Latex Carpet Compound Rheology

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Abstract:
This is a study of three-phase foam rheology to qualify penetration in to backing webs during frothed carpet compounds applications. Transient viscosity as a function of shear rate under a short time period is proposed to characterize flow of these compounds in response to a rapidly changing shear field during their application. We developed a fluid dynamic model that predicts the shear and pressure distributions in the compound during its processing in a metering nip based on process parameters and rheological results. We tested frothed compound formulations that are empirically known to be "penetrating" and "non-penetrating" based on the choice of soap (frothing surfactant). Formulated at the same froth density, penetrating to carpet backing compounds had large froth bubbles, relatively low transient shear viscosity and showed increasing foam breakdown due to shear when compared to non-penetrating compounds. Such frothed compounds readily collapse under shear and have relatively low dynamic stability, so the transition from a three-phased (air/aqueous/solid) to a two-phased (water/solid) system occurs much easier and faster during application. The model predicts the shear rate development and a small difference in the pressure distributions in the applicator nip between these formulations, but reduction in drainage for the non-penetrating formulation.

Zusammenfassung:
Die vorliegende Arbeit befasst sich mit der Rheologie von Dreiphasen-Schaumklebstoffen, um deren Eindringen in die Trägerbahn während der Herstellung von Teppichbahnen zu bewerten. Die zeitliche Änderung der Viskosität als Funktion der Scherrate während einer kurzen Zeitdauer wird als Maß zur Charakterisierung der Strömung dieser Komponenten, als Antwort auf ein sich rasch änderndes Scherfeld während der Verarbeitung, vorgeschlagen. Die Autoren haben ein fluiddynamisches Modell entwickelt, das die Scherkraft- und Druckverteilung im Verbundwerkstoff während seiner Herstellung in einem Dosierspalt einer Rollenbeschichtungsanlage in Abhängigkeit von den Prozessparametern und der Klebstoffrheologie vorhersagt. Es wurden Rezepturen untersucht, die empirisch als „penetrierend" oder „nicht-penetrierend" auf der Grundlage der verwendeten Tenside bekannt sind. Es stellte sich heraus, dass bei gleicher Dichte die in den Träger penetrierenden Klebstoffe größere Blasen aufweisen, eine relativ niedrige transiente Scherviskosität besitzen und eine zunehmende Tendenz zu Schaumzerfall durch Scherkräfte zeigen, verglichen mit nicht-penetrierenden Klebstoffen. Solche geschäumten Komponenten kollabieren leicht unter Scherbelastung und haben eine relativ niedrige dynamische Stabilität, so dass der Übergang von einem Dreiphasen-System (Luft/Wasser/Feststoff) zu einem Zweiphasen-System (Wasser/Feststoff) während der Verarbeitung viel leichter und rascher auftritt. Das Modell sagt die Entwicklung der Scherrate sowie einen kleinen Unterschied in der Druckverteilung im Auftragsspalt zwischen diesen Formulierungen voraus, darüber hinaus eine Reduzierung der Entwässerung für die nicht-penetrierende Formulierung.

Résumé:
C'est une étude rhéologique sur une mousse à 3 phases dont le but est de caractériser la pénétration des composés au verso des tissus (tapis) pendant les applications de colle sous forme de mousse. Le changement temporel de la viscosité en fonction du taux de cisaillement pendant une période de temps court est proposé pour caractériser le flux de ces composés en réponse à un domaine de contraintes changeant rapidement pendant leur application. Nous avons développé un modèle dynamique de fluide qui prédit les distributions de cisaillement et de pression dans le composé pendant son passage dans le nip du metering basé sur des paramètres de process et des résultats rhéologiques. Nous avons testé des formulations de composé sous forme de mousse, qui sont connus d'expérience pour être "pénétrant" et "non-pénétrant:, en rapport avec le choix du savon (surfactant moussant). Formulés à la même densité de mousse, les composés "pénétrant" le dos des tapis présentaient de larges bulles de mousse, avec un faible changement temporel de viscosité, et montraient une rupture de mousse croissante due au cisaillement, quand comparés à des composés "non pénétrants". De tels composés mousseux s'effondrent facilement sous cisaillement et ont une stabilité dynamique basse, de telle sorte que la transition d'un système 3 phases (air/eau/solide) à 1 système 2 phases (eau/solide) arrive plus facilement et plus vite pendant l'application. Le modèle prédit, pour ces formulations, le développement du taux de cisaillement et une petite différence dans les distributions de pression dans le nip de l'applicateur, et par ailleurs une réduction de drainage pour la formulation "non pénétrante".

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$$\frac{\partial P}{\partial x} = \mu \frac{\partial^2 v_x}{\partial y^2} \tag{A1}$$

Where P is pressure, μ is the viscosity, and v_x is the velocity in the x-direction defined in Figure 2. The boundary conditions for velocity are at $y = 0$, the top surface of the porous web, the velocity is U_2, and at the surface of the top roll, $y = h(x)$, the velocity is U_1. The velocity profile, between the web and the roll surface is then:

$$v_x = \left(y^2 - yh\right)\frac{1}{2\mu}\frac{\partial P}{\partial x} + \frac{\left(U_1 - U_2\right)y}{h} + U_1 \tag{A2}$$

The shear rate is the derivative of the velocity profile. At the web surface, it is:

$$\dot{\gamma} = \frac{\partial v_x}{\partial y} = \frac{\left(U_1 - U_2\right)}{h} - \frac{h}{2\mu}\frac{\partial P}{\partial x} \tag{A3}$$

The first term in Eq. A3 is from the simple velocity differences between the roll surface and the second term comes from pressure driven flow. A mass balance in any slice forces the total flow rate through the nip, including what has been forced into the porous web, to be constant. Mass balance generates the equation:

$$Q = h_i U_1 = \int^{h} v_x dy + U_2 L\left(x\right)\epsilon \tag{A4}$$

Where Q is the total flow into the nip, that must equal the inlet thickness of the fluid, h_i, multiplied by the top roll surface speed U_1. This total flow must also match the net flow rate in the fluid between the web and the top roll plus the fluid carried along in the pores, $U_2L(x)\epsilon$, where $L(x)$ is the depth of penetration of fluid into the pores and ϵ is the void fraction of the porous media. Inserting Eq. A2 in to Eq. A4, integrating, and arranging in terms of the pressure gradient, we obtain the differential equation for pressure:

$$\frac{dp}{dx} = 12\mu \frac{\left(\frac{\left(U_1 - U_2\right)h\left(x\right)}{2} + U_2 L\left(x\right)\epsilon - U_1 h_i\right)}{h\left(x\right)^3} \tag{A5}$$

The top roll can be any speed relative to the web. Eq. A5 represents the mass and momentum balance for this situation for a Newtonian fluid. An approximate method to account for shear thinning is to use an appropriate viscosity in Eq. A5 that relates to a relevant shear rate at that vicinity of the flow field. Eq. A3 in combination with the power-law model given in Eq. 1 is one way to do this. A complete analysis would lead to finite element analyses. Darcy's law links penetration rate into the web with the local pressure field. Assuming that the air pressure in the porous web is atmospheric, the penetration rate would be:

$$v_{y=0} = \frac{K_p P\left(x\right)}{\mu L\left(x\right)} \tag{A6}$$

Where K_p is the Darcy permeability coefficients of the web, and $v_y = 0$ is the penetration velocity. The velocity above is the rate of change of penetration volume per unit area into the web:

$$v = \frac{dV}{dt} \tag{A7}$$

Where V is volume per unit area of the fluid that penetrates the web. From a mass balance, the volume is related to the depth of penetration:

$$L_p = \frac{V}{\epsilon} \tag{A8}$$

The geometry between the two surfaces is well defined and follows the expression:

$$h\left(x\right) = 2\left(R + h_o - \sqrt{R^2 - x^2}\right) \tag{A9}$$

Where R is the roll radius and ho is the minimum gap between the rolls at $x = 0$. Carvalho and Scriven [11, 15] suggested a boundary condition for the film split location:

$$P_e = \frac{-\sigma}{R_m} \tag{A10}$$

Where R_m is the radius of curvature of the film-split meniscus, and σ is the fluid surface tension. The radius of curvature is then:

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$$R_m = \frac{Q_e}{2.68 Ca^{2/3} U} \quad \text{(A11)}$$

With Q_e being the volumetric flow rate per unit length at the exit and Ca the capillary number $Ca = \mu U/\sigma$. The meniscus location is found by matching the circular meniscus to the asymptotic solution of the flow on a flat plate being withdrawn from a pool of liquid. For a speed ratio of unity, the film-split height at the exit he is:

$$h_e = \frac{Q_e}{U}\left(1.644 + \frac{2}{2.68 Ca^{2/3}\sqrt{1+.414(3Ca)^{2/3}}}\right) \quad \text{(A12)}$$

The inlet pressure is assumed to be atmospheric. However, the inlet location is not known a priori. Therefore, a trial-and-error method was employed to find the inlet location, where the fluid first contacts the web; this location was estimated and the pressure field was integrated. The exit pressure must match the pressure given in Eq. A10. If not, the entrance location was modified. The details of the exit location and pressure condition are not critical to the predictions of the model.

Numerical integration of the coupled differential equations, Eqs. A5 and A7, along with Eqs. A6, A8 and A9 gives the pressure distribution in the rolling nip and the depth of fluid penetration in to the web. Shear thinning is taken into account through an approximate method by modifying the viscosity value used in Eqs. A5 and A6 with the power-law expression, using the shear rate at the surface of the porous web.

REFERENCES

[1] Moody V, Needles HL: Tufted Carpet, William Andrew Publishing, New York (2004).

[2] Westfall PM, Conn W, Brown, RL: Foamed Latex Technology: Applications and Economics, Clemson Nonwovens Forum Collected Papers, June 1978.

[3] Bikerman JJ: Foams, Springer-Verlag Inc., New York (1973).

[4] Bikerman JJ: Foams and Emulsions: Formation, Properties and Breakdown, In Chemistry and Physics of Interfaces, American Chemical Society Publications, Washington (1965).

[5] Triantafillopoulos N: Rheology of carpet compounds & adhesives, OMNOVA Solutions Report (1996).

[6] Pugh RJ: Experimental techniques for studying the structure of foams and froths, Adv. Colloid Interface Sci. 114-115 (2005) 239-251.

[7] Martin PJ, Odic KN, Russell AB, Burns IW, Wilson DI: Rheology of commercial and model ice creams, Appl. Rheol. 18 (2008) 12913.

[8] Barigou M, Deshpande NS: The glow of gas-liquid foams in vertical piles, Chem Eng. Sci. 55 (2000) 4297-4309.

[9] Ninness B, Bousfield DW, Triantafillopoulos NG: Fluid dynamics model of the film-fed nip with a porous web, Proceedings of the TAPPI Coating Conference, TAPPI Press, Atlanta (1998) 515-530.

[10] Kubota T, Scriven LE: Forward roll coating in the runback feed condition, Proceeding of the IS&T Coating Conference (1993) 309.

[11] Carvalho MS, Scriven LE: Capillary and viscoelastic effects on eleastohydrodynamic lubrication in roller nips, ASME Transaction 118 (1996) 872-879.

[12] Coyle, DJ: Forward roll coating with deformable rolls: A simple one-dimensional elastohydrodynamic model, Chem. Eng. Sci. 43 (1998) 2673-2684.

[13] Coyle DJ, Macosko CW, Scriven LE: Film-splitting flows in forward roll coating, J. Fluid Mech. 171 (1986) 183-207.

[14] Coyle DJ: Roll Coating, In Modern Coating and Drying Technology, Cohen E, and Gutoff E (Eds.) VCH Publishers, New York (1992).

[15] Carvalho MS, Scriven LE: Capillary and viscoelastic effects on elastohydrodynamic lubrication flow and film-splitting in roller nips, Proceedings of the International Printing and Graphic Arts Conference (1994) 259-266.

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