Journal of Advanced Research in Applied Mechanics

Journal homepage: https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

SEMARAK ILMU PUBLISHING

Analysis of Insulation Properties for High Voltage Applications – A Review

Muhammad Syahmi Jerferi[1], Nor Akmal Mohd Jamail[1,*], Nor Shahida Mohd Jamail[2], Qamarul Ezani Kamarudin[3]

1 Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, 86400 Batu Pahat, Johor, Malaysia
2 Prince Sultan University, Riyadh 12435, Saudi Arabia
3 Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, 86400 Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 21 September 2024
Received in revised form 23 October 2024
Accepted 29 October 2024
Available online 30 November 2024

Keywords:
High voltage; insulation; XLPE; HDPE; LDPE; LLDPE

ABSTRACT

Four popular plastic polymers (LLDPE, XLPE, LDPE and HDPE) that are frequently utilised in high voltage applications are thoroughly examined in the review. It highlights how crucial it is to choose the right insulating material based on your needs. HDPE is perfect for pipes and packaging due to its density and crystallinity. Because of its superior mechanical and thermal properties due to the cross-linking process, XLPE is the material of choice for electrical insulation. The low density, impact resistance and flexibility of LDPE are well known. The essay also examines initiatives to improve these materials, such as the use of nanofillers for XLPE in HVDC cable applications and the addition of alumina nanoparticles to HDPE to boost its dielectric qualities. In conclusion, XLPE excels in thermal stability and electrical insulation, HDPE in toughness and chemical resistance and LDPE in flexibility and impact resistance. The best material to use depends on the needs of the high voltage application. Overall, the essay offers a complete analysis of the characteristics and possible applications of LLDPE, XLPE, LDPE and HDPE in high voltage insulation.

1. Introduction

The proper insulating material selection in high voltage applications is essential for guaranteeing the safe and efficient operation of electrical equipment. Performance and dependability of insulating materials are essential for preventing electrical failures and maintaining the integrity of high voltage systems. The necessity to analyse and compare different insulation materials in order to pinpoint the best solutions for high voltage applications grows as technology progresses and the demand for higher voltage and power densities rises. From Ghani, Mohd Din and Jalil [1], polymer blending is also one of the methods for the development of new materials with a variety of properties and superior than the individual component polymer. It is one of the efficient ways to reduce the crystalline content, as well as to improve the amorphous content. Generally, the polymer materials are

* *Corresponding author.*
E-mail address: norakmal@uthm.edu.my

https://doi.org/10.37934/aram.127.1.6476

insulators and they blend with conductive filler to improve its conductivity properties stated by Ghani, Mohd Din and Jalil [1].

In order to compete with other materials, this material also needs to have high thermal conductivity, a low coefficient of thermal expansion and a low dielectric constant. Numerous studies are now being undertaken to enhance the performance of insulating materials used in high voltage applications. This substance used as a shield to protect conductors from the earth or other conductors. Many different types of materials have been employed as insulation. Only four favoured materials were studied in this work. Low-density polyethylene (LDPE), cross-linked polyethylene (XLPE), linear low-density polyethylene (LLDPE) and high-density polyethylene (HDPE) are these four substances. The review's goal is to determine the best insulating material utilisation for high voltage applications.

2. Methodology

2.1 Polyethylene (PE)

Polyethylene (PE) is the type of plastic that is used the most frequently worldwide. Its structure is the most straightforward of all the polymers used in industry. Polymer molecules have a high molar mass and a lot of replication units. Polymers both natural and artificial were present. Natural polymers include those found in proteins, carbohydrates, cellulose and latex. The entire family of substances referred to as plastics is made up of synthetic polymers.

The thermoplastic nature of polyethylene (PE) resins causes them to soften or fuse when heated and harden and solidify once more when cooled without significantly altering their chemical composition. Polyethylene was produced using ethylene gas. Natural gas feedstock or petroleum byproducts are cracked in order to produce ethylene gas. Depending on the kind of polyethylene, ethylene can polymerize at varied pressures, temperatures and catalysts to produce extraordinarily long polymer chains. It is possible to produce a wide range of polyethylene resins by employing different reactor technologies, running several reactor configurations or copolymerizing ethylene with other gases like vinyl acetate or other olefins like butene, hexene or octene. Polyethylene resins can be used to make a variety of things, such as packaging films, hard food cans, milk and water bottles, big toys, etc.

There are many different physical features that can be observed when the polymerization methods of the resins of the PE family are compared. Before pelletizing the resulting polyethylene products in both cases, additives including antioxidants and processing aids were introduced to compound extruders. The polymerization of ethylene during the creation of polyethylene is shown in Figure 1 stated by dos Santos *et al.*, [30].

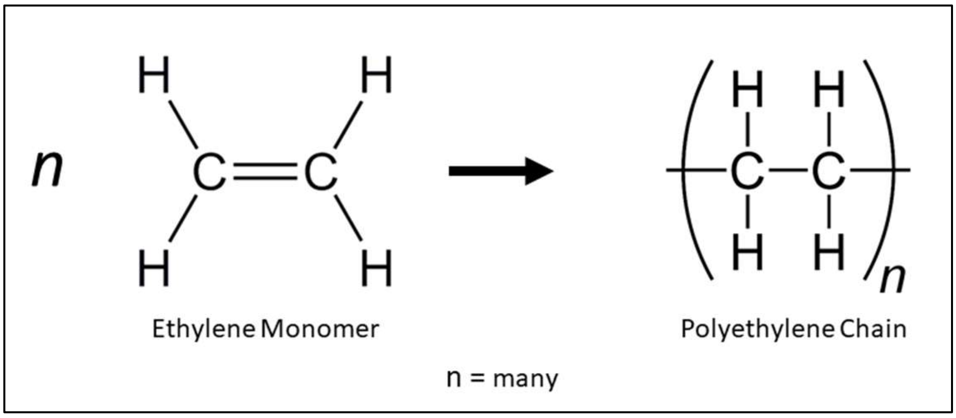


Fig. 1. Ethylene is polymerized to create polyethylene

Polyethylene was split into various classes according to density and branching as shown in Figure 2. Aljoumaa and Allaf [2] stated heir branching size and form, crystal concentration and molecular mass all had a significant impact on their mechanical properties. High density polyethylene (HDPE), linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE) and cross-linked polyethylene (XLPE) make up the majority of polyethylene sales.

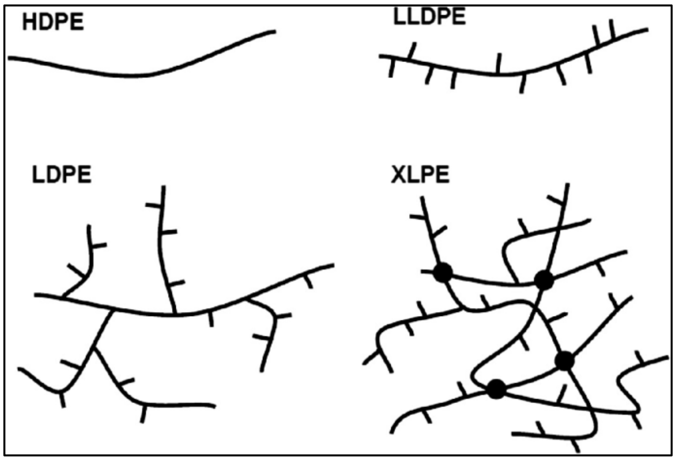


Fig. 2. The HDPE, LLDPE, LDPE and XLPE polymer chain branching diagram

In addition to polyethylene, polypropylene (PP) has been investigated as a base material for HV insulating materials. As an insulating material for high voltage applications, polypropylene has been researched by Reed [3]. This is a simple polyolefin that is derived from petroleum and is similar to polyethylene. While the polypropylene chains feature methyl (-CH_3) alternative carbon atom side groups, the neighbouring -CH-groups on the polyethylene chains are arranged either (usually) linearly or branchedly. Due to van der Waals forces, polypropylene has a greater glass transition and crystalline melting point than polyethylene. This allows it to reach temperatures beyond 100°C and perhaps even briefly as high as 140°C. In addition, the researchers found that polypropylene has a variety of drawbacks, which necessitates innovation through co-polymers or blends with polyethylene or other polymers to solve such drawbacks. The dielectric strength of the polyethylene samples was greater than that of the polypropylene samples. The samples of polyethylene and polypropylene are summarised in this publication. For HDPE, LDPE and PP, the corresponding average breakdowns were 70, 79 and 55 kV/mm. When polypropylene was combined with LDPE and HDPE, its breakdown strength increased. Combining PP with HDPE or LDPE accelerated the breakdown of PP. In comparison to pure HDPE and LDPE, the breakdown strengths were still lower stated by Ahmed Dabbak *et al.*, [4].

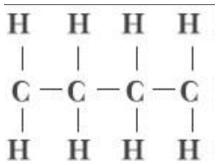
Hanley *et al.*, [5] state that spherulites are composed of polyethylene, which is typically 15–40% crystalline and is best described as a cluster of lamella crystallites surrounded by amorphous regions. The mechanical and electrical properties of the material are influenced by the spherulite's size; this article will focus on the production temperatures and cooling speeds. While quenching results in smaller spherulites and lower crystallinity, annealing creates larger spherulites and higher crystallinity. To lessen the possibility of void formation, extruded cables undergo precise heating and cooling under high pressure in an inert atmosphere. The further cooling is done in water under the same pressure as the previous phase.

The research cited above indicates that polyethylene is currently the most effective material for usage as a high voltage insulating material. In this application, various types of this material are utilised. Based on the preparation and assembly methods used with the polyethylene, the material was categorised. The most common forms of polyethylene used in insulation are reviewed here.

2.2 High-Density Polyethylene (HDPE)

HDPE was a versatile plastic polymer with many applications. Slurries, solutions and gas-phase reactors can all produce polymers. Transition metal catalysts were frequently employed in HDPE processing to produce polymer chains with little branching and good tensile strength. The packing density of HDPE is higher than that of other polyethylene varieties. Branch management and reduction can be accomplished by using particular catalysts during the production process. Many HDPE copolymers contain butene, hexene and octene. Ethylene was polymerized without the use of a co-polymer to create HDPE homopolymers. The final products are the densest and crystallin of all the members of the PE family. The HDPE's characteristics were shown in Table 1 from Sam *et al.*, [31].

Table 1
The general properties of HDPE

Property	High Density Polyethylene (HDPE)
Melting Point	~$135°C$
Crystallinity	Highly Crystalline (>90% crystalline). Has a side chain ratio of 200 carbon atoms or less, resulting in long linear chains with uniform packing and good crystallinity.
Flexibility	Increased crystallinity causes it to be stiffer than LDPE.
Strength	Strong due to the regular packing of polymer chains.
Heat Resistance	Useful above $100°C$.
Transparency	It was more crystalline than LDPE but less transparent.
Density	Greater density than LDPE at 0.95 to 0.97 g/cm3.
Chemical Properties	Chemical inert.
Schematic Diagram	
Applications	Freezer bags, water pipes, wire and cable insulation, extrusion coating.

In terms of modulus, yield and tensile strength, HDPE was comparable to LLDPE and MDPE. Additionally, it is denser than LDPE. Due to its higher crystallinity, HDPE is unable to match the purity of LDPE or LLDPE film. Extruded HDPE pipe was frequently utilised to transport natural gas and potable water. Blow-moulded packaging for industrial and home chemicals, such as bottles for soap, shampoo and bleach, is another significant use.

HDPE was the material of choice in many industries due to its various distinguishing characteristics. Due to its high stiffness and chemical resistance, HDPE made an excellent material for trays and tanks. Due to its adaptability and excellent strength, HDPE made a fantastic material for pipe applications. Additionally, due to its superior impact resistance, light weight, low moisture absorption and tensile strength, HDPE is suitable for usage in heavy-duty industries such as construction and vehicle manufacturing stated by Schulte and Von Lacroix [6].

Due to its numerous advantages, HDPE was the preferred material in a number of sectors. According to Tanaka [7], modified HDPE cables offer remarkable DC characteristics and improved breakdown characteristics comparable to Polypropylene Laminated Paper (PPLP) Cables. Phenolic antioxidant and chlorine catcher are both present in the modified HDPE. This modification has increased the inherent breakdown strength because of the high crystallinity of the basic polyethylene and the sparse grafted modifying group distribution. Additionally, it has remarkable thermal properties, particularly thermal resistance, which is comparable to around 60% oil-impregnated paper and 80% XLPE. Allowing for greater current loading. However, compared to XLPE, modified HDPE has a cable core that is approximately 2.5 times more rigid when bent stated by Tanaka [7].

In the meanwhile, experimentation was conducted by Ramkumar and Pugazhendhi [8], the experimental findings of this study shown that compositions of HDPE at 3 weight percent with AI_2O_3 nanofiller had improved HDPE qualities in terms of capacitance value. This mixture of AI_2O_3/HDPE has a dielectric constant of 3.332, up 20.18% from pure HDPE, which has a dielectric constant of 2.774. When compared to pure HDPE, the dissipation loss of 7 weight percent AI_2O_3/HDPE was determined to have a value of l. The dissipation factor is decreased because alumina naturally has a higher thermal conductivity than other materials. The breakdown voltage of HDPE with a 5 wt% AI_2O_3 composition is 16.3% higher than pure HDPE, according to this study. HDPE's dielectric characteristics can be improved by adding AI_2O_3 nanoparticles at the suitable weight percentage. Since adding more additives produces more conducting ions and speeds up breakdown, the precise amount of nano filler used is crucial. Conclusion: Compared to pure HDPE, alumina and HDPE have the strongest break-down strength at 5 weight percent while also having a higher dielectric constant.

2.3 Cross-Linked Polyethylene (XLPE)

Cross-linked polyethylene (XLPE), is improved through the use of a cross-linking process. The cross-linking develops a three-dimensional network structure, which enhances the material's mechanical and thermal properties. XLPE is frequently utilised as electrical insulation in high voltage cables and wires. It ensures effective power transfer, lowers power loss and reliable insulation. The material's low dissipation factor and dielectric constant help it operate electrically better. XLPE is used for construction insulation, plumbing and automotive parts in addition to electrical insulation. Due to its resistance to chemical corrosion, scaling and pressure, XLPE is utilised in plumbing for pipes, fittings and tubing.

Because of its superior thermal stability, XLPE can keep its structural integrity even at high temperatures. Additionally, it demonstrates high mechanical toughness, strength and resistance to impact, abrasion and stress cracking. Its longevity and dependability are facilitated by these qualities. Another benefit of XLPE is its chemical resistance, which makes it appropriate for applications involving exposure to acids, alkalis, solvents and oils. When in touch with different chemicals, it keeps its qualities, minimising degradation and providing dependable performance. Extrusion, injection moulding and compression moulding are all processes that can be used to process XLPE, enabling the creation of intricate parts and unique designs. Due to its adaptability, the material can be used in a variety of applications. The XLPE's characteristics were shown in Table 2 [32].

Table 2
The general properties of XLPE

Property	Cross-Linked Polyethylene (HDPE)
Thermal Stability	Excellent ability to withstand elevated temperatures.
Electrical Insulation	High dielectric strength, low dielectric constant.
Mechanical Strength	Enhanced resistance to stress cracking, impact and abrasion.
Chemical Resistance	Good resistance to acids, alkalis, solvents and oils.
Durability	Long-lasting material with resistance to degradation.
Application Areas	Electrical cables, plumbing, automotive components, insulation.
Thermal Conductivity	Low thermal conductivity.
Flexibility	Exhibits flexibility for ease of installation and use.

In conclusion, Cross-Linked Polyethylene (XLPE) stands out for its exceptional thermal stability and resistance to high temperatures, making it appropriate for applications where thermal endurance is essential. In terms of electrical insulation and heat stability, it performs better than LLDPE, HDPE and LDPE. Because of its outstanding mechanical strength, impact resistance and endurance, XLPE can perform for an extended period of time under harsh conditions. LLDPE and LDPE offer more flexibility, but HDPE and LDPE have similar mechanical strength characteristics. Another crucial feature is chemical resistance and XLPE excels in this area thanks to its excellent resistance to acids, alkalis, solvents and oils, which allows it to keep performing even when exposed to harsh materials. While LLDPE and LDPE only offer moderate chemical resistance, HDPE exhibits high chemical resistance, making it the best choice for applications involving corrosive substances. It is possible to process XLPE, HDPE, LLDPE and LDPE utilising a variety of methods, giving manufacturers more freedom to create complicated components and one-of-a-kind designs that adhere to particular specifications. When it comes to toughness, XLPE stands out for its enduring performance, which keeps its qualities over time and ensures dependability in demanding applications. HDPE is frequently utilised in pipes, containers and industrial applications because of its remarkable durability. Compared to XLPE and HDPE, LLDPE and LDPE offer a moderate amount of durability. Overall, XLPE combines mechanical strength, chemical resistance, electrical insulation and thermal stability, making it a preferred option for applications needing exceptional performance in challenging environments.

Mecheri *et al.*, [9] looked at the performance of XLPE, the substance used as insulation in MV 18/30 kV cables, in relation to the effects of thermal ageing conditions. Significant material degradation was observed under situations of high stress that mimicked overload and short circuit occurring in insulated power cables at temperatures of 135°C and 150°C, respectively. A thermal degradation mechanism that involves breakdown reactions, chain breakage and oxidation can be assumed based on the impact of temperature on material performance. During this degradation, which is marked by an increase in the dissipation factor and mass loss, all parameters, including volume resistivity, dielectric strength, elongation at rupture and tensile strength, decrease stated by Mecheri *et al.*, [9].

In order to improve the material's properties and solve the issue that pure XLPE had in HVDC cable applications, the introduction of XLPE with nano filler material was made by Kaihao *et al.*, [10]. The organic nanofiller silicon oxide, SiO2, is added by the researcher to the XLPE. This filler was discovered to serve a function in improving heterogeneous nucleation, speeding up crystallisation, shrinking crystal size and dispersing crystals even more equally. XLPE with Aluminium Oxide (AI_2O_3/XLPE) nanofiller, XLPE without nanofiller and XLPE with filled polymer were all used in the study to compare conduction currents at various temperatures stated by Eirinakis *et al.*, [11]. This investigation reveals that filled polymer XLPE conductivity is inferior to AI_2O_3/XLPE. Thermal activation energies for nano AI_2O_3/XLPE composite, 1.35eV for polymer-filled XLPE and 0.84eV for pure XLPE. According to this study's findings, adding nanofiller has less of an impact on thermal activation energy than adding polymer filler does.

2.4 Low-Density Polyethylene (LDPE)

The thermoplastic polymer known as low-density polyethylene (LDPE) is a member of the polyethylene family. It is distinguished by having a low density, which is made possible by its distinct production procedure and molecular makeup. Ethylene gas is high-pressure polymerized to create LDPE, which has a branched structure and a significant amount of short and long chain branching. LDPE is renowned for its superior impact resistance, flexibility and toughness. Because of its low density, which typically ranges from 0.91 to 0.925 g/cm^3, LDPE has unique characteristics including being flexible and malleable. Due to its flexibility, LDPE works well in applications that call for bending, folding or shaping, such as flexible packaging materials, plastic bags and films.

The outstanding chemical resistance of LDPE is one of its main benefits. Acids, bases, alcohols and solvents are just a few of the compounds that it can withstand. LDPE can be employed in a variety of applications when contact with corrosive substances is anticipated due to its resistance to chemical attack. For instance, LDPE is frequently used in laboratory equipment, chemical-resistant linings and chemical storage containers. Additionally, LDPE has high electrical insulating qualities. It still offers sufficient electrical insulation for low voltage applications despite not having the same high dielectric strength as other polyethylene types. Lower voltage electrical lines and cables frequently have LDPE employed as an insulating material. The resistance to moisture of LDPE is another noteworthy quality. It is suitable for applications where contact with water or moisture is frequent due to its low water absorption characteristics. Waterproof films, barrier protection and water-resistant coatings are all common uses for LDPE. When it comes to processability, LDPE demonstrates good melt flow characteristics that make processing and moulding simple. It can be shaped into a variety of shapes and forms via extrusion, blow moulding, injection moulding and thermoforming. Manufacturers may create a wide variety of LDPE-based products with various sizes, thicknesses and geometries thanks to the flexibility of processing techniques. The LDPE's characteristics were shown in Table 3 from Sam *et al.*, [31].

Table 3
The general properties of LDPE

Property	Low-Density Polyethylene (LDPE)
Melting Point	$\sim 115°C$
Crystallinity	Low Crystalline (>90% crystalline).
Flexibility	Reduced crystallinity makes it more flexible than HDPE.
Heat Resistance	Maintains flexibility and toughness across a broad temperature range, although density plummets significantly above room temperature.
Transparency	Since it is more amorphous (has noncrystalline sections) than HDPE, it offers good transparency.
Density	0.91-0.94 g/cm3 lower density than HDPE.
Chemical	Chemical inert.
Properties	Strength and tear resistance are lost when exposed to light and oxygen.
Applications	Flexible packaging, plastic bags, films, coatings, insulation.

As a thermoplastic polymer with many uses, low-density polyethylene (LDPE) is renowned for its low density, high flexibility and exceptional toughness. It has minimal water absorption qualities, good electrical insulation for low voltage applications and good chemical resistance. Due to its simplicity in processing and moulding, LDPE is appropriate for a variety of uses, including flexible packaging, plastic bags, films, coatings and insulation. High-Density Polyethylene (HDPE) and Linear

Low-Density Polyethylene (LLDPE) have higher densities and demonstrate intermediate toughness and chemical resistance when compared to other polyethylene kinds like LDPE. The cross-linking process that Cross-Linked Polyethylene (XLPE) goes through improves its electrical insulating capabilities while also giving it a low density, making it appropriate for high voltage applications. Every variety of polyethylene has unique benefits and uses. Flexible packaging uses LDPE, while pipes and containers frequently use HDPE. While XLPE is used for high voltage cables and insulation, LLDPE offers moderate toughness and flexibility. It is possible to choose the right material for a certain application by understanding the special characteristics of LDPE and how it differs from XLPE, HDPE and LLDPE.

David *et al.*, [12] was motivated by this to investigate LDPE-based nanocomposites enhanced with magnesium oxide (MgO), polyhedral oligomeric siloxanes (POSS) or zinc oxide (ZnO), either by mechanical alloying or melt mixing. For low loadings between 0 and 5 wt%, the dielectric characteristics were investigated to see how effectively the compounding process improved them. The addition of MgO nanoparticles—whether treated or untreated—improved the material's resistance to space charges amassing in a field similar to the operational field in power cables under a much higher electrical field. ZnO or POSS did not significantly change the behaviour of the material with regard to space charges. From Kikuma *et al.*, [13], measurements of the dielectric characteristics of LDPE and MgO nanocomposites were made. Between 278K and 363K, the resistivity rises with the addition of filler up to 5 phr but falls at 10 phr. Given that the conductive current is one of the primary sources of tan A, it seems sense that this sequence is exactly the reverse of that of tan 3. The right number of nano-fillers, which helps electronic or ionic charge carriers escape traps by hopping around in molecules.

Castellon *et al.*, [14] discovered that the material's space charge accumulation was reduced by the nanofiller's presence. When tested under various poling conditions where they applied electric field and time, MgO nanoparticle-containing nanocomposite sample develops less space charge than reference sample. Following the application of a weak electrical field, MgO and POSS polyethylene composites both demonstrated their capacity to endure the accumulation of space charges. When a strong electrical field is provided and a long poling period is used, the nanocomposites created by melt mixing with silane-treated nanoparticles acquire less space charge than their untreated counterpart. LDPE blends with fillers had been examined by Guastavino *et al.*, [15]. The test results show that because pure blends have greater voltage endurance coefficients than composites, they behave better over the long run. At the maximum voltage, the filler content exhibits very poor performance. It is because a bigger amount of filler was inserted, which often results in a percolating effect and an exfoliated structure.

2.5 Linear Low-Density Polyethylene (LLDPE)

Linear Low-Density Polyethylene (LLDPE) has a linear molecular structure. LLDPE is created when ethylene is copolymerized with comonomers such 1-butene, 1-hexene or 1-octene. LLDPE gains distinctive features from the comonomer addition during the polymerization process, making it a flexible material for a range of applications. LLDPE demonstrates a number of distinctive traits that make it stand out. First of all, it is less dense than LDPE and HDPE, often weighing between 0.915 and 0.935 g/cm3. A material with superior flexibility and elongation qualities will be lighter because to the decreased density.

The better film-forming capabilities of LLDPE are one of its salient benefits. It is easily processed to create films with remarkable clarity, flexibility and heat-sealing qualities utilising methods including extrusion and blow moulding. LLDPE films have many uses in the packaging industry, including stretch films, food packaging, agricultural films and industrial packaging. Due to its strong chemical resistance, LLDPE can endure exposure to a variety of solvents, acids and bases. In applications where the material might come into touch with chemicals or stress-inducing agents, it provides resistance to environmental stress cracking, which is very advantageous. Additionally, LLDPE is ideal for outdoor applications such as geomembranes, pond liners and protective covers because to its outstanding resistance to UV radiation, weathering and outdoor exposure. LLDPE has greater tensile strength, impact strength and puncture resistance than LDPE. In contrast to LDPE, LLDPE could have a little less clarity and flexibility. The LLDPE's characteristics were shown in Table 4 [33].

Table 4
The general properties of LLDPE

Property	Linear Low-Density Polyethylene (LLDPE)
Density	Low to medium density: 0.915 - 0.935 g/cm³.
Flexibility	High flexibility and good elongation properties.
Tensile Strength	Excellent tensile strength.
Impact Strength	High impact resistance.
Puncture Resistance	Good resistance to punctures.
Chemical Resistance	Good resistance to chemicals, acids and bases.
UV Resistance	Excellent resistance to UV radiation and weathering.
Crystallinity	Semi-crystalline, level between 35 to 60%.
Environmental Stress Cracking	Resistance to stress-induced cracking.
Applications	Packaging films, agricultural films, geomembranes, pond liners, protective covers.

In conclusion, Linear Low-Density Polyethylene (LLDPE) is a versatile kind of polyethylene that differs from Cross-Linked Polyethylene (XLPE), High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE) in that it has unique features. High flexibility, great tensile strength, impact resistance and puncture resistance are all characteristics of LLDPE. Similar to XLPE but with a lower density than HDPE and LDPE. LLDPE is useful for a variety of applications due to its strong chemical resistance, UV resistance and film-forming capabilities. LLDPE is distinguished from other polyethylene kinds by having greater tensile strength, impact resistance and film-forming capabilities. In terms of flexibility, chemical resistance and UV resistance, it is comparable to HDPE and LDPE. However, XLPE might provide improved chemical resistance and distinct film-forming properties due to its cross-linked structure.

Due to its special characteristics, LLDPE is frequently chosen in applications where flexibility, toughness, impact resistance and puncture resistance are essential. It is a good fit for industrial packaging and packaging films thanks to its film-forming capabilities. LLDPE is more suitable for a variety of outdoor and industrial applications thanks to its chemical and UV resistance. When choosing a material for a given application, it is important to be aware of the special qualities of LLDPE and how it differs from other polyethylene materials. LLDPE is a useful polymer in a variety of industries, from packaging to agricultural, thanks to its adaptability and dependability. These industries benefit from its superior mechanical and chemical qualities, which enable maximum performance and long-lasting durability.

Go *et al.*, [16] tested the blend films made from LLDPE and ethylene-vinyl acetate with weight percentages of 80:20, 70:30, 60:40 and 50:5O. The research and comparison of the physical characteristics and dielectric strength to pure LLDPE. The outcome demonstrates that samples with a 70:30 and 50:50 ratio have superb insulating and dielectric characteristics. Pure LLDPE is less stable at various temperatures and thicknesses than the other two samples. For each specimen, virgin LLDPE has the highest dielectric strength while virgin EVA has the lowest. Mixed film has somewhat lower dielectric strengths than virgin LLDPE, but it is more stable at changing temperatures. It is concluded that the performance of PE can be enhanced by combining LLDPE with EVA stated by Go *et al.*, [16].

According to Chen *et al.*, [17], when nano alumina was added to LLDPE, the material's I-V properties changed. The number of nano alumina particles has a significant impact on the alternation. The material's I-V properties are improved for a little amount, like 1% by weight. The conduction current reduces at lower applied voltages as the number of nano alumina particles rises, but it increases significantly at higher applied voltages. A small percentage of alumina in the mixture shows that charge is dispersed throughout the majority of the substance. As alumina content changes, polyethylene's conduction current rises stated by Chen *et al.*, [17]. The results of Li *et al.*, [18] investigation showed that at $30°C$, LDPE-based material can endure a stronger DC field than LLDPE-based material. On the other hand, the DC breakdown strength of LDPE-based materials decreases at $90°C$, by more than 50% and by more than 50% at $70°C$. At a temperature of 30 °C, LLDPE-based materials have a lower DC breakdown strength than LDPE-based materials. However, the DC breakdown strength of LLDPE-based materials only marginally reduces when the temperature rises. In terms of thermal stability, LLDPE-based materials perform better than LDPE-based materials stated by Li *et al.*, [18].

The PDC values can be reduced when nanoparticles are introduced to LLDPE nano composites and varied filler concentrations can have a variety of outcomes. It has been discovered that at 1% by weight of nano alumina and titanium particles, the conduction current exhibits a minimum. Researchers found that adding MgO nanofiller to LDPE enhances its volume resistivity stated by Jamail *et al.*, [19]. The conductivity investigation demonstrates that the polymer's insulating capabilities were improved by the addition of nanofiller. With a specific amount, the nanofiller exhibits a considerable drop in DC conductivity; this behaviour is consistent across all fillers and materials. The dielectric permittivity of LLDPE was discovered by Zhang *et al.*, [20] to exhibit a slight effect on frequency in the range of 10^4 to 10^6Hz. According to Zhang *et al.*, [20], the dielectric permittivity increases as the alumina concentration is raised in the LLDPE. Due to the LLDPE's lower dielectric permittivity than the alumina concentration, this is the case. While other studies from Jamail *et al.*, [21], Salleh *et al.*, [22], Aziz *et al.*, [23], Jamail *et al.*, [24], Piah and Hassan [25,26], Razali *et al.*, [27] and Makmud *et al.*, [28] have looked at the possibility of incorporating additional nanofiller into the LLDPE-NR material's framework. The finding shows that both composites enlarge with increasing nanofiller weight percentage. TiO_2 composite, which is made of titanium oxide, will make the dielectric of LLDPE better whereas SiO_2 composite will worsen it. In terms of the lowest polarisation and depolarization current values as well as the lowest conductivity level, it is discovered that the LLDPE-NR over SiO_2 at 5 wt% is the optimal composition for HV insulation. According to the study of Lebedev, Gefle and Zakurdaev [29], LDPE has a 104°C melting point compared to 125°C for LLDPE. The average breakdown strength and breakdown voltage readings have increased by about 12–15% in comparison to LDPE since the sample test. By substituting LLDPE for LDPE, large sizes can considerably improve their thermal, electrical and mechanical properties.

3. Conclusions

The four materials that have been carefully scrutinised are linear low-density polyethylene (LLDPE), cross-linked polyethylene (XLPE), low-density polyethylene (LDPE) and high-density polyethylene (HDPE). These insulation materials are made primarily of polyethylene (PE), the most popular type of plastic. Its superior chemical resistance, rigidity and impact resistance make HDPE, a dense and crystalline version of PE, useful for a variety of applications. The breakdown properties and thermal resistance of modified HDPE have been improved by the addition of additives like phenolic antioxidants.

To improve its mechanical and thermal qualities, cross-linking is applied to XLPE. It has exceptional mechanical strength, thermal stability, electrical insulation and chemical resistance, which makes it the perfect choice for applications demanding endurance in challenging environments. Due to its low density, LDPE provides the best impact resistance, flexibility and toughness. Even though it doesn't have the same degree of mechanical strength as HDPE and XLPE, it can still be used in a variety of applications. Overall, due to its combination of mechanical strength, chemical resistance, electrical insulation and thermal stability, XLPE stands out as the preferable material for applications needing high performance in demanding situations. While LDPE excels in flexibility and impact resistance, HDPE is preferred for its durability.

Further study has looked at adding nano fillers to XLPE and HDPE to increase their characteristics, leading to better dielectric properties and thermal activation energy. In conclusion, the safe and efficient operation of high voltage systems depends on the choice of insulation material. Making wise decisions in high voltage applications requires an understanding of the characteristics and capabilities of various materials.

Acknowledgement

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) for the financial support. This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through GPPS (vot Q226). The authors also gratefully acknowledge Kvolt Focus Group Team and Prince Sultan University, Saudi Arabia for technical support.

References

[1] Ghani, Supri A., Siti Hajar Mohd Din and Jalilah Abd Jalil. "Properties of Poly (vinyl chloride)/poly (ethylene oxide)/polyaniline Conductive Films: The Effect of Poly (ethylene glycol) Diglycidyl Ether." *Polymer-Plastics Technology and Engineering* 55, no. 9 (2016): 929-936. https://doi.org/10.1080/03602559.2015.1132440

[2] Aljoumaa, Khaled and Abdul Wahab Allaf. "Morphology, structure, properties and applications of XLPE." In *Crosslinkable Polyethylene: Manufacture, Properties, Recycling and Applications*, pp. 125-166. Singapore: Springer Singapore, 2021. https://doi.org/10.1007/978-981-16-0514-7_6

[3] Reed, C. W. "An assessment of material selection for high voltage DC extruded polymer cables." *IEEE Electrical Insulation Magazine* 33, no. 4 (2017): 22-26. https://doi.org/10.1109/MEI.2017.7956629

[4] Ahmed Dabbak, Sameh Ziad, Hazlee Azil Illias, Bee Chin Ang, Nurul Ain Abdul Latiff and Mohamad Zul Hilmey Makmud. "Electrical properties of polyethylene/polypropylene compounds for high-voltage insulation." *Energies* 11, no. 6 (2018): 1448. https://doi.org/10.3390/en11061448

[5] Hanley, Tracey L., Robert P. Burford, Robert J. Fleming and Kenneth W. Barber. "A general review of polymeric insulation for use in HVDC cables." *IEEE Electrical Insulation Magazine* 19, no. 1 (2003): 13-24. https://doi.org/10.1109/MEI.2003.1178104

[6] Schulte, Karl and F. R. A. N. K. Von Lacroix. "High-density polyethylene fiber/polyethylene matrix composites." (2000): 231-248. https://doi.org/10.1016/B0-08-042993-9/00065-6

[7] Tanaka, T. "High performance HVDC polymer cable." *Jicable'99* (1999).

[8] Ramkumar, R. and Sugumaran C. Pugazhendhi. "Investigation on the electrothermal properties of nanocomposite HDPE." *Journal of Nanomaterials* 2019 (2019). https://doi.org/10.1155/2019/5947948

[9] Mecheri, Yacine, Slimane Bouazabia, Ahmed Boubakeur and M. Lallouani. "Effect of thermal ageing on the properties of XLPE as an insulating material for HV cables." In *Proceedings of the International Electrical Insulation Conference, IET Centre, Birmingham, UK*, pp. 29-31. 2013.

[10] Kaihao, Jin, Di Donghe, Xian Richang, Wang Xiaoqiang, Yang Peijie and Li Xiufeng. "Study on dielectric structure and space charge behavior of XLPE/SiO 2 nanocomposites." In *2018 12th International Conference on the Properties and Applications of Dielectric Materials (ICPADM)*, pp. 921-924. IEEE, 2018. https://doi.org/10.1109/ICPADM.2018.8401213

[11] Eirinakis, Pavlos, Kostas Kalaboukas, Stavros Lounis, Ioannis Mourtos, Jože M. Rožanec, Nenad Stojanovic and Georgios Zois. "Enhancing cognition for digital twins." In *2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, pp. 1-7. IEEE, 2020. https://doi.org/10.1109/ICE/ITMC49519.2020.9198492
[12] David, E., J. Castellon, M. Fréchette, M. Guo and E. G. E. E. Helal. "Dielectric properties of various metallic Oxide/LDPE nanocomposites compounded by different techniques." In *2017 IEEE Electrical Insulation Conference (EIC)*, pp. 151-154. IEEE, 2017. https://doi.org/10.1109/EIC.2017.8004675
[13] Kikuma, Toshiaki, Norikazu Fuse, Toshikatsu Tanaka, Yoshinao Murata and Yoshimichi Ohki. "Dielectric properties of low-density polyethylene/MgO nanocomposites." In *2006 IEEE 8th International Conference on Properties & applications of Dielectric Materials*, pp. 323-326. IEEE, 2006. https://doi.org/10.1109/ICPADM.2006.284181
[14] Castellon, J., Hanen Yahyaoui, O. Guille, E. David, M. Guo and M. Fréchette. "Dielectric properties of POSS/LDPE and MgO/LDPE nanocomposites compounded by different techniques." In *2017 IEEE Conference on Electrical Insulation and Dielectric Phenomenon (CEIDP)*, pp. 457-460. IEEE, 2017. https://doi.org/10.1109/CEIDP.2017.8257513
[15] Guastavino, F., L. Della Giovanna, E. Torello, N. Garcia and P. Tiemblo Magro. "Electrical aging tests on nanocomposite polymer blends based on LDPE." In *2015 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, pp. 812-815. IEEE, 2015. https://doi.org/10.1109/CEIDP.2015.7352136
[16] Go, Si-Hyeon, Seong-Pil Kim, Min-Woo Seong, Chung-Ho Lee, Su-Won Lee and Jin-Woong Hong. "AC dielectric strength due to the mixture ratio of LLDPE and EVA." In *Proceedings of the 6th International Conference on Properties and Applications of Dielectric Materials (Cat. No. 00CH36347)*, vol. 2, pp. 911-914. IEEE, 2000. https://doi.org/10.1109/ICPADM.2000.876378
[17] Chen, George, J. T. Sadipe, Y. Zhuang, C. Zhang and G. C. Stevens. "Conduction in linear low density polyethylene nanodielectric materials." In *2009 IEEE 9th International Conference on the Properties and Applications of Dielectric Materials*, pp. 845-848. IEEE, 2009. https://doi.org/10.1109/ICPADM.2009.5252208
[18] Li, Yinge, Lisheng Zhong, Liang Cao, Haiyang Ren, Wei Zhao and Jinghui Gao. "DC breakdown characteristics of LLDPE-based XLPE with different crosslinking degrees." In *2018 Condition Monitoring and Diagnosis (CMD)*, pp. 1-4. IEEE, 2018. https://doi.org/10.1109/CMD.2018.8535819
[19] Jamail, Nor Akmal Mohd, Mohamed Afendi Mohamed Piah, Nor Asiah Muhamad, R. A. Zainir, N. F. Kasri and Qamarul Ezani Kamarudin. "DC conductivity of polymer nanocomposites for different types and amount of nanofiller." *International Journal of Electrical Engineering and Informatics* 5, no. 2 (2013): 217-225. https://doi.org/10.15676/ijeei.2013.5.2.9
[20] Zhang, Chao, Ralf Mason and Gary C. Stevens. "Dielectric properties of epoxy and polyethylene nanocomposites." In *Proceedings of 2005 International Symposium on Electrical Insulating Materials, 2005.(ISEIM 2005).*, vol. 2, pp. 393-396. IEEE, 2005. https://doi.org/10.1109/ISEIM.2005.193571
[21] Jamail, N. A. M., M. A. M. Piah, N. A. Muhamad, Z. Salam, N. F. Kasri, R. A. Zainir and Q. E. Kamarudin. "Effect of Nanofillers on the Polarization and Depolarization Current Characteristics of New LLDPE-NR Compound for High Voltage Application." *Advances in Materials Science and Engineering* 2014, no. 1 (2014): 416420. https://doi.org/10.1155/2014/416420
[22] Salleh, Nor Izzati Mohd, Nor Akmal Mohd Jamail, Nishanti Suntharasakan, Nor Shahida Mohd, Mohamad Farid Sies Jamail, Qamarul Ezani Kamarudin and Mohamed Afendi Mohamed Piah. "Analysis of HVDC breakdown characteristic of LLDPE-natural rubber added with biofiller as high voltage insulating material." *Indonesian Journal of Electrical Engineering and Computer Science* 20, no. 3 (2020): 1203-1209. https://doi.org/10.11591/ijeecs.v20.i3.pp1203-1209
[23] Aziz, M. S. A., N. A. Muhamad, N. A. M. Jamail12 and Q. E. Kamarudin. "Effect of Surface Tracking on LLDPE-NR/TiO2 Nanocomposite Conductivity Using PDC." *SMR* 105: 60.
[24] Jamail, Nor Akmal Mohd, Mohamed Afendi Mohamed Piah and N. A. Muhamad. "Effects of SiO 2 nanofillers on Polarization and Depolarization Current (PDC) of LLDPE-NR nanocomposite insulating materials." In *2012 IEEE International Conference on Power and Energy (PECon)*, pp. 707-711. IEEE, 2012. https://doi.org/10.1109/PECon.2012.6450306
[25] Piah, M., Ahmad Darus and Azman Hassan. "Effect of ATH filler on the electrical tracking and erosion properties of natural rubber-LLDPE blends under wet contaminated conditions." *Journal of Industrial Technology* 13, no. 1 (2004): 27-40.
[26] Piah, M. A. M., A. Darus and A. Hassan. "Electrical tracking performance of LLDPE-natural rubber blends by employing combination of leakage current level and rate of carbon track propagation." *IEEE Transactions on Dielectrics and Electrical Insulation* 12, no. 6 (2005): 1259-1265. https://doi.org/10.1109/TDEI.2005.1561806
[27] Razali, Muhammad Iqbal Hafifi Mohd, N. A. M. Jamail, M. A. A. Azmi, N. H. Zulkifli and N. A. A. N. Zarujhan. "Insulation Characteristics of LLDPE-NR Compound with MMT/Clay Nanofiller for HV Insulation Purposes." PhD diss., Universiti Tun Hussein Onn Malaysia, 2015.

[28] Makmud, Mohamad Zul Hilmey Bin, Aulia Sayuti, Yanuar Z. Arief and Mat Uzir Wahit. "Insulating performance of LLDPE/natural rubber blends by studying partial discharge characteristics and tensile properties." In *Proceedings of the 2011 International Conference on Electrical Engineering and Informatics*, pp. 1-4. IEEE, 2011. https://doi.org/10.1109/ICEEI.2011.6021551
[29] Lebedev, Sergey M., Olga S. Gefle and Ivan Y. Zakurdaev. "Usage of LLDPE for producing large-size HV polymeric insulation." In *2013 International Siberian Conference on Control and Communications (SIBCON)*, pp. 1-3. IEEE, 2013. https://doi.org/10.1109/SIBCON.2013.6693608
[30] dos Santos, Everton Ranny Ferreira. "Nanostructure Materials as Catalysts for the Degradation of Polyolefins." PhD diss., Instituto Superior Técnico, 2018.
[31] Sam, S. T., M. A. Nuradibah, H. Ismail, N. Z. Noriman and S. Ragunathan. "Recent advances in polyolefins/natural polymer blends used for packaging application." *Polymer-Plastics Technology and Engineering* 53, no. 6 (2014): 631-644. https://doi.org/10.1080/03602559.2013.866247
[32] XLPE Cable. “Cross-linked Polyethylene Manufacturer.” *Performance Wire and Cable*, (2022).
[33] Omnexus. “Polyethylene (PE) - Properties, Uses & Application.”