Analysis of Viscoelastic Web in Wound Roll Under Air-Elastohydrodynamic

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Abstract

This paper describes the characteristics of web in wound roll with viscoelastic thin film material. When the thin film web is moving between the upper roller and the lower roller, air-entrainment occurs due to shear flow to supply air into the contact region called air-elastohydrodynamic (Air-EHL). The compressible time dependent modified Reynolds equation, air film thickness, equilibrium equation and viscoelastic deformation equation were solved numerically to obtain air pressure distribution, air film thickness distribution and friction coefficient in the contact region. Air film thickness between upper roller and lower roller is large for the viscoelastic web when compared with elastic material.

Keywords: Web handing system, viscoelastic web material, air EHL.

1. Introduction

In the present, thin film materials have been utilized broadly in many applications, for example paper, plastic film, metal foil, textiles, optical film and magnetic tape which are normally stored at least on an intermediate basis in wound rolls to accommodate high speed, automated manufacturing operations. For manufacture of thin film materials have been known well in the other word: the web handling systems that require a lot of knowledge for reducing material damage such as air foil baring; behavior of the material and design technique. The part of damages is deformation of thin film materials because the maximum stress of web living near core is higher than yield strength.

In 2006, P.M. Lin and J.A. Wickert [1] suggested about corrugation and buckling defects in wound rolls. They described the wound roll defects depended on functions of winding tension and roll size. This occurrence is called V-buckling that usually appear in core region when each web layer is added to the roll, stresses develop within it in response to the web's material properties, the winding tension, and the compliance of the support condition along the roll's inner periphery.

In 1994, J.K. Good, Z. Wu and M.W.R. Fikes [2] studied the influence of nip-load on winding roll and comparing the results of radial stress between without nip-load effect and nip-load effect. In case of nip-load effect, the radial stress is higher due to increasing of friction between nip roll and winding roll.

During contracting between the nip roll and winding roll, the surrounding air web flows into the web and web roll interface so each web layers will have the layer of air film thickness, which are very thin about 1-10 μm. This behavior have been called air elastohydrodynamic lubrication (Air-EHL) presented in 1996 by Chang, Chambers and Shekton[3].

Both Air elastohydrodynamic and web permeability had been investigated by K. Tanimoto, K. Kohno, S. Takahashi, M. sasaki, and F. Yoshida[4] in 2003. They studied the influence of air-entrainment in the wound roll and compared the radial stress from the numerical calculation with the experimental results.

In addition, the high-speed transportation of paper web sometime leads the web handling system into unstable state due to the excessive air-entrainment between a roll and web that presented in 2006 by Hiromu Hashimoto[5].

However, almost all of the research works so far have been considered only elastic thin film material. But there are many web handling systems which thin films are viscoelastic polymer material so this research work will focus on the characteristics of winding system with viscoelastic thin film web.

2. Theory

2.1 Viscoelastic model

Viscoelastic behavior can be simplified as linear viscoelastic model. This model is composed of the stiffness and viscosity that describe both elastic and viscous behaviors respectively [1]. When thin film material is moving to pass between nip-roller and reel-roller, nip-load should be applied in order to control the stability of the winding system. In this case both nip-roller and reel roller are long roller so when both roller contact together, it can be followed as the case of line contact [2], [3]. Viscoelastic deformation along the coordinate x can be expressed as.

$$\delta(x,t) = -\frac{1}{\pi E_q(t)} \times \int_{x_{in}}^{x_{out}} (p - p_a) \ln(x - x')^2 \, dx' \quad (1)$$

Where $E_q(t)$ is the equivalent modulus that depends on time, Poisson's ratio and viscous damping. In the case of two contact surfaces are both viscoelastic material and can be written as [4].

$$\frac{1}{E_q(t)} = \left(\frac{1-\upsilon_a^2}{E_{fa}} + \frac{1-\upsilon_b^2}{E_{fb}} \right) + \left(\frac{1-\upsilon_a^2}{E_{Sa}} + \frac{1-\upsilon_b^2}{E_{Sb}} \right)\left(1 - e^{-t/\tau}\right) \quad (2)$$

Where $\nu_{a,b}$ are Poisson's ratio and subscript (a) and (b) are the two surfaces in the contact region. E_f, E_S are modulus of elasticity in linear viscoelastic model, t is time and τ equal to the ratio of η_S and E_S. At time equal to zero, the material property become linear elastic.

2.2. Air elastohydrodynamic

The time dependent modified Reynolds equation under air-EHL for incompressible fluid and isothermal condition can be written as

$$\frac{\partial}{\partial x}\left(h^3 p \frac{\partial p}{\partial x} + 6\lambda_a p_a h^2 \frac{\partial p}{\partial x} \right) = 12\mu u \frac{\partial (ph)}{\partial x} + \frac{\partial (ph)}{\partial t} \quad (3)$$

Where p is air pressure distribution in the contact region, h is air film thickness, U is average velocity between nip-roller and reel roller with radius R. μ is air viscosity. p_a is P_{atm} and λ_a is molecular mean free path. Air film thickness equation included both surfaces roughness δ(x,t) and the viscoelastic deformation D(x) can be expressed as[6],[7].

$$h = h_0 + \frac{x^2}{2R} + \delta(x,t) + D(x) \quad (4)$$

$$\int_{x_{in}}^{x_{out}} (p - p_a)\, dx = F(t) \quad (5)$$

The integration of net pressure with respected to x is equal to the applied nip load in winding web as shown in equation (5). In addition, nip-load in this work are both static nip-load and dynamic nip-load. The dynamic nip-load; F(t) can be written as.

$$F(t) = a.\log(t) + (F_0 + b) \quad (6)$$

Where F_0 is initial nip-load at time equal to zero. a and b are constant.

3. Numerical results and Discussions

The property of thin film material for this calculation was shown in Table 1. The result of tangential stress was presented in figure 1 and figure 2.

Table 1 Property of thin film material

(Web thickness mm)	$19.3\text{x}10^{-3}$
Core stiffness ,Ec (MPa)	$2.57\text{x}10^{3}$
Modulus of web E_f (MPa), $E_S = 4E_f$	0.26
Coefficient of friction	
- Static friction	0.38
- Web/nip roll	0.30
Poisson's ratio	0.30

The variation of tangential stress in the web was presented in figure 1. The condition of web in roll can be kept for long time without wrinkle problem when tangential stress is larger than zero as shown in the figure.

The tangential stress at 24 hour after winding and at 400 N/m tension under varying nip load was shown in figure 2. The winkle of web occurs due to tangential stress.

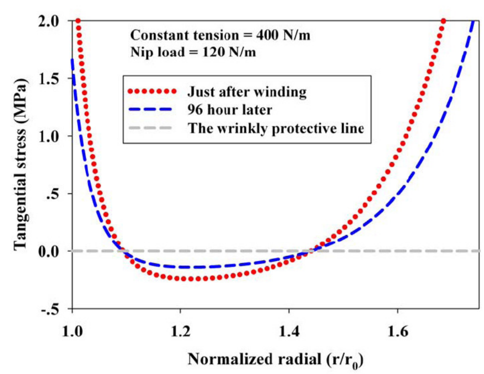

Fig. 1 Variation of tangential stress under the effect of time for viscoelastic web

The air film pressure distribution and air film thickness distribution in the contact region were shown from figure 3 to figure 8 respectively. The results for elastic web are compared with the results for viscoelastic web under varying roller speed and varying nip-load condition.

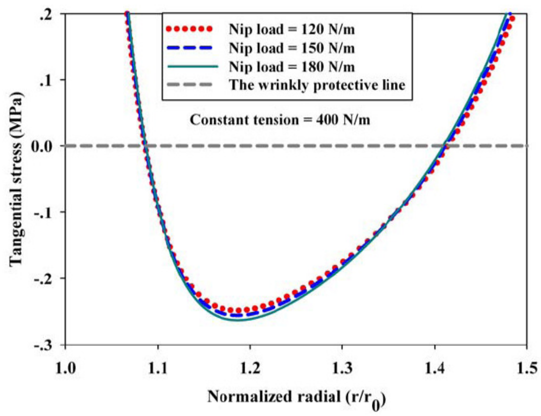

Fig. 2 Variation of tangential stress with varying nip load at 24 hour after winding

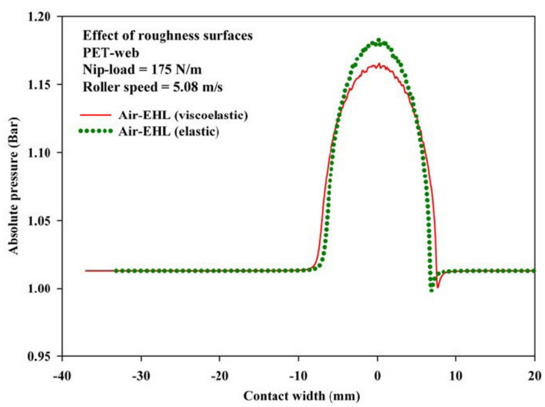

Fig. 3 shown the air pressures comparison between elastic and viscoelastic

Normally, thin film material with viscoelastic behavior is softer than thin elastic film material so the deformation of viscoelastic web is more than the deformation of elastic material. Therefore, air film thickness for viscoelastic web is larger than the film thickness for elastic web.

Therefore, the air film pressure is lower than the air film pressure for elastic web as shown in figure 3 and figure 4.

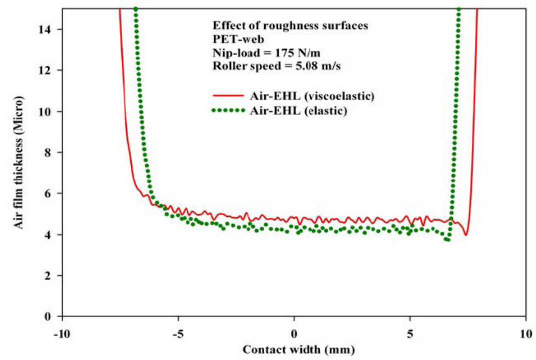

Fig. 4 Air film thickness profile for elastic web and viscoelastic web

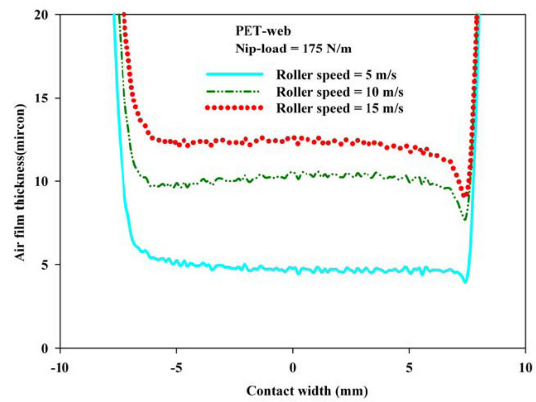

Fig. 5 Air film thickness profile for various roller speeds

When roller speed is increased from 5 m/s to 15 m/s as shown in figure 5, the air film thickness increases rapidly as the roller speed is increased.

For the condition of increased nip-load from 150 N/m to 200 N/m as shown in figure 6, the air film pressure rise because of the increasing of nip-load. However, air film thickness decreases when the nip-load is increased as shown in figure 7. Figure 8 shows the effect of air-entrainment; the air layer between web and the roller is too large as the roller speed increased that can cause web handling system become unstable.

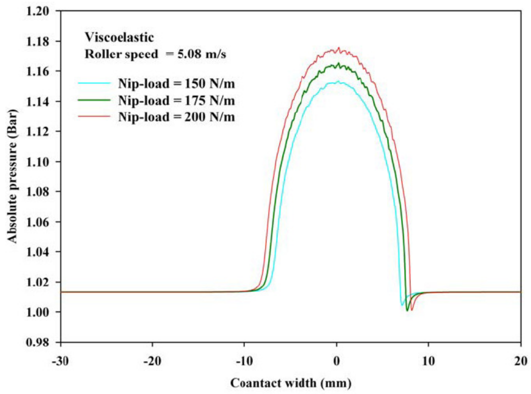

Fig. 6 shown absolute pressure distributions for varying nip-load

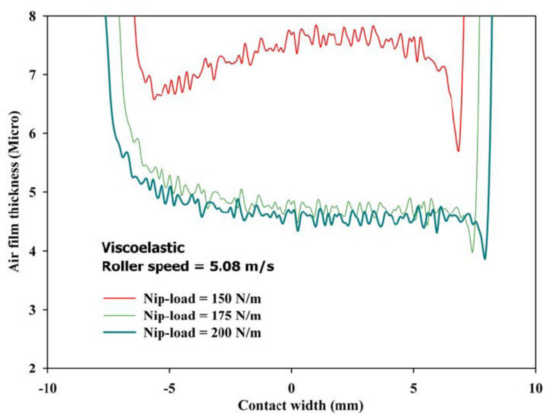

Fig. 7 shown air film thickness distributions for varying nip-load

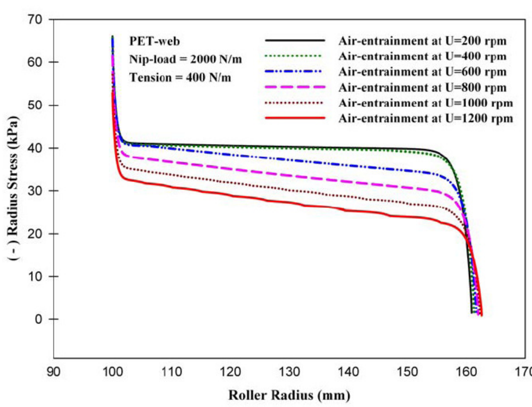

Fig. 8 shown the effect air-entrainment for varying roller speed

4. Conclusions

The characteristics of web in wound roll with viscoelastic thin film material have been examined numerically. Viscoelastic behavior and air-entrainment are the critical factors in the process of winding web. The property of viscoelastic thin film material is softer than the web with elastic material; as a result, the air film thickness distribution at nip region of viscoelastic web is larger than the air film thickness of elastic web at nip region. The air-entrainment is significant factor in the process of winding web.

5. References

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