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Study on Pyrolysis Characteristics of Cross-linked Polyethylene Material Cable

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Abstract

Wire and cable potential fire hazard is mainly due to cable sheath material and insulation coating material is flammable. Combustible pyrolysis process is the first stage of development in cable fire. To study on pyrolysis characteristics of insulating and sheathing materials of electric cables is vital for the analysis of cable fire causes and characteristics. The cross-linked polyethylene material cable is widely used in construction. This paper mainly introduces the characteristics of XLPE cable material, discusses and analyzes materials thermal decomposition behavior and kinetics of pyrolysis process of the cross-linked polyethylene cable by using thermogravimetry and differential scanning calorimetry (TGA-DSC) technique.

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Keywords: cross-linked polyethylene cable; TGA-DSC; insulation coating; thermal decomposition

1. Preface

If symbols are used extensively, a nomenclature list arranged alphabetically, with Greek, subscript and superscript symbols listed separately, should be provided. Put a nomenclature above the main text if necessary, in a box with the same font size as the rest of the paper. Otherwise all symbols should be identified when first used in the text. The unit of the nomenclatures should be clarified following the description text. Authors are expected to use the SI system of units. Use MATHTYPE software to edit nomenclatures with Greek characters. Here introduce the paper, and the paragraphs continue from here and are only separated by headings, subheadings, images and formulate. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

The cable is the production of social life in an important and indispensable infrastructure, with the high-speed development of national economy, science and technology make a spurt of progress, industrial development scale increasing, energy demand increases increasingly, accordingly in the modern large-scale petrochemical enterprises and other industrial and mining enterprises in the cable use is on the rise substantially, especially in power supply in the system, the cable also occupies a very important position. For example, with a capacity of 250000 kilowatts of power plant, use a total cable length is more than 200000 meters, in which the cable is to tunnel, channel, shaft and suspension form beam laying. However, due to safety awareness is weak and the science and technology is limited, cable brings convenience to people at the same time it also brings fire risk, due to several of reasons cable fire occurred frequently, resulting in more and more major casualties and lost of property. Wire and cable what in the high temperature environment can be ignited potential fire, that hazard is mainly due to cable sheath material and insulation materials are flammable and decomposed of combustion. The worldwide cable sheathing and insulation materials include polyethylene, PVC, such as polytetrafluoroethylene.

Polyethylene (PE) is one of the largest amounts of plastic resin. Due to its structure feature, polyethylene often cannot withstand the high temperature, the mechanical strength of it is insufficient, and that restricted its application in many areas.

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In order to improve the performance of polyethylene, many modification methods is studied, the polyethylene cross-linking, through the polyethylene intermolecular covalent bond to form a reticular structure, rapid improvement of the polyethylene resin properties, such as: thermal deformation, wear resistance, chemical resistance, resistance to stress cracking of a series of physical, chemical properties.[1]

XLPE is the English abbreviation of cross-linked polyethylene. Structure of polyethylene is a linear molecular, that is easy to be deformed at high temperature. Cross-linked polyethylene process made it into a mesh structure. This structure also has strong anti-deformation capability even at a high temperature.

XLPE cable is a kind of organic peroxides such as DCP (dicumyl peroxide) polyethylene. The peroxide makes a chemical action with polyethylene at high temperature and in an inert gas atmosphere, so that the thermoplastic polyethylene becomes into thermosetting (elastomer) polyethylene, or XLPE.

XLPE cable has excellent electric performance. Dielectric loss should be small than paper insulation and insulation of PVC. XLPE cable capacitance is weak too. So in the grounding system absence of effective star can reduce the charging current and fault current.

Easy installation is another advantage of XLPE cable. XLPE cable has a smaller radius of curvature, compared with other similar cable is light and has relatively simple terminal processing. XLPE cable is not oily, so that XLPE cable is laid without taking into account the route and dripping oil to laying condition.

Excellent anti-aging properties and super heat-resistant deformation determines the XLPE cable at the normal operating temperature (90℃), short-time fault (130℃) and short circuit (250℃) conditions can allow a large current to pass through.[2]

In this paper, for research on the pyrolysis characteristics of cross-linked polyethylene material, cables are tested with the TGA-DSC spectrometer about thermal decomposition process of their cross-linked polyethylene material insulation and got the relevant data.

2. Study on pyrolysis characteristics of cross-linked polyethylene material

2.1. Physical properties of cross-linked polyethylene material

Cross-linked polyethylene insulated for the proportion of 0.92g/cm^3.The PVC insulated for the proportion of 1.35g/cm^3.Because XLPE insulating properties are better than PVC, according to the national standard (GB/T12706-2002) allows that the cross-linked polyethylene insulation's thickness could be thinner than PVC insulated, therefore, cross-linked polyethylene insulated cable's diameter can be smaller, lighter weight, more convenient installation, simpler attachment joints than PVC insulated, and widely used.[2]

2.2. Cross-linked polyethylene material Compared with traditional materials

At present, polyvinyl chloride (PVC) cable's amount in the cable industry is the largest and most widely used, this is mainly because of PVC with low price and good flame retardance. For communication cable, cross-linked polyethylene most economic significance is improving the original PVC/PE cable insulation material heat-resisting temperature from 65 ～ 75 ℃ to 90 ℃~120 ℃, which means cable current carrying capacity will be increased substantially. Under the same load, cable selection area decline, for the country's benefit, the property will be reflected in terms of saving large amount of nonferrous metal, in the user's standpoint, they can reduce the unit cost of transmission. In addition, due to its low density, excellent electric performance, not melting properties, reduce the consumption; improve the users' safety, i it's widely used in high-rise buildings and important places. At present in developed countries ,XLPE cable consumption accounted for 60% a 80% in all polyethylene cable, but our country is still less than 5%, therefore, at the beginning of this century, China will vigorously develops and applies cross-linked polyethylene cable.

PVC insulation cable's technology performance is good, easy processing, high chemical stability (resistance to acid, alkali and corrosion), non-flame spread properties, high production efficiency, low price, simple installation and maintenance; polyethylene insulation cable has good dielectric properties, dielectric loss angle tangent value is small, high insulation resistance; good technological properties, easy processing, good moisture resistance, small specific gravity, but the cable anti corona performance is poor, being easy to deformation or crack, and for higher operating voltage level, must join the special additive; cross-linked polyethylene insulated cable with good electrical performance, high breakdown field strength, small dielectric loss angle tangent value, high insulation resistance; higher heat resistance and aging resistance performance, allowing high working temperature, large carrying capacity, suitable for high drop height and vertical installation, is a very promising kind of high voltage cable.[3] Table 1 lists 3 kinds of plastic performance comparison.[4]

Table 1 comparison of PVC, PE, XLPE plastic performance

Performance	PVC	PE	XLPE
Density /g·cm-3	1.4	0.92	0.92
Insulation thickness /mm	1.0	0.70	0.70
Maximum temperature /℃	60～70	75	95
Softening temperature /℃	120	105～115	127
Instantaneous short-circuit temperature /℃	135	150	250
Insulation resistance /mΩ·Km-1	20	1000	1000
Volume resistivity /Ω·cm	1012～1015	1017	1017
Dielectric strengthKv·cm-1	20～35	20～35	35～50
Dielectric constant (60HZ)	6～8	2.3	2.3
Dielectric loss tangent (60HZ)	0.1	10-4	10-4
Weathering resistance	excellent	reduced	common
Aging resistance	reduced	common	excellent
Oil resistance	reduced	common	excellent
Embrittlement at low temperature	reduced	common	excellent

2.3. Polymer combustion process

Pyrolysis is a moderate thermal behavior of the material when heated below the ignition temperature ; and the combustion reacts more vigorously when material heated at or above the ignition temperature .Combustible pyrolysis process, trigger a combustible ignition and subsequent fire spread process to provide the necessary volatile fuel. Therefore, the pyrolysis process plays a key role concerning the occur of fire or not, as well as fire spread processes can be control or not.[5]

Cross-linked polyethylene is a molecular structure of the mesh of the high molecular weight polymer. Polymer decomposition combustion process is divided into four stages. First of all, heated by an external heat source, the temperature increases gradually, in a narrow temperature range, high polymer change from harder, more brittle glass material into the viscoelastic state material, the temperature is as same as the glass transition temperature, PVC glass transition temperature is 80 ℃, PE glass transition temperature is -125℃, XLPE glass transition temperature higher than 130℃; the temperature continues to rise to the thermal stability of the worst bond breaking temperature, the polymer begins to degrade, the molecular weight of the polymer, polymer material (plastic) decreased physical decline, PVC material at 200 ℃ ~300 ℃ begins to break down, thermal decomposition temperature of PE is 335 ℃ ~450 ℃, XLPE decomposition temperature is 450 ℃ ~500 ℃, producing combustible gas and micro carbon soot and smoke badly, polymer decomposition may produces two kind of matter, one kind is the polymer chain residue, they still have some structural integrity, another is type of polymer fragments, they are very easy to be oxidized. at a high enough temperature; and oxygen presence, polymer fragments to be oxidized at high speed, the heat generated in the gas phase combustion is sufficient to trigger, and even can make the solid residue of glowing light. After complete combustion, the final product is HCL, CO, CO2, H2O.[3] in order to obtain the mechanical and flame retardant, aging resistance performance, often accompanying stabilizer (PbO), a plasticizer (primarily for phosphate), lubricant, filler (calcium carbonate), a colorant material according to a certain proportion to join. So the combustion products will have a certain degree of PbCl2, CaCl2 etc.[6]

2.4. Cross-linked polyethylene pyrolysis experiment

TGA-DSC was mainly used to test pyrolysis kinetics of XLPE cable structure of the combustible materials. The physical and chemical changes in the material heating or cooling processes , often accompanied by endothermic and exothermic phenomenon, recording the specimen temperature versus time curve, can directly reflect the change of specimen‘s physical or chemical, this is the classic method of thermal analysis. In this paper, the author get the data using Belgium SDT company made Q600 V20.9 thermogravimetry and differential thermal analyzer measurement. The TG-DSC technique is used mainly because it can solves the problems that can not be solved with TG or DSC technology alone.TG can determine sample weight changes, DSC can determine the thermal effect. These two techniques can be complementary, mutual complement, mutual confirms. Most physical changes and chemical reactions accompany by both weight change and energy

change, there is only the energy change but no weight change, such as melting, crystallization, crystal transition, solid phase reaction, using TG-DSC technique some other changes can be distinguished, often on the interpretation of the thermal analysis curves is very good.[5]

The temperature testing, using a programmed temperature control technology, with 40 ℃ /min heating rate from room temperature to 800 ℃, measures thermal decomposition weightlessness of cables. Environmental gas is nitrogen or air, the gas velocity is 20ml/min, measuring sample the crucible materials three two aluminum oxide ($A1^2O^3$), sample weight range is about 80mg.[7]

The experimental sample is a bit of flame retardant XLPE cable insulation material.

3. The experimental results and analysis

The heating rate is under certain condition, with the increase of temperature, the pyrolysis of the samples has experienced several stages. Figure 1 shows the TG cable curves , DTG curves and DTA curves, in the heating rate and under P=40 ℃ /min, air as the atmosphere , following in order to analyze the cross-linked polyethylene cable material of the pyrolysis process.

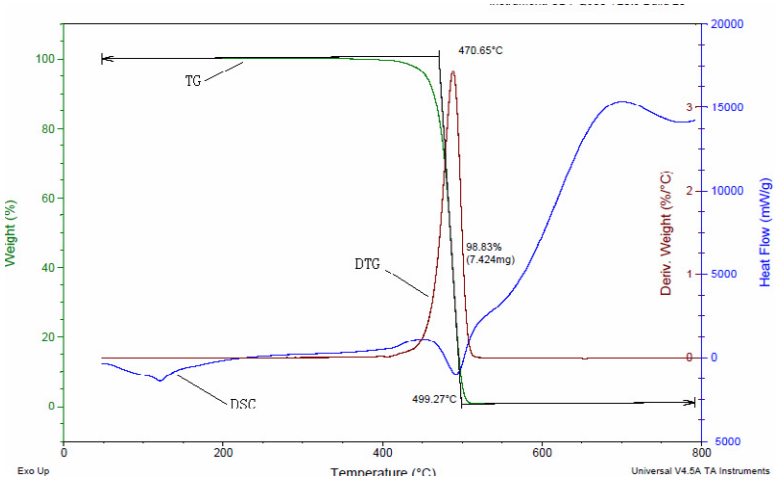

Fig. 1. TGA-DSC curve on XLPE cable material.

Figure 1 shows that the cross-linked polyethylene cable materials mainly goes through a thermal weight loss stages: from 400 ℃ - 500 ℃, this stage is the main stage of the pyrolysis process, most of the weight loss occurred in the specimen stage, weight loss rate was 98.83%, the phase of the DTG curve changes dramatically, reaching the peak value at 484.96 ℃.Combined with DSC curves, this stage could be observed within an endothermic peak, shows that this stage is mainly chlorine free radicals, thereby generating a large number of hydrogen chloride; observation of DSC curves at 550 ℃ of 690 ℃, a large exothermic peak, indicating that the stage is mainly XLPE and various additive interactions between some restructuring, such as a small amount of hydrogen chloride production, isomerization, cross-linking and aromatic [7].

4. Conclusion

This paper compares the performance of cross-linked polyethylene cable material with the traditional polyvinyl chloride and polyethylene cable, and introduces the superiority at the aspect of softening temperature and aging resistance. Using thermogravimetry and differential scanning calorimetry, pyrolysis and pyrolysis kinetics of PVC cable materials are studied. The result shows that: XLPE cable mainly experiences 1 stage of heat loss, due to the adding of additives, making the XLPE cable material of thermal weight loss stages since 400℃. The cable absorbs heat, generating free radicals and a large amount of hydrogen chloride gas. Thermal decomposition happens at 550~~690 ℃, during this time XLPE cable material and various additive interact accompanied by some reforms of structure.

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