BOPP FILM TRENDS; SOME TECHNOLOGY IMPLICATIONS

by

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ABSTRACT

Biaxially oriented polypropylene (BOPP) is an extremely versatile film that has demonstrated enormous growth in commercial usage over the approximately 40 years since its first introduction. A combination of material, web handling and process technology developments has continued to expand the range of film structures that can be produced. This has enabled polypropylene to cost effectively replace competing materials in many applications. Other than those companies with a pure low-cost producer strategy, BOPP manufacturers must introduce new products and extend their product ranges in order to maintain or increase their competitive positions. As new markets are identified, product line extensions commonly involve the introduction of new technology (eg for the development of very thick films). At the same time as diversifying the product range, even those suppliers with a differentiated product strategy must identify ways to contain or reduce manufacturing costs, while also increasing manufacturing flexibility.

In order to continue to accomplish these conflicting goals, further developments are needed in web handling and film making technologies. Specifically our ability to quickly, easily and accurately model equipment performance and film-equipment interactions must be extended. The range of requirements is broadened as film manufactures produce more complex film structures and strive to increase overall equipment performance (line speeds, uptime, waste reduction etc) across a diversifying product range, and customers process BOPP using many more downstream technologies (metallizing, printing, sheeting, guillotining etc).

The objective of this paper is to further illustrate these issues and to describe some of the progress made while also indicating priority areas for further work.

NOMENCLATURE

LSL	Lower Specification Limit
USL	Upper Specification Limit
$\bar{x}$	Mean Value
s	Standard Deviation

INTRODUCTION

While biaxially oriented polypropylene (BOPP) films have continued to grow strongly in their traditional markets, they have also seen extensive penetration into new markets and applications via material substitution or film/structure property enhancements. The North American market has historically grown, for example, at about 6% per year and now represents a total usage of about 1 billion pounds of film per year. This growth has brought with it a number of challenges, many of which result in significant and exciting opportunities for both product and process technology development. BOPP is being used in more complex and demanding applications that often involve many more distinct processing steps than has traditionally been the case. In order to satisfy the spectrum of applications, product ranges are becoming much larger and product life cycles are shortening.

Severe competition and over-supply has brought with it the need for continuous cost reduction throughout the whole supply chain. Customers have introduced more rigorous product qualification protocols while, in many cases at the same time, reducing their engineering support and quality control/inspection resources. This puts a premium on both product quality and consistency. The trend is for multinational companies to purchase globally with increased desirability for products to be acceptable in more geographically and technologically diverse production/processing environments.

These market trends have immediate impacts on the need for example, for (a) increased production scale, line speeds and efficiencies, (b) on-line quality assurance, (c) rapid product changeovers, (d) increased automation, (e) larger rolls of film (diameter and width) with higher, more consistent roll quality, (f) down-gauging of products, (g) more flexible equipment performance, and (h) improved predictive models to reduce product and process development/experimental time and cost. When errors arise, they tend to be more costly and have a larger impact than in the past.

PRODUCT RANGE AND APPLICATIONS DEVELOPMENT

Product Ranges

BOPP was first introduced as monolayer transparent films in the early 1960's, initially to replace cellophane. Since then, the introduction of significant new technologies (called product development platforms) such as, multilayer coextrusion, voiding technology, opaque films, corona discharge and flame treatment, new polymers (eg copolymers and terpolymers), and coatings (eg acrylic and PVdC) has greatly increased the number of film types and associated applications areas (Figure 1). While monolayer films are still in use, three layer coextruded films are by far the most common. There are also 4 and 5 layer coextruded BOPP films on the market. The outer layers of a coextruded product are commonly called "skin layers". The number of layers in a film structure increases when out-of-line process technologies, such as coating or metallizing, are used. A full-range film producer will have a product line of 80-100 films (not counting different gauges), including the following major film types –

- transparent
- coated
- opaque solid core
- opaque voided core
- metallized
- embossable

These film types are offered in a variety of gauges with many property/performance options such as:

- nonsealable
- 1 or 2 side sealable layers
- specified static and dynamic coefficients of friction (COF)
- specified seal initiation temperatures (SIT)
- with or without hot tack
- specified gloss and clarity levels
- yield
- etc.

They are also offered in combination, e.g., coated opaque or metallized transparent.

Product ranges are therefore not only increasing in size but also in diversity. Films are now available in a thickness ranges from 40 gauge to over 10 mils. They have a wide range of densities, mechanical properties and surface characteristics which all impact the processing requirements in every stage of their manufacture and subsequent uses. Suppliers and customers must learn to manufacture and use more films with greater effectiveness and efficiency. The range of film properties and application types makes this a technologically demanding objective.

Complex Application Processes.

The early applications of BOPP films involved converting and perhaps laminating processes by film customers. Processing steps using rolls of film have now increased in both number and complexity. One consequence is that the number of unwinding and rewinding processes a roll of film experiences has increased. A very common example is the production of film with a thin coating of aluminum metal. The metal is added for aesthetic reasons (to increase shelf appeal) and/or to increase moisture vapor barrier (to increase product freshness/shelf life). In this case, a roll of film is loaded into a large vacuum chamber (Figure 2) and the whole chamber evacuated to low pressure. Aluminum metal is vaporized and deposited (typically to a thickness of 50-200Å) on the film web at high speed and the roll rewound within the vacuum chamber. The chamber is then opened and the roll removed. Note that the roll is rewound under vacuum and is rewound hot due to the high thermal energy of the aluminum atoms. Films are typically rewound and reslit as soon as possible after being removed from the chamber. Metallizing is a batch production process using expensive equipment so there is continuous pressure to improve the economics by using large diameter (40 in. plus) and width (120 in. plus) rolls and to increase metallizing speed. The combination of speed, roll size, vacuum operation and heat increases the process difficulty and because of the costs, waste must be kept low.

New developments in labeling technology have further increased the subsequent processing steps. Plastic labels offer several advantages over paper such as durability and improved graphics. There is a common method called "cut and stack" labeling which requires film labels being produced in a form similar to a several inches thick stack of playing cards. These stacks are loaded into a magazine and dispensed at high speed [600 per minute or greater] in a labeling machine and applied to a container using an adhesive. The film used will undergo many of the operations shown in Figure 3. Thus a film may be wound 4 times in its life, during which it will have its surface properties significantly modified (applications of aluminum metal, protective overlacquer, ink etc).

With applications, such as these, the ability to easily handle webs or sheets with varying characteristics, while retaining quality and performance, is paramount.

Developments in Materials and Analytical Techniques

There have been significant developments in the materials used to make BOPP particularly in the last 10-15 years. High speed packaging machinery has required the development of stiffer films with lower SIT coextruded skin polymers so that packages can be sealed at high speeds. These skin polymers are more difficult to process in a tenter as a result of their increased tendency to stick to rolls or to incur surface damage during, for example, a machine direction orientation process. Figure 4 shows some curves of seal strength versus sealing temperature for a range of sealant polymers. The SIT is usually defined as the temperature at which a material achieves a specific seal strength eg 200g/in. The progression to lower sealing temperature materials is clearly evident.

These difficulties are enhanced when developments in core polymer technology are also considered. Figure 5 shows the situation schematically. The capability to easily and effectively process a polypropylene polymer at high speed and with good line continuity is often inversely related to the desirability of its performance in the final product! While future polymer developments will undoubtedly address this trend, at least in part, we need better ways of handling soft or sticky webs including when under high tension such as in the forward draw step of a tenter process. This is an increasing problem as skin polymers have lower softening points but core polymer developments or increasing line speed requirements increase the heat loads on the film structure. The problems are at there most severe when very high surface quality is needed eg for graphics applications.

In many applications the surface properties of films are of great importance. The required properties include for example:

- high, controlled surface energy for ink receptivity in printing applications
- the appropriate combination of surface "flatness" and surface chemistry for good adhesion to aluminum metal
- control of COF for good packaging or labeling machine performance.

These properties are becoming increasingly tailored to specific applications and machine types. The benefits can be significant. Figure 6 shows a graph of the best moisture vapor barrier that has been obtained over time for metallized BOPP. This improved performance, which translates directly to improved quality of product in packaging applications, would not have been possible without the correct web handling and winding techniques in the vacuum metallizer and slitting machines.

Film surfaces are becoming more complex. They are modified using a range of techniques (singly or in combination) such as blending of dissimilar polymers, incorporating organic or inorganic particulates, using flame or corona discharge treatment and through the inclusion of migratory additives. The handling (over guide rolls, through nips, winding, sheeting etc) of these films is becoming increasingly difficult. Models are needed to assist rapid process development and optimization. It is also clear that measurement and characterization techniques are needed that more completely define film surfaces so that the inputs to models can be more sophisticated. Single parameters eg

COF are often no longer good enough. Materials with identical COF can have very different application performance, all other things apparently being equal, because their detailed surface structures are different.

Optical microscopy and scanning electron microscopy have been used for surface characterization for many years. Figures 7 shows electron microscope images of two very different surfaces. One has substantial amounts of particulates added to it while the other shows the underlying structure of the polymer surface. It is clearly inappropriate to treat either of these as planes. More recently new optical methods for measuring surface profiles have become more common. Like conventional optical microscopy, they can be used in air, are of high resolution and are non destructive. These techniques have the advantage of measuring the surface profile directly by scanning across the surface. The data is stored directly into a computer and is then amenable to analysis via a range of standard techniques for charactering "roughness". For example one can measure the maximum peak to valley distance or the mean square deviation from a theoretical surface drawn at the mean height. The most effective parameter to use is dependent on the intended application. For visual assessment, data can also be plotted using a color scale for height similar to that used in topological maps.

Voided polypropylene films are in common use. The voids are created using for example small inorganic particles such as calcium carbonate dispersed in the polymer before the film drawing process. Figure 8 shows a cross section of such a film. Voids created by the combination of the draw process and the presence of the particles are evident. Light scattering by the voids causes these films to be white in color and to have a degree of opacity controlled by the nature and extent of the voiding as well as the film thickness. Voided films typically have densities in the 0.6-0.7 g/cm3. New applications are tending to change densities and opacities. These changes have significant effects on the physical properties of the films including their compressibility and ease of surface damage. Effective handling techniques including web transport, winding and rewinding technologies are increasingly important in making these films.

COST OF QUALITY DEFECTS

The combined effects of minimizing production costs to remain competitive, and the increasing use of BOPP in higher value (usually also higher total manufacturing cost) applications results in very high costs associated with quality losses throughout the supply chain. For a large BOPP film producer (the actual numbers will vary by producer- these are intended only to indicate the magnitudes of the effects):

- Average core losses of say 2.5% would result in production losses of 6-7MM lbs of film per year. This is equivalent to 40-50% of the typical output of a 5.5m wide tenter production line;
- If each product changeover required one hour of lost production, film losses would be similar in magnitude to the above;
- Each 1% loss in slitting efficiency equates to some 2-3MM lbs per year;
- If film is returned from customers at a rate of 0.5-1.0% of revenues, then the cost of film alone is $1.5-3.0MM. This does not include the associated costs of freight, problem investigation, customer contact, manufacturing cycle interruption for re-supply or, significantly, the adverse effects on the performance and reputations of both the film company and the customer businesses.

The large impact of defects is a strong motivator for product and process improvement. There are major opportunities for new technology developments to help with;

- faster product changeovers
- reduced edge trim, core, start-up and roll conformation losses
- designing equipment with wider operating windows
- the rapid detection and correction of web and roll defects

These and other issues will be addressed below.

PRODUCT QUALITY & CONSISTENCY

Many companies have their "product quality" as a stated value. Inherent in this is the requirement for consistency over long time intervals. Customers and suppliers are increasingly interested in the use of standard statistical techniques and measures, for example, Cpk, where values above 1.33 are desirable.

$$\text{Cpk} = \text{minimum of } \frac{\text{USL} - \bar{x}}{3s} \text{ or } \frac{\bar{x} - \text{LSL}}{3s} \qquad \{1\}$$

Operating windows along the supply chain are narrowing with an increased reluctance by customers to customize machine conditions to optimize film performance. Total product consistency (film + roll properties) is therefore more essential than ever. Some specific challenges are:

- Increased use of on-line monitoring and control
- More effective process models
- Non-destructive, quick, easy methods for the assessment of roll quality
- Equipment design that is robust to scope-of-use changes

On-Line Monitoring and Control

Many tenter frame processes use only a single direct measurement of the film properties – gauge, using nuclear, infrared or x-ray methods. More recently the sophistication of the infrared technique has been increased. With the advent of low cost diode array detectors and rapid data acquisition electronics, it is now possible to collect the whole infrared spectrum (intensity as a function of wavelength) of the moving web at each measurement point in the scan rather than using a filter technique to collect only part of the spectrum as a single data point. If the layers of a multilayer film are significantly different chemically, then these new detector systems allow the thickness of the individual layers to be determined. For films with reduced density (eg voided BOPP) the use of interference fringes arising from the different path lengths due to reflection from the opposite sides of a film allows a direct measurement of thickness. This phenomenon is physically different from the absorbance measured from the infrared spectrum, which is related to the total amount of material in the film. A combination of these two measurements can, in principle, be used to control film density (which is related to the film yield ie surface area per unit weight) on-line. Yield is an important sales parameter. Current methods for measuring yield are laboratory based, rely on taking production samples and are hence an inherently slow method of feedback. Spectral measurements may also eventually allow more fundamental characterization to be made on-line such as orientation. Information on fundamental properties or non-uniformity in a web will be beneficial, for example orientation is known to have an effect on wrinkling.

Control of web and film properties is predominantly through the measurement of indirect variables, such as temperature, airflow, power, etc. The trend to on-line property measurement and control has been slow. The Web Handling Research Center at Oklahoma State University (WHRC) and Advanced Web Systems have been involved in an interesting development in the direct measurement of tension that could be used to control web properties in real time. The "on-line non-contact tension measuring system"

[1] can measure widthwise (TD) web tension at fast scan speeds. Since web contour defects such as flatness, wrinkles and MD corrugation are associated with varying levels of web slackness, the system offers the potential of quantifying these defects and controlling the process. Physically the system consists of a pneumatic pulse generator and two microphones mounted on a traversing unit. Pulses of air are used to generate transverse waves in a film web and the time difference between the microphones measures their time of flight (TOF) through the web. Film tension is calculated from the measured TOF using the ribbon equation resulting in a direct measure of transverse direction (TD) tension profile on-line. This instrument can be used either in a static or in a scanning mode. Web camber can readily be detected and, with the appropriate feedback loop, could be corrected on-line. The result of an experiment carried out such equipment is shown in Figure 9. The plot represents the calculated web tension as a function of position across a web. Data has been generated using intentionally distorted webs to confirm that the trace corresponds to a real situation. This is one example of an interesting, relevant development that could ultimately be used to control operating conditions. Further work is needed on this and other direct web measurement systems.

Process Models

We require effective first principle models in areas such as:

- Tension control
- Winding and slitter machinery control/design/operation
  - force control
  - tension control
- Web transport
  - wrinkling
  - traction
  - nip mechanics
  - air entrainment
  - web path
  - idler and transport rollers
  - tension control systems
- Material properties

Some useful models developed by the WHRC and the International Advisory Board are:

- "Winder" provides sensitivity of wound roll stress to operating variables, such as tension, nip force and speed. While all film types are susceptible to defects at high radial pressures, low SIT films are particularly prone to blocking.
- "3D Winder" (under development) is a 3 dimensional model that can show the impact of gauge variation on roll quality issues, such as baggy lanes. BOPP film made by both the tenter and double bubble process has moderate gauge variation, unlike oriented polyester (OPET).
- Web Transport Systems (WTS) is a multi-span software used to simulate the effects of a tension disturbance (e.g., eccentric roller or unwinding roll). This is a valuable tool to determine web path sensitivities, controller tuning, etc., to tension stability.
- Nip Mechanics models incorporate the latest properties of rubber materials (contact mechanics, strain rate impact, hardness, etc.), and their impact on shear wrinkling, lateral stability, etc. It is applicable to heat transfer and surface treatment processes.

• Wrinkling models show sensitivity of wrinkling to process variables, such as speed, tension, etc., and material properties, such as modulus, COF, etc. This software is useful as it exists today, or when incorporated into the WTS module.
• Viscoelastic material parameters are very pertinent for all polymeric materials in winding and aging. Incorporating these material properties into a winding model, and predicting baggy lanes is beneficial to study the effect of hot winding.
• Standalone Lateral web stability models (or incorporated into WTS) showing the criticalities (sensor location, entering span, pre-entering span lengths, etc.) and stability of web guiding systems, are useful for our operations since we use such systems.
• Incorporating overall transfer functions (incorporating sensor, motor and mechanical systems) for tension control into WTS provides useful and realistic guidelines for frequency response of such systems.
• Winding and Web Transport models for thick materials (i.e., high bending stiffness) are useful for the new development in very thick films, specifically those including materials stiffer than BOPP.

Currently too much time and resources is utilized in diagnosing, understanding, and empirically correcting problems associated with change (process variables, film gauge or type, surface treatment, etc.). Better more comprehensive models will help equipment manufacturers to design and build more flexible equipment and their customers to utilize it more effectively.

Non-Destructive Assessment of Roll Quality

A direct consequence of the trend to increasing automation is that slit rolls are less likely to be inspected than is the case with manual slitting operations. Finished rolls are generally getting larger (diameter and width) and are required to run in both film producer and customer environments at higher and higher speeds. In some industries, rolls are small (8-16lbs) but are used in large quantities on fully automated machinery. The need is clearly to quality assure roll products. Excellent equipment design and control are essential to this. There is, however, a critical need for a routine non-destructive technique that can evaluate roll structure throughout a whole roll (radially and along the width). Such a technique could be used both for process optimization and quality control. To be useful in both the production environment and the laboratory, the method must not be sensitive to different operators. Techniques in routine use, such as the Rhometer or Schmidt Hammer yield only information across the width of a roll and are sensitive only to the outer layers unless the roll is unwound and the measurements repeated. This is time-consumming and usually destructive.

A potentially promising technique[2] is to make use of the fact that the time-of-flight (TOF) of a sound wave through a material is dependent on both the elastic moduli and material stress. If a sound transducer is placed on the outside of a roll and microphone along the radius at the inside of the core, then the time-of-flight through that section of the roll can be measured. An alternative is to have the microphone on the outside and a "hammer" to hit the inside of the roll core. Moving the microphone and transducer together along and around the roll will allow measurement of TOF at many positions throughout the whole roll. Although there is no unique correlation between the stack structure and the TOF, significant variations in TOF will indicate variations in roll quality. Also, for a defined winding process, the TOF measurements can be used to back calculate winding process variables and hence lead to changes in winding parameters to improve quality. The BOPP industry will benefit significantly when this or another appropriate technique is readily available.

EQUIPMENT DESIGN

In placing equipment orders (winders, slitters, etc.) users are usually asked to supply information, such as product roll dimensions, gauge range, film types, expected operating line speeds etc. This leads to effective short to medium term utilization of equipment that typically has a very long life. As new requirements arise, (e.g., very different film types or the need for higher speed operation) serious limitations can arise due to vibration or other phenomenon. Equipment is required that is either more tolerant to changes or is easily and quickly upgraded. This can be at least partially achieved through closer working between the customer and supplier at the design level. Discussion and specification should involve parameters, such as methods of tension control, web path requirements, contact roller dimensions and deflection, component tolerances, etc. Equipment must be designed to operate at higher turndown ratios and to accommodate a wider variety of materials including those exhibiting time and temperature dependent stress recovery.

ACKNOWLEDGEMENT

I would like to thank Raj Ranjan for his advice on a variety of topics pertinent to this paper.

BIBIOGRAPHICAL REFERENCES

1. Vickery C.M., "Use of Pneumatic Pulse Stimulus for Inducement of Large Amplitude Flexural Waveforms in Web Materials for the Purpose of Local Tension Measurement", PhD Thesis, College of Engineering, Architecture and Technology, Oklahoma State University, May 1992

2. Swanson R.P., "Determination of Wound Roll Structure Using Acoustic Time of Flight Measurement," MS Thesis, College of Engineering, Architecture and Technology, Oklahoma State University, May 1992

Some BOPP Applications

Labels
Snacks
Confectionary
Tobacco overwrap
Bakery
Cereal Bars
Ice Cream Novelties
Condiments
Powdered Drink Mixes
Graphic Arts Laminating
Release Sheets
Document Protection
Capacitors
Sheet protectors

Pressure sensitive Tape
Fresh-Cut Produce
Photo Album Overlays
Coffee bags
Compact disc overwrap
Cheese wrapping
Multi-wall Shipping Sacks
Pasta
Pharmaceutical Packaging
Synthetic paper
- tags
- photomedia

Building/roofing

Fig. 1 Examples of the applications of BOPP films.

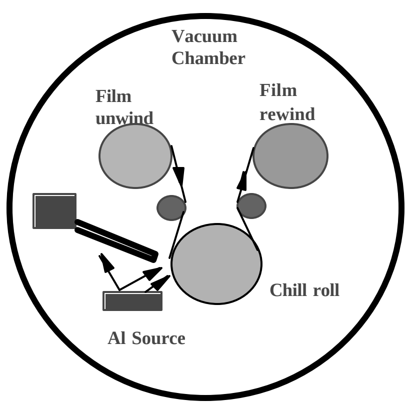


Fig. 2 Schematic of a vacuum metallization chamber showing the heated aluminum source, unwind and rewind sections and the chill drum used to control the temperature of the web.

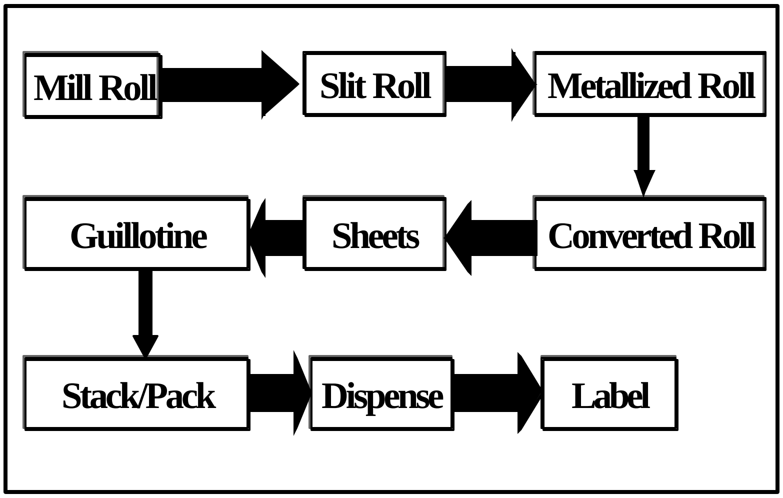


Fig. 3 Example of a mu lti step process. Cut and stack labeling requires the BOPP film to be printed, cut into sheets and then die cut or guillotined before stacking and dispensing on a labeling machine. The metallizing step is optional.

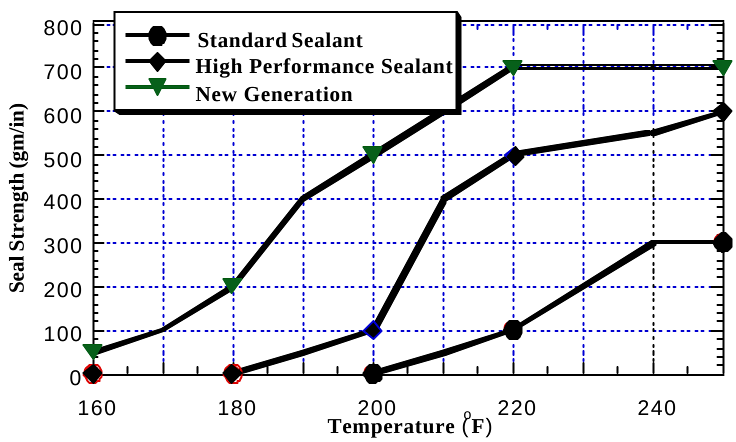


Fig. 4 Heat seal curves for a variety of polymers. The SIT can be obtained by determining the temperature at which the seal strength equals a defined value (eg 200g/in.)

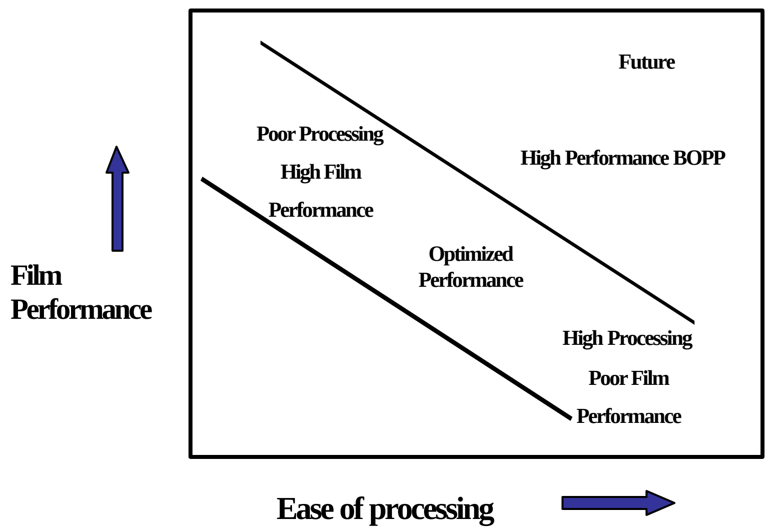


Fig. 5 Schematic representation of the current compromise between ease of film processing on a film manufacturing line and the desirability of some final film properties.

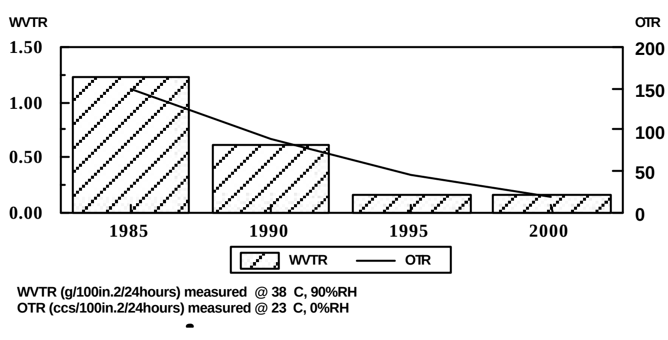
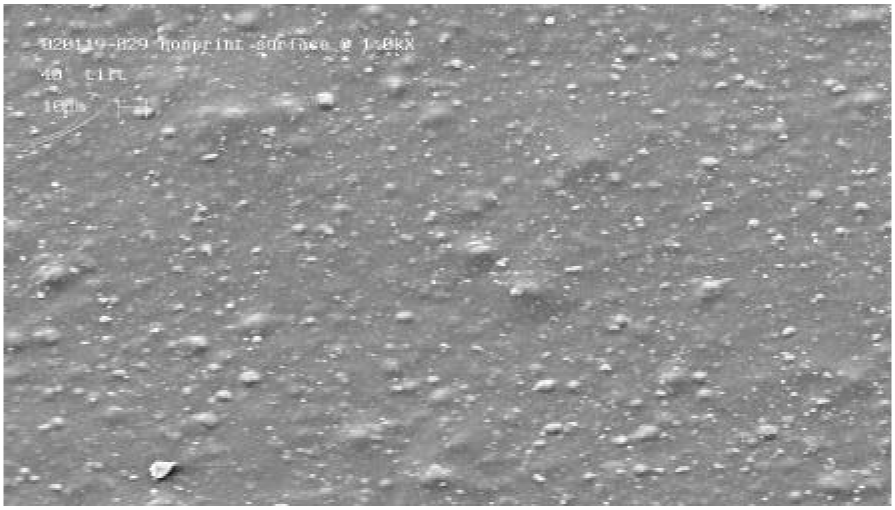
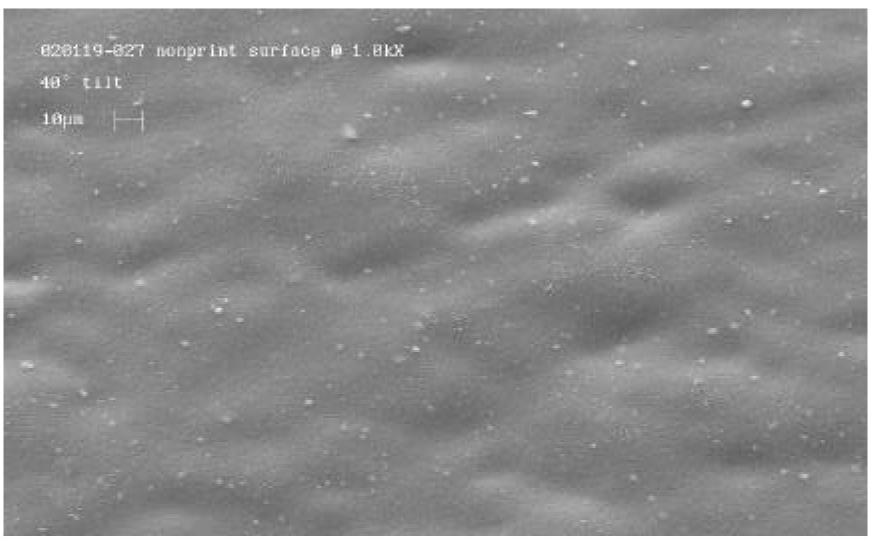


Fig. 6 Plot of typical water vapor transmission rate and oxygen transmission rate of metallized BOPP films obtained using the technologies available between the years 1985 and 2000.



10 microns (a)



10 microns (b)

Fig. 7 Scanning electron microscopy pictures of two different film surfaces.
(a) Surface contains a high density of particulates.
(b) Surface contains few particulates and the polymer surface texture is clearly seen.

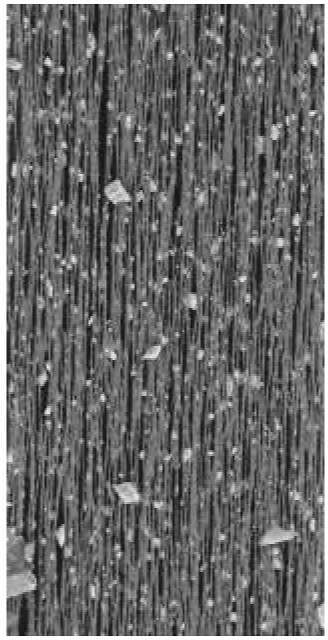


Fig. 8 Cross section of a voided BOPP film obtained using an electron microscope. The irregular bright objects are calcium carbonate particles. The voids are the dark structures elongated in the vertical direction.

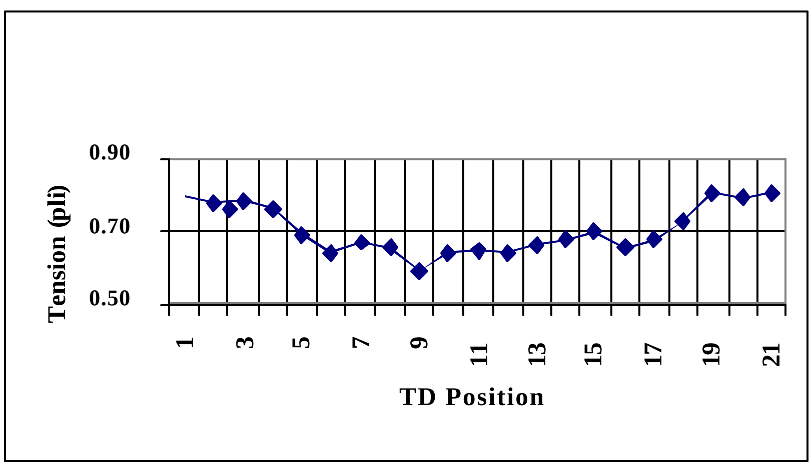


Fig. 9 A plot of the calculated tension (pli: pounds per linear inch) as a function of position across a moving web. The data was obtained using the non-contact in-line tension measuring device described in the text.

Keynote Presentation - *Films Business Trends and their Technology Implications* **J. Howard** – AET Films, USA

Name & Affiliation	Question
J. Shelton – OSU	On one of your slides you showed the term "transverse pressure wave". I believe that it was the velocity of a longitudinal pressure wave that was being measured. Were the microphones spaced apart in the machine direction?
Name & Affiliation	**Answer**
J. Howard – AET Films	The microphones were separated in the machine direction. Raj, could you comment?
Name & Affiliation	**Comment**
R. Ranjan – AET Films	The microphones are spaced in the machine direction. It is a transverse wave traveling longitudinally down the web in the machine direction whose travel time is related to the web tension.
Name & Affiliation	**Question**
D. Pfeiffer – JDP Innovations	I wondered, Dr. Howard, about the recyclability of your scrap material. Polyesters are a write-off, but how about polypropylene?
Name & Affiliation	**Answer**
J. Howard – AET Films	In product designs, recyclability is always a critical factor. When the product is pure polypropylene, we really have no issue due to the breadth of product lines that we have. It becomes more critical when we have polypropylene in combinations with other non-polypropylene materials. Typically, we recycle those products back into themselves. We design for that recyclability. I do know some businesses use 100% virgin material and then sell off the scrap. I don't know if you can survive financially doing this, unless you are dealing with very high added value products.
Name & Affiliation	**Question**
G. Homan – Westvaco	Westvaco is a paper company. I do not know what OPP means.
Name & Affiliation	**Answer**
J. Howard – AET Films	OPP is an acronym for Oriented Polypropylene. So it's polypropylene that's been drawn in 2 directions at right angles.
Name & Affiliation	**Question**
D. Wager – Dupont	You discussed a 10 m wide line; an impressive line! In our polyester film production, we have a 9 m line. We were presented with a lot of problems due to the width and the required speeds. Do you think that we are reaching a limit with web widths of 10 m? Is there potential for developing yet wider machines or do you think we are encouraging greater rejects of film by simply trying to go faster and wider?

Name & Affiliation	Answer
J. Howard – AET Films	No, I believe we're not at the limit. We are happy with our 10 m line but if there are any competitors here, don't buy one! What I do not see in the industry now is the reinvestment economics to allow you to build a large line.
Name & Affiliation	**Question**
R. Lucas – GL&V	I have a question relative to your 10 m wide line & 48" diameter wound rolls. What kind of process problems have you had around the core that have determined the diameter of the core for such a width? And what size core was it?
Name & Affiliation	**Answer**
J. Howard – AET Films	The core is over 50 cm in diameter. Obviously there was optimization to do. We were fortunate, as I've said a couple of times during the presentation, to have very knowledgeable people within the company so we could be really intelligent purchasers. To me, that's absolutely crucial. And that has allowed us to make some very good design decisions. Details of which we would not share.
Name & Affiliation	**Question**
A. Konnerth – Parkinson Technologies	You mentioned the importance of understanding and modeling the performance of your machinery so that you understand it's process and how you can change it in the future. I was curious whether you developed that model in-house or do it with machinery suppliers or have an ongoing project to do that?
Name & Affiliation	**Answer**
J. Howard – AET Films	We don't do it entirely in-house. We have people with the right skills in-house but we do it by linking both with people in this room and with the suppliers. Our suppliers have their own mechanical and electrical expertise. We have web handling knowledge. We know a lot about materials. We put all that together and you get a very good result.