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Preparation and application of a polyethylene foam packaging material

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Abstract: *With the development of science and technology, packaging materials play an important role in the safety, hygiene and transportation of goods. Polyethylene foam has become the core component of the modern packaging industry because of its lightweight, sound insulation, heat insulation, shock absorption and other characteristics. However, its production and use also bring environmental protection and recycling problems. In this paper, the preparation, modification and application of polyethylene foam will be discussed in depth, aiming to provide ideas and suggestions for solving problems. It is hoped that the research will lead to the development of a more environmentally friendly and sustainable packaging material, which will contribute to the sustainable development of mankind.*

Keywords: *Polyethylene Foam, Preparation, Modification*

1. Introduction

1.1 Introduction to Packaging Materials

Packaging materials are various materials used for manufacturing, packaging and transporting commodities, and they play a vital role in the process of commodity circulation. Common packaging materials are:

(1)Plastic packaging materials: mainly plastic woven bags, plastic film, plastic composite materials, plastic foam materials, etc., common polyethylene, polypropylene, polyester, nylon, polystyrene and so on. (2) Metal packaging materials: is a metal as the main component of packaging materials. (3) Glass packaging materials: is used to manufacture glass containers, to meet the specific packaging requirements of the material. (4) Paper packaging material: it is an environmentally friendly, recyclable packaging material, mainly including paper bags, paper boxes, cartons and so on. (5) Composite Packaging Material: It is a new type of packaging material composed of two or more materials.

Plastic packaging is not easy to degrade, metal materials consume large resources and high environmental pressure, glass is heavy and fragile, paper packaging is weak and waterproof, and composite materials are difficult to separate from recycling. Polyethylene foams have been developed as a solution to improve these drawbacks due to their light weight, sound and heat insulation, and excellent shock absorption properties.

1.2 Polyethylene foam

1.2.1 Properties of polyethylene foams

The polyethylene foam material is formed into a lightweight and porous structure through a special foaming process, which has excellent shockproof performance. Its internal bubble network efficiently absorbs and disperses the impact force, which is converted into heat energy or pressure changes, effectively reducing impact damage to the package. Because of its low density and high deformation ability, it is especially suitable for the packaging of consumables such as electronics and precision instruments. Compared with traditional packaging materials, polyethylene foams show significant advantages in terms of shock protection.

(1) Polyethylene foam material is an ideal choice for thermal insulation and thermal insulation applications due to its low thermal conductivity and porous structure, inhibiting heat transfer and keeping the internal temperature stable.

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(2) The material is easy to process, has good plasticity and toughness, and can be processed into different shapes and sizes through a variety of processes such as hot press molding, cutting, bonding and sewing. At the same time, it has strong chemical stability, resistance to acid and alkali corrosion, and is suitable for use in a wide range of environments.

(3) The internal bubbles give the polyethylene foam a certain strength and toughness, which can maintain structural stability when stressed, and meet the basic bearing requirements of various application scenarios.

1.2.2 Classification of polyethylene foams

The classification of polyethylene foam is shown in Table 1.

Table 1: Classification and performance comparison of polyethylene foams

name (of a thing)	performances
High Density Polyethylene (HDPE)	Density 0.93-0.97g/cm3 , high strength, good toughness, rigidity, high tensile strength, high impact strength, low water absorption, good anti-permeability, resistance to acid, alkali and various salts corrosion, heat resistance, cold resistance is good
Low Density Polyethylene (LDPE)	Density 0.91-0.93 g/cm3 , poor mechanical strength, low tensile strength, low impact strength, poor moisture and air barrier, acid, alkali and salt solution corrosion resistance, low heat resistance
Linear Low Density Polyethylene (LLDPE)	Density 0.92-0.935g/cm3 , high strength, good toughness, rigidity, high tensile strength, high impact strength, low water absorption, good anti-permeability, resistance to acids, alkalis, organic solvents, heat resistance, cold resistance performance is good

1.2.3 Current Problems of Polyethylene Foam Materials

(1) Environmental problems: polyethylene materials are difficult to degrade, and microplastics are seriously polluted; Production consumes a lot of energy and emits a lot of emissions, which aggravates climate warming.

(2) Resource challenges: the growth of raw material demand increases the pressure of exploitation, and the environmental pollution in the production process is heavy.

(3) High cost: The price of resin is high, the production process is complex and the energy consumption is large, involving multiple chemical reactions and high-temperature and high-pressure operation steps.

(4) Safety risks: high flammability, fast combustion speed and the release of toxic smoke, posing a threat to people and the environment.

(5) Recycling problem: additives affect the difficulty of recovery, require complex treatment technology, and may lead to secondary pollution. The density of materials is small and easy to mix, and the bottleneck of recycling technology limits its effective reuse.

2. Preparation and modification of polyethylene foams

2.1 Pre-foaming stage

First, the polyethylene pellets containing additives such as blowing agents are preheated, softened, and expanded. After the steam is heated to the decomposition temperature of the foaming agent, the gas is quickly generated to form microbubbles, which causes the internal pressure of the particles to increase and significantly expand into loose pre-foamed beads. The beads are then matured to ensure that the blowing agent is completely decomposed and the gas is evenly distributed, and finally cooled to solidify the structure for further processing.

2.1.1 Conventional pre-foaming technology

In the foam industry, the traditional pre-foaming technology is widely used in PE and other thermoplastics, using the expandable bead method. In this method, polyethylene resin granules containing foaming agents and additives are placed in a pre-foaming equipment with controlled temperature and humidity, and heated by steam. When the temperature rises to the decomposition point of the blowing agent, the gas is generated and fills the inside of the particles to form microbubbles, causing them to expand to tens or even hundreds of times, and finally produce soft, lightweight pre-foamed beads.

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2.1.2 New pre-foam technology

The aim of this project is to produce high-performance polyethylene foam packaging materials using bimodal polyethylene resins with bimodal molecular weight distribution: one peak ensures processing fluidity and is derived from low molecular weight components; Another peak gives strength and durability to the material, which comes from the high molecular weight components. The team has developed a novel blending technology to precisely prepare bimodal polyethylene feedstock with this special molecular structure.

This project uses a series slurry ring tube reactor and a special fluidized bed gas phase reactor to achieve efficient mixing and melting of bimodal polyethylene. High process flexibility for controlled molecular weight distribution: low-molecular-weight LDPE is produced from supercritical propane diluents in ring-tube reactors; Polymer mass LLDPE is generated in gas phase reactors to meet specific mechanical and processing performance requirements. The newly designed bimodal production equipment is equipped with an independent temperature control system, which can precisely adjust the temperature of each melting zone and optimize the pre-foaming process conditions.

2.2 Foaming stage

In the foaming process, the raw material needs to be preheated to the melting point, and the beads obtained by pre-foaming can be used or PE resin containing foaming agent can be used directly. The material is heated to a molten state in the extruder, and the blowing agent is then heated to decompose to produce gas, and the gas is evenly dispersed in the molten polymer to form microbubbles. Gas molecules assemble and develop into a core, expanding the bubbles through diffusion. The molten and aerated PE mixture is extruded from the die and cooled rapidly, at which point the polyethylene cures faster and the internal foam structure is finalized.

2.2.1 Traditional foaming technology

The temperature control of the foaming extruder is divided into two stages, the first stage is mainly melting and mixing, and the temperature requirements are relatively wide, and the allowable fluctuation ± 3-5 °C; The latter section is responsible for cooling and stabilizing the bubble to ensure that the homogeneous system is stable and not separated above the supercritical pressure, and to ensure the accurate control of product quality and melt temperature, so the temperature control accuracy of this section needs to be within ±1°C.

(1) The rear cooling system of traditional foam extruder generally adopts water cooling or air cooling. Due to the lack of cooling efficiency will cause the temperature error to intensify, thermal inertia and hysteresis increased phenomenon. There is a low condensation efficiency and condensate is usually discharged, less recycling, easy to cause water waste phenomenon.

(2) The traditional temperature control system of extruder adopts resistance heater, which has the characteristics of nonlinearity, large hysteresis and large inertia. Although it is controlled by intelligent PID algorithm, it is still difficult to eliminate the defect of response delay. When the temperature control meter gives a signal to stop heating, it will cause the temperature to rise for a period of time. When the cooling system stops and the heater works, the hysteresis of heat transfer will make the actual temperature decrease again. In an extruder with poorly matched heat balance, the temperature error may reach 10°C or more.

In order to improve the cooling efficiency and the rapid exchange of shear heat out of the system, the team finally chose to develop its own condensation extrusion foam technology to improve the condensation efficiency.

2.2.2 New foaming technology

(1) Condenser design: the team designs the closed condenser and installs two sets of spraying equipment in the condenser, which are installed on the upper side and lower side of the inlet of the condenser. It greatly improves the cooling effect after foaming and avoids the influence of dust, microorganisms and other impurities in the air and chemical emissions on the product quality. The internal design of the condenser temperature control system can effectively control the temperature reduction.

(2) Cooling mode design: the condensing system takes the form of atomisation, through the compressed air to make the coolant atomisation through the nozzle after spraying to achieve the cooling treatment of the foamed material, the minimum can be reduced to 15 ℃. Spray equipment

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using compressed air in the condenser to complete the condensation of the gas temperature sinking through the end of the condenser at the end of the lower part of the outlet to leave the condenser, outside the machine cooling liquefaction through the collection can be put back into the condensing use. The other part of the gas that has not reached the purpose of condensation will move upward through the recycling port at the upper part of the condenser end and return to the condensate storage bin along the pipeline, and then be put back into the condensing use to avoid the waste of resources.

Spray evaporation condensation with a mixture of coolant and air as a cooling medium. Among them, the gaseous refrigerant condensation process released by the latent heat of condensation mainly rely on the evaporation of cooling water to take away, cooling water in the water-cooled condenser in the temperature rise of only 6 ~ 8 ℃, that is, 1 kg of water to take away only 25 ~ 35 kJ of the sensible heat, while 1 kg of water absorbing heat and evaporation can take away 2,450 kJ of the latent heat, so that the spray evaporative condenser actual operation of the water-cooled water amount of 30% to 45%, saving water. Save water resources.

2.3 Modelling stage

When the foam molding material is cut, the size and shape need to be fixed first to prevent movement; Use the ruler template to accurately calibrate the cutting position line. According to the thickness and requirements of the polyethylene sheet tube, manual cutting, electric circular saw, jigsaw, hot knife or special plastic cutting machine can be selected.

2.3.1 Traditional modelling techniques

(1) The plasticity of traditional foam materials can only be achieved by cutting, punching, and then pasting or sewing, which is difficult to shape and the labour cost is too high.

(2) Traditional moulding machines such as the Z5040 moulding machine in the mould heating method using electric heating, this way of heating efficiency is low, at the same time will lead to energy waste and environmental pollution.[1]

(3) The selection of mould materials has a great impact on product quality and production efficiency. Traditional mould materials are mainly aluminium alloy and steel, these materials have high thermal conductivity, which will affect the foaming performance of the product.

2.3.2 New modelling techniques

In order to simplify the moulding stage the team adopted moulding technology. The moulding machine is able to achieve one-time moulding and polymerisation of multiple functions at the same time, solving the pain point that traditional foam-type packaging materials are unable to mould complex shapes quickly.Adopt more efficient and environmentally friendly infrared radiation heating. Infrared is the use of infrared electromagnetic radiation absorbed by the heated object to achieve the purpose of heating, for the non-contact heating method, thus avoiding any medium in the heating process, also avoid the loss of energy. It effectively shortens the heating time and improves the heating efficiency.

Carbon fibre composites with low thermal conductivity are used to make the moulds, and their thermal conductivity is generally between 0.6-6.0 W/mk, which conducts less heat to the material during the moulding process and has a low impact on its foaming properties.The infrared heating taken in moulding shape is to use the radiation effect of infrared rays to transfer heat to the illuminated object, and its efficiency is determined by whether the wavelength of infrared emission is consistent with the wavelength of infrared absorption of the molecules of the illuminated object itself. If the wavelength is the same, that is, the incident infrared frequency and molecular thermal movement of the intrinsic frequency is equal, the molecules will absorb infrared radiation, and infrared energy into molecular thermal movement energy, that is, resonance occurs, the temperature rises, accelerated reaction, improve the rate of modelling, reduce the impact on the material.

2.4 Recycling degradation phase

The waste expanded polyethylene product recycling process involves collection, sorting, cleaning and decontamination, followed by crushing and fine sorting to remove impurities. The treated fragments melt at high temperatures, and the blowing agent decomposes and evaporates in the process. The melt is extruded into strips through a mold and formed into recycled pellets by a water-cooled pelletizer. Recycled granules need to meet the quality inspection standards, and the formula may be

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adjusted to add stabilizers and other additives to improve the quality and meet the needs of subsequent processing. [2]

2.4.1 Traditional recycling degradation technologies

(1) The key to the ratio of degradants: chemical degradation requires reasonable addition of oxidants, acids and alkalis, etc., and the concentration and proportion are very important to the degradation effect and rate. If it is insufficient, the degradation efficiency is low and time-consuming.

(2) Temperature and reaction time control: The process needs to accurately control the temperature and reaction time to optimize the degradation effect. Increasing the temperature can speed up the reaction, but overheating can lead to untargeted decomposition and affect the quality of recovery.

(3) Treatment of harmful products: traditional degradation is easy to produce harmful by-products, which need to be effectively removed. Adsorption, filtration and other methods are used to purify to ensure that the recycled materials meet environmental protection standards.

2.4.2 Novel recycling and degradation technologies

The team adopts chemical degradation and regeneration technology to thoroughly decompose the macromolecular chain of the polyethylene foam packaging materials after use, followed by purification and separation treatment to remove harmful substances and improve the quality and purity of the recycled products in order to obtain high-purity compounds. The high-purity compounds can be put back into the market after treatment, which solves the pain point of high labour and energy consumption caused by the high cost of traditional recycling and the need to go through multiple processes of decomposition. The residual degradants are also treated to ensure compliance with environmental requirements.

2.5 Performance comparison before and after modification

The team developed a new polyethylene foam packaging materials using linear low-density polyethylene (LLDPE) and low-density polyethylene (LDPE) through a number of production processes and independent foam, tensile, compression resistance is higher, more elasticity, compared with the same type of products shock absorption and compression resistance has been greatly improved, as a packaging material to better protect the product, following the first-generation polystyrene and the second generation of pearl wool after the It has become a practical technology product after the first generation polystyrene and the second generation pearl cotton,The performance comparison of the three generations is shown in Table 2. It can be used in packaging scenes such as fresh food e-commerce, cold chain distribution, takeaway courier, etc. It can also be used in thermal insulation scenes such as pipeline insulation layer and heat insulation board of the external wall of the building, with excellent thermal insulation performance and good heat-resistant properties. [3]

Table 2: Products Performance Comparison

name (of a thing)	expanded polystyrene (EPS)	Pearl cotton (conventional foamed polyethylene)	Innovative foamed polyethylene
operating temperature	0°C-70°C	-60°C-+80°C	-40°C-+90°C
melting point	240°C	70-90°C	110-125°C
impact strength	13.6kJ/m2	20kJ/m2	37.5kJ/m2
tensile strength	2.3-2.9 kg/cm3	2.8-3.5kg/cm3	3.4-3.9kg/cm3
compressive strength	150-700kPa	240-780kPa	350-850kPa

3. Application of polyethylene foam

3.1 Application of polyethylene foam in the food industry

Polyethylene foams are widely used in the food industry for packaging and preservation. (1) Packaging: Because of its excellent shock and compression resistance, it can effectively protect the integrity of fragile, deformed or perishable food during transportation and storage. (2) Thermal insulation: It has good thermal insulation performance, and the incubator made of it can maintain the temperature of food for a long time and enhance the eating experience. (3) Moisture-proof and dust-proof: The material has excellent moisture-proof function, which can effectively isolate moisture

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and dust and ensure that the food is dry and clean.

3.2 Application of polyethylene foam in the logistics industry

Polyethylene foams are mostly used in the logistics industry to prevent shocks, moisture, protection and securing goods. (1) Cushioning packaging: It has superior cushioning and can absorb impact to prevent transportation damage. (2) Moisture-proof and dustproof: good sealing, effectively blocking the invasion of moisture and dust. (3) Support protection: moderate strength and toughness, as a support to fix the goods, to prevent displacement and damage. (4) Customized packaging: flexible design and processing to meet the special needs of different goods. (5) Lightweight advantages: the material is light, reduces the weight of packaging materials to save transportation costs, and facilitates handling, loading and unloading, and improves logistics efficiency.

3.3 Polyethylene foam in the construction industry

Polyethylene foams are mainly used in the construction industry for insulation components and special purposes. (1) Exterior wall insulation: Because of its superior thermal insulation performance, it is often used as a wall insulation layer. (2) Pipe insulation: Wrap outside the pipeline to reduce heat loss or cold intrusion, and ensure the stability of the internal medium temperature. (3) Moisture-proof and earthquake-resistant: It has good moisture-proof performance, and is suitable for moisture-proof treatment of basements, toilets and other humid areas and shock-absorbing treatment of building structures.

4. Challenges and Future Developments of Polyethylene Foam in Packaging

Degradable and recycled polyethylene foam materials are the key to green packaging, which is of great significance for reducing "white pollution" and achieving the goal of carbon neutrality. The global plastic ban policy has spurred a surge in market demand, creating huge room for the industry to grow.

The polyethylene foam material can be degraded by photothermal and chemical action under natural conditions, and the breakage of the polymer chain leads to the degradation and embrittlement of mechanical properties, and finally decomposes. Its excellent performance is the result of rational formulation design and process tuning to meet the needs of multiple uses. However, the material faces challenges: degradation can produce harmful substances that threaten environmental health; Production costs constrain the scope of application. There is an urgent need for scientific research and innovation to solve problems and promote its popularization and application in more fields.Degradable and recyclable polyethylene foam as a green packaging material with broad market prospects and great social significance to maximise environmental protection and economic benefits.

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