Recent Development in Photoinitiated Crosslinking of Polyethylene and Its Industrial Applications

Baojun Qu, Qianghua Wu, Wenfang Shi/Department of Polymer Science and Engineering,University of Science and Technology of China/ Hefei 230026, China

Abstract

The recent development in the photoinitiated cross-linking of polyethylene and the significant breakthrough of its industrial application are reviewed. A new technique of photocrosslinked XLPE-insulated wires and cables is described in detail. It can be expected that the future applications of photocrosslinking technique of polyolefins are very promising.

Keywords: Polyethylene, photocrosslinking, properties, wire, cable

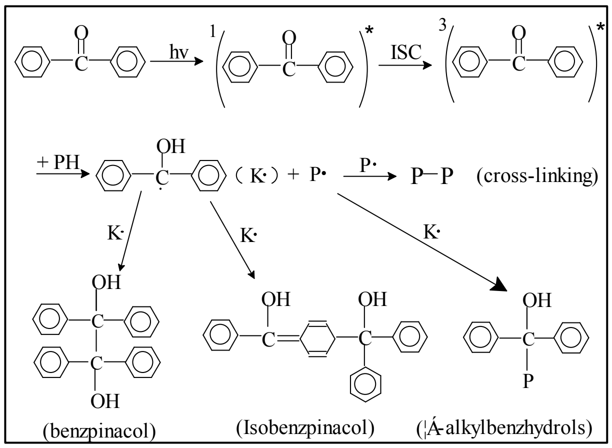
1. Introduction

The photocrosslinking process for polyethylene and its industrial irradiation apparatus have been developed recently and applied successfully for industrial manufacture of photocrosslinked polyethylene (XLPE)-insulation wires and cables. Polyethylene (PE) resin is mixed homogeneously with the desired amounts of additives, such as photoinitiator, multifunctional crosslinker etc. in the melt. The admixture of PE is granulated, and then extruded on a conductor wire. The coated PE layer in the melt is subsequently irradiated in a specially designed UV irradiation apparatus for 2-3 seconds to obtain the XLPE-insulated wires and cables. The photocrosslinked XLPE-insulation low voltage (1 kV and below) and medium-high voltage (10-35 kV) power cables manufactured by this advanced technology possess excellent electrical and mechanical properties and much lower operating cost compared with the present traditional crosslinking techniques, such as peroxides chemical crosslinking, alkoxy silane crosslinking, and high-energy electron beam irradiation crosslinking methods. Moreover, the photocrosslinking technique has unique advantages, such as low investment cost, simple operation process, easy maintaining, saving energy, environment-friendly, high production efficiency, etc.

Four Chinese patents were authorized with the present invention and an international (PCT) patent was applied.

2. Principle and Process of Photocrosslinking

Polyethylene (PE) material with the desired amounts of photoinitiator additive system is irradiated by UV light, in which the photoinitiator absorbed the energy of UV light is excited to the triplet excited state and then abstract hydrogen from the PE chains to form the macromolecule radicals. These macromolecule radicals combine with each other to form a three-dimensional network XLPE crosslinking structures.



The advanced manufacturing technology of photocrosslinked XLPE-insulation wires and cables contains three parts: i) Special photocrosslinking cable materials; ii) Specialy designed UV irradiation equipment; iii) Technical processing. This technology can be applied for manufacturing various low voltage wire and cable (1 kV and below) and medium-high voltage power cables (10-35 kV).

A. Photocrosslinking process of low voltage wires and cables

The photocrosslinking process of low voltage wires and cables is as follows:

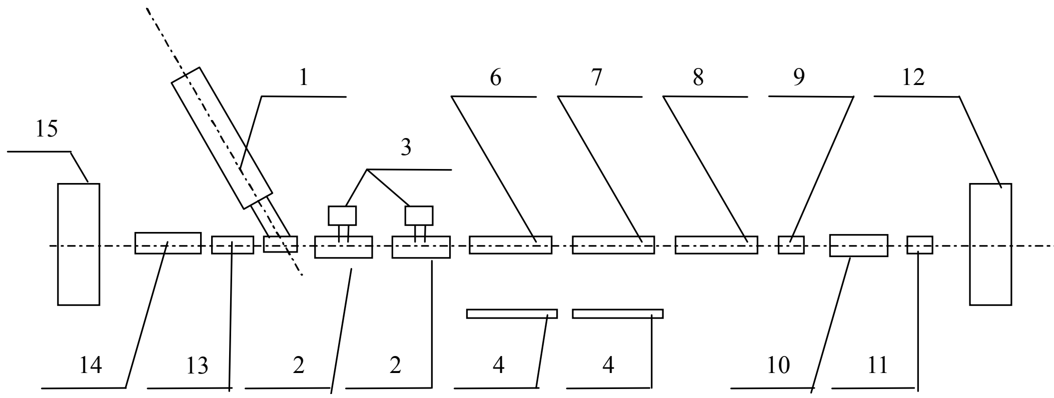
(1) Mixing and granulating. PE resin with the desired additives is mixed homogenously in the melt and granulated to a size of about of 2-5 mm^3 using an extruder.

(2) Extruding PE admixure on conductor wire. The photocrosslinkable admixure granules in the melt are coated on conductor by extruder to form the PE insulation layers.

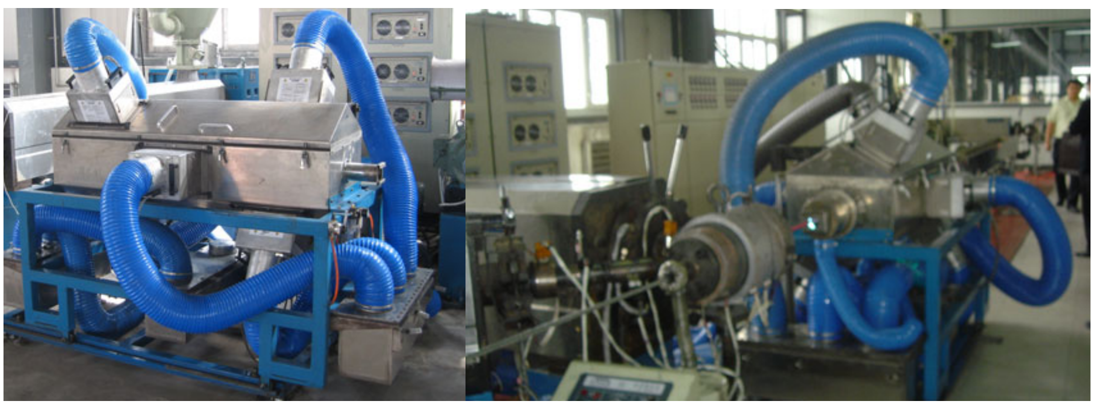
(3) Photocrosslinking of PE insulation layers. The above insulation layers coated on the conductor are subsequently crosslinked in the melt by UV irradiation in a specially designed apparatus.

(4) Subsequent processing: According to the traditional process, the above photocrosslinked XLPE insulated cables are armored and/or coated by jacket materials.

A block diagram of commercial process of photocrosslinked polyethylene cables is shown in the following figure.



1. extruder; 2. UV irradiation unit; 3. exhaust fan; 4. cabinet of electric controller; 5. cabinet of electrical system; 6. hot water tank; 7. warm water tank; 8. cool water tank; 9. length counter; 10. down-drawing; 11. machine of breakdown; 12. take up; 13. preheater; 14. up-drawing; 15. pay-off.



B. **Photocrosslinking process of medium-high voltage power cables**

The insulation materials of medium-high voltage power cables have a three-layer structure of inside semiconductive screen/PE insulation/outside semiconductive screen. The carbon black in the semiconductive screen can absorb the most UV energy and prevent photoinitiator to initiate the photocrosslinking reactions of PE. Therefore, a new processing named as "2+1" extrusion-photocrosslining process is developed for manufacturing the photocrosslinked XLPE insulated medium-high voltage cables . The "2+1" extrusion-photocrosslining process is as follows:

(1) Mixing and Granulating of photocrosslinging cable formulation materials.
(2) Double layered co-extrusion of inside semiconductor screen and PE insulation on conductor. The inside semiconductor screen and photocrosslinkable compounds are coated on conductor at the suitable temperature by double layered co-extrusion to form the inside semiconductor screen and insulation layers.
(3) Photocrosslinking of PE insulation. The above PE insulation layers coated on the conductor are subsequently crosslinked in the melt by UV irradiation in a specially designed apparatus.
(4) Extrusion of outside semiconductor screen: After photocrosslinking of PE insulation layers, the

outside semiconductor screen is immediately coated on the XLPE insulation.

(5) Subsequent processing: According to the traditional process of power cable, the above photocrosslinked XLPE insulated cables are armored and/or coated by jacket materials.

3. Properties of Photocrosslinked XLPE Materials and Cable Products

The properties of the photocrosslinked XLPE materials applied for medium-low voltage cables are summarized in Table 1. The results demonstrate that the photocrosslinked XLPE materials possess not only excellent electrical properties, such as volume resistivity, discharge breakdown, and dielectric properties, but also excellent mechanical properties measured by tensile, elongation, heat aging tests, and brittleness at low temperature. All these properties meet the requirements of XLPE insulation materials for both low voltage and medium-high voltage (35 kV) power cables. Table 2 and Table 3 list the properties of photocrosslinked XLPE 1 kV and 10 kV cables.

Table 1 Properties of Photocrosslinked XLPE Materials [a]

Items of Test	Results
1. Mechanical Properties	
Original tensile strength, MPa	22.4
Original elongation at break, %	550
2. Heat Aging Test, 150 ºC × 7 days	
Tensile strength (T. S.), MPa	24.2
Retention of T. S., %	108
Elongation (EL) at break, %	490
Retention of EL, %	90
3. Heat Extension Test, 200 ºC × 15 min	
Extension under load test, %	32.5
Permanent extension, %	0
4. Gel Content, %	82
5. Low Temperature Test, -76 ºC	Pass
6. Volume Resistivity, Ω-cm	
20 ºC□	2.4×10^{16}
90 ºC	3.0×10^{16}
7. Discharge Breakdown, kV/mm	41.6
8. Dielectric Dissipation Angle, tg δ	3.26×10^{4}
0. Dielectric Constant , ε	2.2

[a] The results were reported by Shanghai Institute of Cables, the Ministry of Mechanics and Electronics Industry of China.

Table 2 Properties of Photocrosslinked XLPE Insulation of 1 kV Power Cable

Items of Test	Results
1. Mechanical Properties	
Original tensile strength (T. S.),, MPa	18.1
Original elongation at break (EL), %	520
2. Heat Aging Test, 145 ºC × 7 days	
Retention of T. S., %	107
Retention of EL, %	104
3. Heat Extension Test, 200 ºC × 15 min	
Extension under load test, %	60
Permanent extension, %	0
4. Heat Shrinkage (130 ºC, 1h), %	1.5
5. Degree of Water Absorption (85ºC, 14d)	0.04
6. Volume Resistivity, MΩ-km (90 ºC)	22600
7. Withstand Voltage Test	pass
(2.4kV, 5h)	

[a] The results were reported by China State Center of Supervision and Proof-test of Wire and Cable Equalty.

Table 3 Properties of Photocrosslinked XLPE Insulation of 10 kV Power Cable

Items of Test	Results
1. Mechanical Properties	
Original tensile strength, MPa	21.2
Original elongation at break, %	480
2. Heat Aging Test, 135 ºC × 7 days	
Tensile strength (T. S.), MPa	22.4
Retention of T. S., %	106
Elongation (EL) at break, %	465
Retention of EL, %	974.
3.Heat Extension Test, 200 ºC × 15 min	
Extension under load test, %	75
Permanent extension, %	0
4. Heat Shrinkage (130 ºC, 1h), %	1
5. Degree of Water Absorption (85ºC, 14d)	0.01
6. discharge capacity, PC	3
7. Withstand Voltage Test	pass
(22kV, 5min)	
8. tg δ (95-100 ºC, ≥2 kV)	0.0005

[a] The results were reported by China State Center of Supervision and Proof-test of Wire and Cable Equalty

4. Unique Advantages of Photocrosslinking Process

Comparison with the peroxides chemical crosslinking, alkoxy silane crosslinking, and high-energy electron beam (EB) irradiation crosslinking, the photocrosslinking technology for manufacturing the XLPE insulation cables has some unique advantages:

- Much lower primary investment of about 1/20-1/5 cost of EB and chemical crosslinking;
- Simple control conditions, easy operation and maintenance;
- Occupying a smaller space for the apparatus, which is easy to incorporate into the normal production line of wire and cable;
- Lower operating costs for excellent ratio of properties and price of products;
- High production efficiency;
- Saving energy and environment-friendly, and so on.