Process Control and Defects Monitoring in Vacuum Web Coating

A. Fusi and F. Rimediotti, Galileo Vacuum Systems, Prato, Italy

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ABSTRACT

The mechanism of vapors and gas transfer through metallized plastic films is rather complex and governed by a number of factors, not all fully explained; however, there is commonly accepted evidence that the presence of defects on the surface of a coated material is often strongly related to the phenomenon of the loss of barrier of metallized materials. In industrial practice, there are various factors that may generate defects on the product and efforts to eliminate the causes involve virtually all steps in the production line. This paper will concentrate on the most recent machine design features and process control to pursuing a high quality standard in industrial metallization with special emphasis on the on-line defects monitoring systems.

INTRODUCTION

The permeability of vacuum coated flexible substrates is a complex phenomenon and many studies have been published, also recently, that try to identify the variables and to describe the mechanisms that are at the basis of the test results. It would be crucial, for the industry, confronted with the requirement of setting higher standards and to ensure consistency of results, to have guidelines for the process control. A brief and synthetic review of the barrier related factors follows. In the production chain of a metallized plastic film, some of the variables that affect the barrier properties of the final products are:

- The nature of the base film: it is well known that the intrinsic permeability of the base polymer sets the level of the barrier properties of the vacuum coated material.
- The type of the surface treatment: corona, flame, primer coating
- The surface pre-treatment in vacuum (plasma)
- The thickness of the coating layer (metal or oxide)
- The uniformity of the coating layer
- The integrity of the surface
- The storage and handling care.
- The downstream processing (wet or dry lamination, extrusion coating, slitting).

Several studies agree, however, that for, a given polymer and coating type, the behavior of a vacuum coated material and its permeability coefficient can be related to the number or density of surface defects. There are many evidences of the validity of a rather simple mechanism of transfer through micro-holes on the coated surface for the measure of the barrier to oxygen gas. This property is very important both for food packaging materials (oxygen contact with food triggers oxidation and taste spoiling) and for many technical applications. Less simple mechanisms drive the barrier for water vapor or aromas, even though the presence of scratches and pinholes on the surface have, again, an effect on the final barrier performance.

The very simple model of gas transmission through coated films is schematically represented in Figure 1. It was proposed many years ago and was reviewed and compared with later works in the frame of an European Funded Project "Thematic Network" coordinated by The Fraunhofer Institute of Freising [4].

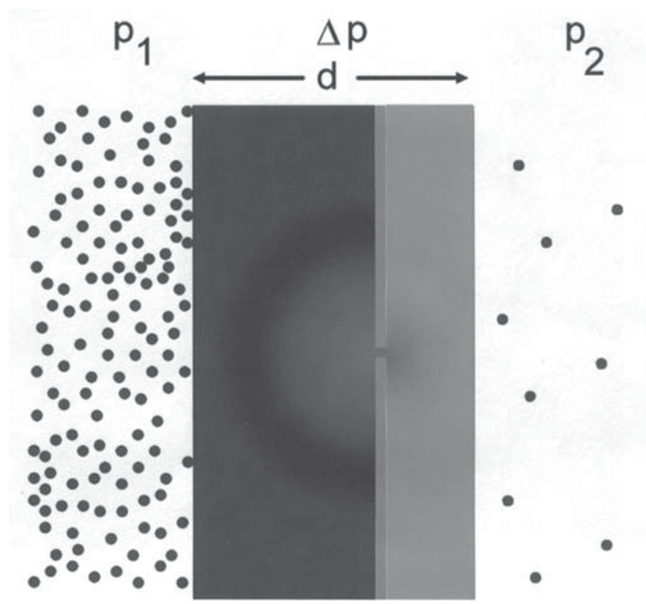

Figure 1. Model of gas transmission

It may represent, in spite of differences in the complexity and structure of the model, a number of other contributions, recently presented, [3],[6],[2], all stating the strong influence of the surface defects on determining the film barrier proper-

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ties. A punctual and comparative analysis of the proposed models is beyond the scope of this presentation. It is from the basic concepts introduced by these studies, however, that we set up industrial research, still in progress, aimed to demonstrate the feasibility of an on-line defects detection and monitoring system, able to ensure a control of the vacuum coated surface integrity with the purpose of maintaining consistent and constant barrier properties.

BARRIER: A DEFECTS CONTROLLED PROPERTY

Figure 1 shows the schematic mechanism of oxygen transmission through a vacuum coated film. The experimental defects detection has been done by light microscope. On the assumption of cycle-shaped defects on the coated metal layer and homogeneous polymer, a very simple mathematical model is the following:

$$\mathbf{Q = Q_0\, n\, \pi\, r_0^2\, (1+1.18\, d/ r_0)}$$ where

r_0 = average pore radius
d = thickness of the substrate polymer
n = number of pores per unit area
Q_0 = transmission rate of uncoated polymer

This model is in fair agreement with the measures when the defect size is lower than the substrate thickness; in the case of larger defects size, an even simpler equation has been proposed:

$$\mathbf{Q = Q_0\, n\, \pi\, r_0^2}$$

The “light holes”, counted and measured looking by transparency at a vacuum coated surface under a microscope at about 200 magnifications, are in the micron range and their concentration is of a few thousand per cm^2 (or sq. inch).

The same study suggests an intriguing interpretation of the impact of several process variables on the oxygen barrier properties: the effect of plasma treatment, of coating thickness, process speed in changing the permeability of the film would be related to the tendency to modify the defect density.

DEFECTS ON METALLIZED FILMS: TYPE AND SOURCES

We will concentrate on the surface defects, i.e. holes, scratches, uneven coating areas or lines, that impair the substrate coverage: the aim will be to translate the findings and the models of the research laboratories into the quality assurance procedures of an industrial metallizer. By the QC engineer of a Metallizing Company, the samples of the finished materials are checked by means of such tools as a back lighted table, a magnification lens and, possibly and in special cases, by a microscope. The sample will be qualitatively compared with a standard which, depending on the application, guarantees industry acceptance. The somehow arbitrary classification of surface defects of Table 1 is useful for practical purposes:

Table 1

Description	Avg. Size	Avg. Density	Causes
Distributed micro-holes	1-100 microns	10-100/ mm^2	• Substrate roughness • Uneven treatment • Dust • Slip agents • Micro-scratches
“Macro-pinholes”	0.1-1 mm	Random; 0.01-1/ sqmt	• Metal Spitting • Dust inclusion
Scratches	W/l: 0.01/5 mm	Random or regularly spaced	• From slipping on dirty rollers • Antiblocking additives
Tram lines	From 0,5 mm width	1-3 MD lines, continuous	Gauge bands, baggy lines on film Thermal wrinkles in metallization

The table shows that three out of the four categories feature defects that are relatively large in size and detectable by means of sample illumination and moderate magnifications. The “distributed micro-holes” are the only one that require a light microscope to be viewed and are the only group considered in the models of gas transmission through defects, described in this papers abstract. Figures 2, 3, 4 and 5 illustrate samples of commercially metallized film, which contain the most common type of defects. All the original pictures where taken at 50 magnifications except the last one (10 x).

PROCESS CONTROL TO ACHIEVE CONSISTENT QUALITY

All the types of surface imperfections listed in the table are critical for the metallized film applications:

- All are likely to have some impact on barrier properties
- Visible defects are critical for all decorative applications and unacceptable for hot stamping and security features
- Pinhole count is a very severe constraint for the manufacturing of film for metallic yarn.

Many solutions have been implemented or proposed to minimize or avoid defects in metallization: in many instances, a multifaceted approach to the specific problem is required and troubleshooting also require practical expertise and dedication to trial and error.

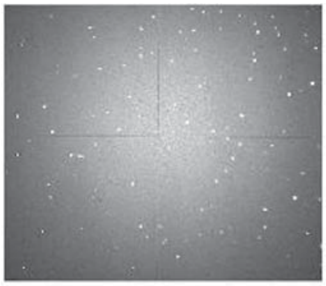
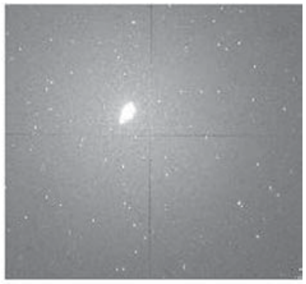

Figure 2: (Left) Microholes : N=15/mm^2 Avg. size : 20 micron

Figure 3: (Right) Macrohole 0.25 mm^2


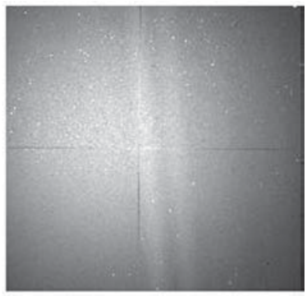

Figure 4: (Left) A scratch 0.5 mm

Figure 5: (Right) Tram line : 3 mm wide

Considering the characteristic of the classified defects and their source, the general approach to the solution should be the following:

- The tiny and diffused micro holes are most frequently generated by the properties of the polymer material or the impact that the film has on the metallizer design. On the other hand, due to their size and density, they can only be detected in a well-equipped laboratory. Various authors have analyzed the surface of metallized films by using different inspection techniques. An example is a comprehensive report, dating back to 1983 [1]. The authors proposed that the observed pinholes, in the size range of 1 to 50 microns, were caused by dust particles sticking on the film surface, which would develop into holes by rubbing during winding. The conditions of film manufacturing have improved in the last 20 years, but the primitive source of this defects category still lies in the design and manufacturing of the metallization substrate. The impact of vacuum coating is critical because the film tends to be heated. The metallized film is wound without the effect of an air layer interposing between coils and thus, it is more prone to stress and to magnify the existing defect. At the film manufacturing plant, quality improvement can be achieved by process control and polymer design optimization. Thickness variations, slitting sharpness, contamination, additives, treatment levels and uniformity are the main issue for a metallizing grade material. From the vacuum metallizer design and operational control, key quality factors are: accuracy in tension regulation, minimization of the roller inertia to prevent scratches and stresses, material cooling [5]. Plasma treatment is a key feature to remove surface contaminants, including loosely bound molecules and moisture, or to solve adhesion problems.

- The defects of the other categories are mostly caused by the vacuum metallizer (spitting, scratching); the evaporation and the winding system are the most frequent responsible. Various design improvements have been implemented to minimize the occurrence of <u>spitting</u>:
  - Optimization of aluminium evaporation “boats” in terms of geometry, heat distribution, wettability from the molten metal with particular focus on the first runs when the ceramic bars are more prone to uneven behavior causing aluminium projections.
  - Improvement of the power supply in terms of constancy, precision and firmness of the contacts.
  - Aluminium wire feed control: in terms of feed stability and constancy, protection against any possible wire vibration, automatic control.

There are, also, principles of machine design for avoiding <u>scratching</u>; they may include:

- The use of light weight rollers to minimize inertia: for wide web machines special materials like carbon fibres are already in use
- The use of surface of special rubber to guarantee grip and avoid slipping.
- Care in web path and in tension control design.

When a defect occurs and is detected in time, adjusting the metallizer running variables is often sufficient to get rid of it. The operator’s alertness and ability to intervene is crucial in limiting the impact and minimizing the possible off-spec material. An automatic defect detection and monitoring system for the metallized material was recently introduced to work on-line on a roll-to-roll vacuum coater as a quality control tool. In the last part of this paper, we will show an industrial application of this instrument, capable of high speed scanning the web and monitoring the surface of the metallized film.

THE ON-LINE DEFECT MONITOR

This applies the same principle used for web inspection in the laboratory. That is, to check the product sample placed in front of a retro illuminated board, the web, exiting from the metallization zone, is scanned by a special camera, which identifies light holes, “windows” or areas with a pre-set difference from the average density of the web. Among the optical instruments for artificial vision available on the market, the system suitable for the specific function on a metallizer had to comply with following requirements:

- Wide web scanning capability: to be installed on the state-of-the-art metallizers
- Full web scanning coverage without compromising with the web speed: designed up to 1000 mpm.
- Integration with the machine control software for an accurate roll mapping.
- Selectivity of defects in regard to size and distribution.
- In addition, it should have the versatility of being placed in the metallizers as a modular unit without interfering with the standard machine functioning.

Figure 6 shows the installation on a typical metallizer: the camera is mounted outside the chamber and the web is viewed from a dedicated window on the walls. The system consists of linear video cameras: depending on the metallizer width, they can be one or more, arranged in a row.

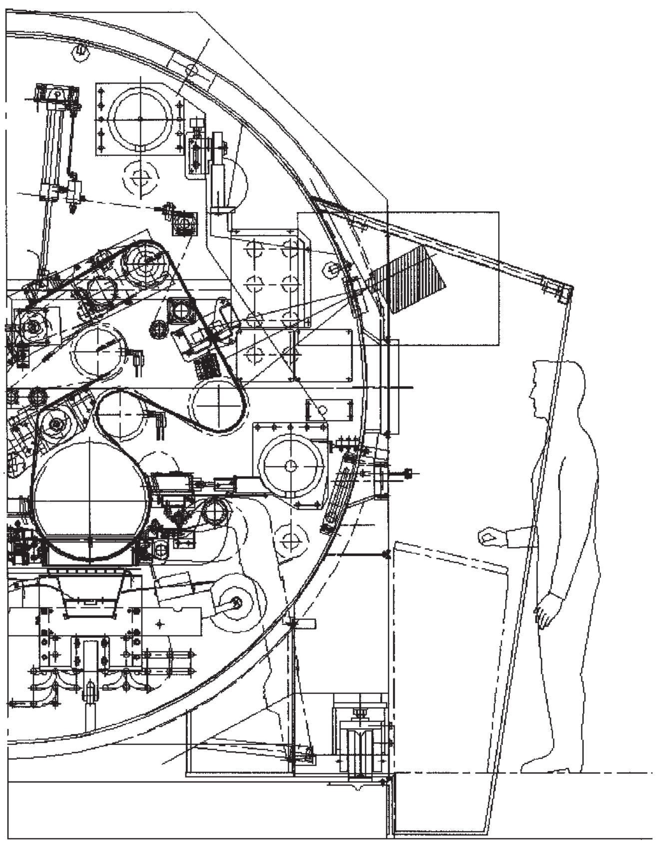

Figure 6. System installation

The resolution is web speed dependent and is currently 0.09 mm^2 up to 800 mpm and 0.12 mm^2 for faster run. Considering the classification of Table 1, the instruments can cover the defects belonging to all groups except the "micro-holes", that is, all imperfections that can be can be identified by an expert human eye checking a web sample in the laboratory. Those are, also, all defects that can be corrected by adjusting the metallizing process parameters or by maintaining the machine.

The light holes, scratches, and tramlines can be grouped into different categories in relation to their size and transmitted light density: the limits of these ranges are pre-settable by the user and are instrumental to establish acceptance standards and to set warning levels. An example currently on test at a metallizing plant is shown in Table 2:

Table 2

Cat.	Name	Size range (mm^2)	Type of defects
1	Small	0.09- 0.8	-Pinholes, pin-windows -Micro scratches
2	Medium	0.8 – 4	-Pinholes -Scratches
3	Large	> 4	-Macro-holes, windows -Scratches -Metal pickoff -Tramlines
4	Diffused	Large areas, at lower than avg. density	-Lack of treatment -Electrostatic

Figure 7 shows a typical display during film processing: the web image is shown in the upper window and defects are highlighted and mapped as soon as they are detected. At the same time they are counted and plotted according to their category. Figure 8 shows various type of defects reproduced on the display.

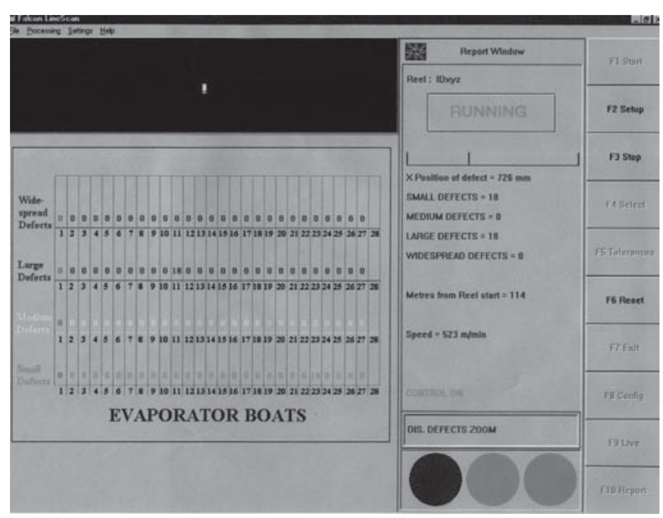

Figure 7: Process display

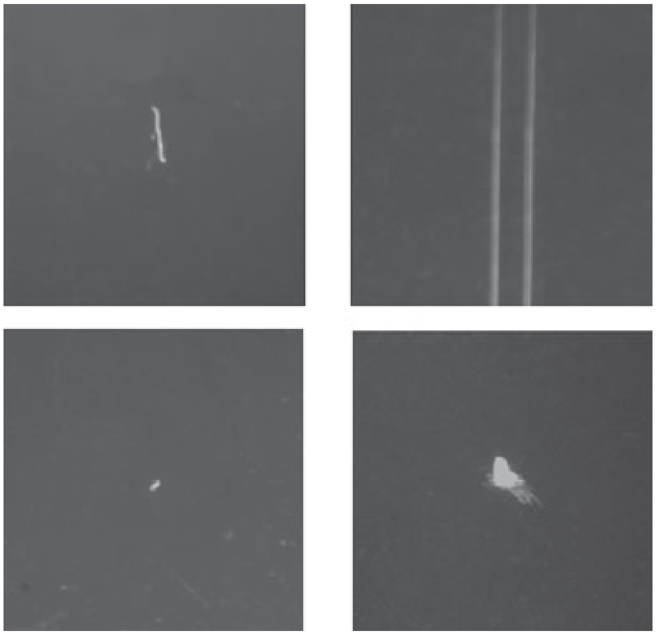

Figure 8: Reproduced defects

The reports at the end of the process give a full map of the roll surface with a statistical analysis (Figure 9). The system described is a powerful tool to monitor the surface quality of metallized film with 100% roll coverage. All the defects, which are usually the source of quality issue and claims from the industry, are mapped. A more ambitious project is, however, in progress: to collect enough industrial experience to establish standard, based on the density and size of defects detected, that can ensure predictable and consistent barrier properties.

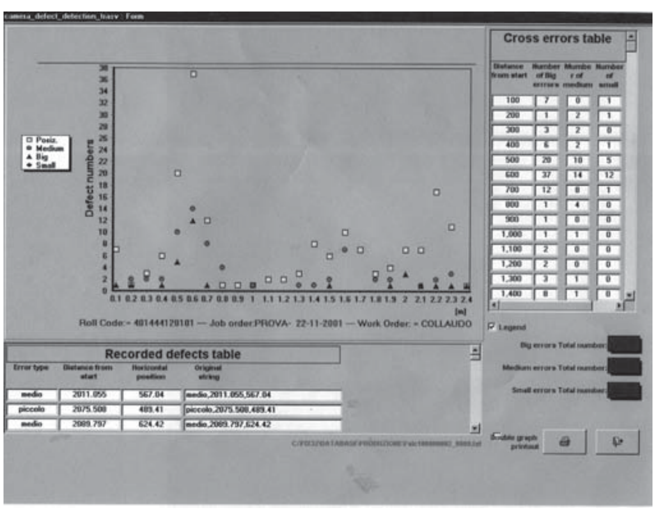

Figure 9: Report

CONCLUSION

There are many reasons to believe that the focus on quality metallizing will require an increased attention to minimizing defects; this paper reported the approach of a project, still in progress, aimed to link the findings and models of the Research Institutes (the barrier properties are controlled by defects in the micron size range) with the current quality standard of the industrial metallization. There is still a gap between the surface analysis on which the barrier models are grounded and the tests procedures routinely carried out in the laboratory at the metallizing plant. The imaging and vision technology available today with the possible future development is a promising way to pass from an effective trouble-shooting, as it already is, to a certification of functional properties of metallized materials.

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