Extensional Viscosity of Coating Colors and its Relation With Jet Coating Performance

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Abstract:
An orifice flowmeter was used to measure the extensional viscosity of several non-pigmented fluids and paper coating colors containing calcium carbonate as pigment in the context of a jet coating application. The orifice flowmeter was first calibrated in terms of a dimensionless Euler number versus Reynolds number curve with Newtonian fluids. The calibration curve was then used to determine the apparent extensional viscosity of coating colors. In the strain rate range investigated, all the fluids were found to exhibit strain-thinning and the Trouton ratio of the coating colors was in the range 5 to 20. Jet coating tests were also carried out in order to evaluate the effect of the extensional viscosity on the jet performance. The extensional viscosity was shown to be a key parameter determining the configuration of the downstream meniscus in the web contact region.

Zusammenfassung:
Ein Düsenrheometer wurde benutzt um die Dehnviskosität von mehreren nicht pigmenthaltigen Flüssigkeiten und Papierfarbbeschichtungen mit Kalziumkarbonat als Pigment in Bezug auf die Jet-Beschichtungen zu untersuchen. Das Rheometer wurde zunächst mit newtonschen Flüssigkeiten mittels der Auftragung von Euler- gegen Reynoldsnummer kalibriert, so dass im Anschluss die scheinbare Dehnviskosität der Farbbeschichtungen bestimmt werden konnten. In dem untersuchten Dehnratenbereich zeigten alle Proben ein scherverdünnendes Verhalten mit einem Troutonverhältnis von 5 zu 20. Den Einfluss der Dehnviskosität auf die eigentlichen Jet-Beschichtung wurde in Folge untersucht, wobei gezeigt werden konnte, dass sie der Schlüsselparameter zur Kontrolle des Ablösemeniskuses von Substrat ist.

Résumé:
Un rhéomètre à orifice a été utilisé pour mesurer la viscosité extensionnelle de plusieurs fluides non pigmentés et de sauces de couchage prépareés à base de carbonate de calcium dans le cadre d'une application de couchage par jet. Le rhéomètre à orifice a été tout d'abord étalonné en utilisant une courbe du nombre d'Euler en fonction du nombre de Reynolds avec des fluides newtoniens. Cette courbe d'étalonnage a par la suite été utilisée pour déterminer la viscosité extensionnelle apparente des sauces de couchage. Dans l'intervalle des vitesses de déformation étudié, tous les fluides ont montré une rhéofluidifiance en extension, le rapport de Trouton des sauces de couchage étant compris entre 5 et 20. Des essais de couchage par jet ont été aussi menés dans le but d'évaluer l'effet de la viscosité extensionnelle des sauces de couchage sur la performance du jet. Il s'est avéré que la viscosité extensionnelle est un paramètre clé déterminant la configuration du ménisque en aval de la région de contact sur le substrat.

Key words: Extensional viscosity, orifice flowmeter, entry pressure method, coating color, jet coating

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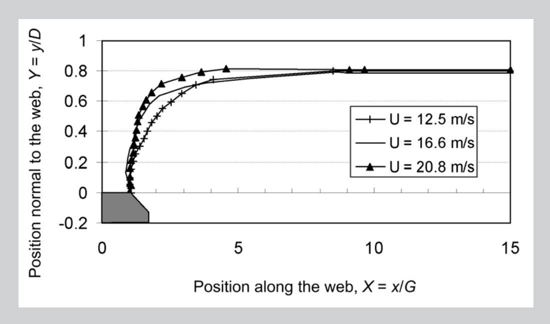

Figure 12: Downstream meniscus configuration for C65-0 at three different web speeds.

tions, the downstream meniscus tends to recede with increasing web speed as illustrated in Fig. 12 for C65-0 at three different web speeds (U = 12.5, 16.6 and 20.8 m s^{-1}). However, the observations of Fig. 12 could be largely due to inertia effects under such high jet velocities.

CONCLUSION

In this work, the apparent extensional viscosity of non-pigmented fluids and coating color formulations containing calcium carbonate as pigment was determined at high strain rates typical of jet coating process. For this purpose, an orifice flowmeter, whose operating principle is based on the pressure drop-flow rate relationship for the flow through a small size orifice, was used.

A strain-thinning behavior was observed for all the coating liquids. The Trouton ratio of the coating colors was found to be around 10 for $\bar{\dot{\gamma}}$ < 6000 s^{-1}. This result is in good agreement with to that reported in the literature for the high concentrated suspensions. In jet coating, the coating colors are submitted to extensional strain rates around 5000 s^{-1}, in the application region, so that the extensional viscosity could reach values 10 times larger than shear viscosity. This could be very useful information to explain some phenomena in jet coating process, such as the jet stretching, the increase of the back flow on the nozzle, the jet tearing preventing the entire coating film to be transferred to the web surface, etc. The extensional viscosity was found to be slightly sensitive to the amount of thickener, but practically insensitive to the addition of latex. The amount of solids contained into the coating colors strongly affects the extensional viscosity.

In addition, the extensional properties were related to the jet stretching in the application region via the downstream meniscus configuration. Low extensional viscosity promotes an increased curvature of the downstream meniscus. From a processing point of view, a low extensional viscosity is beneficial for a good runnability, since it increases the curvature of the downstream meniscus and consequently reduces the distance required for the coated film to reach its final thickness. Finally, the results presented here should be regarded as estimates of the rheological properties in extension with the intention to better interpret the jet coating process hydrodynamics.

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NOTATION

d_o	Diameter of the orifice [m]
d_c	Inner diameter of the cylinder [m]
D	Distance between the nozzle exit and the web [m]
Eu	Euler number
Eu_{corr}	Corrected Euler number
G	Half-gap of the nozzle slot [m]
G'	Storage modulus [Pa]
G''	Loss modulus [Pa]
e	Extensional consistency index [Pas^t]
m	Shear consistency index [Pasn]
n	Shear power-law index
Q	Flow rate through orifice [m^3s^{-1}]
Re	Reynolds number
t	Extensional power-law index
T_f	Thickness of the coated liquid film [m]
T_j	Jet thickness [m]
Tr	Trouton ratio
U	Web speed [ms^{-1}]
V	Jet velocity [ms^{-1}]
V_o	Average velocity of the fluid at the orifice [ms^{-1}]
x	Position along the web [m]
X	Dimensionless position along the web
y	Position normal to the web [m]
Y	Dimensionless position normal to the web
α	Impingement angle [°]
$\dot{\gamma}$	Shear rate [s^{-1}]
$\bar{\dot{\gamma}}$	Effective strain rate [s^{-1}]
γ_c	Critical strain amplitude
δ	Loss factor [-]
ΔP_E	Pressure drop due to the extensional flow [Pa]

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ΔP_S	Pressure drop due to the shear flow [Pa]
ΔP_T	Total pressure drop for the orifice [Pa]
$\dot{\epsilon}$	Extension rate [s^{-1}]
η_E	Apparent extensional viscosity [Pas]
η_S	Apparent shear viscosity [Pas]
η_∞	Infinite shear viscosity [Pas]
μ	Newtonian shear viscosity [Pas]
ρ	Density of the fluid [kgm3]

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