WINDING OF PLASTIC BARRIER FILMS

By

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ABSTRACT

High quality plastic films are produced using the cast or blown film extrusion processes. Several kinds of resins are coextruded in a film of up to 11 layers to generate the best technical properties at competitive costs. A state-of-the-art film for food packaging has 5 layers including a 3-10 µm thin oxygen barrier layer of the high cost ethylene vinyl alcohol copolymer. The film is pre-treated for the subsequent processes of printing and lamination. The biggest challenge in this context is that some winding defects are able to destroy complete rolls. Two of the most common winding defects for barrier films are cross direction wrinkles and air knots.

Cross Direction (CD)-wrinkles are directly related to the blown film process, though they might be detected only after lamination. The core area is especially prone to these kind of wrinkles, but they can appear everywhere in a roll. A measurement device for the roll hardness is established and used to document the aging of the rolls. In addition to that, the core pressure is measured and analyzed. A high resolution thickness scan of a complete roll shows the web's thickness profile and how it is affected by the oscillation.

Air knots are small spot-like air entrapment zones between the web layers of the roll which can deform the film permanently in combination with the pressure build-up inside the roll. This defect can occur on film rolls of very different resins. Furthermore, the effect is influenced by the pre-treatment process that modifies the surface structure of the web. Experimental winding tests and analytical winding models are used to investigate the correlation between pre-treatment dosage and air knots.

NOMENCLATURE

AFM	Atomic Force Microscopy
CD	Cross Direction
EVOH	Ethylene Vinyl Alcohol
MD	Machine Direction

PE Polyethylene

INTRODUCTION

Flexible packaging solutions have become an integral part of everyday life all over the world and account for 24% of the global plastic consumption [1]. Flexible packaging has a wide application range from medical to food and from primary packaging of the product to secondary packaging for load stability during transport. In the case of primary packaging for food applications the preservation, the shelf life, and the pack integrity are the market drivers. According to a study of the Food and Agriculture Organization of the UN (FAO) in 2011 about 30 % of the global food production is wasted along the process chain or by the end customers [2]. Flexible packaging based on specialized plastic films can offer solutions to help minimize food loss and food shortage.

The success of plastic films for food applications is based on the innumerable possibilities to optimize the film properties by coextrusion of up to 11 layers with different resins [3]. Each layer fulfils a different function in the assembly and contributes to the overall performance of the film. The main design goals are mechanical stiffness and toughness, barrier against gases or aroma, barrier against light, optical haze and gloss, sealability, machinability for converting and cost efficiency. A lid film for food packaging concentrates on a low permeability for water and oxygen combined with a high transparency and good mechanical properties. A typical lay-out is a 5-layer barrier film of about 50µm thickness that is laminated to an orientated polyethylene terephthalate (OPET) film with the print inside (Figure 1).

Figure 1 –Lid Film for Food Packaging

Polyethylene (PE) is used as a cost efficient base resin that gives mechanical toughness, good sealability of the lid film to the base tray and good adhesion for the lamination glue. Ethylene Vinyl Alcohol (EVOH) is used because of its excellent barrier properties with very low permeability for oxygen and water vapor, ensuring that the EVOH barrier layer itself only needs a 3-5 µm thickness. The tie layers guarantee good adhesion of the EVOH layer to the PE layers.

Successful coextrusion of barrier films needs sophisticated equipment and well trained personnel. Additionally, the prices for barrier resins are higher than commodity resins. All in all, barrier films are high technology products within the film application range. During the extrusion process, the barrier film is wound into rolls that are stored and then transported to the lamination facilities. Laminating the already printed OPET film onto the barrier film, gives further ‘added value’ to the product. The solventless laminated film roll is then stored in a temperature controlled warehouse in order to let the glue bond with the help of the pressure inside the wound roll. Finally, the laminated film rolls are rewound and slitted into the varied final application widths. The biggest challenge in this process chain is the long lead time between extrusion and slitting of the final film product. It was found that some winding defects are able to destroy complete rolls of formerly best quality film. Additionally, the winding defects can grow during the aging time in storage, so that complete production lots are at stake. Sometimes the defects are not detected until rewinding at the slitting station. Two of the most common winding defects for barrier films are cross direction (CD) wrinkles and air knots which can cause production losses of up to 10%.

WINDING OF PLASTIC FILMS

Barrier films for flexible packaging can be extruded using three different technologies [4]. The technologies of cast film, blown film and water-quenched blown film promote different film properties when extruding the same resins. The blown film technology for example offers a higher modulus of elasticity due to the higher crystallinity caused by the smaller cooling rate of this process. Another characteristic is the biaxial orientation of the film material due to the simultaneous take-off and inflation process. As a result, films with balanced mechanical properties in machine and cross direction can be produced.

In a blown film line multiple extruders provide different melt flows (Figure 2). These streams are then fed to the so-called die head [5]. Inside the die-head the melt flows are converted into a multilayer annular flow. After emerging from the die gap, the plastic melt is drawn vertically upwards by means of a haul-off. The melt tube is inflated by air pressure and simultaneously air cooled on the inside and outside. Then the tube is laid flat in the collapsing frame and finally nipped between the chilled haul-off rollers. Collapsing frame and haul-off are able to rotate 360° around the film tube and thus oscillate the thickness profile of the film. A secondary nip-unit draws the film downwards from the haul-off through the corona treater towards the winders. At the secondary nip the tube is slitted in the folded edges to get two flat films. Each film can be further slitted into multiple ups that are usually wound on cardboard cores. Typical film thicknesses for blown film are ranging from 8 to 250 µm, the maximum film width is 3600 mm. Maximum outputs of 1500 kg/h and web speeds of up to 200 m/min can be achieved. Barrier film production is usually running well below 100 m/min.

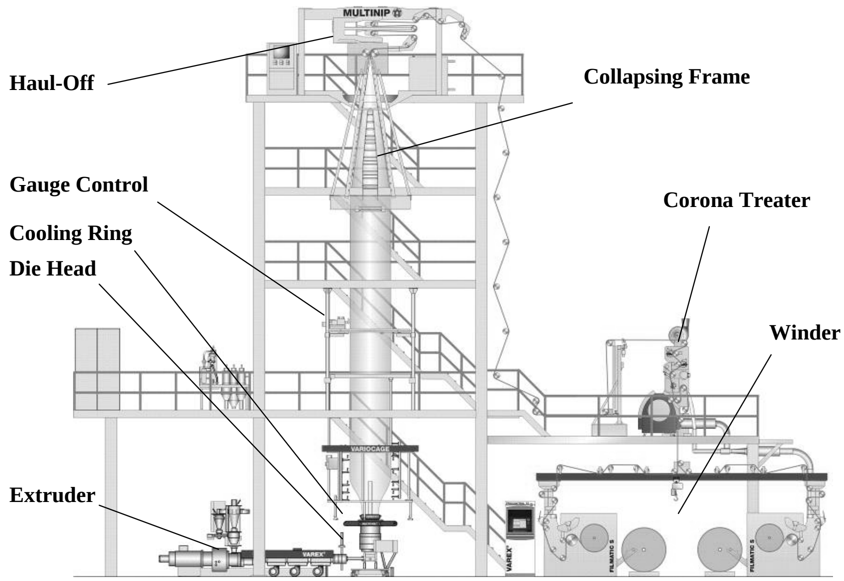

Figure 2 – Lay-out of a blown film extrusion line

The inline film treatment is very important for the subsequent lamination process in order to get a good wettability and adhesion of the glue [3]. The standard treatment technology in extrusion lines is the corona treatment. The system consists of an electrical grounded roller that is covered with a dielectric sleeve (e.g. silicone) and an aluminum high voltage electrode. The air in the gap between roller and electrode is ionized and modifies the film surface chemically and physically. A regular system consists of two rollers to treat both outer surfaces of the film tube, but specialized system can even treat in- and outside. At higher power levels the film can be heated up considerably by the treatment. Therefore it's necessary to cool the film again in the secondary nip unit above the winders.

Winders for barrier films usually are center-surface winders that provide all three ways to control the wound in tension (WIT) inside the roll, web Tension, Nip pressure and center drive Torque (TNT) [6]. This is necessary to adapt the winding process to slippery as well as slightly sticky film surfaces that are produced on the same extrusion line. Since barrier films tend to have higher production costs it is important to use every metre of the roll from the core to the very outside. High end winders achieve that goal using a center drive already at the roll start and a perfect rectangular cut without any fold-back by the patented vacuum cut drum.

Concerning winding and lamination, the mechanical properties of the barrier film are important. The barrier layer is very stiff with a young's modulus of about 3000 N/mm² while the PE layers could have a young's modulus of only about 200 N/mm². During production, these values can vary significantly, since the individual layer and film properties are very sensitive to processing parameters, but the scale of difference shows that the necessary winding web tension is extremely dependent on the barrier layer's thickness and properties. It proves to be almost impossible to predict a good web tension based on literature values, when there are up to 11 layers with mixed resins in each product. Therefore, an extensive experience is needed to wind these kinds of film to perfection. Another important factor to be considered is the aging of the film after the extrusion process. Shrinkage and post-crystallization during the storage increases the roll hardness and thus amplifies winding defects.

WINDING DEFECTS

Cross Direction Wrinkles

Typical stiff film defects are CD wrinkles that appear especially after aging. The wrinkles appear at an edge and can reach as far as the middle of the roll (Figure 3). After post-crystallization in an aging room, defects start to grow and are found while rewinding the rolls. While the outside of the roll seems good the inside is waste.

Smith [7] states that CD wrinkles might be caused by loose winding at the core and then winding tightly on top of the loose web. The web on the inside is tightened by the outer layers and builds up waves in CD. It might also be possible that there is a loss of web tension at the beginning of the roll. As CD wrinkles are found mostly on one side of the roll, there might also be a relationship to the flatness or the thickness profile of the web. A baggy web causes multiple issues during winding, as the film builds up wrinkles as the winder tries to even out the tension differences inside the roll [8]. Likewise, winding a non uniform thickness film causes non uniform radial pressures that lead to CD wrinkles.

In order to visualize aging effects, a hardness measurement device was established. This system measures the hardness by hitting the roll surface with a steel probe. The velocities before and after the impact are set in relation and define the roll hardness in Leeb. Figure 3 shows the aging effect displaying time shifted measurements after production. It is obvious that hard areas are getting harder, as the entrained air is pushed to softer areas of the roll. These areas soften and contribute to an uneven hardness distribution throughout the roll that may cause roll defects. Measuring the core pressure indicated that the pressure increased during aging in the first place, but then decreases again after half a day in storage.

Defect: CD Wrinkles

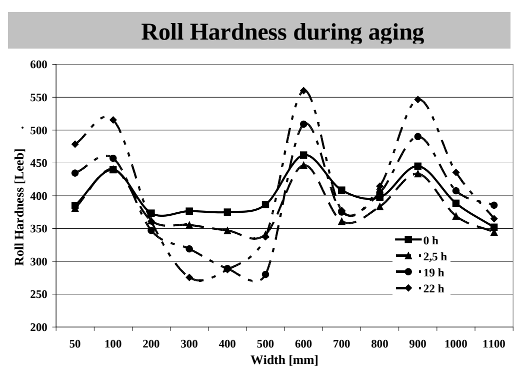

Figure 3 – CD wrinkles on unwinding station and roll hardness during aging

In order to avoid CD wrinkles, the first countermeasure is to wind the web tight on the core and to taper the tension when increasing the roll's diameter. A high resolution thickness profile measurement of affected rolls was conducted for the further investigation of the defect causes. The scan in Figure 4 shows the gauge variation with a colour gradient. It shows that the profile of the web was not uniform and changed significantly during production of one roll. It was possible to identify the profile control to be an important influence parameter on the CD wrinkles. In the case shown below, the CD wrinkles were induced by changing the factors of the control system (figure 4). It is obvious that the control settings influence the thickness profile significantly. Setting 2 and 3 indicate a high variation, whereas the Setting 1 seems smooth and without peaks. In this case, the production loss was decreased from 10% to 1% by the optimization of the profile control in Setting 1. Nevertheless, even with improved profile and flatness of the film the winding parameters, especially the taper settings are critical for optimal results.

Figure 4 – Thickness profile of a roll

Air Knots

Whereas CD wrinkles are detected after rewinding, air knots can be found directly during production. Smith [7] defines air knots as “bumps that appear in the wound film over an inclusion”. Heinzler [9] describes the knots as “small local compacted air volumes”. As shown in Figure 5, the air knots are very hard spots with a diameter from less than 1 mm up to 10 mm that emerge from the roll surface. While producing a roll, air knots begin to form slowly. Often the edges of a roll are affected but it is also common that they are found on the complete surface. It is also noticed that knots form around one starting “brood cell”.

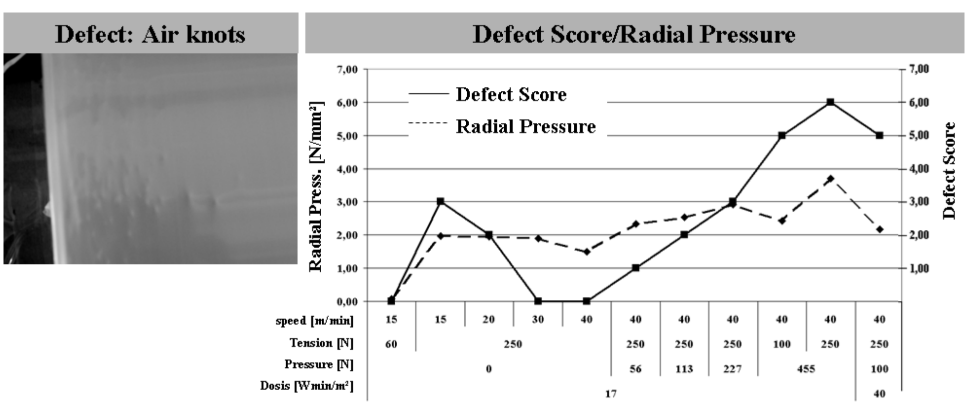

Figure 5 – Air knots and air knot appearance in correlation with winding parameters

It is known [7] that air knots are influenced by the coefficient of friction between the film layers inside a roll. The higher the friction the more knots appear. Furthermore the WIT has a similar effect; the higher the radial pressure the more knots appear.

In this project it was analyzed how a pre-treatment of the film influences the film roughness and how this contributes to air knot formation. In order to detect the influence of a corona treater, a PE film of 1200 mm width and 60 µm thickness was pre-treated and its surface analyzed using a non contact Atomic Force Microscopy (AFM) device. Figure 6 shows some samples that were treated with various dosage levels. It is obvious that the untreated film shows a completely different surface than the film that is treated with a medium intensity. When increasing the dosage level excessively small melted areas are found. The induced heat is so high that small spots on the surface are re-melted.

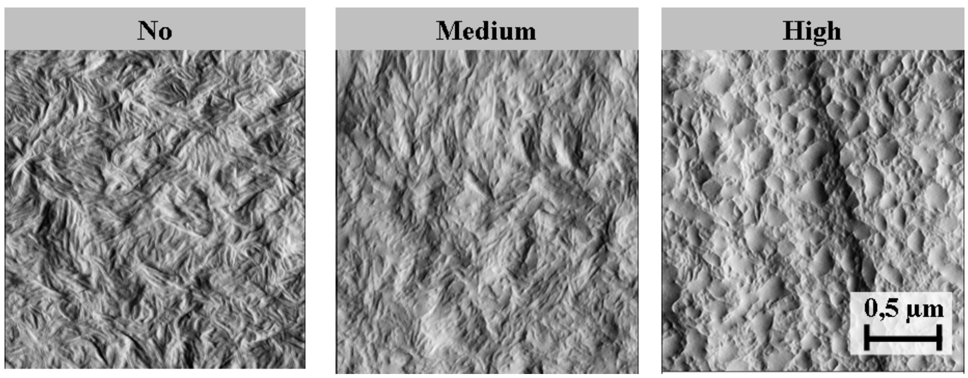

Figure 6 – AFM of film surface at certain pretreatment levels

In order to verify that an increased pre-treatment level leads to a higher air knot formation, a winding test was executed. A monolayer PE film was pre-treated with a fixed dosage level and then wound onto a roll. After winding the amount of air knots was determined using a scoring system. Therefore the roll was divided in 3 parts; right, left and middle area of the roll. Each part was given a score from 0 – no air knots – up to 3 – air knots all over the roll. The scores were summed up.

Thus a correlation between the amount of air knots and an increased contact pressure is drawn. Figure 5 shows, that for an increased contact pressure level an increased air knot formation is detected. At a tension of 250 N and a contact pressure of 56 N, the air knot formation is rated with a score of 1. By increasing the contact pressure to 455 N, a score of 6 is reached.

It is remarkable that not only the contact pressure but also the winding tension is causing air knots. Winding in gap mode at a tension level of 250 N can also lead to air knots. In this case the web speed was increased from 15 m/min to 40 m/min, entraining more air and decreasing the radial pressure. The score decreases while increasing the web speed, as shown in Figure 5. A similar conclusion can be drawn by varying the pre-treatment level. By keeping all other winding parameters at a constant level, the air knot severity changes while increasing the pre-treatment level. It is shown that a correlation between contact pressure, winding tension and knot formation is possible. Indeed it should also be possible to draw a direct correlation between the radial pressure and the knot formation. For this reason, it is assumed that the same radial pressure, independent of inducement by winding tension or contact pressure, causes the same amount of knot severity. For this reason, a winding model based on Hakiel's formulation [10] was set up.

Using the machine parameters, the radial pressure at the beginning of the roll was calculated and compared to the defect score. As Figure 5 indicates, the simulation of radial pressure induced by winding tension and contact pressure does not correspond. A radial pressure of 2 N/mm² induced by winding tension leads to a score of 3, whereas the same score induced by contact pressure is estimated with 3 N/mm². This shows that current winding models are not sophisticated enough to describe the winding defects of barrier films.

CONCLUSIONS

In blown film extrusion, the winding of high quality barrier film requires skilled personnel and a sophisticated machine set-up. Expensive raw materials and roll defects that grow in the aging room are challenging tasks that require a detailed understanding of the complete extrusion line. There are many influencing parameters on the roll quality. Identifying the root cause of a defect is not easy and often requires additional equipment. In this project a roll hardness measurement device and high resolution thickness scans were established.

It was shown that during aging the hardness distribution changes. Hard areas of a roll get harder and push the entrained air into soft areas. CD wrinkles that grow during storage may have their origin in thickness profile in combination with the winding parameters.

Therefore it is be appropriate to develop a control system that automatically adapts the winding parameters to film thickness or film width variations and thus helps to avoid winding defects. Furthermore the simulation of WIT needs to be improved.

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