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Temperature- and time dependency on high friction poly(styrene-co-butyl methacrylate) coated paper

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ABSTRACT

For several industrial applications, high friction surfaces with low adhesion are essential. Here, a poly (styrene-co-butyl methacrylate) polymer latex is coated on paper to achieve a high static friction at the interface between a coating and e.g. a wood pallet. At this interface, the adhesion should be low enough for easy removal of objects placed on the coated paper. The static friction is measured with a custom designed and constructed frictometer and is investigated as a function of temperature from 25 to 55 °C and the resting time. Furthermore, the static friction is investigated with varying coating thicknesses and coatings containing calcium based fillers. Results show that the static friction is increasing non-linearly with both temperature and resting time. Furthermore, an amount of 10 wt% filler increases static friction. In conclusion, the static friction coefficient between coated paper and wood are up to 700% of uncoated paper depending on temperature and resting time.

1. Introduction

Materials with high friction combined with low adhesion are important for applications such as automobile tyres, shoes, etc. For such applications, it is important that the object experience a firm grip to the desired surface, but without adhering to it. Friction data for engineering purposes are often presented by a single coefficient for the static and/or dynamic friction, incorrectly implying that the friction coefficients are independent of contact time, contact load [1–3], sliding velocity [4], and/or temperature [5]. For example, the contact temperature may vary depending on the contact load and velocity, thus considerably changing the contribution of temperature on the friction [6]. Static friction typically increases as two surfaces remain in stationary contact [7], as an increase in contact size and number of contacts with contact time is observed [8]. The increase in static friction with longer resting times for a polymer coated surface can be understood as a combination of; creep of mated materials resulting in a larger contact area [9], water adsorption into the contact area which leads to greater meniscus effects [7,10,11], chain inter-diffusion [12], and shear stress relaxation at the interface [13,14]. A complete tribological description of the process, where two surfaces move relative to each other, is thus a complex system with mechanisms at different length scales [15].

This work aims at understanding friction of polymer coated paper under different environmental conditions and with an addition of calcium based particles. Coating at different thicknesses (< 160 μm) are applied and analysed; by Scanning Electron Microscopy (SEM), gravimetrically, and ATR FT-IR. Wear is examined by repeated friction measurements followed by SEM inspection. The temperature effect (25 to 55 °C) on the static friction as a function of contact time (< 10 min) of mating surfaces is investigated. The static and dynamic friction is determined by a custom-built frictometer designed for high load and large geometrical contact area.

2. Materials and methods

2.1. Coating

Paper (Kraftliner 110 g/m^2, Smurfit Kappa) is coated with poly (styrene-co-butyl methacrylate) latex (49.25 ± 0.01% solid, Dana Lim, Denmark) using hand coaters (standard close wound K bar from Largo AB, Sweden) with wet layer thicknesses of 24, 40, 60, 80, 100, 120, 150, 200, and 300 μm. The chemical composition (FT-IR shown in Supporting information Fig. S1) of the polymer dispersion was altered using a low and high poly(butyl methacrylate) content, where a low poly(butyl methacrylate) content indicates that a higher relative content of polystyrene is present. Dry coating mass was determined by weighing 10 × 10 cm pieces dried in an oven overnight at 100 °C.

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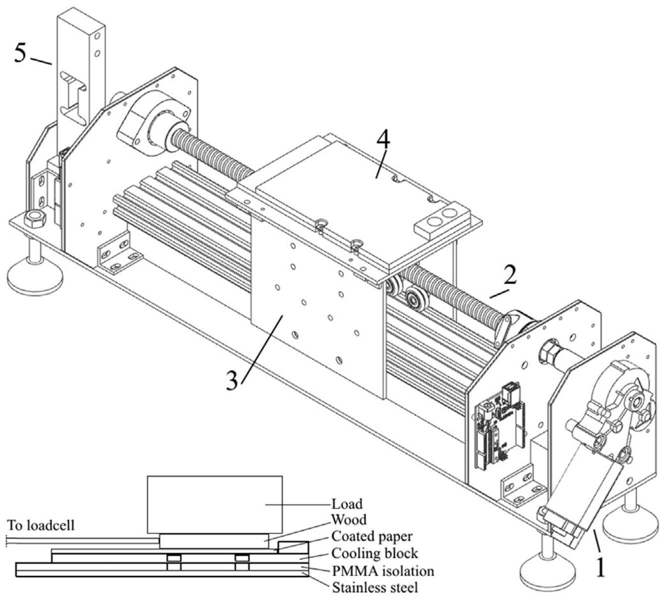

Fig. 1. Frictometer. (1) DC motor; (2) 16 mm ball screw; (3) movable sled; (4) cooling block; (5) load cell.

2.2. Filler

Calcium based filler (Rollovit 0–30 μm, Lhoist) was added (10, 25, and 50 wt%) to the latex. For the 25 and 50 wt% additional 5 wt% water was added to ease the handling of the dispersion.

2.3. Friction measurement

The designed and build frictometer (illustrated in Fig. 1) outputs the load cell (5), either 30 or 75 kg, signal to a computer via an A/D converter at 100 Hz (Supporting information Fig. S2). The sled (3) is moved away from the load cell at either 100 or 200 mm/min and the contact pressure kept constant at 10.8 or 155 g/cm^2. The interfacial temperature is controlled from 25 to 55 °C at 10 °C intervals by a water heated copper block (4) directly under the paper. The time a section cut from a wooden pallet rests stationary on the coating before measuring is varied from 5 s to 10 min controlled by the computer. Each measurement is repeated 5–7 times.

2.4. Wear

Wear was determined (setup as described above) at room temperature by measuring the dynamic friction coefficient 20 times passing the same part of the coating, One measurement included one pass to get a measurement and another pass to reset for next measurement resulting in 40 passes in total (Supporting information Fig. S5). Wear determined at 55 °C was performed with a single pass for the measurement.

2.5. Scanning electron microscopy

SEM images were made on a FEI NOVA nanoSEM 600, LVD detector, 60 Pa water, accelerating voltage of 5 kV, and spot size of 3. The SEM was controlled by the software xT Microscope Control. Samples consists of dried poly(styrene-co-butyl methacrylate) latex on paper cut to size.

3. Results

3.1. Coating

SEM images of uncoated and coated papers are shown in Fig. 2. Fig. 2 clearly shows that the coating, with a dry thickness of 10 μm, completely covered the paper surface and only larger paper structures were visible beneath the coating. At higher thicknesses the paper structure was no longer visible but lines from the coating bars became visible (Supporting information Fig. S3).

Gravimetrical results showed a linear relation between coating dry mass (m_D) and wet coating thickness (L_w) (Supporting information Fig. S4). Assuming a water density of 1 g/ml the dry coating thickness (L_D) can be directly estimated by $L_D = 0.526 \cdot L_w - 2.09$, with L_D and L_w in μm.

Wear examined at ambient conditions showed no diminishing effect on the dynamic friction (average dynamic friction coefficient was 0.35 ± 0.01 (Supporting information Fig. S5) and thus no significant wear was observed. At 55 °C and 90 s resting time, the coating showed significant adhesion (qualitative observation) towards the wooden surface and coating detachment was observed after a single measurement as shown by SEM images in Fig. 3.

As seen in Fig. 3 the coating detachment seems to happen by splitting the paper matrix, as paper fibres are clearly visible on the underside of the peeled coating.

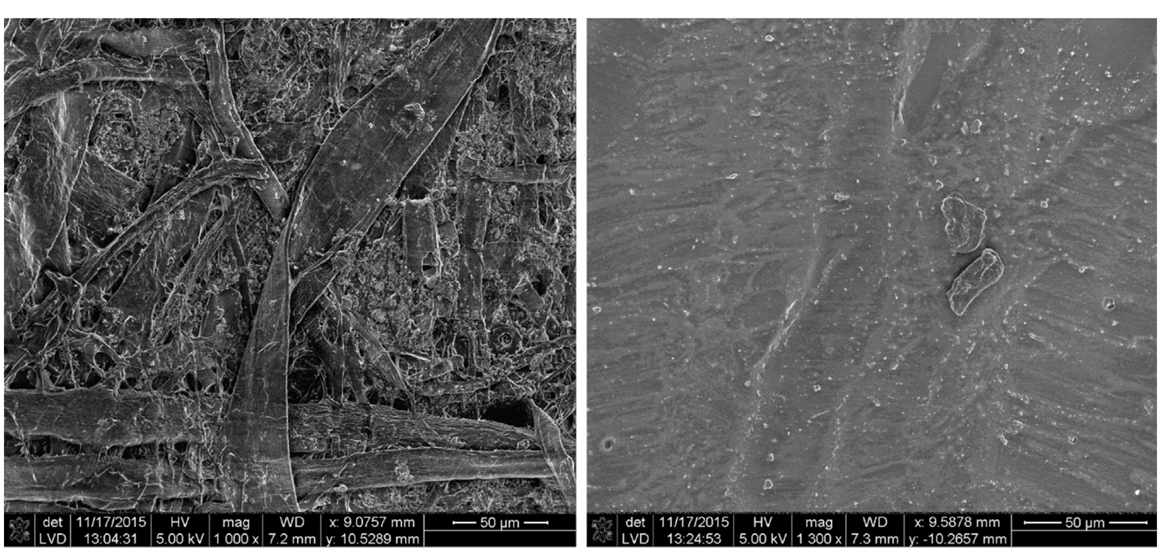

Fig. 2. SEM images. (left) Uncoated paper. (right) Coated paper, 10 μm dry thickness.

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