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Influence of Various Pulp Properties on the Adhesion Between Tissue Paper and Yankee Cylinder Surface

Jonna Boudreau* and Ulf Germgård

The strength of the adhesion between the paper and the drying Yankee cylinder is of great importance with respect to the final properties of a tissue paper product. Therefore, the effects of a few potentially important pulp properties have been evaluated in laboratory experiments. Four highly different kraft pulps were used, and the adhesion strength was measured by means of the force required when scraping off a paper from a metal surface with a specifically designed knife mounted on a moving cart. The adhesion strength was observed to increase with increasing grammage and increasing degree of beating of the pulp. It was also found that pulps containing more fines, or with higher hemicellulose content, gave rise to higher adhesion strength.

Keywords: Adhesion beating; Creping force; Fines; Hemicellulose; Tissue paper

Contact information: Department of Engineering and Chemical Sciences, Karlstad University, SE-651 88 Karlstad, Sweden; *Corresponding author: jonna.boudreau@kau.se

INTRODUCTION

The process of creping has a major influence on the properties of the final tissue paper. The creping process involves a fine balance between adhesion forces and release forces. These forces are dependent upon the adhesive chemicals and the release oil that are sprayed onto the Yankee cylinder. This balance is also influenced by the pulp properties. Earlier, when no adhesive chemicals were used on the Yankee cylinder, the adhesion force was determined by the hemicellulose content in the paper web and this caused a natural adhesion layer between the paper and the cylinder. Today, coating chemicals are always used, and these are sprayed onto the Yankee cylinder to control the adhesion forces.

An important property of the coating layer is the ability to rewet (Furman and Winston 1993) and thus to create a tacky coating surface for the wet paper web is pressed onto the drying cylinder. Ramasubramanian and Crewes (1998) have reported that the concentration of adhesive matter used in the experiments and the grammage of the paper were very significant parameters. These were more important than the type of adhesive used in regards to the shear strength needed to separate the paper from the metal. Ramasubramanian and Shmagin (2000) have also reported that several parameters have an influence on the creping force during creping but they did not investigate the influence of different types of pulps. The laboratory creping device used in their trials was designed by Shmagin (1997) to be able to study the creping mechanism, using a creping blade to shear off the adhered paper from the metal surface, as in the industrial tissue production.

Beating the pulp increases the adhesion strength (Fuxelius 1967), due to several reasons: 1) beating increases the flexibility of the fibres, which results in a stronger fibre network, 2) beating increases the contact area in between the fibres and between fibres and the Yankee cylinder, and 3) beating increases the amount of fines. Fines have a larger

surface area than compared to fibres at a given weight, which contributes to a larger surface area available for fibre-fibre bonds (Htun and De Ruvo 1978) and between the fibres and the metal surface.

The hemicellulose content in the white water will also affect the adhesion (Fuxelius 1967, Grigoriev *et al.* 2008). In general a higher hemicellulose content increases the adhesion strength. The amount of dissolved hemicellulose is also increased with higher pH (Fuxelius 1967).

The adhesion strength is also affected by the moisture content at the pressure nip where the paper comes into contact with the drying cylinder and adheres to the metal surface. Increasing dryness of the wet paper to be attached to the Yankee cylinder lowers the adhesion strength (Fuxelius 1967; Nordman and Ugglå 1978). The heat of the metal at the adhering point could also affect the adhesion strength. Fuxelius (1967) did not observe any difference between the temperatures 80 °C and 120 °C, while Nordman and Ugglå (1978) noticed a lower adhesion at higher temperatures when changing from 65 °C to 95 °C. At a higher temperature the rate of evaporation is very fast at the Yankee cylinder, and this results in a very short contact time between fibres in the wet state before the solids are in direct contact with the metal surface.

Creping Mechanism

A uniform coating layer is important, as this will result in stronger adhesion between the paper and the Yankee cylinder. It also becomes easier to obtain uniform paper properties. If the adhesion is strong and even, the fibre to fibre bonds will break inside the paper sheet when the doctor blade makes contact with the paper web. This is beneficial for the quality of tissue paper, since it creates bulk, which leads to better absorbency. However, the adhesion can also become too strong, and this can in fact lead to web breaks. Conversely, if the adhesion is too weak, the paper can fall off the cylinder before the paper hits the doctor blade, resulting in no creping of the paper.

To achieve a strong and even adhesion, the sheet has to be pressed to the cylinder when the coating is as sticky as is possible. To spread the coating chemicals with ease, high surface energy of the cylinder and a low surface energy of the chemicals is preferred (Kinloch 1980). The paper dries on the Yankee cylinder in approximately one second; roughly three quarters of a turn around the Yankee cylinder. Thereafter it is scraped off the cylinder with a doctor blade. The creping action gives bulk to the sheet and creates a more porous structure when fibres are pulled away from the surface of the web.

The objective of the study was to determine whether and how certain specific parameters, affect the adhesion force between the paper web and the metal surface, simulating the surface of a Yankee cylinder. Parameters studied were: quantity of fines, quantity of hemicellulose, and the degree of beating of the fibres (SR).

EXPERIMENTAL

Material

Fibre furnish

The pulp used in the majority of the trials was Q-OP-Q-PO bleached kraft pulp from Södra Cell (Black 85Z). The pulp was produced from roundwood chips with 70% spruce and 30% pine.

In the adhesion test three other pulps were also used:

1. Södra Green softwood kraft which was Q-OP-(Q-Paa)-PO bleached and contained 70% spruce and 30% pine. This pulp consists mainly of sawmill chips from South Eastern Sweden.
2. Södra Gold Eucalyptus; an elementary chlorine free (ECF) hardwood kraft pulp of *Eucalyptus grandis* 75% and *E. globulus* 25%.
3. An ECF bleached *Eucalyptus eurograndis* from Brazil.

The degree of beating was measured as Shopper Riegler (°SR) according to ISO standard 5267-1. The fibres were tested in a Fiber Master Tester (Lorentzen & Wettre) with ISO 16065-2. The results obtained are shown in Table 1.

Table 1. Furnish Data for the Four Different Unbeaten Pulp Types

Furnish	SR Before beating	Fiber length (mm)	Fiber width (μm)	Fines For (%)	Brightness (ISO, %)	Kappa no after cooking	Kappa no after O ₂	Hemicellulose (mg/g dry pulp)
SW roundwood	14.5	2.2	29	6.0	86	29	12	169
SW sawmill chips	14.1	2.63	31	6.0	86	28	9.1	169
<i>Eucalyptus</i> <i>eurograndis</i>	20.1	0.78	16.6	4.3	90	-	-	164
<i>Eucalyptus</i> <i>grandis</i> (75)/ <i>globulus</i> (25)	29.3	0.75	19	10.0	90	16	8-9	204

Chemicals

The adhesive used in the trial was a cationic polyamide-amine epichlorohydrin (PAAE), Eka Soft B15 from Eka Chemicals AB, Sweden. Two different batches were used. The first had a dry content of 0.81% and was used to build up the layers quicker. The second batch had a concentration of 0.38% dry content and was used just before adhering the paper strips.

Equipment

A Formette Dynamic Sheet Former (DSF) was used to make anisotropic papers with a grammage of 40 g/m². This number is high for a tissue paper but was chosen to reduce the experimental scatter between the creping experiments. The former was set to produce papers with a machine direction/cross direction (MD/CD) of 2.2. In the trial no pressing was used on the papers before adhesion in order to achieve as high a moisture content as possible.

Method

In total, 0.54 g/m² of dry adhesive was sprayed onto metal strips, resembling the Yankee cylinder surface, and the strips were heated to 100-105 °C. The quantity of coating applied in the last layer before adhering the paper was according to the previous studies in "Chemical and Morphological Analyses of the Tissue Yankee Coating" (Boudreau *et al.* 2009). The papers with a moisture content of approximately 30% were adhered to the acid-proof steel strips with the same surface roughness as an industrial Yankee cylinder. The dry papers were scraped off the metal strips by a creping device

using a creping blade at a line load of 3 kN/m and a creping angle of 89°. The device was pulled forward at a speed of 2 m/min by a tensile tester. The creping force is measured by the tensile tester and includes the adhesion force between paper and metal surface and the buckling of the paper. The method is described in more detail in the paper "Laboratory creping equipment" (Boudreau and Barbier 2013).

The influence of beating was investigated with paper samples produced from softwood kraft pulp from roundwood. The beating was made at 0 (SR 14.5°), 190 (SR 15.8°), 570 (SR 16.8°), and 1000 (SR 19°) rotations in a PFI mill. Papers were produced in a dynamic sheet former at grammages close to 40 g/m² and a dryness content of around 30%. The fiber orientation had anisotropy between 2.1 and 2.9. For every test point, some papers were restrained dried to be able to calculate grammage and measure tensile stiffness (kN/m) in the tensile tester (in machine direction (MD)).

RESULTS AND DISCUSSION

Beating

Figure 1 shows that there was a correlation between the tensile strength of the uncreped paper and the creping force, for the paper made from SW roundwood pulp. The variation in the tensile strength was obtained by beating in a PFI mill. The beating levels correspond to SR: 14.5°, 15.8°, 16.8°, and 19°. It can be seen in the figure that increasing tensile strength, obtained through increasing degree of beating, clearly increased the creping force.

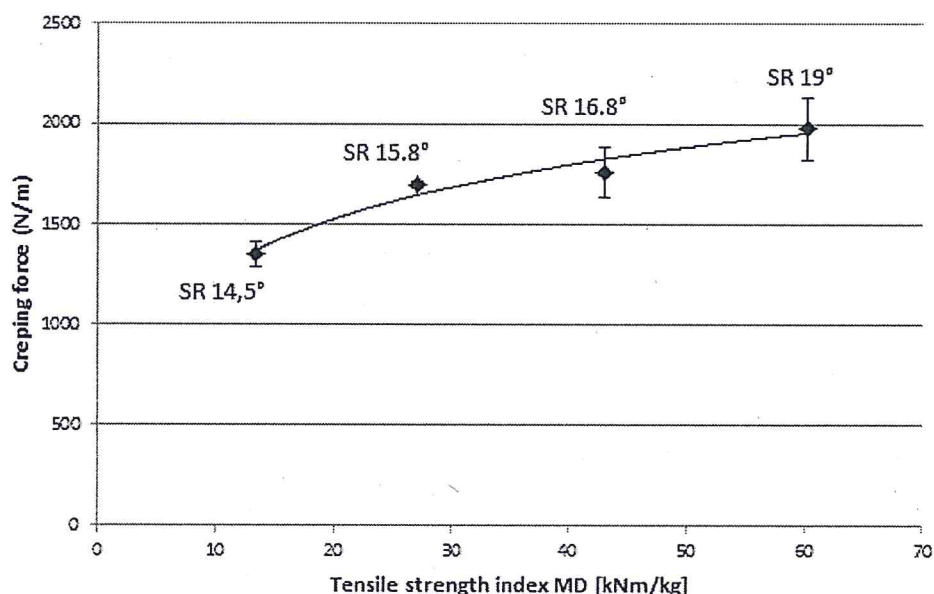


Fig. 1. Creping force for the SW roundwood pulp at various beating levels: unbeaten (SR 14,5°), 190 revolutions (SR 15,8°), 570 revolutions (SR 16,8°), and 1000 revolutions (SR 19°). The error bars are based on 95% confidence intervals of ten samples.

The reason for the beating effect is that beating leads to internal- and external fibrillation of fibers (Bristow *et al.* 1992), and the amount of fines will therefore increase. The fines will be mixed into the coating layer on the metal plate when the paper is adhered, and these fines will contribute to the adhesion between the paper and metal surface. Beating will also increase the bonded area between the fibres, and the tensile strength is therefore increased (Gigac and Fisěrová 2008) due to more hydrogen bonds (Persson 1996) in between the fibres.

The fibrillation will increase the flexibility and contact surface area of the fibres and therefore the possibility of bonding to the Yankee cylinder surface. The tensile strength, measured on the uncreped paper, has an increasing effect on the creping force when the creping force is measured as the force needed to scrape off the paper from the metal.

There is also a contribution to the creping force from buckling of the paper at the creping point. The thicker the paper, the higher the bending stiffness of the samples, and this contributes to the creping force (Boudreau 2013).

Different Pulp Types

The paper made of *Eucalyptus grandis/globulus* showed the highest adhesion force compared with that of the papers made from *Eucalyptus*, Softwood (roundwood) and Softwood (chips) (Fig. 2). The Softwood (sawmill chips) gave rise to the lowest creping force. The softwood paper results can be explained as a consequence of pulp made from roundwood, which had shorter and more slender fibres than pulp from sawmill chips due to the difference in fiber properties in the tree. The heartwood has shorter fibres than sapwood, and as a sawmill chip has a larger contact area for fiber-fiber bonds, this results in a stronger adhesion force.

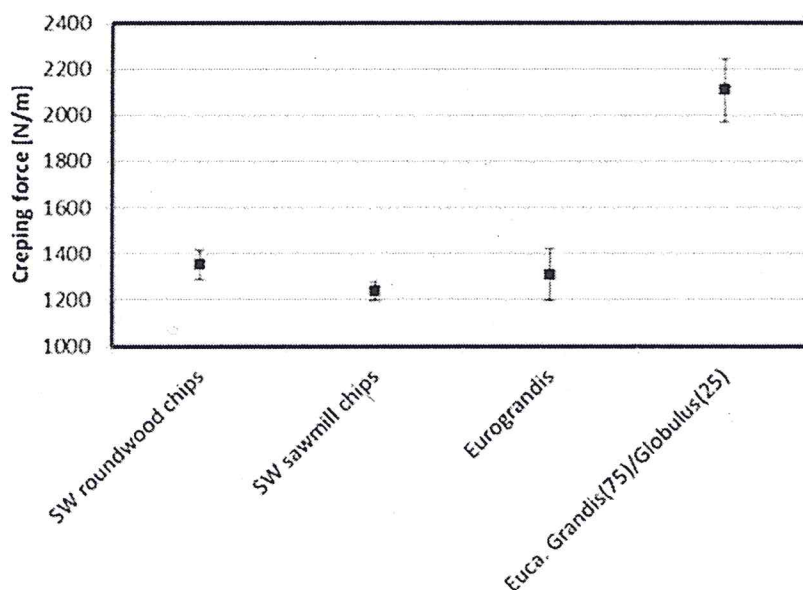


Fig. 2. Creping force, with 95% confidence intervals based on ten samples, for two types of softwood and two types of Eucalyptus pulps.

One reason for the difference in results for the two eucalyptus pulps could be due to the higher content of hemicellulose in *Eucalyptus grandis*(75)/*globulus*(25) (Table 1). A higher hemicellulose content results in greater possibility to adhere to the metal (Fuxelius 1967; Grigoriev *et al.* 2008). This pulp also had more fines, contributing to a larger contact area and a stronger adhesion. The grammage of the paper made from *Eucalyptus grandis*(75)/*globulus*(25) was higher than the corresponding paper made for *Eucalyptus eurograndis* (Table 2).

Table 2. SR Values for the Pulps and Moisture Content for the Papers at Adhesion Point

Furnish	°SR Unbeaten pulp	Dryness (%)	Grammage (g/m ²)	MD Tensile Stiffness Index (kNm/kg)	Creping Force (N/m)
SW roundwood chips	14.5	29.0	43	2030	1350
SW sawmill chips	14.1	32.6	41	2730	1230
<i>Eucalyptus</i> <i>eurograndis</i>	20.1	25.8	43	2960	1310
<i>Eucalyptus</i> <i>grandis</i> (75)/ <i>globulus</i> (25)	29.3	27.3	56	3590	2110

The paper dryness can affect the adhesion, but the samples used in this trial were of low dryness; therefore any differences in paper dryness likely had negligible effects upon the results. However, generally speaking, the dryer the paper when adhering to the metal surface; the more cockling of the paper will occur due to variation in drying tension before the paper is adhered to the metal strip. The uneven paper prevents the bonding spots on the fibres coming into contact with the coating chemicals on the metal. Rewetting of the cylinder coating is affected by the moisture content in the paper at the adhering point, which in turn affects the tackiness of coating.

Another parameter likely to affect the adhesion results is the stiffness of the paper, which will influence the buckling of the paper during the creping action. The creping force measured with the scraping equipment was probably due to both the adhesion between the paper and metal surface but also the buckling of the paper. Thus, the grammage difference for the *Eucalyptus* pulps may be a contributing factor in the difference between the two *Eucalyptus* pulps.

Table 3 shows a comparison of the different pulp samples and how the parameters, according to the currently established understanding of fiber bonding, should influence the creping force. The basic experimental data used for the comparison is given in the tables and figures in this report, and the theoretical influence of a certain parameter is given as minus, zero, or plus, depending on its influence. As illustrated, the *Eucalyptus grandis/globulus* pulp achieved the greatest number of plus symbols, while the lowest number was obtained for the softwood sawmill pulp. The other two pulps both got one plus each. As is shown in the table the individual ratings of the four pulp samples are in good agreement with the creping force values obtained in the experiments. Thus, this type of simple comparison between different paper grades can give a relatively good explanation of the results obtained for the paper samples studied in this project.

Table 3. Factors and their Effect on the Creping Force

Furnish	Grammage (g/m ²)	Dryness	SR	Fines	Hemicellulose	Sum	Creping Force (N/m)
SW sawmill	0	0	0	0	0	0	1230
<i>Eucalyptus eurograndis</i>	+	0	+	-	0	+	1310
SW roundwood	+	0	0	0	0	+	1350
<i>Eucalyptus grandis/glob</i>	+++	0	++	++	++	++++ +++++	2110

CONCLUSIONS

1. Four very different pulps were used in a study of the adhesion between a paper web and a heated metal surface. The metal surface resembled the surface of a Yankee cylinder in a tissue paper mill, and it had the same surface roughness. The force to scrape off the adhered paper was measured and this was the major analysis parameter.
2. In laboratory experiments the highest creping force was obtained for papers of high grammage, low dryness at adhesion, high SR, high fines content, and high hemicellulose content. The highest creping force was obtained for an ECF bleached *Eucalyptus grandis/globulus* pulp.
3. It was proposed at the start of this study that the creping force could be influenced by the paper grammage, the dryness of the paper at the adhering point, the degree of Shopper Riegler, the fines content in the paper, and the hemicellulose content. When comparing the four pulps in this manner it was found that the creping force results obtained could be largely explained by the results obtained in the test parameters.

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