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Coating of paper with highly filled powders

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ABSTRACT

The purpose of this study was to evaluate the feasibility of using highly filled powders as electrostatically applied paper coatings. Powders prepared by two different methods were suitable for electrostatic deposition and they attached to the paper surface with a grounded backing. Pressing at elevated temperatures turned out to be a crucial process step for improving the adhesive and cohesive strengths of the powder coating layer on paper. Limited mechanical interlocking with the base paper and an uneven pressure profile were factors impairing the surface strength of the coated paper. On the other hand, factors such as higher polymer content, higher pressing temperature, pre-heating the paper prior to coating, and increasing the number of hot roll nips increased adhesion between the coating and the base paper. Powder coatings as such had uneven thickness, and they displayed a relatively broad pore size distribution.

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1. Introduction

Electrostatic powder coating has potential as an innovative and water-free coating process for paper, and similar processes have been used earlier for specialty papers as presented in Refs. [1–5] with a comprehensive review on water-free surface treatment technologies. The idea of electrostatic powder coating is to charge and guide powder particles with an electric field, often assisted by a carrier gas, to the surface to be coated [6]. A defect-free loosely packed powder layer should be formed and stay attached to the surface until it reaches the fixing and fusing unit. This study is focused on electrostatic deposition and coating trials applying highly filled experimental powders.

Charged powder particles are affected during deposition by the electrical, gravitational and aerodynamic forces within the intermediate air gap [7]. After the particles reach the surface, also short distance interactions, such as van der Waals attraction, electrostatic, and, in some cases, capillary forces, become important [8,9]. A grounded backing is typically used for creating and maintaining the electrostatic forces with insulating substrates, such as dry paper, all the way to the fixing step. The electrostatic attraction force decreases strongly with increasing distance from the grounded backing. Alternatively, conductivity of the substrate surface can be created by surface wetting, heating, or by a pre-application of a conductive coating. Increasing the thickness of the loosely packed powder layer increases also the charge within the coating layer. Eventually, the trapped air in the coating pores can become ionized, causing coating defects and limiting the overall layer thickness achievable [10].

Due to limited polymer flow during thermal fixing, highly filled powders require densification via compaction with a hot roll nip or multiple nips [2–5,11]. Pressing at elevated temperatures improves both particle packing and cohesive strength. Decreased porosity is necessary for controlled offset ink absorption during printing, to enable cohesive strength within the coating, and/or to create favourable conditions for adhesive bonding between the coating and the substrate surface [12–14]. High coating porosity is also linked to poor surface strength in the case of conventionally coated papers [15]. Coated paper has to have good cohesive and interfacial strength in order to withstand various mechanical stresses during subsequent processing, such as printing with high tack inks and during converting, including, for example, extrusion coating and application of viscous polymer melts.

There are several adhesion theories [16]. Mechanical interlocking into paper surface pores and fibre micro-roughness contributes significantly to the adhesive strength between aqueous pigment coatings and paper [17]. Aqueous coatings and coating components are known to penetrate into the base paper [11,18]. On the other hand, physico-chemical interactions cannot be ruled out either. There are indications of chemical interactions between, for example, polymers and pigment surfaces [19]. Coating of paper with polymer powders has resulted in cellulose fibres becoming embedded in a polymer mass, and thus providing mechanical interlocking [2,4].

The purpose of this study was to evaluate the feasibility of using highly filled powders as electrostatically applied paper coatings. We begin by describing the materials used and continue with a description

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of the coating methodology and trials. The study undertakes to evaluate laboratory deposition tests prior to performing electrostatic coating trials.

2. Experimental details

2.1. Powders

Table 1 lists the powders prepared and the processes used. 100 parts per weight of calcium carbonate ($CaCO_3$) were used as the total coating pigment in all the experimental powders. The styrene acrylate latex binders A and B used in this study were the same or similar to those used in conventional paper coatings. These together with the semicrystalline polymers were chosen by the collaborating companies.

Two processes were used for preparing the powders: (i) pseudo-fluidized bed mixing, allowing high solids content, thus significantly reducing the amount of water required to be removed, and (ii) preferential adsorption, utilizing the finding that freshly ground $CaCO_3$ readily adsorbs certain chemical compounds. In this latter case $CaCO_3$ was wet ground without dispersant together with the polymer, and the polymer adsorbed in-situ in colloidal form onto the $CaCO_3$ particles. The final agglomerate size was also affected by spray drying. Such highly filled powders were evaluated as being feasible for electrostatic coating based on previous laboratory tests and theoretical calculations [20].

2.2. Laboratory deposition tests

The deposition unit at KCL consisted of a manual Sure Coat spray gun and a control unit (Nordson). A stationary paper sheet was attached on a grounded metal plate placed in a fume hood. The spray gun was mounted on a rack, the distance of which from the metal plate was adjustable. The shooting of powder was done by pushing the trigger on the gun or by a timer. The charging voltage was typically 95 kV negative voltage relative to ground. The powder was mixed with air in a small hopper (fluidized bed) or under vibration (larger quantities), or in most cases using a combination of these. Wood free papers were typically used as the base substrate. Powder layers were pressed with a laboratory press (MTS Systems Corporation) at Aalto University (formerly Helsinki University of Technology).

2.3. Coating trials

Coating trials were performed at Tampere University of Technology, Automation and Control Institute. In the dry surface treatment (DST) the paper substrate is coated with electrostatically charged powder particles. Charging was carried out with a 95 kV negative voltage relative to ground (Sure Coat, Nordson). Particles attach to the paper and form a porous layer to be fixed in a hot roll nip formed by a polytetrafluoroethylene covered roll and a further polymer coated backing roll. Adhesion to the substrate and surface smoothening are induced during this process step. Fig. 1 shows the DST system [11]. Large quantities of charging ions are generated with high-voltage electrodes to charge the coating particles. The electric field formed between the grounded electrode and the corona electrodes causes ion-particle collisions and the field establishes a force between the charged particles and the paper surface.

Further off-line pressing tests were performed for the DST coated samples using the laboratory MTS press at Aalto University (formerly Helsinki University of Technology), and with laboratory sheet fed and web calenders at KCL. The sheet fed calender was temperature restricted to 75 °C, while the maximum roll temperature was 200 °C for the web calender. However, in contrast, the line load was lower in the web calender.

Table 1
Experimental powders, their composition and preparation processes. All powders contained 100 parts per weight of $CaCO_3$. Numbering is in line with our previous article [20].

Powder	Polymer	Process
5	10 parts semicrystalline polymer 1	Pseudo fluidized bed mixing
6	10 parts semicrystalline polymer 2	Pseudo fluidized bed mixing
7	10 parts semicrystalline polymer 1	Preferential adsorption
8	0.5 parts semicrystalline polymer 1, 9.5 parts SA latex B	Preferential adsorption
9	0.5 parts semicrystalline polymer 1, 9.5 parts starch stab. SA latex A	Preferential adsorption
10	10 parts semicrystalline polymer 3	Preferential adsorption
11	20 parts semicrystalline polymer 3	Preferential adsorption

2.4. Characterization of samples

Coat weights were calculated from the ash contents in the case of the DST coated samples. Mercury porosimetry measurements were performed with AutoPore IV 9500 by Micromeritics Corp. in the USA to study the coating structure. Images of samples were taken with an optical microscope and by scanning electron microscopy (SEM). Burnout tests were performed in order to study coating coverage.

Three different tests were used to evaluate adhesion. In the tape test, a tape (Scotch Magic Tape 810) was applied with a specific force (roller of 1.5 kg) onto the coated paper surface. The tape was then removed manually with constant speed and angle of 180°, and the force required, the mode of failure and the amount of coating detached from the paper were estimated visually. If such a test is performed for standard coated papers, the paper itself is typically delaminated or nothing is removed from the coating. Tape tests have also been used to study adhesion in extrusion coating, printing, metallizing, and surface strength of paper [21].

Picking resistance is a method used to evaluate paper and board for printing with offset or letterpress. The picking resistance was determined using an IGT AIC2-5 according to ISO 3783:1980, using the accelerating nip mode. Low viscosity oil was used, and the final speed reached was 0.5 m/s. The linear load applied by the contact roller was 35 kN/m, and four parallel measurements were performed for each sample. The picking resistance is defined by the lowest printing speed (m/s) at which the picking occurs under specific conditions.

Internal bonding strength of the coated samples was measured using the Huygen Internal Bond Tester (TAPPI T 833). The Huygen Internal Bond Tester is used to produce a high speed out of plane rupture of paper and paperboard. This method has been used, for example, for

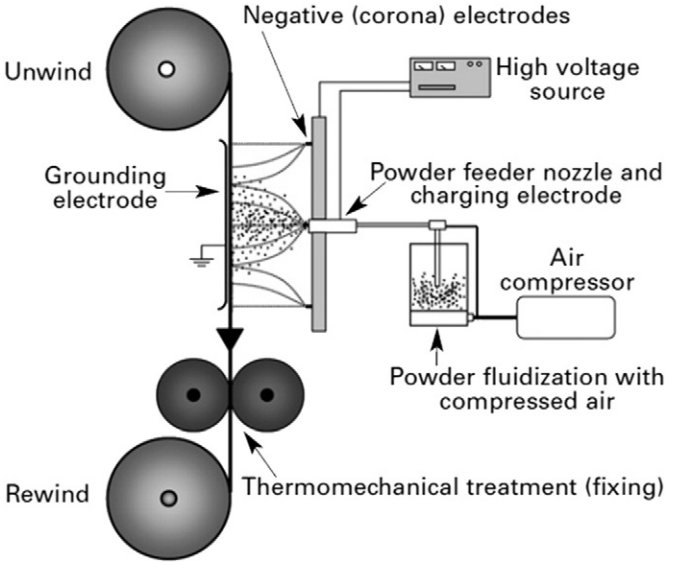

Fig. 1. Schematic illustration of a dry surface treatment (DST) unit used in the coating trials [11]. Reprinted with permission from TAPPI.

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