Visualization of wire-wound-rod coating defects

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ABSTRACT *Wire-wound-rod applicators have been used in the adhesives and coating industries for many years. Such coaters boast low-cost equipment and excellent coat-weight versatility as major advantages. A disadvantage has been the quality of the coating, which can have defect lines running in the machine direction. These defect lines are often referred to as "rod streaks," and the assumption is that the defects are caused by the wire wrap on the rod or the contact of particulate matter in the coating with the rod. This paper presents photographs of a rod coater in a dynamic coating situation. The photographs show that the number and frequency of rod-streak defects can be altered through manipulation of various machine conditions. The evidence indicates that rod-streak defects are more closely related to the "ribbing" type of defect seen in roll coating. It may be possible to reduce the severity of rod-coating defects by applying concepts derived from roll-coating research.*

KEYWORDS
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Defects
Image analysis
Metering equipment
Quality control
Rod coaters
Roll coating
Streaking

Coating with a wire-wound rod is probably one of the least-complex methods for applying adhesives or other coatings. In this method, an excess of material is applied to the web by a coating roll. The web is then drawn over a steel rod wrapped with wire. The rod meters the amount of material to remain on the web, and coating thickness is easily adjusted by changing the gauge of the wire wrapped around the rod. A larger-diameter wire allows more material to remain on the web, while a smaller-diameter wire reduces coat thickness. The simplicity of this coating method allows for low equipment costs, easy cleanup, quick production changes, and great versatility in the coatings to be used.

The method is not without drawbacks, however. Rod coaters function within a limited viscosity range, and the metering effectiveness of the rod diminishes with increasing viscosity. The rod coater also does not deal well with dimensional inconsistencies in the web. Both of these problems are related to a lack of direct pressure holding the web in contact with the rod. The hold-down rolls in a rod coater are typically offset upstream and downstream of the rod, allowing the web to float either across the entire width of the rod because of pressure from the coating fluid or intermittently because of inconsistencies in the web. A gravure coater, on the other hand, has a backup roll that holds the web firmly against the gravure cylinder. No reasonable amount of hydrodynamic pressure or bagginess in the web will affect this contact.

Coating defects are another problem associated with rod coating. These usually appear as streaks in the coating running in the machine direction. Many of these defects are caused by particulate matter trapped between the rod and the web. "Rod streaks" are another common group of these defects. It is often thought that rod streaks are imparted by the wire pattern on the rod. The assumption is that the passage of the web over the wire wraps on the rod causes the streaks, which remain in the coating and do not level out.

The source and onset of rod streaks was studied by photographing a rod coater under dynamic conditions. The photographs presented in this article depict several rod-streak defects. The discussion includes possible explanations for the observed phenomena. The work was carried out with the assistance of the staff at the Center for Interfacial Engineering at the University of Minnesota's Department of Chemical Engineering and Material Science.

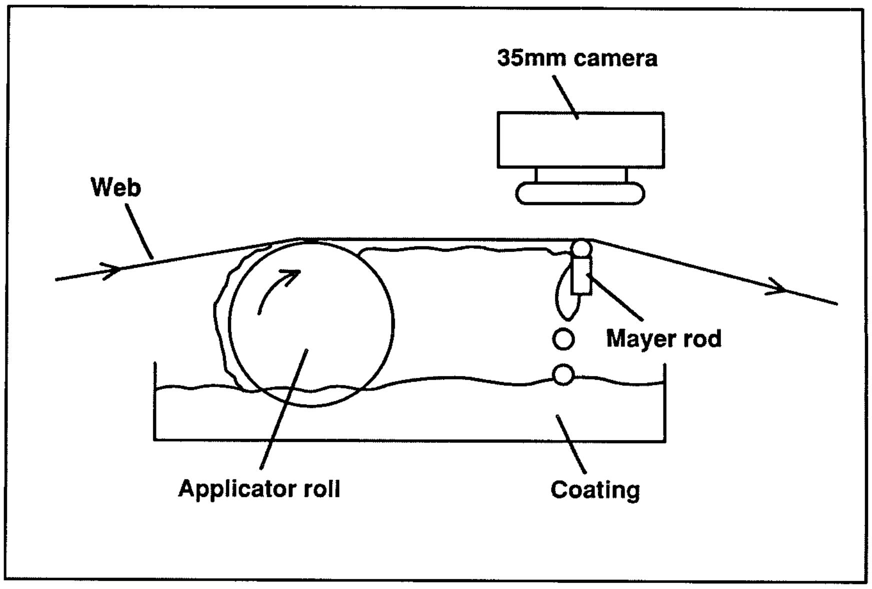
Experimental methods

All work for this investigation was performed on a Geometric Model 400 pilot coater/laminator. This machine can be configured for a wide variety of coating methods, web paths, and lamination types. For this study, the machine was configured for normal wire-wound-rod coating, but with a special web path to accommodate the imaging equipment. The web was 2-

mil transparent polyester, which allowed the camera to be positioned above the web, as shown in **Fig. 1**.

Photographs were taken with a Nikon F3 equipped with a microscope. All images were recorded on Kodachrome 64 slide film. Additional light was supplied by a standard electronic photoflash positioned above and to one side of the web. The coating fluid was an acrylic pressure-sensitive emulsion. This particular emulsion was chosen because its viscosity was appropriate for rod coating and its opacity gradient provided the visual differentiation needed to accentuate the coating defects that were recorded in the photographs. Line speeds were low for this study, with a range of 6–60 ft/min chosen for control. The other variables that were controlled in the experiments were rod number, web tension, rod direction and speed, applicator roll direction and speed, and angle of web wrap about the rod.

1. Camera placement on pilot coater.



Observations

The four photographs presented here record dynamic coating with a No. 16 rod (rod diameter of 13 mm and wrapping wire with a diameter of 0.4 mm). The wire-wrapped rod in each photograph is visible beneath a transparent web traveling toward the bottom of the page. The top of each photo represents the web coated with excessive adhesive. The short vertical black lines at the top of each photo are the wire wraps viewed through the unmetered web. The frequency of the wire wrap can be seen clearly in all photos, and a quick calculation shows that the 50 wraps translate to a 2-cm segment of rod. The series of downward-pointing white arcs immediately beneath the row of short black lines represents the meniscus formed by the adhesive at the line of separation between the web and the rod. The view beneath this line of separation is through the web after it has been metered by the rod. The bright bar of light across the center of each photo is merely the intense reflection of the photoflash off the metal of the rod. The various defects in the lower portion of the photos were induced by changing machine conditions (line speed, rod speed, and tension).

Figure 2A shows only two defects in the field of view. The areas with no defects have a very consistent coating, while each defect consists of a strip of heavier coat weight with areas of lighter coat weight on both sides. Such defects typically do not level out, and they are often mislabeled as rod marks. The defects are the result of the rod, but it is clearly evident that they are not the result of the individual wire wraps on the rod. Other forces are causing the defects. Another characteristic of the defect-free areas is the correspondence of the black areas of wire contact at the top of the photo with the points on the meniscus of separation. At standard rod-coating viscosities, the defect-free coating will seem very glassy, as the small imperfections derived from the wire wrap tend to level very quickly.

Figure 2B shows an area of the rod with defect-free coating, a narrow transition area, and a broad area of defects. In the defect area, the coating looks very consistent in its heavy and light pattern. However, it is difficult to identify the end of the meniscus of separation. This may be due to a different alignment of the meniscus arcs with the wire wraps. In the defect area, the point where the meniscus peak is expected corresponds to the spaces between the wires rather than to the wires themselves. It is obvious as well that the frequency of the defects is exactly one-half that of the wire wrap. The transition area shows the coating moving from a defect-free state to a defect state with the 0.5 frequency. Inconsistent flows and coating patterns are apparent over a span of several wraps of wire. This area of transition is the only area of flow inconsistency in the photo.

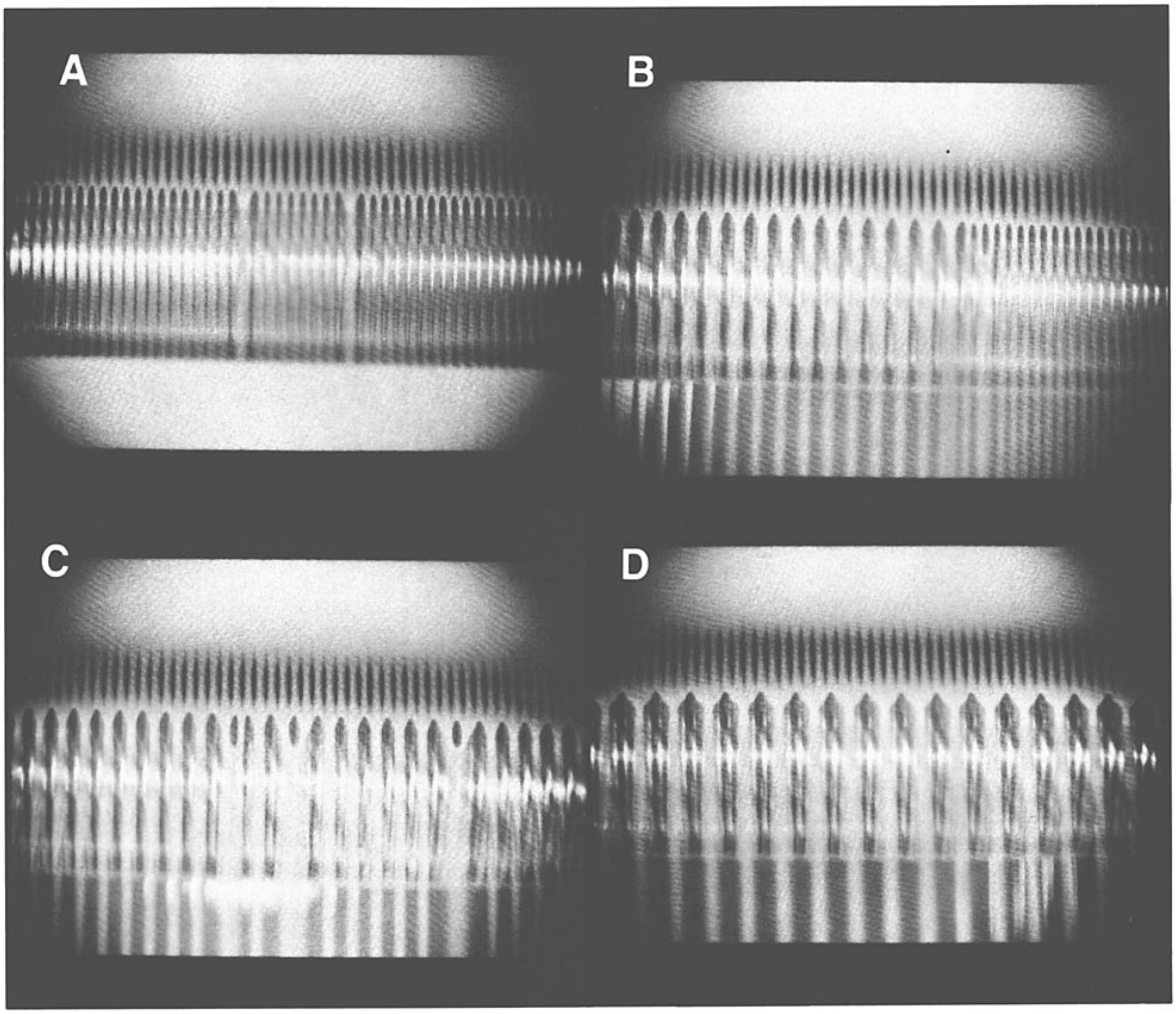
Figure 2C shows a 2-cm span of rod metering the coating in the defect mode of 0.5 frequency, the same as in Fig. 2B. In this case, though, additional defects of greater severity are beginning to appear. The frequency of the new pattern cannot be determined from this photo.

Figure 2D shows a new pattern of coating defects. The frequency here is one-third that of the defect-free coating. This is the culmination of the incipient pattern in Fig. 2C. Note in this photo that the shape of the meniscus has changed. It is no longer a set of arcs, but a set of modified arcs. The would-be points of the meniscus are still difficult to identify, but once again, the expected positions of the points correspond to a black contact point of the wire with the web. The heavy-to-light coating pattern is very evident in this photo. If this were viewed on the coater, these defects would be obvious and might be blamed on the wire pattern. The defects are in a ratio to the wire wrap, but it is clear that the wire is not causing the defects directly.

Discussion

Rod-coating defects occur on a strict

2. Four photographs of a No. 16 wire-wound rod (13-mm-diam. rod wrapped with 0.4-mm-diam. wire) metering the coating on a transparent web under various machine conditions. The web is traveling toward the bottom of the page, and the rod is beneath the transparent web. The top third of each photo is a view through the unmetered web, while the bottom two-thirds of the photographs show the web after being metered by the rod. The rod segment visible across the width of each photo is approximately 2 cm in length.



frequency ratio, while defects in roll coating occur on a size continuum. In both coating systems, something disrupts the smooth coating and causes defects. In the case of roll coating, the roll itself is the primary disruptive agent, and no other significant disruptions exist. In the case of the rod coating, the cylindrical steel rod is the primary disruptive agent, acting in a manner similar to the roll in a roll-coating operation. The wire wrap around the rod is the second disruptive agent.

Even when there are no defects, the wire on the rod imparts some pattern to the coating. However, when a defect is created by the rod, the wire wraps modify the defect. If the defect is smaller than the distance between wire wraps, the disruption from the rod wipes out the defect. The defect is visible only if it is large enough to span the distance between two wraps and thus overcome the disruption caused by the rod.

The rod tends to disrupt the edges of the defect and restore some order. This disruption from the wire becomes the determining factor in the character of the coating on either side of the defect. The defect is always channeled to be contained between wire wraps, which explains why the defects in rod coating occur in a stepwise fashion. If the defect is large enough, the defect can encompass the span of three wire wraps rather than two.

These differences can be seen in the four photos in Fig. 2. In Fig. 2A, the defects are small enough that the wire effect determines the smoothness of the coating. In most of Figs. 2B and 2C, the defects are large enough to span two wire wraps. In Fig. 2D, the defects are large enough to span three wire wraps. In each case, the wire rod imposes order on the edges of the defects. The effects of the wire can even be seen in the meniscus in Fig.

2D, where the modified arc shape is the result of the wire wrap and its effect on the geometry of separation for the web and the rod.

The photos in Figs. 2A-2D show rod-coating defects occurring with differing frequencies and characteristics. The defects are clearly not the result of particulate contamination or wire marks. It is hypothesized that these defects are caused by the same factors that cause ribbing in roll coating.

A cursory review of the literature on roll-coating research identifies several factors that contribute to ribbing defects (*1-4*). These factors include roll radius, roll gap or nip clearance, and capillary number. Most of these parameters can be related to a rod coater. The capillary number is usually defined as the viscosity multiplied by the roll speed divided by the surface tension. Surface tension and viscosity (at proper shear rates) can be measured. Roll speed can be defined as the relative speed difference between the rod and the web. While roll radius is difficult to describe, the roll gap can be related to some combination of the gauge of wire wrapping the rod and the degree of web float over the rod. Consideration of these factors along with unique factors affecting rod-coater performance should provide a basis for explaining how defects appear and disappear. With this information at hand, it should be possible to identify process modifications that will reduce the severity of such defects.□

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