Progress in Organic Coatings 123 (2018) 138–145

Contents lists available at ScienceDirect

Progress in Organic Coatings

journal homepage: www.elsevier.com/locate/porgcoat

Production and mechanical characterization of free-standing pigmented paper coating layers with latex and starch as binder

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ARTICLE INFO

Keywords:
Free-standing pigmented coating
Latex
Starch
Cracking
Mechanical properties

ABSTRACT

The mechanical properties of paper coating layers are important in various converting processes such as printing and folding of the paper. A method was developed to produce free-standing pigmented coating layers thick enough to be tested in bending as well as tension. The mechanical properties of these coating layers were characterized. Free-standing films with two types of binder formulations, pure latex or latex-starch combinations, with different binder content were prepared through an innovative film forming method that allows uniform drying of the coating layer while minimizing cracking. Tensile and flexural samples were cut out of these films. Tensile and flexural tests were carried out on samples and the results were compared. Tensile and flexural moduli were found to be similar. However, both stress at failure and strain at failure were higher in flexural tests compared to those in tensile tests. Three different types of paper were coated with these formulations and their failure during printing was evaluated through a standard ink picking test. Papers with different basis weights and porosities were found to have different picking resistance values. An interesting result was that the picking resistance did not correlate with the elastic modulus of the coating, but with the strain at failure behavior. This result indicates that the stiffness of the coating layer is not as critical during printing compared to its flexibility.

1. Introduction

Paper and paperboard are often coated to improve some properties required in the final product such as optical properties and print quality. The coated paper or paperboard will be subject to different mechanical stresses such as tension during printing and bending during folding, which can potentially damage the coating layer through cracking. The mechanical properties of coating layers are important to understand in order to optimize the coated paper system to meet the processing and application requirements.

Coated paper is a composite structure of paper and a coating layer. The coating layer is composed of pigment particles held together with an organic binder such as latex, starch or protein. Knowing the properties of each layer should help to predict the final product performance. For each layer, the elastic modulus, the ultimate stress at failure, and the strain at failure are important parameters defining the mechanical performance of the coated paper system. Since both the base paper and the coating layers are composite structures by themselves, the tensile properties may not fully predict the behavior in bending modes.

A number of papers report on the tensile properties of free-standing coating layers [1–4]. These works have made it clear with regard to the influence of pigment shape and deformation rate on the tensile properties. Clay-based coating films showed lower stiffness in comparison with ground calcium carbonate (GCC)-based coatings attributed to inherent material properties. GCC-based coatings are more isotropic than clay based coatings. To our knowledge, the bending behavior of free-standing coating films has not been reported with the exception of our preliminary work [5]. This lack of results may be related to the difficulties to produce crack-free coating layers that could be tested in bending. In addition, the relationship of these properties to picking resistance during printing is not clear.

Many studies have been reported that evaluate the behavior and properties of coated paper. Cracking of clay-based and GCC-based coating formulations has been evaluated [6]. The authors have shown that the difference in particle shape results in different cracking behavior at the fold. In clay-based formulations cracking may start anywhere in the coating layer and can be expanded in the thickness direction, but in GCC-based coatings cracks initiate at the surface of the coating and then propagate through the thickness. The mechanical properties of

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https://doi.org/10.1016/j.porgcoat.2018.07.009
Received 10 March 2018; Received in revised form 20 June 2018; Accepted 5 July 2018
0300-9440/

coating layers were investigated using Finite Element Method (FEM) [7]; they showed that the amount of latex as the binder of these formulations and type of pigment affected mechanical properties of the coating layer. The type of latex and the glass transition temperature (Tg) of the latex would also affect the properties of the coating layer. Styrene-butadine with lower Tg showed greater interaction within the coating film in comparison with a styrene-acrylate with higher Tg, which results in smaller and fewer cracks [7]. Another study also analyzed tensile and shear stresses in coating layer formulations using FEM during the folding event [8]. These models based on FEM need good input parameters that will describe the deformation behavior in tension and bending. Recently, researchers studied the effect of starch in the binder composition of coating formulations and the effect of double layer coatings on the cracking area in these formulations [9]. Starch in the coating increased the cracking area at the fold. With having starch in the pre-coating layer, cracking area was larger in comparison with those papers where a starch-containing formulation was applied on top of the pre-coated layer. In another work, researchers gave results with regard to the influence of coating composition and fold direction on cracking during folding [10].

During the printing of paper, the viscous ink generates a large normal force to the paper surface as the paper leaves the impression nip [11]. The magnitude of this force is related to the coating composition and how rapidly the ink is absorbed by the pores and latex [12] as well as the press speed, paper properties, and ink viscosity [13]. A finite element analysis of the deformation of multi-layered paper or paperboard during printing is possible if the mechanical properties of each layer is known [14]; this analysis shows the propensity of the paper to bend at the exit of the printing nip as the paper experiences the normal tack force. To simplify the complex interactions of ink viscosity and press speed, researchers often report the maximum velocity-viscosity product that the sample can experience before coating layer failure is noticed.

The IGT picking test, is a method in printing studies to evaluate the tensile stress of ink films at the nip of rollers, where the paper roller and the ink roller get in contact and then separated [11]. This separation at the nip of rollers, loading in z direction, will cause delamination or picking in coated papers. In industrial process, this delamination will result in lint built-up or pigment transfer [11,13]. There are different methods to test pick resistance in coated papers, Z-Directional Tensile Strength test (ZDTS), Scott Bond Test (SBT), Wheel Delamination Test (WDT) and the IGT method [14].

In this work, free-standing coating layers are produced and tested both in tensile and bending modes. A novel method is shown to produce uniform crack-free films of the material that are thick enough to test in a three-point bending configuration, even when starch is one component of the binder system. The flexural properties are compared with the tensile properties. The coating formulations are applied to three different paper grades. The propensity of the coating layers to fail or pick during printing of these coated paper grades is reported and discussed.

2. Materials and methods

2.1. Production of free-standing coating films

Free standing films were prepared with fine GCC (Covercarb HPL 70.5 OMYA, Johnsonburg, PA, USA) as coating pigment and styrene-butadiene copolymer latex (Genflo 5086 OMNOVA, Calhoun, GA, USA) with low Tg (5°C), and ethylated starch (Ethylex 2025 Tate & Lyle, Houlton, ME, USA) as binders of coating formulations. Three different mixing ratios of pigment and latex, 78% pigment volume concentration (PVC) (90% pigment and 10% latex based on weight), 62% PVC (80% pigment and 20% latex based on weight), and 42% PVC (70% pigment and 30% latex based on weight) for latex binder systems were used. For starch-containing formulations the same pigment volume concentrations of 78% PVC (90% pigment, 8% latex and 2% starch or 90% pigment, 6% latex and 4% starch based on the weight), 62% PVC (80% pigment, 16% latex and 4% starch or 80% pigment, 8% latex and 12% starch based on the weight) were used. The solids content of all formulations were between 60% and 65% based on weight.

The pigments and latex were mixed for 20 min with a shear mixer at 600 rpm. After this mixing, they were mixed at a lower speed, about 220 rpm for an additional 10 min to remove air bubbles in the mixtures. The starch was cooked by using a standard starch cooker for 60 min at 90 °C at 25% solids before it was mixed into the coating formulations.

Free standing films of coating formulations were prepared using a Gardco Micorm II Film Applicator (Pompano Beach, FL, USA) on a porous cellulose acetate membrane (0.2 μm pore size, Sterlitech Corporation, Kent, WA, USA). After applying the coating formulation on the membrane, it was placed in a laboratory oven at 40 °C for about 20 min. With a razor blade, sides of the semi-dried films were cut to prevent cupping and cracking caused by dissimilar drying rates on the edges. A fresh membrane was placed on the semi-dried films' top surface and the films were turned over so they would dry from the other side under the same conditions for another 20 min. Slowly and carefully, the first membrane was peeled from the film and after another 10 min the second membrane was carefully removed. The free standing-films were dried in the oven for another 20 min at 40 °C. Drying the films at high temperature, not removing the sides when the film is semi-

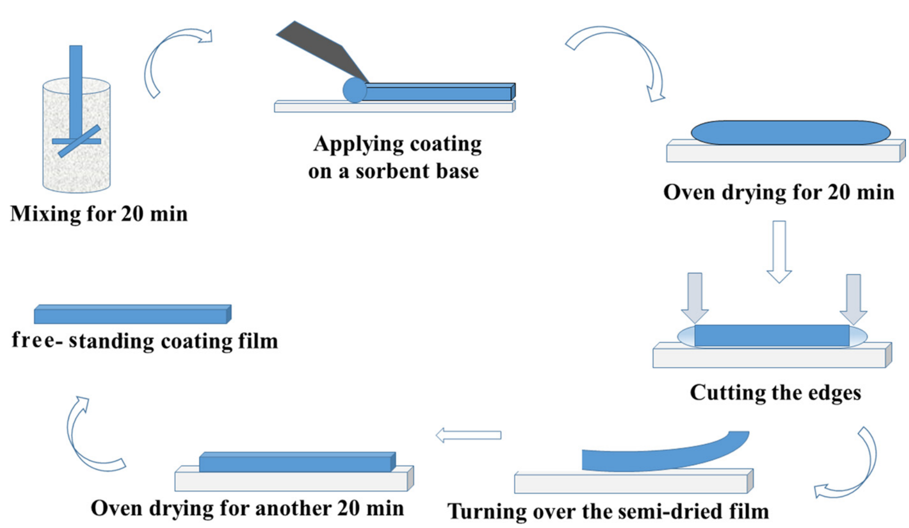

Fig. 1. Schematic of the method developed for the production of free-standing coating layers.