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The effect of rewetting on the adhesion tendency of styrene–butadiene latices on steel surfaces

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ABSTRACT

Styrene–butadiene latices are widely used as binders in pigmented coatings for the paper and board industry, primarily because of their good ability to bind pigments and fibres. White pitch deposition is a well-known problem at the drying section of paper machines using coated broke as a raw material. The main component of white pitch is latex, such as styrene–butadiene. The viscoelastic properties of styrene–butadiene latex affect white pitch formation.

In this paper, we studied the sticking potential of different styrene–butadiene latices by using a cylindrical probe tack method under dry and wet conditions and varying the cross-linking density of the latex. In addition, the tackiness of the latices was measured as a function of decreasing moisture content to simulate the process in the drying section of a paper machine. The results show that the sticking potential can be derived from the storage modulus in dry conditions. The presence of water in the styrene–butadiene structure changes the sticking behaviour, and the results support the hypothesis of water acting as a plasticiser for latex.

1. Introduction

During paper production, a proportion of the product becomes waste, which is further in-house recycled and mixed back into a raw material. This recycled material is called broke. Fine papers are coated with a mixture that comprises mainly a pigment and a binder. Therefore, in fine paper mills, the broke contains sticky binder particles, which cause the problem of white pitch deposition in the paper machine, particularly at the dryer section. White pitch depositions have a detrimental effect on paper quality, and they deteriorate the machine productivity due to increased web breaks and washing shutdowns. When the binder for the coating mixture is selected, not only paper properties but also sticking tendency must be taken into consideration to avoid economic losses. The most common binder in the coating mixtures is styrene–butadiene latex (SB-latex), which is tacky material at elevated temperatures [1,2].

During the papermaking, coated broke is disintegrated in water via a slushing process. In this stage, SB-latex is rewetted and mixed to paper furnish. The SB-latex binder characteristics known to facilitate the formation of deposits include a low glass transition temperature and a low degree of cross-linking. The deposition tendency of the SB-latex is thus related to viscoelastic properties and should be taken into consideration when choosing a binder for paper coating [3].

As shown by Vähäsalo et al. [2] the formation of binder-rich particles during disintegration of the coated broke is mainly dictated by the tackiness of the binder latex measured in dry conditions at the prevailing temperature. These binder-rich particles are flake-like agglomerates containing a high proportion of binder latex, and they are usually found to be present as a white pitch deposition in the dryer section o f paper machines.

Brown et al. have studied the role of viscoelastic properties on the adhesion of styrene–isoprene–styrene block copolymers. High adhesion energy is obtained when the dissipative factor $\tan\delta > 0.2$ due to the large amount of deformations at the adhesive layer during debonding. Below that value, the initiation of failure occurs at the interface between the adhesive and the substrate with much less energy dissipation, and the adhesive energy remains relatively low. The mechanisms of debonding are reasonably well predicted by the viscoelastic moduli [4]. The viscoelastic modulus is dependent on temperature. In the paper machine drying section, the low glass-transition temperature of SB-latex, which is typically 10–30 °C, leads to white pitch problems. In contrast, a T_g significantly above room temperature would lead to brittleness of the coating layer in the end product and is thus not practically usable. A high cross-linking density is used to increase the modulus in the rubbery region of the polymer to decrease sticking. However, too high of a cross-linking density may retard the interparticle entanglement and impair the coating film forming process in the paper machine [5].

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Water in the polymer structure has been found to drastically reduce the T_g [6]. Lowering of the T_g can lead to sticking problems. However, the adhesion of polymers in aqueous conditions mainly depends on the surface energies and interfacial tension between the adherent and adhesive. The work of adhesion decreases when the polar component of the surface energy increases. The requirements for good adhesion are entirely different in air and in water [7].

The adhesion of polymers to metal surfaces with different viscoelastic properties in dry conditions has been widely studied. However, the sticking of SB-latex on surfaces in wet and partly wet conditions is not well understood. The aim of this paper was to study how absorbed water in SB-latices changes the adhesion tendency in different latex samples [8].

The deposition tendency of three different SB-latices was investigated using a probe tack tester. The adhesion of the SB-latex to a steel surface was measured in dry and wet conditions to demonstrate the different paper processing phases in paper machines. In addition, the adhesion of a drying latex film with a decreasing moisture content was studied to simulate the conditions of a paper sheet in the dryer section of a paper mill.

2. Materials and methods

2.1. Latices

Three different styrene–butadiene latices used in this study, named with letters *A*, *B* and *C*, were supplied by Dow Europe GmbH, Switzerland. The latex films used in the measurements were made from an aqueous dispersion with a film applicator gap size of 400 μm. The latex film thicknesses were 150 ± 5 μm.

2.2. Dynamic mechanical analysis

The viscoelastic properties of latex films were determined as a function of temperature using the parallel plate geometry on a Rheometrics RDS-II dynamic mechanical analyser (Rheometrics, UK). The heating rate was 10 °C/min, the frequency 1 Hz and the applied strain 0.05%. The elastic modulus, loss modulus and tan δ of the latex films were determined at a temperature range between −20 and 120 °C.

2.3. Probe tack test

Adhesion measurements were performed using a probe tack tester designed and constructed at the University of Oulu. In all of the following adhesion studies, the same test parameters were used. The contact pressure was 1 N, which is equivalent to a pressure of 15.7 kPa. The speed of the probe was 0.6 mm/s, and time at full contact pressure was 1 s. The temperature of the latex film was monitored with a digital IR surface thermometer (SKF TMTL 260).

2.3.1. Adhesion under dry conditions

In the dry adhesion test, the latex films were fixed to the flat surface. A cylindrical probe was brought in contact with the SB-latex film at a constant speed. The contact force was increased to 1 N and kept constant for 1 s before detaching the probe from the latex film. The maximum detachment force was recorded during debonding. Dry adhesion tests were conducted in the temperature range of 35–100°.

2.3.2. Adhesion under wet conditions

The latex films used in this test were wetted in a water bath for 24 h at room temperature before the measurements. The latex film was fixed mechanically to the bottom of a petri dish that was filled with water. The test procedure was similar to the test performed in dry conditions, but the contact between the latex film and the probe was made in an aqueous environment. Adhesion tests were made in the temperature range of 35–70 °C with three duplicate measurements of each sample.

2.3.3. Adhesion of drying latex films

The latex films wetted in a water bath for 24 h at room temperature were also measured during the drying process. The wet latex film was fixed mechanically onto a heating plate with the temperature set to 60 °C to simulate the early stage conditions in the paper machine drying section where deposition problems primarily occur. The latex film was allowed to dry while measuring the adhesion using a probe tack test over 20-s intervals for several minutes. The measurement was concluded when the latex film was dry.

3. Results

3.1. Gel fraction

The gel fractions of latices *A*, *B* and *C* are 78, 85 and 47, respectively. The results of the gel fraction tests indicate that latex *B* is the most cross-linked, latex *A* has slightly less cross-links than *B* and latex *C* has a significantly lower cross-linking density compared with other latices.

3.2. Viscoelastic properties

The results of the dynamical mechanical analysis of the studied SB-latices investigating the elastic modulus, *G*′, the loss modulus, *G*″, and tan δ are shown in Figs. 1, 2 and 3, respectively. Fig. 1 displays the storage modulus as a function of temperature. At a temperature of −20 °C, the *G*′ values of *A*–*C* are very close to each other. In the case of latex *B*, the fall in *G*′ starts at −20 °C, and it continues slowly through the glass transition temperature region. The storage modulus of latex *B* is higher at temperatures above 30 °C compared with latices *A* and *C*. In the case of latex *C*, there is a sharp fall in *G*′, and at temperatures above 50 °C, the storage modulus is lowest compared with latices *A* and *B*. Fig. 2 shows loss modulus curves as a function of temperature. Compared with the storage modulus curve, the results are of the same order of magnitude at the temperatures used in the adhesion measurements.

Fig. 3 displays the variation of tan δ with temperature. The curve of latex *B* is lowest, and the curve of latex *C* is the highest. The sharp peak of latex *A* indicates the homogenous structure of the latex.

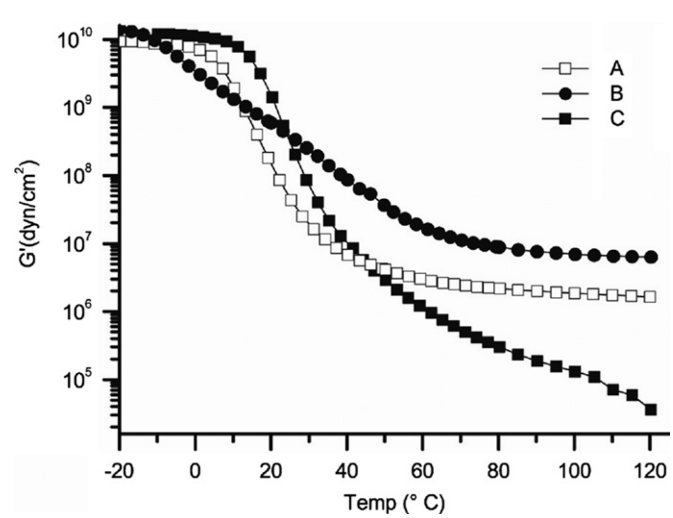

Fig. 1. Storage modulus of studied latices *A*–*C*.