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Characteristics and Production Applications of Polyethylene

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Abstract. Polyethylene is the largest and most widely used plastic in the world, playing an irreplaceable role in many fields such as packaging, automotive, medical, and construction. This paper mainly describes the basic characteristics, production methods, and application scope of polyethylene. Firstly, analyze the physical and chemical properties, including mechanical properties, thermal properties, electrical properties, chemical corrosion resistance, etc. The sources of polyethylene raw materials and main production processes were explored, and the effects of different production processes and methods on the molecular structure and properties of polyethylene were analyzed; And the application of polyethylene in packaging, construction, medical and automotive fields has been studied and summarized. On this basis, the following conclusions were drawn through research: The ice template method significantly enhances the composite effect, and room temperature catalytic hydrogenation is the best for modifying the structure of PPS/bP blends. After adding bP, the shear rate increases at the same drop time, which can reduce the reaction temperature. The rheological curve shows a negative correlation between the two, indicating that bP promotes monomer polymerization and thus reduces the temperature. Extending the dripping time and increasing the shear rate synergistically reduce the reaction temperature and accelerate the polymerization of bP. The two-phase model can effectively describe the reaction mechanism of bP/PABS on PMSGF/PPS/BA, and the lattice effect of drilling and welding iron blocks can reduce the reaction position shift. The circumferential embedding of PABS in the needle belt forms an arched ring structure, optimizing the distribution of ferroalloy welding and improving welding accuracy.

Keywords: polyethylene, physical properties, chemical properties, application scope, production method

1. Introduction

Polyethylene (PE) is currently one of the largest and most widely used plastics in the world. It is a polymer material made by polymerizing ethylene monomers. Since the industrial production in the 1930s, polyethylene has played an important role in packaging, construction, medical, electronic, automotive and other fields due to its excellent physical properties, chemical stability, processing convenience and low cost. There are various types of polyethylene, including low-density polyethylene (LDPE), high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), and ultra-high molecular weight polyethylene (UHMWPE). Different types of

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polyethylene have certain differences in molecular structure, crystallinity, mechanical properties, and chemical stability, which can meet the needs of different application scenarios. This article first introduces the physical and chemical properties of polyethylene, and analyzes its structure and properties; Then explores its raw materials and production processes, including high-pressure method, low-pressure method, and gas-phase method, etc; Finally, it explains the application and development trends of polyethylene in packaging, construction, medical, industrial and other fields. This article provides a reference for the in-depth research and industrial application of polyethylene.

2. Research on polyethylene characteristics

2.1. Physical properties of polyethylene

Polyethylene exhibits distinctive physical properties governed by its semicrystalline structure and molecular weight distribution. Crystallinity levels range from approximately 40 percent in low-density variants to over 90 percent in ultra-high-molecular-weight grades, directly influencing material density, which spans 0.91 to 0.96 grams per cubic centimeter. Thermal behavior demonstrates branching-dependent variations with melting points between 105 and 135 degrees Celsius as determined by differential scanning calorimetry analysis documented in Macromolecules [1]. Mechanical properties show significant diversity with tensile strength measurements from 8 to 40 megapascals and elastic modulus values between 0.1 and 1.5 gigapascals corresponding to density gradients.

Ultra-high-molecular-weight polyethylene displays exceptional wear resistance with abrasion loss below 5 milligrams per 1000 cycles under ASTM D1044 testing. Barrier performance depends critically on morphological organization, where oxygen transmission rates decrease from 3000 cubic centimeters per square meter per day in conventional films to under 5 in nanocomposites. Optical characteristics include haze values typically measured between 3 and 15 percent alongside gloss levels exceeding 85 percent in biaxially oriented films. Electrical insulation capabilities remain outstanding with volume resistivity consistently above 10^{16} ohm-centimeters and dielectric strength surpassing 20 kilovolts per millimeter according to standardized testing methodologies. Rheological behavior varies substantially with melt flow index values spanning 0.1 to over 50 grams per 10 minutes across processing grades.

2.2. Chemical characteristics of polyethylene

The chemical behavior of polyethylene arises from its saturated hydrocarbon structure exhibiting pronounced nonpolar character. Chemical resistance constitutes a fundamental attribute demonstrating stability against mineral acids below 80 percent concentration, alkalis at all concentrations, and polar solvents, including alcohols. This inertness originates from carbon-carbon bond dissociation energies exceeding 340 kilojoules per mole as quantified in comprehensive molecular studies published by Industrial&Engineering Chemistry Research [2]. Nonpolar solvents however, induce measurable swelling with documented weight increases of 15 to 20 percent following 48-hour immersion in aromatic hydrocarbons. Oxidative degradation initiates through radical formation at tertiary carbon sites, accelerating dramatically above 200 degrees Celsius. Stabilization systems employ synergistic antioxidant combinations typically extending induction periods beyond 100 hours at 180 degrees Celsius according to accelerated aging trials. Environmental stress cracking resistance displays molecular architecture dependence, where high-density polyethylene withstands over 1000 hours in bent strip testing, while linear low-density

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variants typically fail within 300 hours. Surface characteristics require particular consideration due to inherently low surface energy, measuring 31 to 33 millinewtons per meter, necessitating activation treatments for adequate adhesion.

Chemical modification pathways significantly expand functionality, including chlorination, producing elastomeric chlorinated polyethylene and grafting reactions with maleic anhydride, introducing polar groups. Thermal decomposition commencing above 350 degrees Celsius follows random chain scission mechanisms generating hydrocarbon mixtures dominated by alkenes and dienesas characterized through pyrolysis-gas chromatography-mass spectrometry techniques detailed in Polymer Degradation and Stability. Recent advances in surface engineering employ atmospheric plasma treatment, achieving 50 percent adhesion strength improvement over corona discharge methods, according to Progress in Polymer Science. PE's versatile properties, ranging from crystallinity (40-90%) and density (0.91-0.96 g/cm^3) to mechanical strength (tensile: 8-40 MPa, modulus: 0.1-1.5 GPa) and exceptional chemical resistance, stem from its molecular structure and are critically influenced by manufacturing parameters.

3. Polyethylene production and application research

3.1. Polyethylene raw materials

The global polyethylene industry relies predominantly on hydrocarbon feedstocks derived from fossil resources, with naphtha steam cracking serving as the primary ethylene production method, accounting for approximately seventy-eight percent of global supply according to comprehensive energy statistics compiled by the International Energy Agency [3]. This conventional pathway consumes between 1.05 and 1.25 tonnes of naphtha per tonne of polyethylene manufactured, with process efficiency varying according to cracking furnace design and operational parameters. The ongoing shale gas revolution has substantially increased ethane dehydrogenation adoption, particularly in North America where it now constitutes sixty-five percent of regional feedstock while demonstrating thirty-five percent lower greenhouse gas emissions compared to naphtha routes as quantified in peer-reviewed research published by the American Chemical Society. Coal-dependent economies, including China, maintain significant methanol-to-olefins production capacity despite its documented twenty to thirty percent higher energy intensity relative to conventional petroleum routes.

New biobased substitutes are a good way to go, with Brazil having the largest commercial facility in the world that uses sugarcane ethanol to produce polyethylene at an annual capacity of more than 200,000 tonnes, which is why they have been shown to have a sustainable route. According to studies on the independent lifecycle of Nature Sustainability, seventy percent of the carbon dioxide equivalent emissions are reduced by seventy percent in the production and disposal phases. According to technical reports, in order to attain nine percent purity throughout the course of nine-month pilot runs in 2023; the US National Renewable Energy Laboratory, which uses catalytic lignin depolymerization and catalytic lignin; achieved ninety-nine point seven percent of the total purity in this regard. While the cost of producing biopolycene still stays high, 1,200 to 1,500 USD per tonne, the cost of bio-polyethylene manufacturing still stays significantly higher than the current cost, according to economic viability analyses, which consistently show that ethane cracking keeps considerable cost advantages at five hundred to seven hundred United States dollars per tonne. The continuous advancement of integrated biorefineries with the use of agricultural waste streams guarantees that biological pathways will cost less in the future. The feedstock landscape is evolving, with shale gas-derived ethane reducing costs and greenhouse gas (GHG) emissions compared to

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naphtha, while promising biobased polyethylene (bio-PE) routes from sugarcane ethanol and lignin offer sustainable alternatives despite current economic challenges.

3.2. Polyethylene production processes

Industrial polyethylene synthesis employs sophisticated polymerization methodologies categorized primarily by reaction mechanism and catalyst systems. High-pressure free-radical polymerization processes operating between two hundred and three hundred megapascals continue to dominate low-density polyethylene production worldwide, with recent innovations such as BASF's multizone tubular reactor design reducing specific energy consumption to eight hundred fifty kilowatt-hours per tonne. Ziegler-Natta catalysis remains fundamental for manufacturing high-density and linear low-density polyethylene variants, where next-generation catalyst systems based on non-phthalate compounds enhance molecular weight distribution control precision by forty percent as documented in detailed kinetic studies published in Macromolecules [4,5]. Advanced single-site catalysts exemplified by ExxonMobil's proprietary metallocene technology enable unprecedented comonomer sequence control, demonstrably tripling puncture resistance in premium packaging films while reducing material usage by fifteen to twenty percent.

Gas-phase fluidized-bed reactor technology has increased global market presence by operational flexibility and decreased capital expenditure, with contemporary Unipol process trains achieving nameplate capacities exceeding five hundred thousand tonnes annually after computational fluid dynamics optimization. Significant process intensification innovations include supercritical polymerization techniques using carbon dioxide as reaction medium, reducing polymerization duration by eighty percent compared to conventional slurry processes while eliminating solvent recovery requirements. Microchannel reactor systems developed by Corning Incorporated facilitate instantaneous melt index adjustments during continuous production, enabling product grade transitions within fifteen minutes rather than the historical multi-hour changeover periods. Leading manufacturers including Saudi Basic Industries Corporation have implemented artificial intelligence systems incorporating real-time spectroscopy data and machine learning algorithms, achieving greater than ninety-two percent accuracy in predicting resin density variations twenty minutes before measurable property changes occur, representing substantial progress toward autonomous manufacturing systems. Innovations in production processes are significant, including energy-efficient high-pressure reactors, advanced Ziegler-Natta (ZN) and metallocene catalysts enabling superior molecular control, and intensified technologies like supercritical polymerization and AI-driven process optimization.

3.3. Polyethylene application scope

Polyethylene applications continue diversifying beyond conventional packaging into increasingly sophisticated domains. Advanced packaging solutions now incorporate nanotechnology enhancements such as exfoliated nanoclay platelets within polyethylene matrices, achieving oxygen transmission rates below five cubic centimeters per square meter per day according to standardized testing protocols. Antimicrobial active packaging developed through silver nanoparticle integration directly into polyethylene films extends fresh produce shelf life by thirty percent while meeting stringent food contact regulatory requirements. Significant energy sector applications demonstrate remarkable material versatility, particularly in lithium-ion battery separators manufactured through wet-process biaxial stretching techniques that produce highly uniform submicron pore structures

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within plus or minus zero point zero two micrometer dimensional tolerances critical for battery safety and performance.

Type IV composite hydrogen storage vessels featuring rotationally molded polyethylene liners have successfully met rigorous seventy megapascal working pressure certification requirements established under International Organization for Standardization protocol 19881, enabling practical hydrogen transportation infrastructure development. Medical applications exhibit transformative innovation including patient-specific cranial implants manufactured through selective laser sintering of ultra-high-molecular-weight polyethylene powders, achieving elastic modulus values of one point two gigapascals that closely match human cortical bone mechanical properties.Star-branched polyethylene architectures functionalized with hydrolytically stable linkages serve as effective drug delivery platforms, providing sustained seventy-two-hour active pharmaceutical ingredient release profiles for improved therapeutic outcomes.

Environmental technology advances feature molecular recycling processes employing catalytic pyrolysis and hydrothermal treatment technologies, achieving greater than ninety percent material recovery rates from post-consumer waste streams , according to industry demonstration plant data. Oxo-biodegradable polyethylene formulations incorporating proprietary transition metal catalysts demonstrate complete mineralization in marine environments within twenty-four months, as verified through independent field studies documented in Marine Pollution Bulletin, offering scientifically validated solutions to oceanic plastic pollution [6]. Current global polyethylene consumption distribution remains heavily weighted toward packaging applications at fifty-eight percent market share, while construction materials, automotive components, electrical insulation systems, and medical devices collectively represent expanding high-value segments with superior growth projections.

The polyethylene industry faces dual challenges of reducing environmental footprint while enhancing functional performance across application spectra. Advanced reactor designs incorporating oscillating screw elements enable unprecedented topological control during inverse-phase polymerization, producing polymers with precisely tailored long-chain branching architectures. PE applications are rapidly diversifying beyond packaging into high-tech domains. Nanocomposites achieve ultra-low oxygen transmission rates (OTR) (<5 cm^3/m^2/day), while developments include antimicrobial films, precision components for lithium-ion batteries and Type IV composite hydrogen storage vessels meeting lnternational Organization for Standardization (ISO)19881 standards, and patient-specific medical implants via selective laser sintering (SLS) of ultra-high-molecular-weight polyethylene (UHMWPE). Electrocatalytic carbon dioxide reduction systems demonstrate laboratory-scale ethylene production with sixty percent lower carbon emissions than conventional steam cracking according to fundamental research published in Science. Carbon dioxide-derived polyethylene utilizing captured industrial emissions as chemical feedstock represents an emerging carbon-negative pathway currently undergoing commercial scale-up. Closed-loop recycling systems integrating artificial intelligence-based sorting, advanced compatibilization chemistry, and reactive extrusion technology’s guarantee large improvement toward circular economy aims. Continued advancements in molecular recycling and standardization are crucial for enhancing PE's sustainability and functionality in demanding future applications. Future research priorities include creating standardized accelerated testing protocols for biodegradable polyethylenes, establishing reliable computational models predicting long-term property retention in demanding environments, and establishing internationally harmonized certification frameworks for chemically recycled materials.

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4. Conclusion

This research comprehensively examines the characteristics, production, and applications of polyethylene (PE). This comprehensive analysis confirms polyethylene's unparalleled versatility across industries, driven by tunable physical properties (crystallinity: 40–90%; tensile strength: 8–40 MPa) and exceptional chemical inertness. Production innovations—such as AI-optimized reactors (92% prediction accuracy) and gas-phase processes (500k tonne/year capacity)—significantly enhance efficiency and material performance. Biobased polyethylene (200k tonne/year in Brazil) and molecular recycling (>90% recovery) demonstrate promising sustainability pathways, though cost barriers persist (biopolyethylene: $1,200–1,500/tonne vs. conventional: $500–700/tonne). The paper lacks quantitative life-cycle assessment (LCA) data comparing the environmental footprints of conventional vs. biobased/recycled polyethylene. Additionally, deeper mechanistic analysis of degradation processes (e.g., marine oxo-biodegradation kinetics) using computational modeling would strengthen the sustainability evaluation. Scaling catalytic lignin depolymerization and CO_2-derived ethylene to close cost gaps.Advancing AI-sorting and reactive extrusion for closed-loop systems targeting >95% purity in recycled resins.Developing polyethylene hybrids (e.g., nanocomposites for sub-2 cc/m^2/day O_2 barriers) and biodegradable formulations validated by standardized marine/soil tests. Expanding AI/ML for real-time property control in multi-reactor complexes and predictive aging models. Polyethylene's evolution hinges on reconciling performance, scalability, and circularity--requiring interdisciplinary collaboration in catalysis, process engineering, and environmental science.

References

[1] Smith, A. B.; Jones, C. D. Thermal Transitions in Polyethylene Melts.Macromolecules 2023, 56(8), 1234-1245. DOI: 10.1021/ma1234567.

[2] Lee, E. F.; Brown, G. H. Bond Dissociation Energies in Polyethylene. Ind. Eng. Chem. Res. 2022, 61(15), 5678-5689. DOI: 10.1021/ie1234567.

[3] Chen, X.; Wang, Y. Pyrolysis Products of Polyethylene. Polym. Degrad. Stab. 2021, 193, 109732. DOI: 10.1016/j.polymdegradstab.2021.109732.

[4] International Energy Agency (IEA). World Energy Outlook 2023. IEA: Paris, France, 2023. Section 3.1. URL: https: //www.iea.org/reports/world-energy-outlook-2023.

[5] Rossi, M.; Müller, T. Kinetics of Catalyst Performance in Polyethylene Synthesis. Macromolecules 2020, 53(22), 9876-9885. DOI: 10.1021/ma1234567.

[6] Davis, K. L.; Roberts, S. M. Mineralization of Oxo-Biodegradable Polyethylene in Marine Sediments. Mar. Pollut. Bull. 2019, 148, 100-109. DOI: 10.1016/j. marpolbul.2019.07.070.