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Formulating substrates for winding in vacuum metallization

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Abstract:

This talk will focus on the special formulation requirements of vacuum metallization substrates. In particular it will look at the special requirements for winding and transporting films in vacuum. A review of existing substrate slip and antiblock technologies and their relative impact on winding and web transport will be presented and then the winding requirements for metallization will be reviewed. Film surface formulations and substrate structure will be examined for its impact on roll formation in the presence and absence of air.

Introduction:

Film winding if done improperly will lead to many problems generally rendering the film unusable or at best giving high yield losses. In most instances, film is wound in air and the success of the winding operation is a combination of technologies which combine together to create a film to film separation and roll structure which minimizes the risk of blocking, telescoping, hard bands (gauge bands), MD corrugation, crushed cores etc. In almost all instances of film winding, there is a reliance on winding into the roll an air layer between the layers of film which serves to separate the film surfaces.

During the winding process, air and film are wound together in a composite structure. Generally the structure of the roll is controlled by controlling the air layer thickness using winding tension and down pressure from surface contact rollers (center surface winding). It has been shown[1] that for webs moving over a rotating surface that the air thickness at the roller surface under the film is calculated from equation 1

$$t = 0.65 * R\left[12\mu\frac{V}{T}\right]^{\frac{2}{3}}$$

where:

μ = fluid(air)viscosity

R= radius of surface

V = velocity of the velocity

T = web tension

Equation 1

From Equation 1 we see that in addition to winding speed, web tension and down pressure of nip rollers, the air layer is determined by the roll diameter and the viscosity of the air at the winding conditions. This indicates that the air layer thickness will vary through out the build of the roll and potentially from season to season if the air or film temperatures are significantly different in the winding areas.

The authors of reference 1 indicate that a balance between the film roughness and the trapped air layer permits “a controlled degree of film-to-film contact” and that the foil bearing equation is thought to mimic what is happening in the roll winding process. This comment addresses the main concern of this paper which is how best to control the film roughness necessary to control the degree of film to film contact between layers in wound rolls.

Body:

Original polymer films were used to replace paper in packaging and typically were produced as single layer polymers (Cellophane and oriented polyester [PET]). These films were often times coated and the coatings were modified to improve film handling properties making the film slippery and non-blocking. “Slip” was a migratory additive such the fatty acid amides and “anti block” was a fine particle clay. Antiblock was limited in its application due to its impact on film optical properties (Haze and gloss). These surface modifications when combined with skilled slitting operators to control the air layer during winding were often times adequate to produce film commercially. The introduction of oriented polypropylene (OPP) films started with the same cellophane and PET film surface modifying coatings. However, the introduction of coextruded OPP films obviated the need for surface coatings in some applications making film core and skin layer formulations for slip and antiblocking important. Slip modification was generally done to the core of the film while antiblocking was limited to the skin to minimize the impact on film haze (Figure 1).

1 micron Skin layer for printing	Copolymer or homopolymer PP + 0 – 3000 ppm antiblock
Core layer	Homopolymer PP + 2000 – 3000 ppm Erucamide
1.5 micron Skin layer for heat sealing	Copolymer PP + 1000 -5000 ppm antiblock particles

Figure 1: Early coextruded OPP film slip and anti block formulation technology

In comparison, relatively few PET films are coextruded and it is generally not possible to modify PET with migratory additives like the fatty acid amides. Consequently, all uncoated PET surface modifications are made with particulate additives in the bulk of the film layer, only a small fraction of which are active at the film surface. the remaining particles only add to the haze of the film and don’t help with the winding properties.

Then the world of film winding changed. Suddenly there was a demand for vacuum metallized films to improve film appearance, light barrier and barrier properties. Suddenly the films had to be unwound and rewound in a vacuum without the benefit of the air layer to separate film layers. Based upon early experience with winding in vacuum, it was apparent that the air layer was an important factor in winding of existing film formulations. The absence of air in the metallizing chamber leads to many film defects. Rewinding metallized film tight enough to prevent telescoping, will generally result in hard rolls with pronounced gauge bands, knife edges and the significant possibility of metal pick off and film blocking. Winding metallized film loose enough to prevent pick off, blocking, knife edges, gauge bands etc generally increase the likelihood of catastrophic telescoping and extremely soft rolls which are hard to rewind. Also, with soft rolls, when the metallizing chamber is opened to atmosphere the rolls are

"crushed" by the atmosphere causing significant TD buckling and corrugation in the rolls. On unwinding a corrugated roll the film will scrape against the film below it and can cause significant film scratching (Blushing if in patches). In addition the move from unsupported metallizing chambers to supported chambers with metallizing speed increases made film to chill roll friction control (again no air layer to float the film on the roll) more important

It was clear that something had to be done. However, simply making the film more slippery with migratory additives was not a viable approach as it was known that migratory additives in too high a concentration would cause aluminum adhesion problems[2] and as seen in figure 2 would cause significant appearance problems.

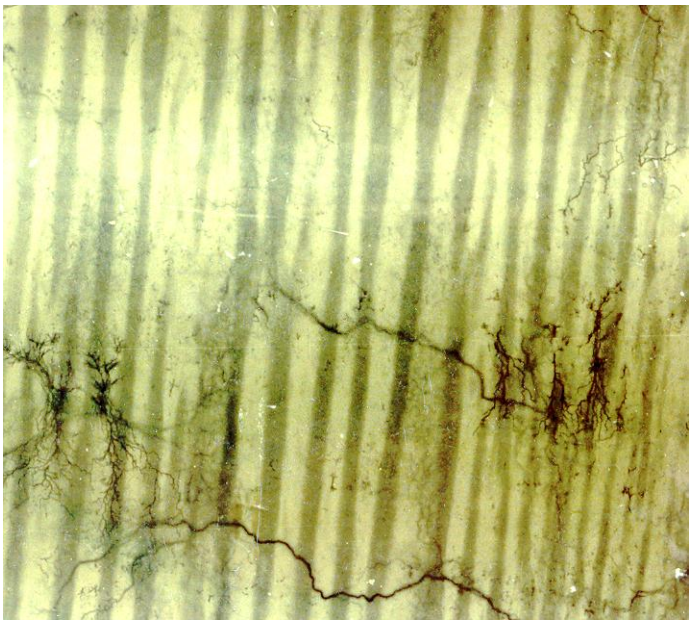

Figure 2: variation in metal OD due to variations in additive boom in OPP film. Bands are approximately 6 -8 mm (~ 0.25 inches) wide (also visible are dark static discharge tracks)

However, what is really wanted is to develop "a controlled degree of film-to-film contact" in the metallizing chamber without the presence of air. While this is a necessary condition for good winding in the metallizer, it may not be a sufficient condition to prevent defects due to roll collapse during vacuum chamber evacuation and during re-pressurization of the chamber.

Ultimately, what is desired is a film to film spacing larger than the expected air layer so that air can easily escape and enter from the wound ends. i.e. to control the film layer to layer spacing and make it so that the predicted air layer would be thinner than the film to film spacing. This is what I term formulating films for winding and is a critically important concept in film manufacturing.

Formulating films for winding in vacuum has the added advantage of making film winding in air more effective as it removes the need to manage the sir layer by winding tension. For what ultimately impacts the winding outcome is the ability to control the film to film spacing of multiple layers in a roll as it is being formed and after it sits allow it to "out gas" without collapsing. For both in the vacuum chamber and at atmospheric pressure, too much air outgassing leads to internal roll collapse and the

formation of corrugations in the roll. This will always occur for film wound with air layer control because the films are in compression in the lower layers and in tension in the outer layers.
In my estimation, the best way to control film to film spacing by particles added to the film surface. Control of the film to film spacing with particulate film additives permits better control of wound roll density and removes some of the sensitivities to winding quality from tension settings and tension variations. It is also easier to substitute film tension with down pressure when winding films with particulate controlled spacing larger than the air layer.

So what should the film to film spacing be, or put another way what should the particle diameter added to the film be? Using equation 1 to calculate the air layer as a function of roll diameter will be instructive. For room temperature (air viscosity of 0.39×10^{-6} lb_f-sec/ft^2, 1.87×10^{-5} Pa-sec), a line speed of 1500 ft/min (457 m/min) a winding tension of 0.25 lb/in (43.4 N/M) and a roll diameter ranging from 6 to 24 inches (15.2 to 61 cm) in diameter this would predict a film air layer of from 2.1 microns to 8.7 microns in thickness (Figure 3). This would suggest a film to film spacing of greater than 2 microns is desired.

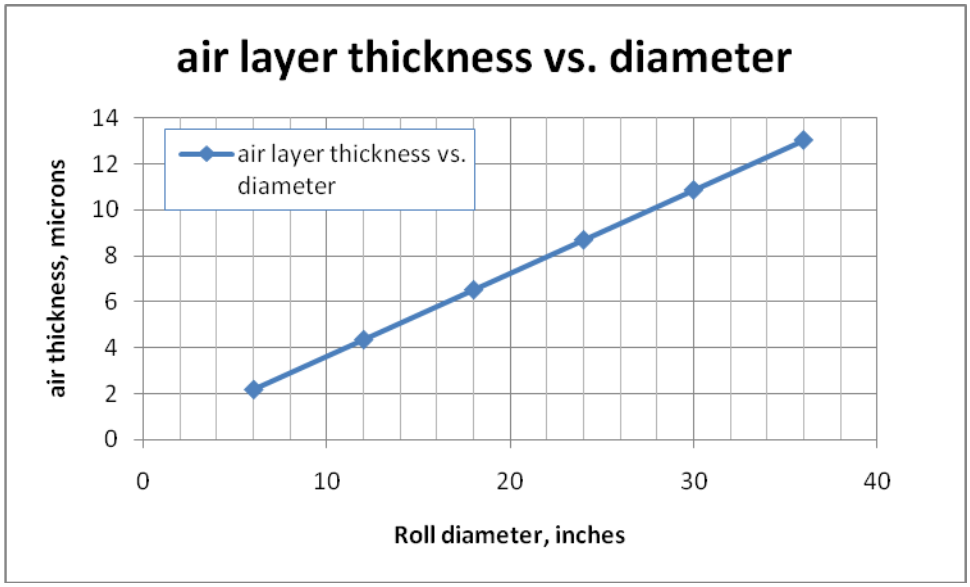

Figure 3: plot of air layer thickness as a function of roll diameter predicted from equation 1 and the conditions in the text.

This spacing of greater than 2 microns would be achievable by coextruding a thin surface layer on the film surface with a particulate diameter larger than the skin thickness. This concept is extendable to all films from cast PE, amorphous polyester (APET), polypropylene (CPP) films to oriented PET, polylactic acid (PLA) and OPP. However, it is easier to accomplish with oriented films due to the thinning of the coextruded skin during stretching. For instance in oriented PET the coextruded skin layer is thinned approximately 12-16 times during orientation while in OPP the skin is thinned approximately 40 times. This allows particles larger in diameter than the final skin layer thickness to remain in the skin due to adhesion to the skin polymer, but to stand higher than the surrounding skin surface. For particles which do not adhere strongly to the skin polymer they may remain physically locked into eh skin layer, or come free and control film to film spacing free on the film surface. Free particles on a film surface will sometimes leave particle deposits on operating equipment surfaces which must be periodically cleaned off.

In cast films it may be necessary to increase loadings of particles in the skins and perhaps use larger particles to better improve the surface roughness relative to the 2 micron target. This is in part due to the use of relatively thick surface layers in cast films (6 to 12 micron skins in a 25 to 50 micron film respectively) relative to oriented films. Higher particle loadings are typical of cast films because many of the particles will be below the film surface and to increase the number at the surface the total number must be increased. But the use of larger diameter particles in cast films would be beneficial.

For OPP films, sealant layers tend to range from 1 to 1.5 microns in thickness[3] so a particulate with a diameter of 4 microns or greater should give a film to film separation of at least 2.5 microns. Larger diameter particles and mixtures of various diameter particles can be explored as well as varying particle concentrations. But in general particle diameters of at least 4 microns should be considered when designing film structures for winding control[4]. Reference 4 clearly demonstrates that coextruded films for metallization with particulates of 2.5 micron diameter are not as effective as films layers prepared with particulate diameters of 4-5 microns in a skin layer of 1.5 micron thickness (Figure 4).

0.5 micron Skin layer for metallization	Copolymer or homopolymer PE + 0 ppm antiblock
16 micron Core layer	Homopolymer PP
1.5 micron Skin layer for heat sealing	Copolymer PP + 3000 ppm 4-5 micron spherical particles

Figure 4: Product design of a metallized OPP film optimized for winding in vacuum

The incorporation of a low concentration of larger diameter particles in the film can also be beneficial especially as roll diameters are increased.

In general the particulate should be added to the unmetallized film surface to prevent the formation of pinholes in the metal surface from particle loss or from shadowing of the film surface during deposition due to the surface roughening particles. This is especially true of high barrier metallized films and less so for metallized films targeted for decorative applications.

Particles can be comprised of many substances. Typical particles for film manufacture are based on coated and uncoated amorphous and ground silica, crosslinked PMMA (Epostar®), crosslinked hydrocarbyl-substituted polysiloxane (Tospearl®), hollow ceramic spherical particles (Zeeospheres®) dispersed incompatible polymer phases and others.

In conclusion, the design of film formulations to improve winding in vacuum should be targeted to provide at least one film surface with an average surface roughness of 2.5 microns or greater. This is achieved by incorporating particles into the film which appear at the film surface to give the desired film roughness. This is best achieved by coextruding a surface layer on the film containing the desired particles of 4 microns or greater in diameter. Typically, this would be the unmetallized film surface so that a flat smooth film surface is available for the deposited metal layer

References:

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