Cyclic Olefin Copolymer Blends

A New Approach for High Temperature Polypropylene Film Capacitors
TOPAS Advanced Polymers

TOPAS Advanced Polymers is the world’s leading maker of COC (cyclic olefin copolymer), a glass-clear plastic for healthcare, optics, packaging, and electronics applications. From insulin delivery, to food contact films, to tablet and smartphone displays, TOPAS® COC is the high performance material of choice. The broad global regulatory compliance of TOPAS® COC can make your next development a simpler task.

TOPAS Advanced Polymers also supplies the chemical raw material norbornene. A joint venture of Polyplastics Co., Ltd. and Daicel Corporation, the company is headquartered in Frankfurt, Germany. It operates the world’s largest COC plant in Oberhausen, Germany. TOPAS® COC is a registered trademark of TOPAS Advanced Polymers for its family of cyclic olefin copolymer resins.

Important

The properties of articles can be affected by a variety of factors, including choice of material, additives, part design, processing conditions, and exposure to the environment. Customers should take responsibility as to the suitability of a particular material or part design for a specific application. In addition, before commercializing a product that incorporates TOPAS® COC, customers should take the responsibility of carrying out performance evaluations. The products mentioned herein are not designed or promoted for use in medical or dental implants. Unless specified, the numerical values given in this literature are for reference purposes only and not for use in product design. Without exception, please follow the information and other procedures explained in this literature. This literature does not guarantee specific properties for our company’s products. Please take the responsibility to verify intellectual property rights of third parties.

Published in June 2019
1. Introduction

Renewable energy sources and electro-mobility create a fast growing market for inverter circuits for power conversion. Film capacitors are an important component in all of these. Limitations in operating temperatures of individual components are an obstacle for effective heat management, system integration and miniaturization. This trend creates a demand for higher temperature dielectrics for power film capacitors.

Polypropylene films are the main dielectric for power film capacitors due to their low dielectric loss factors (low self-heating), high breakdown voltages (high operating voltages), and excellent self-healing properties (long term reliability). Manufacturing capabilities for typical capacitor films in thickness range of 3 to 10 µm are well established. Main limitations are operating temperatures rarely exceeding 90 °C in circuit, with down ratings in voltage and current required at elevated temperatures for reliability.

Cyclic Olefin Copolymers are well known for their purity and barrier properties. Typical applications in the pharmaceutical industry are pre-filled syringes or substrates for diagnostic devices. Multilayer films and modification of mechanical properties of polyethylene are applications in flexible packaging. A wide range of products with heat deflection temperatures up to 170 °C is commercially available. Cyclic Olefin Copolymers have been known as desirable high temperature dielectric for capacitor films since more than 20 years - however they have not gained commercial relevance due to the lack of an industrial thin film process. Stretching ratios and process temperatures for this amorphous polymer are not compatible with industry standard film technology.

2. Cyclic olefin copolymer key properties

- Amorphous polyolefin
- Compatible with standard polyolefins
- High purity
- Rigid up to 3.2 GPa
- Dielectric constant 2.35
  Dielectric loss factor < 0.02
- Heat deflection temperatures from 30 to 170 °C

3. New approach: High temperature polypropylene polymer blends (HT-PP blend)

Polymer blends combining desirable properties have been developed based on polypropylene and cyclic olefins. As dielectrics for film capacitors they allow higher operating temperatures while converting can build on established manufacturing processes. The ability to withstand increased temperatures is illustrated by comparison of cast films at elevated temperature in figure 3. Polypropylene essentially loses most of its strength above 90°C. Blend formulations with cyclic olefin copolymers can retain strength over a much wider temperature range, in this example up to 135°C. More generally speaking addition of 5-40 % of a cyclic olefin polymer with suitable glass transition temperature has a significant effect on PP film properties while process ability can be maintained.
This polymer blend approach essentially can provide well known properties of a PP film for capacitors with increased temperature ratings. A defined morphology of finely dispersed cyclic olefin copolymer domains of micron and sub-micron size oriented within the plane of the polymer film is essential for its properties. Typical morphology of a cast film is shown in Figure 4. The reinforcing cyclic olefin copolymer domains in the PP matrix provide additional strength and thermal resistance.

The generation of this morphology is visualized in Figure 7. Elongated COC domains present in the cast film are transformed into platelets oriented in the plane of the biaxially oriented film.

Fig. 3. Storage Modulus of cast films measured by DMTA.

Fig. 7. Schematic drawing of morphology of cast and bi-axially oriented film. Formation of a morphology of platelets of cyclic olefin copolymer embedded in bi-oriented polypropylene. Material selection and property matching to allow formation of this morphology are the key for achieving enhanced high temperature performance and create suitable surface roughness.
In order to maintain these properties in thin films of 3-10 µm for capacitor application it was necessary to develop material combinations suitable for an industrial biaxial film stretching process without compromising properties. Matching viscoelastic properties and glass transition temperatures of the reinforcing cyclic olefin polymer to the polypropylene matrix polymer is required for orientation of both phases without separation or voiding in simultaneous or sequential stretching processes. Figure 5 shows a cross section of bi-axially oriented thin PP-COC capacitor film showing fine dispersion and in-plane orientation.

On the film surface this morphology can generate the required roughness without need for further additives. The surface topography is dominated by a fibrillary peak and valley structure due to the blend morphology. In addition the spherulitic crystallization structures typical for PP capacitor film surfaces can be present. Surface structure can be controlled by film process parameters to achieve roughness in typical range for PP capacitor films. Parameters for roughness control are casting temperature and MDO stretching conditions. Figure 6 visualizes examples of film surface structures by different microscopic methods.

Some spherulitic structures can also be identified. Roughness can be controlled by process conditions within the range typical for capacitor film.
4. Film process for PP-COC blends (HT-PP blends)

The industrial process of polypropylene thin film manufacturing is shown in Figure 8.

For films made of the PP-COC blends described above a standard process can be used. These material combinations are compatible with mono and multilayer film technology and allow higher temperature ratings compared to pure polypropylene films. Brückner Maschinenbau based in Siegsdorf, Germany developed and demonstrated thin film industrial manufacturing capability using both sequential and simultaneous stretching technology.

Process parameters have major influence on film properties and productivity. Essential design parameters have been verified for key components, for example extruders (single or twin screw / screw geometry for pressure stability, homogenization quality, low defects etc.), casting die design (cast film quality essential for improved stretch-ability), Pinning (air knife / vacuum box → line speed ), and roll surface materials (casting and stretching rolls) → Minimize deposits (positive effect on productivity).

The process steps and adaptions required for a thin film production process for the new dielectrics are indicated in the caption of figure 8.

5. Film properties

Film and dielectric properties in comparison to a common PP capacitor film are shown in figure 9 for 8 µm film consisting of 80% PP and 20% of COC with a glass transition temperature of Tg 140 °C. Electrical, mechanical and surface characteristics are in the same range as for polypropylene films, with improved dimensional stability for elevated temperature performance. The dimensional stability is visualized by shrinkage curves showing lower shrinkage at elevated temperatures compared to PP capacitor films in Figure 10.
6. Capacitor manufacturing and evaluation

Downstream processes i.e. metallization, slitting, and capacitor manufacturing and testing have been demonstrated independently by industrial partners. Metallization behavior for typical Zinc or Aluminum based formulations is similar to polypropylene.

Common process steps and formats for manufacturing of dry metalized film capacitors can be applied. For evaluation cylindrical capacitors were manufactured from films of 6-8 µm thickness. The formulations were based on capacitor grade polypropylene with a content of 20-30% cyclic olefin copolymer with heat deflection temperatures in the range of 130 to 150 °C. Metallization was done on industrial metalizers using Zinc and Aluminum based formulations.

In accelerated endurance tests capacitors have demonstrated functionality and stability for 1000h at 125 °C and voltages of 250 V/µm, selected formulations up to 275 V/µm. As an example figure 11 shows capacitance change at elevated temperatures in comparison to PP capacitors. Capacitors made from PP-COC Blend formulations showed lower capacitance change compared to PP. At 120 °C the comparative PP capacitors failed completely while capacitors made from blend formulation maintained capacitance within low variation and without failures.

Ongoing detail analysis reveals differences of long term high temperature performance related to resin formulation as well as film and capacitor manufacturing parameters. This indicates potential for further improvement on the way to industrialization.

Another key element for long term performance of PP capacitors is their self-healing property, i.e. their ability to clear defects such as pores or impurities in the film in operation under the influence of voltage. Compared to other standard and high temperature polymer dielectrics polypropylene films are known for excellent self-healing properties. These are maintained by the PP/COC dielectrics, due to the similarity of chemical composition of two polyolefin components, a significant advantage over other approaches.