Role of Extensional Viscosity in Paper Coating

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Abstract:
In this paper, the role of extensional viscosity in different paper coating processes was evaluated. Numerical models for the various coating application processes (blade coating, film coating, and curtain coating) were constructed to calculate the extension rate. Different rheological methods were employed to measure extensional viscosity versus extension rate for model coating colour systems. Pilot coater trials were carried out to study the performance of each model coating colour in curtain, blade and film coating. It was demonstrated that extensional viscosity of model coating colours depends on the rate of extension, and colours can be extension thickening or extension thinning. With the numerical calculation results of extension rate in coating application processes, the extensional viscosity test results of model coating colours were matched to their performance in pilot coater experiments. It was shown that increasing the extensional viscosity measured at the appropriate extension rate that exists in blade or rod metering increased blade or rod load. Misting in film coating was reduced by low extensional viscosity measured at the appropriate extension rate. Cratering in curtain coating was reduced by increasing extensional viscosity measured at the appropriate extension rate. It was further concluded that the extensional viscosity can be used to predict the coating performance only if it is measured at the prevailing extensional rate of the specific coating process speed.

Zusammenfassung:
In diesem Artikel wurde die Rolle der Dehnviskosität bei verschiedenen Papierstreichverfahren untersucht. Numerische Modelle für verschiedene Streichverfahren (Rakel, Film,Vorhang) wurden erstellt, um die Dehnrate zu berechnen. Modellstreichfarben wurden hergestellt. Verschiedene rheologische Messverfahren wurden eingesetzt, um die Dehnviskosität über Dehnrate für Modellstreichverfahren zu messen. Pilotversuche wurden gemacht, um die Laufeigenschaften der Modellstreichfarben im Rakel-, Film- und Vorhangstreichverfahren zu bestimmen. Es wurde gefunden, dass die Dehnviskosität der Modellstreichfarben von der Dehnrate abhängt, die Streichfarben können pseudoplastische oder dilatante Eigenschaften haben. Für jedes Streichverfahren wurde einen Dehnratebereich rechnerisch bestimmt, in welchem die Modellstreichfarben belastet wurden. Die Dehnviskosität der Modellstreichfarben, gemessen innerhalb des entsprechenden Dehnratebereichs, wurde mit deren Laufeigenschaften korreliert. Es wurde gezeigt, dass eine Erhöhung der Dehnviskosität, gemessen bei einer Dehnrate, die dem Rakel- bzw. Stab-Dosierungsverfahren entspricht, den Druck, der auf Rakel bzw. Stab ausgeübt wird, erhöht. Beim Filmpressstreichen wird das Misting durch niedrige Dehnviskosität, gemessen bei entsprechender Dehnrate, verringert. Beim Vorhangstreichen ist die Anzahl der Krater, die sich bilden, wenn die Streichfarbe auf dem Papier aufgetragen wird, deutlich reduziert bei Erhöhung der Dehnviskosität. Aus diesen Ergebnissen ergibt sich die Schlussfolgerung, dass die Dehnviskosität einer Streichfarbe nur bei einer Dehnrate, die dem Streichverfahren entspricht, eine Vorhersage zum Laufverhalten den Streichfarbe erlaubt.

Résumé:
Dans cet article, le rôle de la viscosité élongationelle dans les différents procédés de couchage du papier a été étudié. Des modèles numériques ont été construits pour calculer la vitesse d'extension pour les différents procédés de couchage (lame, film press, rideau). Différentes mesures rhéologiques ont été utilisées pour déterminer la viscosité élongationelle en fonction de la vitesse d'extension pour des sauces de couchage modèles. Des essais sur coucheuse pilote ont été menés pour caractériser la machinabilité de chacune des sauces modèles selon les trois procédés d'application. Les essais ont montré que la variation de la viscosité élongationelle avec la vitesse d'extension peut présenter un comportement pseudoplastique ou dilatant suivant les formulations. Pour chacune des technologies de couchage, le domaine de vitesse d'élongation a pu être calculé. Le comportement sur machine a ensuite été corrélé à la viscosité élongationelle mesurée pour chacun des domaines de vitesse d'élongation. Ainsi il a été montré que l'augmentation de la viscosité extensionnelle mesurée aux vitesses d'extension correspondantes au dosage par lame ou par barre, augmente la pression exercée par le bain sur la

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some coating colours are extension thickening, while others are extension thinning, depending on their coating components remain unexplained. For extension thickening, a possible mechanism could be the formation of a three dimensional network between latex, pigments and thickener, for example, coating formulations F3 and F4. Similar to the response of high molecule weight polymers to extensional deformations, the network tends to retrograde to its original shape during extension stress. For extension thinning, a possible mechanism could be that there is no such three dimensional network formed in coating colour as a result of the properties of the thickener, for example, coating formulations F1 and F2. Molecule chains have enough flexibility to align themselves under extensional deformations, leading to reduced extensional viscosity under increased extensional rate. However, these fundamental mechanisms need to be further investigated.

Based on our results, it was found that the measurement of extensional viscosity over a wide extension rate range requires sophisticated rheological instruments and data analysis. Model coating colours demonstrated different shear and extensional rheology, and extensional viscosity can be orders of magnitude higher than shear viscosity. Extensional viscosity was dependent on the rate of extension and can be extension thickening or extension thinning. Utilizing the coating process models, it was demonstrated that extensional deformation exists in industrial coating processes at different rates of extension, ranging from 10^{-1} to 10^{7} s^{-1}; the extension rate experienced by coating colours in different coating process could be estimated numerically.

By comparing the extensional viscosity data of model coating colours at process conditions and the coating performance in pilot coater experiments, it was demonstrated that increasing extensional viscosity (measured at the appropriate extension rate) leads to increased blade and rod pressure. Misting in film coating was reduced by lower extensional viscosity and cratering in curtain coating was reduced by increasing extensional viscosity. More importantly, it is concluded from this study that the extensional viscosity can be used to predict the coating performance only if it is measured at the extension rate which prevails in the specific coating process. There are still several areas that need further investigation. It is commonly known that extensional viscosity depends on both the extension rate and strain. Extensional strain in different coating processes may differ. In addition, extensional deformations exist in several other aspects of coating besides the ones studied in this paper, such as, misting generation as a result of centrifugal force, coating levelling and coating pumping. The impact of extensional viscosity on these processes will be a topic for future investigation.

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