility on the PP matrix, with large differences in particle size between particles.

Compared with the prior art, the technical solution of the present invention has the following advantages:

1. The problem of poor dispersibility of EPDM particles on the PP matrix is solved by improving the preparation process (increasing extrusion pressure and injection temperature, and cooling by stepwise temperature reduction).

2. By adding an EPDM elastomer with a nanofiller, the toughness and twist resistance of the polypropylene insulated material are improved, and the interfacial polarization phenomenon between the EPDM elastomer and the polypropylene is alleviated, thereby ensuring that while mechanical properties are improved, electrical properties are also enhanced.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be further described below in conjunction with specific embodiments, so that those skilled in the art can better understand implement the present invention, but the embodiments described are not intended to limit the present invention.

EXAMPLE 1

Standard steps were as follows:

- 1) A nano-doped EPDM elastomer was prepared using, in parts by weight, 100 parts of polypropylene, 15 parts of ethylene propylene diene monomer, and 5 parts of nano-magnesia.

- 2) A conductor core was prepared by stranding metal conductors.

- 3) A crosslinked core was prepared using a three-layer coextrusion production line. A Type 75 screw extruder, a Type 90 screw extruder, and a Type 175 screw extruder were used for a conductor shielding layer, an insulation shielding layer, and a polypropylene insulation layer, respectively.

- 4) The extrusion screw temperature of the conductor shielding layer was set to 7 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C,

zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C. 5) A modified polypropylene material was used for the polypropylene insulation layer, with the screw temperature set in a stepwise configuration, especially: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C.

6) The extrusion screw temperature of the insulation shielding layer was set to 6 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.

7) The prepared crosslinked cable core was passed through a cooling channel. Each zone had the following temperatures: zone 1: 190°C, zone 2: 160°C, zone 3: 130°C, zone 4: 120°C, zone 5: 110°C, zone 6: 100°C, zone 7: 60°C, and zone 8: 30°C.

8) Metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion were performed in sequence to obtain the product cable.

EXAMPLE 2

Standard steps were as follows:

1) A nano-doped EPDM elastomer was prepared using, in parts by weight, 100 parts of polypropylene, 5 parts of ethylene propylene diene monomer, and 1 parts of nano-magnesia.

2) A conductor core was prepared by stranding metal conductors.

3) A crosslinked core was prepared using a three-layer coextrusion production line. A Type 75 screw extruder, a Type 90 screw extruder, and a Type 175 screw extruder were used for a conductor shielding layer, an insulation shielding layer, and a polypropylene insulation layer, respectively.

4) The extrusion screw temperature of the conductor shielding layer was set to 7 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C. 5) A modified polypropylene material was used for the polypropylene insulation layer, with the screw temperature set in a stepwise configuration, especially: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C.

6) The extrusion screw temperature of the insulation shielding layer was set to 6 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.

7) The prepared crosslinked cable core was passed through a cooling channel. Each zone had the following temperatures: zone 1: 190°C, zone 2: 160°C, zone 3: 130°C, zone 4: 120°C, zone 5: 110°C, zone 6: 100°C, zone 7: 60°C, and zone 8: 30°C.

8) Metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion were performed in sequence to obtain the product cable.

EXAMPLE 3

Standard steps were as follows:

- 1) A nano-doped EPDM elastomer was prepared using, in parts by weight, 100 parts of polypropylene, 5 parts of ethylene propylene diene monomer, and 5 parts of nano-magnesia.
- 2) A conductor core was prepared by stranding metal conductors.
- 3) A crosslinked core was prepared using a three-layer coextrusion production line. A Type 75 screw extruder, a Type 90 screw extruder, and a Type 175 screw extruder were used for a conductor shielding layer, an insulation shielding layer, and a polypropylene insulation layer, respectively.
- 4) The extrusion screw temperature of the conductor shielding layer was set to 7 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C.
- 5) A modified polypropylene material was used for the polypropylene insulation layer, with the screw temperature set in a stepwise configuration, especially: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C.
- 6) The extrusion screw temperature of the insulation shielding layer was set to 6 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.
- 7) The prepared crosslinked cable core was passed through a cooling channel. Each zone had the following temperatures: zone 1: 190°C, zone 2: 160°C, zone 3: 130°C, zone 4: 120°C, zone 5: 110°C, zone 6: 100°C, zone 7: 60°C, and zone 8: 30°C.
- 8) Metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion were performed in sequence to obtain the product cable.

Comparative Example 1

The steps were the same as in Example 1, except that the cooling gradient decreases by 30°C per zone.

The specific steps were as follows:

- 1) A nano-doped EPDM elastomer was prepared using, in parts by weight, 100 parts of polypropylene, 5 parts of ethylene propylene diene monomer, and 5 parts of nano-magnesia.
- 2) A conductor core was prepared by stranding metal conductors.
- 3) A crosslinked core was prepared using a three-layer coextrusion production line. A Type 75 screw extruder, a Type 90 screw extruder, and a Type 175 screw extruder were used for a conductor shielding layer, an insulation shielding layer, and a polypropylene insulation layer, respectively.
- 4) The extrusion screw temperature of the conductor shielding layer was set to 7 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C,

zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C. 5) A modified polypropylene material was used for the polypropylene insulation layer, with the screw temperature set in a stepwise configuration, especially: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C.

6) The extrusion screw temperature of the insulation shielding layer was set to 6 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.

7) The prepared crosslinked cable core was passed through a cooling channel, with the cooling gradient decreasing by 30°C per zone.

8) Metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion were performed in sequence to obtain the product cable.

Comparative Example 2

Comparative Example 2: the above steps were completely identical, except that EPDM without nano-MgO doping was added.

The specific steps were as follows:

1) A nano-doped EPDM elastomer was prepared using, in parts by weight, 100 parts of polypropylene, 5 parts of ethylene propylene diene monomer, without doping nano-magnesia.

2) A conductor core was prepared by stranding metal conductors.

3) A crosslinked core was prepared using a three-layer coextrusion production line. A Type 75 screw extruder, a Type 90 screw extruder, and a Type 175 screw extruder were used for a conductor shielding layer, an insulation shielding layer, and a polypropylene insulation layer, respectively.

4) The extrusion screw temperature of the conductor shielding layer was set to 7 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C. 5) A modified polypropylene material was used for the polypropylene insulation layer, with the screw temperature set in a stepwise configuration, especially: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C.

6) The extrusion screw temperature of the insulation shielding layer was set to 6 zones. Each zone had the following temperatures: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.

7) The prepared crosslinked cable core was passed through a cooling channel, with the cooling gradient decreasing by 30°C per zone.

8) Metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion were performed in sequence to obtain the product cable.

Comparative Example 3

The steps were the same as in Example 1, except that EPDM and MgO were added directly to the PP separately.

Comparative Example 4

The steps were the same as in Example 1, except that the amounts of EPDM and MgO were changed; wherein, in parts by weight, 100 parts of PP, 20 parts of EPDM, and 10 parts of MgO were used.

Effect Evaluation 1

In the present invention, it is discovered that the crystallization behavior of the EPDM and PP blend shows that the crystallization temperature and crystal nucleation rate of the blend increase after adding EPDM, indicating that EPDM has a nucleating effect on PP. A decrease in the crystal growth rate indicates a reduction in crystal size, i.e., spherulites are reduced. As a result, EPDM reduces the crystallinity of PP. Since the crystallization temperature of PP is around 115°C, the present invention employs a more dense stepwise cooling in the range of 100-130°C to maintain its original crystallinity.

1) Comparing example 1 and example 2, it can be found that using the preparation method of the present invention can improve both the electrical and the mechanical properties of PP.

2) From comparative example 1, it is found that increasing the cooling gradient during cooling leads to a certain degree of decline in both mechanical and electrical properties compared to Example 2. This is because the increase in the cooling temperature gradient results in poorer crystallization of PP, leading to a larger proportion of amorphous regions.

3) From comparative example 2, it is found that adding only the EPDM elastomer can improve the mechanical properties of PP. However, since the added EPDM forms interfaces with PP, polarization charges appear, leading to a decline in its electrical properties.

4) From comparative example 3, it is found that adding EPDM and MgO separately instead of mixing the two in advance, results in a certain degree of decline in both electrical and mechanical properties compared to example 2. This is because when the two are added separately, MgO cannot be uniformly filled inside the EPDM, partially causing the phenomenon in 3) and leading to a decline in electrical properties.

Table 1 Performance Tests of Examples and Comparative Examples

Item	Example 1 (Conventional Preparation Method, No Filler Added)	Example 2 (Optimal Method According to the Present Invention)	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4
Hardness (Shore A)	50	52	55	55	54	58
Tear Resistance (N/mm)	31.3	34	32.8	32	33	30
Tensile Strength (MPa)	41.9	45	43	44.5	44	44.5
Elongation at Break (%)	580	630	610	590	585	590
Volume Resistivity ($\Omega \cdot \text{cm}$)	4.8e15	4.0e15	4.7e15	5.0e15	3.9e15	4.0e15
DC Breakdown Strength Positive Electrode (kV/mm)	330	380	350	300	320	310
DC Breakdown Strength Negative Electrode (kV/mm)	320	360	340	280	315	300
Space Charge Density (20 kV/mm) (C/m^3)	2.3	1	1.5	3	2	3.5

Obviously, the foregoing embodiments are merely examples for clear description, rather than a limitation to implementations. For a person of ordinary skill in the art, other changes or variations in different forms may also be made based on the foregoing description. All implementations cannot and do not need to be exhaustively listed herein. Obvious changes or variations that are derived there from still fall within the protection scope of the invention of the present invention.

WHAT IS CLAIMED IS:

1. A preparation method for a polypropylene insulated direct-current cable, comprising:

S11: stranding to prepare a conductor core;

S12: preparing a conductor shielding layer, a polypropylene insulation layer, and an insulation shielding layer in sequence using three-layer coextrusion outside the conductor core, from inside to outside, to obtain a crosslinked cable core; the polypropylene insulation layer is obtained by extruding a nano-doped EPDM elastomer through an extruder; in parts by weight, the nano-doped EPDM elastomer is obtained by mixing 100 parts of polypropylene, 5-15 parts of ethylene propylene diene monomer, and 1-5 parts of nano-magnesia; during the extrusion, temperature zones are set to: zone 1: 175°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 195°C, zone 6: 195°C, zone 7: 200°C, zone 8: 200°C, and zone 9: 200°C;

S13: passing the crosslinked cable core through a cooling channel for zoned cooling, wherein temperature zones are set to: zone 1: 190°C, zone 2: 160°C, zone 3: 130°C, zone 4: 120°C, zone 5: 110°C, zone 6: 100°C, zone 7: 60°C, and zone 8: 30°C;

S14: performing metal shielding, cabling, inner sheath extrusion, armoring, and outer sheath extrusion onto a surface of the crosslinked cable core in sequence after zoned cooling in step S13, to obtain the polypropylene insulated direct-current cable.

2. The preparation method according to claim 1, wherein the extruder is a Type 175 screw extruder.

3. The preparation method according to claim 1, wherein in parts by weight, the nano-doped EPDM elastomer consists of 100 parts of polypropylene, 15 parts of ethylene propylene diene monomer, and 5 parts of nano-magnesia.

4. The preparation method according to claim 1, wherein the conductor shielding layer is obtained by extrusion using a Type 75 screw extruder.

5. The preparation method according to claim 4, wherein during extrusion of the conductor shielding layer, temperature zones are set to: zone 1: 165°C, zone 2: 180°C, zone 3: 190°C, zone 4: 195°C, zone 5: 200°C, zone 6: 200°C, and zone 7: 200°C.

6. The preparation method according to claim 1, wherein the insulation shielding layer is obtained by extrusion using a Type 90 screw extruder.

7. The preparation method according to claim 6, wherein during extrusion of the insulation shielding layer, temperature zones are set to: zone 1: 165°C, zone 2: 180°C, zone 3: 185°C, zone 4: 195°C, zone 5: 200°C, and zone 6: 200°C.

8. A polypropylene insulated direct-current cable prepared by the method according to any one of claims 1-7.