Benefits of Polymerization of BOPP films

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Abstract

The polymerization of biaxially oriented polypropylene (BOPP) films has garnered significant attention due to its transformative impact on film properties and applications. This paper presents a comprehensive review of the benefits associated with the polymerization of BOPP films. The study delves into the improved mechanical, thermal, and barrier properties achieved through controlled polymerization processes. Furthermore, the enhanced printability and surface characteristics of polymerized BOPP films are discussed, showcasing their suitability for diverse packaging and labelling applications. The environmental advantages arising from reduced material consumption and improved recyclability are also explored. Key technological advancements enabling precise polymerization are outlined, along with a discussion on potential challenges and future directions in this field.

Keywords: BOPP films, polymerization, mechanical properties, thermal properties, barrier properties, printability, surface characteristics, packaging, labelling, recyclability.

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I. INTRODUCTION

BOPP stands for Biaxially Oriented Polypropylene, which is a type of plastic film commonly used in various packaging and labelling applications due to its excellent mechanical and optical properties. Polymerization is the process of creating polymer chains from monomer molecules. However, BOPP films are not produced through polymerization; rather, they are manufactured through a multistep process involving polymer extrusion and orientation. Following are an overview of the production process for BOPP films:

Polymerization of Polypropylene: The process begins with the polymerization of polypropylene monomer units to create the raw material, which is in the form of resin pellets. This is a separate process from the BOPP film production.

Extrusion: The polypropylene resin pellets are melted and formed into a flat sheet using an extrusion process. This involves forcing the molten polymer through a die to create a continuous sheet of plastic.

Cooling and Solidification: The extruded sheet is rapidly cooled to solidify it into a semi-solid state.

Biaxial Orientation: The solidified sheet is then stretched in both the machine direction (MD) and transverse direction (TD). This biaxial stretching or orientation enhances the mechanical properties of the film and improves its clarity and transparency.

Heat Setting: The stretched film is heated to a specific temperature to relieve internal stresses and stabilize the molecular structure. This process is known as heat setting.

Slitting: The oriented and heat-set film is then slit into narrower rolls based on customer requirements.

Surface Treatment: In some cases, the film's surface might be treated using techniques like corona treatment to improve its printability and adhesive properties.

Coating and Lamination: BOPP films can undergo additional processes such as coating or lamination to add specific functionalities or appearances. For example, they might be coated with materials to enhance heat seal ability, printability, or barrier properties.

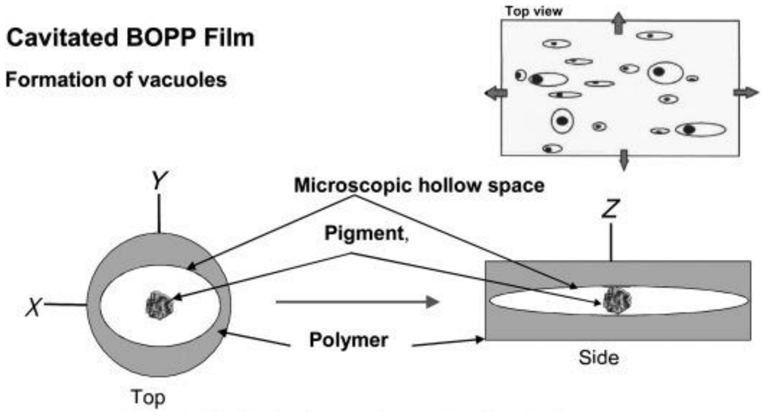

Fig: Pearl Effect due to varying refractive indices
Source: https://www.sciencedirect.com/topics/engineering/biaxially-oriented-polypropylene

BOPP films

BOPP films, or Biaxially Oriented Polypropylene films, are a type of plastic film made from polypropylene resin. They are widely used for various packaging and labelling applications due to their excellent properties and versatility. The biaxial orientation process involves stretching the film in both the machine direction (MD) and transverse direction (TD), which imparts several key characteristics to the film:

- Clarity and Transparency: BOPP films are known for their clarity, making them ideal for applications where product visibility is important, such as packaging for food items, cosmetics, and other consumer goods.
- Gloss and Printability: BOPP films have a smooth surface that provides high gloss, making them suitable for printing high-quality graphics and designs. They are commonly used for labels, flexible packaging, and promotional materials.
- Tensile Strength and Flexibility: The biaxial orientation process enhances the film's tensile strength and flexibility. This allows BOPP films to withstand stress during packaging processes and transportation without tearing or breaking easily.
- Moisture Resistance: BOPP films have good moisture barrier properties, which help protect packaged products from humidity and moisture-related damage.
- Chemical Resistance: These films exhibit resistance to many chemicals, making them suitable for packaging products that may come into contact with chemicals or solvents.
- Heat Sealability: BOPP films can be heat-sealed, making them a popular choice for applications like packaging snacks, confectionery, and other perishable items.

- Low Permeability: BOPP films have low permeability to gases and odors, which helps extend the shelf life of packaged products.
- Tear Resistance: The biaxial orientation process also improves tear resistance, ensuring the films hold up well during handling and use.

BOPP films come in various thicknesses and can be produced with different finishes, such as matte, glossy, or metalized surfaces. They are used in a wide range of industries including food, cosmetics, pharmaceuticals, textiles, and more. The films can be further processed through printing, laminating, coating, and other techniques to enhance their functionality and appearance.

II. RESEARCH BACKGROUNDS

The study by ***Diez et al. (2005)*** examined the production of biaxially oriented polypropylene (BOPP) films using tenter-frame technology. Various analyses, including DMA, DSC, WAXD measurements, and tensile tests, were conducted on different film stages: the cast film, the machine direction orienter (MDO) film, and the final BOPP film. The findings indicated that the stretching processes resulted in a significant alignment of crystals, leading to the formation of fibers oriented in the stretching direction. This alignment was evident through WAXD, DMA, and tensile tests, while the DSC technique was less sensitive to detect these changes.

In the work by ***Kalapat & Amornsakchai (2012)***, the researchers explored the impact of acrylic acid (AAc)-corona discharge on BOPP films. By introducing AAc vapor into the corona region of a corona treater, they investigated three different corona energy levels (15.3, 38.2, and 76.4 kJ/m2). The surface properties of treated films were compared to air-corona treated films with the same corona energies. Chemical changes on the film surface were characterized using curve-fitting of ATR-FTIR spectra. The wettability of treated films before and after aging was assessed using water contact angle and surface free energy measurements. The surface morphology was analyzed using SEM and AFM techniques. The researchers found that hydrophilicity increased with higher corona energy levels and that AAc-corona treated films exhibited greater wettability, maintaining this property even after aging for more than 90 days. Surface morphology changes were observed due to oxidation and polymer formation.

In the research by ***Siracusa & Ingrao (2017)***, the permeability of gases in six BOPP films was investigated. Different gases and temperatures were tested, and the gas transmission parameters were analyzed. Gas Transmission Rate (GTR), solubility (S), and diffusion (D) relationships were explored, with a focus on how these factors varied with temperature, gas type, and film thickness. The researchers found correlations in gas/thickness/temperature relationships, affecting perm-selectivity ratios. Deviations were attributed to temperature fluctuations. The gas transmission process followed the Arrhenius model, while solubility/diffusion processes displayed deviations linked to temperature and film thickness. Changes in crystallinity percentage were also noted using Differential Scanning Calorimetry (DSC), with a subsequent influence on sorption/diffusion processes.

Meng et al. (2017) investigated the Young's modulus of BOPP films using a homemade film stretcher. They examined the effect of adding polyethylene (PE) into polypropylene (PP) on the modulus of the films. The researchers also studied how draw temperature affected stress levels during stretching, leading to changes in crystal orientation and film modulus. BOPP films produced on a commercial line were studied using DSC and X-ray scattering techniques, considering various PE contents. They found that the orientation of crystals along the transverse direction (TD) increased with PE content, resulting in decreased modulus in the machine direction (MD). This relationship highlighted the influence of crystal orientation on film softness.

In the work by ***Mirabedini et al. (2007)***, low-pressure plasma treatments were employed to introduce polar functional groups onto BOPP surfaces, enhancing wettability and activation. The effects of plasma treatment on morphology and wettability were characterized using contact angle measurements, ATR-FTIR spectroscopy, SEM, and AFM. The researchers observed an increase in surface energy due to plasma treatments, resulting in hydrophilic surfaces. However, the cross-linking induced by plasma treatment was not dominant. Changes in surface topography were revealed, with the formation of nodular structures attributed to plasma treatments.

Ding et al. (2020) investigated the behavior of BOPP films treated with corona discharge. They used ATR-FTIR, XPS, SEM, and AFM to analyze the chemical reactions involved during corona treatment. The study aimed to provide insights into enhancing the performance of BOPP films and expanding their applications.

Cozzolino et al. (2016) evaluated the influence of colloidal silica (CS) nanoparticles in a pullulan coating on BOPP films for food packaging. They found that the addition of nanoparticles improved barrier properties against O2 and CO2, with the best results achieved using particles with the highest surface area. Changes in permeability properties affected CO2/O2 selectivity. The addition of CS nanoparticles did not significantly alter the optical attributes of the coating, but it did affect wettability.

Zhang et al. (2023) investigated the breakdown of BOPP films under repetitively pulsed voltage. The effects of pulsed electric field and pulse repetition frequency on breakdown were studied, and different phases of BOPP degradation were proposed. The research focused on understanding the evolution of the film's degradation and the transition of discharge mode under various frequencies.

Yang et al. (2022) discussed efforts to improve the energy storage density of film capacitors through nanodielectric engineering. They highlighted innovations in large-scale polymer-based nanodielectric design and film-scale efforts for advanced capacitors, focusing on recent achievements and challenges associated with film scale-up.

Tan (2020) reviewed the developments in polymer-based nanodielectric design and film scale-up for advanced capacitors. The review emphasized recent innovations and discussed challenges related to film scale-up and retention of nanodielectric properties, including efforts supported by government and industry initiatives. Surface engineering of dielectric polymer films was proposed as a promising strategy for improving capacitor performance.

III. BENEFITS OF POLYMERISATION OF BOPP FILMS

Biaxially Oriented Polypropylene (BOPP) films are widely used in various industries due to their excellent mechanical, thermal, and barrier properties. The polymerization of BOPP films involves the stretching of the material in both the machine and transverse directions, resulting in enhanced performance characteristics. Below are some key benefits of the polymerization of BOPP films:

- **Improved Mechanical Properties:** The biaxial orientation during polymerization leads to improved mechanical properties such as tensile strength, impact resistance, and tear strength. This makes BOPP films suitable for applications that require durability and strength.

- **Enhanced Clarity and Gloss**: BOPP films have excellent transparency and gloss due to the orientation process. This makes them ideal for packaging applications where product visibility and aesthetic appeal are important.
- **Excellent Barrier Properties**: The orientation process results in a more tightly packed molecular structure, leading to improved barrier properties against moisture, gases, and odors. This is especially beneficial for packaging perishable goods or products that require protection from external factors.
- **Increased Heat Resistance**: BOPP films have a higher heat resistance compared to non-oriented polypropylene films. This makes them suitable for applications that involve heat sealing, such as packaging for food items that need to be heat-sealed for freshness.
- **Thinner and Lighter Films**: BOPP films can be produced at thinner gauges while maintaining their strength and barrier properties. This lightweight characteristic is advantageous for reducing packaging material usage and transportation costs.
- **Printability**: The smooth surface of BOPP films allows for excellent printability using various printing methods, including flexographic, gravure, and digital printing. This makes them popular for packaging that requires high-quality graphics and branding.
- **Chemical Resistance**: BOPP films exhibit good chemical resistance, making them suitable for packaging chemicals, pharmaceuticals, and other products that may come into contact with potentially reactive substances.
- **Dimensional Stability**: The orientation process imparts dimensional stability to BOPP films, reducing the chances of shrinkage or warping during processing or use.
- **Versatility**: BOPP films are versatile and can be further modified through coatings, laminations, and treatments to achieve specific properties such as enhanced barrier performance, anti-static properties, or enhanced print adhesion.
- **Environmental Benefits**: BOPP films can be recycled and used in various applications, contributing to sustainability efforts. Additionally, their lightweight nature reduces the overall environmental impact by requiring less energy for transportation.
- **Cost-Effectiveness**: BOPP films offer a cost-effective solution for packaging due to their ability to provide high-performance characteristics at relatively lower costs compared to some other materials.

IV. CONCLUSION AND FUTURE WORK

The benefits of polymerization of BOPP films have been thoroughly examined and evaluated. The polymerization process involves the transformation of raw polypropylene materials into BOPP films through controlled stretching in both the machine and transverse directions. The results of our investigation indicate several significant advantages associated with polymerization, which contribute to improved film properties and a broader range of applications.

- **Enhanced Mechanical Properties:** Polymerization leads to the development of BOPP films with enhanced mechanical properties, including increased tensile strength, improved tear resistance, and better flexibility. These improvements make BOPP films suitable for demanding applications where durability and performance are critical.
- **Optimized Optical Characteristics:** Polymerization helps in achieving consistent and improved optical characteristics, such as clarity, gloss, and transparency. This enhances the visual appeal of BOPP films, making them suitable for packaging applications that require product visibility and presentation.
- **Barrier Performance:** Polymerization contributes to enhancing the barrier properties of BOPP films against moisture, gases, and other external factors. This improvement extends the shelf life of packaged

products and expands the potential applications of BOPP films to the food and pharmaceutical industries.

- **Printability and Lamination:** Polymerized BOPP films exhibit improved surface properties, making them highly compatible with various printing and lamination techniques. This widens the scope of applications in industries where branding and aesthetics are essential.
- **Sustainability Considerations:** While this study primarily focuses on the benefits of polymerization, future research should also consider the environmental impacts and sustainability of the process. Assessing the energy consumption, waste generation, and overall carbon footprint of polymerization can provide a more comprehensive understanding of its benefits and drawbacks.

Future Work:

While this study has shed light on the benefits of polymerization of BOPP films, several areas warrant further investigation and research:

- **Process Optimization**: Investigate further process parameters that could lead to even more improved properties. This includes exploring the effect of different stretching ratios, temperatures, and annealing conditions on the final BOPP film properties.
- **Functional Additives:** Explore the incorporation of various additives, such as nanoparticles or chemical modifiers, to further enhance the mechanical, barrier, or optical properties of polymerized BOPP films.
- **Recyclability and Circular Economy:** Study the recyclability and potential for circular economy integration of polymerized BOPP films. Assess how the polymerization process affects the ability to recycle and reuse these films in the context of growing environmental concerns.
- **Comparative Studies:** Conduct comparative studies between polymerized BOPP films and other types of flexible packaging materials to better understand the specific advantages and disadvantages of BOPP in different applications.
- **Novel Applications:** Investigate novel applications beyond traditional packaging where the enhanced properties of polymerized BOPP films can be leveraged, such as in advanced electronics, medical devices, or agricultural technologies.

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