Application note | LR-100

Twin-screw extrusion

Alginate-based biodegradable films with co-rotating twin screw extrusion

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One of the biggest challenges in moving towards a sustainable future is the use and production of single-use plastics. However, plastic plays a key role in packaging of consumer goods, such as food products. Despite the advances this field has undergone in the last decades, its waste management leaves a significant footprint in the environment. Films and packaging material made of biodegradable and sustainable materials could become an important alternative and help to combat plastic waste. Biodegradable films and plastics are vital for environmental sustainability. They decompose faster than traditional plastics, reducing pollution and landfill accumulation. Made from renewable resources, they also have a lesser carbon footprint than virgin plastics.[1] Biopolymers can be derived from natural sources (mostly waste streams), biosynthesized by living organisms, or chemically synthesized. Most of these materials are polysaccharides, which are often mixed with proteins, lipids and/or plasticizer in order to enhance their mechanical properties. The use of biopolymers adds another important advantage if they are synthesized from the non-edible parts of plants or animals, avoiding the risk of depleting food.[2]

One of the most used biopolymers for film production is alginate. Alginate is a polysaccharide derived from brown seaweed, composed of mannuronic and guluronic acid residues. Due to its non-toxicity and biocompatibility, alginate finds extensive use in the food industry as a thickener and stabilizer; in biomedical applications such as wound dressings and drug delivery; in pharmaceuticals for tablets and capsules; in dental molds; and in biotechnology for cell and enzyme immobilization[3]. Alginate films are often produced by casting methods, which are time consuming and done mostly via batch processing. Testing new formulations, with antibacterial properties and enhanced mechanical properties, could be a lengthy and costly process, as film properties are only assessed offline after drying and demolding.

Twin-screw extrusion offers a modular and flexible method to produce biopolymer films. Film extrusion is a manufacturing process used to produce thin plastic films and sheets for applications in packaging, agriculture, consumer products, and other industries. The process involves melting polymer material in an extruder, forcing it through a die to form a film, cooling the film, and then winding it onto rolls. There are two main types: blown film extrusion, which inflates the film into a bubble, and cast film extrusion, which uses a flat die and chilled rollers. Film extrusion (of either type) offers high efficiency, versatility, and consistent quality, though the process may face material restrictions and challenges in controlling film thickness. In this application note we aim to showcase a Thermo Scientific™ Process™ 11 Twin-Screw Extruder, including some tips for process development to obtain a desired product.

Extrusion process

For this application note, natrium alginate was chosen. A water-glycerol-mixture was used as plasticizer, with glycerol concentration set to 50 wt% in the mixture. (In order to modulate the mechanical properties of alginate films, other concentrations and plasticizer might be used, with concentrations ranging from a few wt% to 100%.) Natrium alginate was fed gravimetrically at the first port with a throughput of 160 g/h and water-glycerol mixtures were added in the third feeding zone using a peristaltic pump with a throughput of 300 g/h. Figure 1 shows an example of the experimental setup. The solid content can be varied, as this affects the mechanical properties of the film and its water/air permeability.

Figure 1. Experimental set-up.

The extrusion speed was set to 400 rpm and temperatures were $T_{barrel2}$= 80 °C, $T_{barrel3}$= 80 °C, $T_{barrel4}$-8= 110 °C, $T_{die\_adapter}$-= 110 °C.

The screw configuration possessed various mixing and kneading zones to ensure polymer melting, adequate mixing, and dispersion of the water-glycerol mixture with the alginate powder.

The die used for film production was a 30 mm slit die with adjustable gaps, which was set to 1 mm height. Figure 2 shows the slit die used for this report. The die was also electrically heated to 100 °C in order to avoid blockages during the extrusion trial. The temperature profile is highly biopolymer dependent and should be chosen accordingly.

Additionally, alginate films were taken off with sheet take-off apparatus located downstream. The extruded film is drawn at a constant speed to ensure uniform thickness and cooled over the course of three rolls. For this, the formulation and the resulting mechanical properties must allow for slight pulling without ripping and for certain flexibility to accommodate to the rolls.

Figure 2. 30 mm slit die with adjustable gap.

Mechanical tests

In order to assess the flexibility and stretchiness of the film, uniaxial quasistatic tensile tests were conducted. The tensile properties of the extrudate were determined using a Thermo Scientific™ HAAKE™ MARS™ iQ Air Rheometer equipped with a furnace (TM-CR-O450), and stress-strain-diagrams were plotted.

For this purpose, a solid clamp geometry for Dynamic Mechanical Thermal Analysis (DMTA) was attached to the rheometer, where two steel clamps were used to hold the film and pull it apart.

Rectangular samples with a width of 9 mm, a thickness of 0.7 mm and a length of 20 mm were cut from the extruded film, with cuts both aligned with extrusion direction (0°) and perpendicular to the extrusion direction (90°). To avoid sample slippage during the test, sandpaper was used to increase friction. During the measurement the temperature was set to 25 °C and controlled by means of a flexible temperature sensor. Additionally, a camera was used to capture the moment the film samples ripped apart.

The samples were pulled apart with a constant speed of 0.1 mm/s; the normal force was recorded with 1000 measurement points taken. Each individual sample preparation was analyzed a minimum of 3 times.

The results of the tensile test for samples prepared with 50:50 glycerol:water mixtures, measured in extrusion direction and perpendicular to it, are plotted in Figure 3.

As seen in Figure 3, there is a clear dependency of the maximum stress and strain required to break the films and the pulling direction. This indicates that the films have an anisotropic structure and are more flexible and elastic perpendicularly to the extrusion

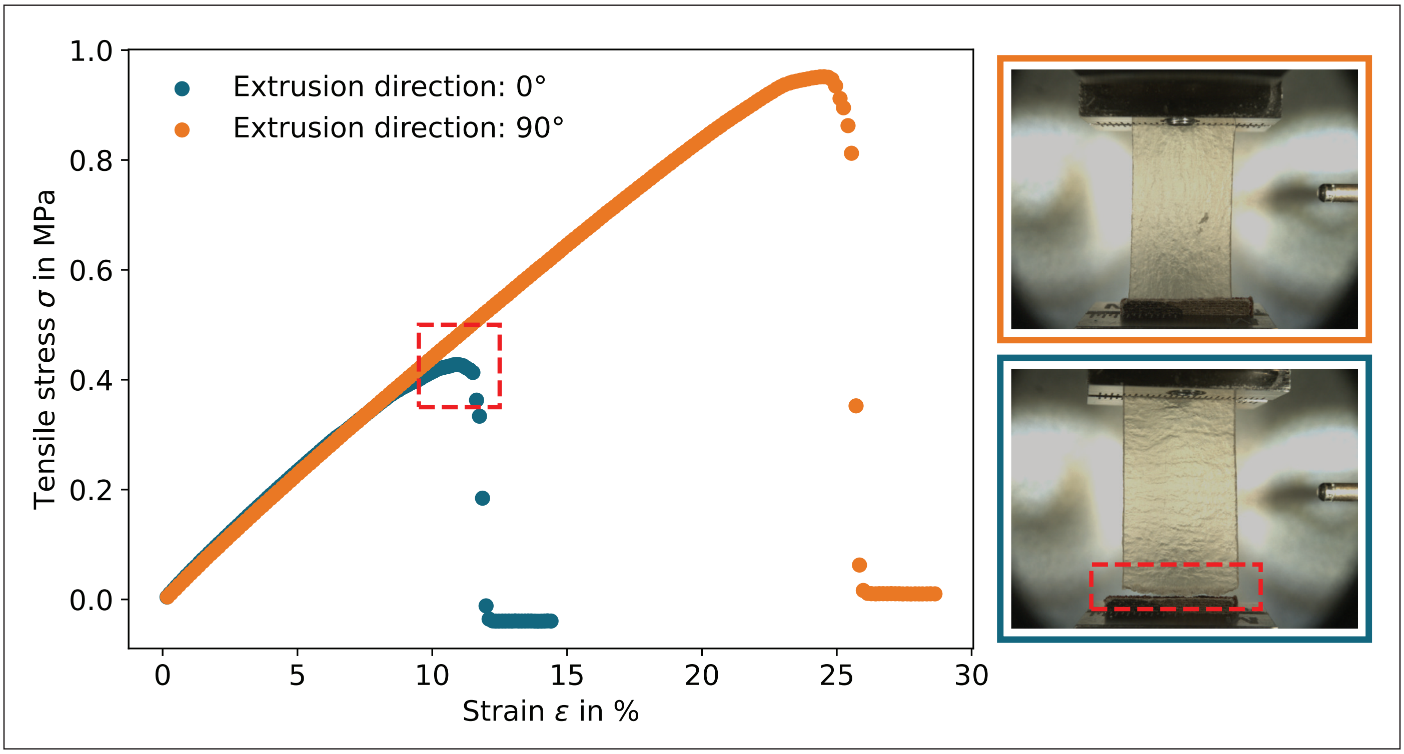

Figure 3. Tensile stress-strain curves of alginate films, extrudate with 50:50 water:glycerol mixtues (32.6 wt% glycerol in end formulation).

direction. This information could be useful when considering blown film extrusion, which requires mechanical stability against stretching forces. Additionally, the point of breakup can be observed in the lower right image. This method provides valuable insights into the mechanical properties of biodegradable films and allows for an objective assessment of their formulation and further processability.

Conclusions

This application note addressed the process design for hot-melt extrusion using a co-rotating twin-screw extruder for the production of biodegradable alginate films.

Find a full video on this topic on the following link:
[Alginate film extrusion]

References

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